Human-wildlife conflict outside protected areas: drivers, consequences, and mitigation strategies

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Photo: Kedar Baral

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Abstract

My thesis investigates the patterns, drivers, and impacts of human-wildlife conflicts (HWC) in the mid-hill region outside protected areas (PAs) of Nepal in order to improve wildlife conservation and human-wildlife coexistence in a human dominated landscape. The forests of this region have been managed under the community forestry (CF) system, where wildlife conservation is less prioritized and less studied due to the timber-oriented forest management system. My study is focused on addressing the knowledge gaps on wildlife conservation and HWC management aspects within the CF system in this landscape.

The content of the thesis is categorized into four broad themes: overall spatial and temporal patterns of HWC in Nepal during the last two decades; drivers of HWC; impacts of HWC; and recommendations to conservation policies and programs. In terms of the drivers of HWC, the study investigates the influences of socioeconomic factors, land use change, predator-prey interactions, climate change, and the policies and practices of the CF program on HWC. Concerning the impacts of HWC, the study investigates the effects on human life, livelihood, and retaliatory wildlife killing. The findings are summarized below by relevant themes.

- Conflicts between people and four large wildlife species, i.e., Asian elephants *(Elephas maximus)*, rhinoceroses (*Rhinoceros unicornis*), tigers (*Panthera tigris*), and common leopards (*Panthera pardus*), have increased in Nepal during the last two decades (2000-2020). The loss of these megafauna is highly correlated with the human losses caused by these species. It demonstrates that retaliatory wildlife loss is the most challenging issue for large animal conservation. Similarly, the extent of agricultural area within the district was

shown to be positively related to both wildlife and human loss, while the literacy rate of people was found to be negatively related to both wildlife and human loss.

- I found 1139 cases of human caused wildlife mortality, and out of four megafaunas, leopards had the highest overall tendency of anthropogenic killing, followed by rhinos, tigers, and elephants. On the other hand, during the 21-year span, I recorded 887 occurrences of human loss. Leopard was the leading cause of human death, followed by elephant, tiger, and rhino. Elephant attacks on humans have significantly increased over the last 21 years, while attacks of the other three wildlife have steadily increased.
- The patterns of wildlife attacks on humans are influenced by spatial and temporal factors. Wildlife attacks increased from September to December. The majority of attacks took place between the hours of 15:00 and 20:00. The majority of the attacks occurred in human settlement areas, followed by agricultural land and forest areas. The likelihood of human attacked by wildlife rises as altitude decreases, village distance from nearest forest area decreases, and people's reliance on forest resources increases. The number of HWC victims was significantly higher among farmers and people under the age of 20.
- Due to the emigration of people, abandonment of agricultural land near villages has increased in mid-hill region. The regeneration of bushes and trees on these abandoned farms has allowed wild animals to move closer to villages, increasing the incidence of HWC. This is a new dimension of HWC in this landscape.
- I assessed density of leopard and relative abundance of prey species using the camera trap method on 200 square kilometers of CFs in Tanahun district. I discovered 14 individual leopards at a density of 16.3 /100 km2 (MARK) and 15.2 /100 km2 (DENSITY) one of the highest leopard densities ever reported in Nepal. However, the Relative abundance of wild

ungulates (barking deer and wild boar) was very low, whereas the abundance of monkeys was highest, followed by large Indian civets, jungle cats, and hares. Similarly, I found 569 number of the preys (livestock + wild species) at the study site using the line transect method, with wild ungulates (conventional wild prey species like barking deer and wild boar) having the lowest detection rate. Leopard scats analysis revealed 15 prey species in the leopard's diet, including wild prey (ungulates, birds, and small mammals) and livestock. Wild ungulates (barking deer and wild boar) accounted for only 12% of the biomass calculated from scat analyses, while livestock accounted for 31% and other wild prey accounted for 57%. Domestic goats contributed the highest relative prey biomass of any species. These studies led to the conclusion that decreased natural prey availability, particularly wild ungulates, may have forced leopards to move into human settlements in search of food, increasing the incidence of human-leopard conflict.

- I investigated the current and potential future ranges of common leopards using MaxEnt modeling. My study classified the leopard's habitat as highly suitable, suitable, marginally suitable, and unsuitable. In the high mountain region, a significant increase in marginally suitable habitat was observed under the climate change scenarios SSP2-4.5 and SSP5-8.5, indicating a shift in habitat to higher elevation areas due to the effects of climate change. I recommend that these potential habitats be managed in a timely manner in order to conserve this vulnerable species and manage potential human leopard conflict in its new habitat.
- Based on an evaluation of past and current policies and practices on CF, I discovered that forest laws, regulations, and guidelines did not include all of the provisions required to address wildlife conservation and HWC mitigation in CFs outside of PAs. Community

Forest Operation Plans (CFOPs) developed in response to these acts and regulations did not adequately integrate such activities and actions into their plans. As a result, cases of HWC in CFs outside of PAs in Nepal are steadily increasing.

- HWC in the mid-hill region had a significant impact on the lives and well-being of local people. During 2015–2019, predators killed 27% of the livestock owned by local people, resulting in a 23% loss of household income. During the same period, local people lost 24% of their crops due to wildlife damage, resulting in a 17% decrease in household income. The most severe impact of HWC is the loss of human life. During the period of 2015-2019, ten people were killed by wildlife.
- Policy recommendations include revising forest laws and regulations to include a wildlife conservation and HWC mitigation provision in the CF management, establishing more PAs in mid-hill regions, conserving wildlife in a landscape approach, establishing a relief fund for wildlife victims at the local level, and linking insurance schemes to crop and livestock loss.
- Controlling habitat fragmentation and carrying out habitat management activities within CFs, carrying out incentive-based agroforestry programs on abandoned agricultural land, conducting mass public awareness campaigns, and controlling retaliatory killing through community-based conservation programs and proper law enforcement are major program-level recommendations.
- The study also recommends strengthening the provincial as well as the national level HWC database and conducting nationwide research on the impact of the CF program on wildlife management and HWC for future planning.

List of abbreviations

BPP-	Biodiversity Profile Project
CBD-	Convention on Biological Diversity
CF-	Community Forestry / Community Forest
CFOP-	Community Forest Operational Plan
CITES-	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DFO-	Division Forest Office / Divisional Forest Officer
DFRS-	Forest Research and Survey Department
DNPWC-	Department of National Parks and Wildlife Conservation
DoFSC-	Department of Forest and Soil Conservation
FAO-	Food and Agriculture Organization
FRA-	The Forest Resource Assessment
GHGs-	Greenhouse Gases
GoN-	Government of Nepal
GSLEP-	Global Snow Leopard and Ecosystem Protection Program
GTF-	Global Tiger Forum
HWC-	Human Wildlife Conflict
IPCC-	Intergovernmental Panel on Climate Change
ITPGRFA-	International Treaty on Plant Genetic Resources for Food and Agriculture
MOFE-	Ministry of Forest and Environment
MoFSC-	Ministry of Forest and Soil Conservation
NRs-	Nepalese Rupees
PAs -	Protected Areas

SAWEN-	South Asia Wildlife Enforcement Network
UNCBD-	United Nations Convention on Biological Diversity
UNCCD-	United Nations Convention to Combat Desertification
UNFCCC-	United Nations Framework Convention on Climate Change
USA-	United States of America
WWF-	World Wide Fund for Nature

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Chapter One: INTRODUCTION

1. A Theoretical Perspective of Human-Wildlife Conflict

Human-Wildlife Conflict (HWC) refers to interactions between humans and wild animals that have a negative impact on people's and/or wild animals' lives (Steidl et al., 2006; Dickman and Hazzah, 2016; Attia et al., 2018). HWC dates back to early human history, when humans exploited the natural resources and encroached upon wildlife habitats (Ogada et al. 2003). The advancement of civilization and technology has resulted in the rapid expansion of the world's population. Human demands on natural resources have caused the destruction of natural environments and wildlife habitats and have increased the competition between humans and wildlife for habitats and resources. This has further aggravated HWC (Harrison, 2019). HWC is a global issue and is intensified in areas where wildlife and humans coexist (Madden, 2004; Carter et al., 2012) and share/compete for limited resources (Wang and MacDonald, 2006). Dense human populations in the close vicinity of nature reserves present the worst situation for HWC in many countries (Distefano, 2005). Conflicts between humans and wildlife are escalating due to increasing human populations, the loss of natural wildlife habitats, and reduced prey populations (Sillero-Zubiri, et al., 2001). In some cases, successful conservation programs result in increased wildlife populations without a sufficient increase in habitats and food resources. Such a situation can also aggravate HWC (Rodgers, 1989; Saberwal et al., 1994; Aryal et al., 2016). HWC is becoming a serious threat to human livelihood as well as the survival of many endangered species in the world (Khan et al., 2018; Aryal et al., 2015; Aryal et al., 2018; Aryal et al., 2016).

The global history of wildlife conservation and the history of the HWC are interlinked. The modern conservation movement was launched in the USA in 1872 with the establishment of Yellowstone

National Park. Since then, a lot of protected areas (PAs) have been established all over the world to conserve wildlife and their ecosystems (Crowe and Shryer 1995; Phillips 2004). In 1962, the first World Park Congress proposed expanding PAs for the protection of human health, the preservation of natural landscapes, and the protection of wildlife in light of the effects of increasing industrialization and environmental degradation (Chape et al. 2008). Furthermore, the Stockholm Declaration of 1972, the Rio Earth Summit of 1992, and the Convention on Biological Diversity (CBD) of 1992 also enforced the conservation of ecosystems and biodiversity. The CBD sets the objectives of conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of benefits from biodiversity conservation. In 2010, the 10th Conference of the Parties (COP) of the CBD in Nagoya, Japan, endorsed the Aichi Conservation Target to safeguard global biodiversity in the presence of 194 signatory countries around the world. The conference decided on effective conservation of at least 17 percent of terrestrial and inland water and 10 percent of coastal and marine areas by 2020. In addition, the COP 15 of the CBD held in 2022 approved the Global Biodiversity Framework (GBF) for the years 2020–2030. GBF replaces the Aichi objectives and aims to conserve and manage at least 30 percent of terrestrial, inland water, coastal, and marine regions effectively by 2030. It also aims to restore at least 30% of degraded terrestrial, inland water, coastal, and marine ecosystems by 2030.

Following these international commitments, many countries promulgated forest, wildlife, and biodiversity conservation policies, laws, regulations, and action plans, and established many PAs. As a result, wildlife populations have increased. The increase in wildlife populations also resulted in increased human-wildlife interactions, causing many negative outcomes for people and wildlife worldwide (Harrison, 2019).

On the other hand, participatory conservation of natural resources became a worldwide adopted model after the 1990s with the philosophy of decentralized environmental governance, which replaced the top-down approach to natural resource management (Akbulut and Soylu, 2012; Harrison, 2019). In this approach, local people are empowered to participate in entire phases of natural resource management, from objective setting, program formulation, implementation, benefit sharing, and monitoring and evaluation. As a consequence, forest areas were restored or increased outside the protected areas (PAs). Such favorable changes have a positive effect on various wildlife populations in the human-dominated landscape outside the PAs. It also resulted in increased interactions and HWC, which pose a threat to the survival of wildlife as well as the lives and livelihoods of people. The negative impact of HWCs on rural communities has been intensified more severely in developing countries than in developed countries (FAO, 2005). Nepal is one of the developing countries but also one of the world's biological hotspots (DNPWC, 2021) and home to many critically endangered species. HWC, land use changes, and global climate change have all posed challenges to wildlife conservation in Nepal.

2. Biodiversity conservation and human wildlife conflict in Nepal

2.1 Biodiversity and conservation

Nepal is one of the biological hotspots and home to many critically endangered species, such as the wild elephant *(Elephas maximus)*, rhino *(Rhinoceros unicornis)*, snow leopard *(Panthera uncia)*, and Royal Bengal tiger *(Panthera tigristigris)*. The country occupies about 0.1 percent of the global area but harbors 3.2 percent and 1.1 percent of the world's known flora and fauna, respectively. Nepal has 5.2 percent of the world's known mammal species, 9.5 percent of bird species, 5.1 percent of gymnosperms, and 8.2 percent of bryophytes (GoN/MoFSC, 2014).

Nepal, a party to the Convention on Biological Diversity (CBD) since November 23, 1993, is committed to the conservation of biodiversity, sustainable use of its components, and fair and equitable sharing of the benefits from the utilization of genetic resources. Nepal has initiated an ecosystem and landscape approach to wildlife and biodiversity conservation to fulfill the dual objectives of conserving biodiversity and enhancing the livelihoods of poor people. The approach to "landscapes that work for biodiversity and people" requires managing farmlands, forests, and rangelands to respond to the triple challenge of anthropogenic biodiversity loss, climate change, and unsustainable land use (Kremen and Merenlender 2018).

Nepal has signed several multilateral agreements such as the United Nations Convention on Biological Diversity (UNCBD), the United Nations Convention to Combat Desertification (UNCCD), the United Nations Framework Convention on Climate Change (UNFCCC), the Ramsar Convention, etc. The country actively participates in international biodiversity conservation activities by: (i) implementing various programs for biological diversity conservation; and (ii) maintaining close relationships with relevant organizations for the implementation of multilateral agreements such as UNCBD, UNFCCC, the Ramsar Convention, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the International Treaty on Plant Genetic Resources for Food. and Agriculture (ITPGRFA), and others. Nepal has been involved in a number of global as well as regional networks and forums for biodiversity conservation, including the South Asia Wildlife Enforcement Network (SAWEN), the Global Snow Leopard and Ecosystem Protection Programme (GSLEP), and the Global Tiger Forum (GTF), etc.

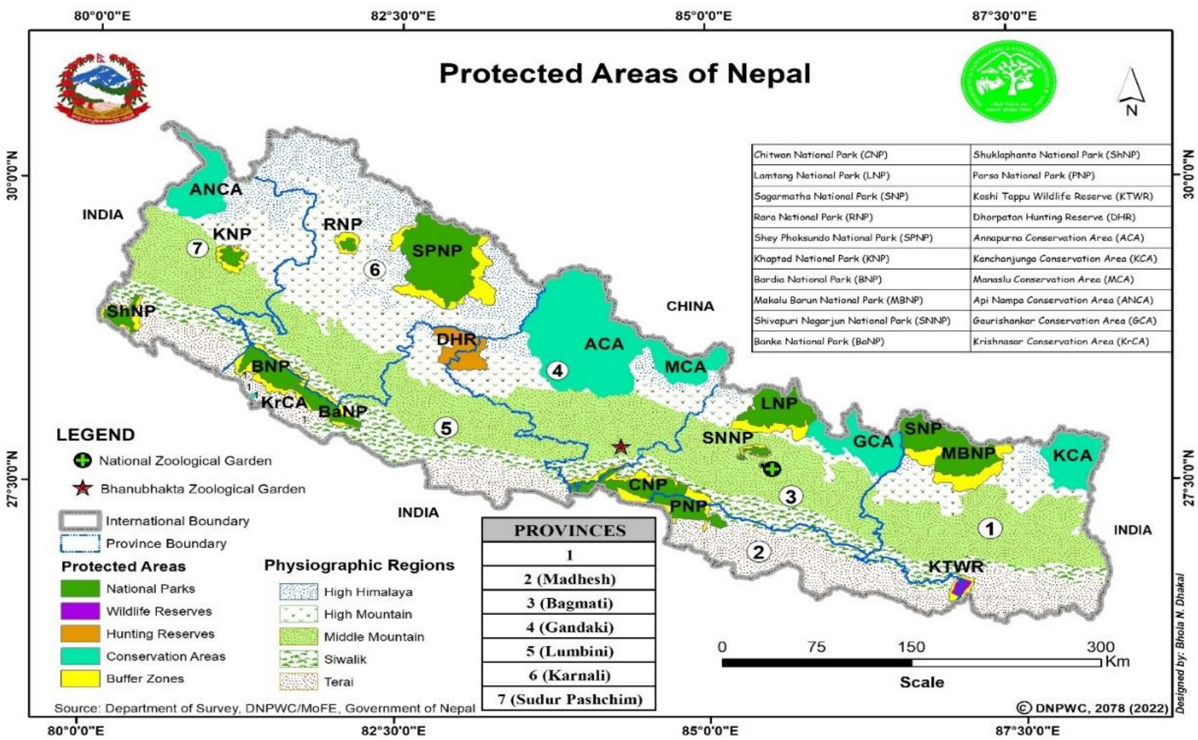
2.2. Policies on Wildlife Conservation in Nepal

The Nepalese Constitution (2015), Section 51 (g) 5, ensures the conservation, promotion, and sustainable use of forest, wildlife, birds, vegetation, and biodiversity, as well as the mitigation of all types of potential risks to the deterioration of these natural resources. Based on this constitutional provision, the government of Nepal has promulgated the Forestry Sector Strategy (2016–2025). One of the major goals of this strategy is to promote *landscape approaches and conserve corridors to manage, restore, conserve, and improve habitats, strengthening biodiversity at the ecosystem, species, and genetic levels.* Despite its relative poverty, Nepal has shown great initiative and leadership in developing innovative conservation practices that attempt to balance species and ecosystem conservation with the needs of local people (DNPWC, 2021).

To minimize the conflict and protect resources, the federal government of Nepal established many acts, rules, and regulations. Among these, the National Parks and Wildlife Conservation Act 1973 is the most important legal document for wildlife conservation in Nepal. The government prioritizes increasing the population of megafauna such as tigers, elephants, and rhinos. (Aryal et al., 2016). More than 23% of the total land area of Nepal is under the Protected Area (PA) system (DNPWC, 2021), namely 12 National Parks, one Wildlife Reserve, one Hunting Reserve, six Conservation Areas, and 13 Buffer Zones, which have been declared and managed as PAs in Nepal and represent more than 80 ecosystems out of a total of 118 found within the country (DNPWC, 2021) (Figure 1). The Federal Forest Act 2019 is another important legal provision for the conservation and management of the forest, wildlife, and biodiversity outside the PAs of Nepal.

However, this act is more focused on the conservation of forests, giving less priority to wildlife conservation (Acharya et al., 2016).

Figure 1: Protected areas of Nepal



(Source: DNPWC, 2022)

2.3 Human wildlife conflict in Nepal

In Nepal, HWC is a multifaceted and persistent problem. The presence of numerous species of wildlife, including large carnivores such as tigers, leopards, and bears, large herbivores such as elephants and rhinoceroses, as well as many birds and reptiles, and the greater reliance of the Nepalese people on forest resources have increased the potential of HWC. Moreover, an increase in population pressure on natural resources and the rapid construction of infrastructure within forests also contribute to the triggering of HWC in Nepal (Lamichhane et al., 2016). The incidence of HWC has been documented across the nation; however, of Nepal's 77 districts, 92% (n = 69) have been severely afflicted by HWC. 26 species were identified as the principal fauna involved in the conflict, of which 69% were mammals and 31% were reptiles (DNPWC, 2017). In addition to the listed species, 60 mammal species, 19 bird species, 20 reptile species, and 51 insect species were also involved in conflicts, but to a lesser extent. In Nepal, tigers, wild elephants, rhinos, and deer have been identified as problematic animals on low land (Gurung et al., 2008; Lamichhane et al., 2018), wild boar, leopards, and monkeys in the middle mountains, and snow leopards in the high mountains (Regmi et al., 2013; Aryal et al., 2014; Pandey et al., 2016; Chhetri et al., 2019).

Previously, HWC was a serious issue in and around the PAs in Nepal; however, in recent years, HWC has been dramatically increasing outside the PAs due to the successful implementation of the Community Forestry (CF) program and increased forest cover near villages (Gurung et al., 2008; Baral et al., 2021). This has resulted in increased human-caused wildlife mortalities and injuries and wildlife attacks on people and their property in Nepal (MOFE, 2019). However, there is limited quantitative data and studies on HWC in outside PAs of Nepal, which has been hindering wildlife management and HWC mitigation in CFs of outside PAs (Acharya, 2016; Scherer, L., et al., 2018; Dhakal et al., 2020).

2.4 Human wildlife conflict at Mid-hill physiographic region outside Protected areas

Nepal's landscape ranges from tropical lowlands with alluvial plains to the rough, snow- and ice-covered Himalayas. The High Himalaya, High Mountains, Mid Hills, Siwaliks, and Tarai are the five distinct physiographic zones in Nepal (Figure 2). Mid-hill is the most diverse physiography in terms of the types of ecosystems and species of flora and fauna. Out of 118 ecosystem types found in Nepal, 53 (45%) are found in the mid-hill region (BPP, 1995). It has a diverse range of terrain types, intensive farming on hillside terraces, and a subtropical to temperate monsoonal climate. It also contains fertile valleys with highly populated cities, notably Kathmandu and Pokhara. This landscape is highly human-dominated since 43 percent of the population of the country resides in this physiography. Additionally, it is Nepal's largest physiographic region, occupying 37.8% of the nation's total forest area and 29% of the country's total land area (Table 1). This physiographic region is, nevertheless the least (0.74%) represented in Nepal's protected area system (GoN/MoFSC, 2014). This is believed to be the primary cause of the continuously rising HWC events in this region over the past few decades. The forests in this landscape have been managed under the community forest system, where more than 53% of the total community forests of Nepal are located (MOFE, 2020).

The Forest Resource Assessment (FRA) 2015, carried out by the Forest Research and Training Centre (FRTC) of the Government of Nepal (GoN), showed that the forest area of Nepal has increased to 44.76 % from 39.6% within a 10-year period, becoming 6.61 million hectares. Of the total area of forest, 82.68% (4.93 million ha) lies outside PAs, and 17.32% (1.03 million ha) lies inside PAs (DFRS, 2015). The forests outside the PAs have a significant number of different species of wildlife. Therefore, the HWC is increasing the number of outside PAs in many parts of the country (Neupane et al., 2018; Adhikari et al., 2018). Out of the total events of HWC during 2015–2019, 67% occurred outside of PA (MoFE, 2019). However, most of the research conducted to date on wildlife ecology, behavior, and their interactions with humans has concentrated on PAs (Gurung et al., 2008; Acharya et al., 2016), ignoring the larger forest area containing a higher number of wildlife (DNPWC 2017). For the improved management of wildlife and mitigation of HWC outside PAs of Nepal, research is vitally needed to fill the enormous information gap.

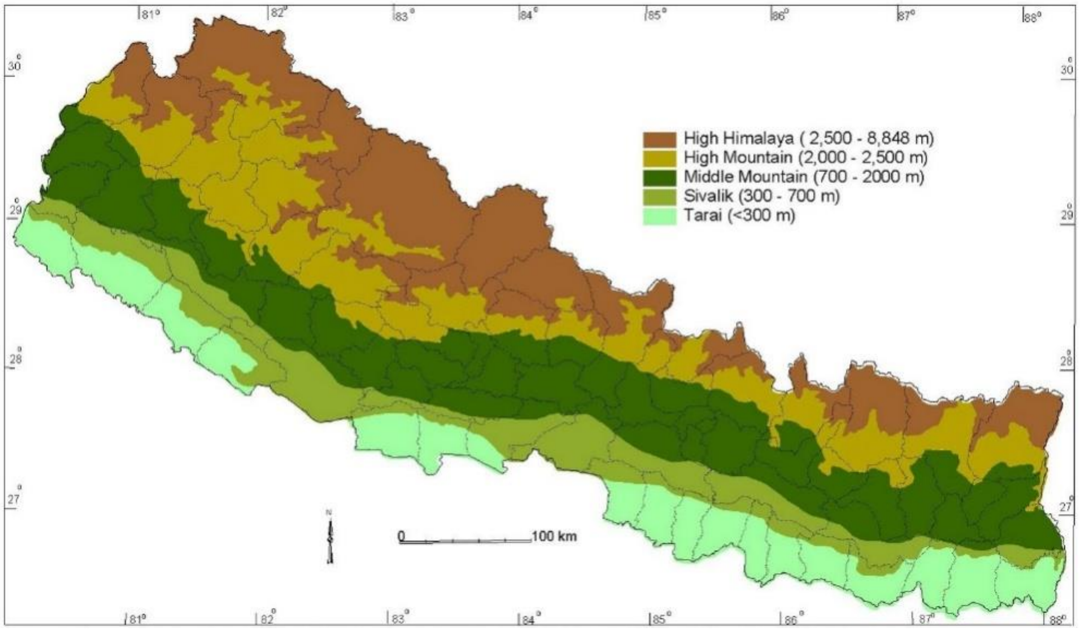


Figure 2: Physiographic regions of Nepal

Table 1: Forest and protected area coverage by physiographic region

Physiographic zone	Land area coverage (%)	Total forest area coverage		Total Protected area (PA) coverage	
		Forest area (ha)	**Coverage %**	**PA (ha)**	**Coverage %**
High himal	23	1922909	32.25	459240	23.88
High mountain	19				
Mid-hills	29	29	2253807	37.8	16669
Siwalik	15	15	1373743	23.04	246750
Tarai	14	14	411580	6.9	69847
Total	100	100	5962038	100	792506

(Source: FRA, 2015)

Tanahun district, Mid-hill physiographic region of Nepal (Photo: Kedar Baral)

2.5 Community forestry management and human wildlife conflict

Community Forestry is the largest forest management program in Nepal. By the end of 2022, the government of Nepal has handed over 22,519 Community Forests (CFs) covering 2.36 million hectares of forest land, or 40% of the forest area of the country (MOFE, 2020). It is one of the participatory forest management programs run in Nepal with the goal of restoring degraded forests and making judicious use of forest products outside of PAs (Karkiet al., 1994; Kunwar and Bhattacharya, 2008). The program is successful in Nepal because it helps in controlling, protecting, and managing local forest resources by rural communities (Gilmour and Fisher, 1998; Acharya, 2003; Springate-Baginski et al., 2003; Heinen and Shrestha, 2007; Acharya *et al.,* 2017). Restoration of CFs, increased forest cover, and improved corridors and connectivity have aided in the recovery of numerous wildlife species (Acharya 2003, Mikkola 2002). However, wildlife conservation and HWC mitigation are given a lower priority in CF policies and plans, which place a greater emphasis on forest product extraction (Acharya et al., 2017). Due to the timber-based forest management operations, fruiting trees and bushes were removed and grasslands were transformed into wooded areas (DOFSC, 2019), reducing the food supply for wildlife. The effects of diminished food availability is supposed to be a major cause for driving wild animals to approach human settlements. HWC has been increasing in and around CFs in recent days, and during the period of 2015–2019, 67% of all HWC events in the country occurred in and around CFs (MOFE 2019). However, the CF management regime outside PAs is mostly disregarded, poorly prioritized, and poorly researched in terms of wildlife conservation and HWC management, with several research and knowledge gaps (Acharya et al., 2016). Particularly, studies on the causes of HWC, its impacts, and mitigation techniques have not been well investigated in this field as of yet (Adhikari et al., 2018; Bista and Song, 2022). Therefore, I chose to conduct my research in this particular physiographic region.

3. Drivers of Human Wildlife Conflicts

3.1 Human-wildlife conflict: spatial and temporal patterns

Temporal factors (year, season, and month) and location (agricultural land, forest land, and home area) are significant factors in determining HWC (Achraya et al. 2017). In addition, proximity to forest areas and PAs might also contribute to the HWC. Most species become more aggressive during the mating season, which may lead to HWC. Various species of wildlife interact with humans in distinct spatial and temporal patterns.

A study carried out by Wilson et al. (2013) on human-elephant conflict in Assam, India, shows that property damage was most extensive between May and June and crop damage between August and December. There was a clear diurnal pattern of events, with the majority of incidents at both sites occurring between 18.00 and 22.00. Attack frequencies of elephants and rhinos were higher in the winter, whereas frequencies were not associated with the season for tigers, bears, and leopards. Kolowski (2006) found that attack frequencies of spotted hyenas, leopards (*Panthera pardus)*, and lions (*Panthera leo*) were higher in the rainy season in Kenya.

Teichman et al. (2013) found that HWC conflicts happened more often near roads and at mid-elevations in British Columbia.A study carried out in two states of India shows that attacks on humans by leopards in Pauri were recorded mostly near areas with dense scrub cover, whereas in North Bengal they were reported within tea estates (Naha et al., 2018). In low-lying areas nearby PAs of Nepal, attacks by elephant and bear were found on farmland, whereas the majority of attacks by rhino and tiger occurred in forest areas (Achraya et al. 2017). Furthermore, a study carried out by Lamichanne 2018 in Chitwan National Parks of Nepal shows that a significantly higher number of attacks by carnivores were recorded near to the forest edge. In the Nepalese context, most of the studies on the spatial and temporal pattern of HWC carried out focused on tigers, elephants, and rhinos in and around the PAs; hence, leopards are the least studied species in the country.

Understanding these spatial and temporal factors is important for coming up with effective ways to cut down on HWC. However, there is very little research on these patterns that concentrates on human-leopard conflicts outside of PAs at midhills, particularly in CF regimes. On the other hand, the majority of HWC is contextual, with varying outcomes in various regions despite the presence of the same wildlife that causes conflict (Linnell et al., 2016; Achraya et al., 2017; Kshettry et al., 2017). The context of CFs is completely different from that of PAs. Hence, my study aims to find out the patterns of HWC in this landscape, focusing on leopard, which will be helpful for the better management of HWC in this region.

3.2 Land use change and HWC

Change in land use patterns, mainly the conversion of forest land for other purposes, greatly affects the interaction of humans and wildlife. The livelihood of the people in developing countries heavily depends on natural resources (land, forest, water, etc.). To fulfill the demand of a growing population, forest land has been converted for agricultural purposes. Similarly, forest land has also been converted to infrastructure development such as roads, irrigation channels, buildings, etc. (Laurance et al., 2000; Chaudhary et al., 2016), which has led to deforestation and forest fragmentation, causing habitat loss and degradation (Laurance et al., 2000). As a result, wildlife face a scarcity of food within forest areas and move closer to the human settlement area, resulting in raiding crops, damaging property, and even causing human mortalities.

On the other hand, the mid-hills region of Nepal has witnessed a higher migration rate of people towards the cities for better education and employment opportunities in recent years (Rimal et al., 2018). This resulted in abandoning or neglecting their agricultural lands (Baral et al., 2021). The scrub and brush on these abandoned farms have quickly grown back, allowing wild animals to come closer to villages and increasing the incidence of HWCs. However, studies to date have primarily focused on habitat fragmentation and degradation as the causes of HWC (Thapa et al., 2011; Acharya et al., 2016). Being a newly emerging challenge, the effects of forest regeneration on abandoned farmland in HWC have not been investigated till date. Thus, the purpose of my research is to assess the effect of farmland abandonment and an increase in forest cover near villages on HWC, which will introduce a new dimension to wildlife management and HWC mitigation.

3.3 Climate change and HWC

Climate change is an important factor that causes habitat alteration, shifts of wildlife habitats, and changes in the behavior of wildlife, which often results in more interaction between humans and wildlife (McRae et al., 2008; Sattar, et al., 2021). Climatic patterns play a fundamental role in shaping natural ecosystems, human economies, and cultures. Each component of biodiversity has a functional role in maintaining the ecosystem's health. However, climate change may result in species losing their functional roles and have negative consequences for the ecosystem (Mooney et al. 2009; Thompson et al. 2009). The United Nations Intergovernmental Panel on Climate Change (IPCC) reported a persistent increase in the earth's mean surface temperature relative to the long-term average conditions due to the higher concentration of greenhouse gases (GHGs). Global temperatures are expected to rise by 1.4–5.8 degrees Celsius by 2100 (IPCC 2014; Aryal 2014; Locky and Mackey, 2009). Climate change increases the severity and frequency of forest fires, increases drought, and alters wildlife habitat (Dale et al., 2001; Thomas et al., 2004; Littell et al., 2016).

According to a study undertaken by Aryal (2014) in the Trans-Himalayan area of Nepal, climate change has reduced grasslands and forests by 11 and 42 percent, respectively. The decrease of grass and shrub species at higher elevations has caused blue sheep (*Pseduois nayaur*) to graze at lower elevations, where they confront and raid human farms. The relocation of the blue sheep to a lower elevation resulted in the downward range shift of the snow leopard *(Panthera uncia)* and an increase in livestock predation, both of which contributed to an increase in the HWC.

Climate change may alter the habitat and distribution of megafauna in the future, creating new challenges to conserve them in new habitats and manage potential conflicts on such sites. However, this aspect is poorly studied in Nepal. The common leopard being a major species involved in HWC in Nepal, my study focuses on the impacts of climate change on the habitat and distribution of this species till 2050 and 2070 and also tries to analyze the future conservation challenges and associated conflicts with the local people.

3.4 Habitat condition and Human Wildlife Conflict

Because of habitat fragmentation and loss, wildlife suffers a lack of food, water, and shelter within the forest, forcing them to seek alternatives outside the forest and resulting in conflict with local people. According to Acharya et al. (2017), habitat fragmentation is highly connected with attacks on humans by four megafaunas (tiger, leopard, rhino, and elephant) in Nepal. The common leopard is the most common wildlife involved in confrontation with humans in Nepal's mid-hill region (DNPWC, 2017, DFO, 2019). During the last five years, this species has killed over 40 people and numerous livestock in Nepal's mid-hill districts. It is believed that the shortage of natural prey species has forced leopards to seek alternate food sources in communities, resulting in conflicts with humans. However, adequate assessment of leopards and their prey species within mid-hill CFs is severely lacking. Thus, the objective of my research is to conduct a census of leopards and their prey species in areas severely impacted by leopard-human conflict. The study's findings will be important for conserving and balancing predator and prey populations in the future, hence reducing human-leopard conflicts.

4. Consequences of Human-Wildlife Conflicts

4.1 HWC and livelihood

Most people in developing countries rely on agriculture and animal husbandry as major sources of income (Shackleton et al., 2001). Humans are frequently attacked by wild animals when they venture into forests for fuelwood, fodder, medicinal plants, or to graze livestock (Chauhan 2003; Dhamorikar et al. 2017). Crop raiding and livestock killing by wildlife are the most common HWC and occur worldwide with varying degrees of severity, which affects the livelihood of local people (Mhuriro-Mashapa et al., 2018) and poses challenges to food insecurity and poverty in developing countries (Gemeda et al., 2018). On the other hand, due to this loss, the migration of people from rural areas and abandoning the fertile agricultural land have emerged as new challenges in many countries (Benayas et al., 2007).

Rao et al. (2002) found that the amount of crop loss significantly differs with the distance between farm and forest and is highest near the forest area in India. Karnth et al. (2018), in a study in India, found a total of 78,656 conflict incidents in 2012–2013. Of these, 73.4% were crop and property damage, 20% were livestock killing, 6.2% were human injury, and 0.4% were human death. Aryal et al. (2014) state that an estimated US$44,213 was lost between October 2009 and June 2011 in the upper Mustang, trans-Himalayan region of Nepal due to the predation of snow leopards. A study carried out by Mhuriro-Mashapa et al. (2018) in Zimbabwe shows that the yearly economic loss per household ranged from US$ 671.00 to US$ 998.21. It shows that the livelihood of the people is highly affected by HWC elsewhere.

Most residents in the mid-hills of Nepal rely on agriculture and livestock for their livelihood. Since the majority of human settlements are surrounded by CFs in Nepal's mid-hills, crop raiding and livestock killing have a significant influence on the livelihood of the locals. However, there is a severe lack of systematic record-keeping and study of how HWC affects livelihood in this landscape. So, my study examines the impacts of the HWC on the livelihood of local people in the mid-hill region.

4.2 HWC and human life

Loss of human life is the most severe type of HWC. In the period of 2010–2014, 463 cases of human casualties and deaths were reported in Nepal. The species involved include elephants (30%), leopards (21%), rhinoceroses (18%), and bears (12%) (Acharya et al., 2017). Human mortality from HWC has many negative impacts. The most vital one is psychological impact, i.e., fear, frustration, and hatred towards wildlife (Bauru, 2013; Kansky et al., 2016), which significantly hinder wildlife conservation efforts. Injury and death from wildlife attacks result in the aggression and retaliatory killing of wildlife worldwide (Lamarque et al., 2009; Acharya, 2017; Khan et al., 2017).

In Nepal, large mammal species like tigers, leopards, rhinoceroses, and elephants have been responsible for human deaths (DNPWC, 2017). For the mitigation of this problem, it is necessary to examine the patterns of human fatalities over a longer period of time in order to identify the trend and drivers of wildlife-caused human mortality. However, such long-term analyses of the pattern and drivers of human mortality caused by large carnivores are very rare in Nepal. Thus, I intend to study the pattern of human fatalities caused by four mega-wildlife species in Nepal over the past two decades in order to provide foundational information for curbing wildlife-caused human mortality and conserving wildlife as well.

4.3 HWC and wildlife mortality

Retaliatory killing of wildlife is a form of HWC that is widespread throughout the globe. Wildlife retaliation or killing refers to the deliberate harming or killing of wild animals in response to actual or perceived damages caused by these creatures (Nyhus, 2016; Treves et al., 2019). Primarily, wildlife is killed in retaliation for crop damage, livestock predation, attacks on humans, or perceived threats to human safety (Dickman, 2010). Retaliatory killing has greatly contributed to the worldwide rapid reduction of carnivore populations (Woodroffe, 2000; Sillero, 2001; Merson et al., 2019). Large carnivores are particularly vulnerable because of their lower population density and birth rate. Likewise, smaller and medium-sized carnivores are also victimized due to their livestock predation (Macdonald, 2015).

In Nepal, human-caused animal mortality is believed to have grown in recent years, but its trend and drivers are poorly understood. Thus, the purpose of my research is to investigate the primary trends and drivers linked with the anthropogenic mortality of four large species, namely the elephant, rhinoceros, tiger, and leopard, over the past two decades. My study's findings would aid in planning and implementing programs to prevent wildlife retaliation, thereby supporting the long-term conservation of these endangered species.

5. Mitigation of Human-Wildlife Conflict

HWC often transfers costs to individuals and society. Damage to crops, animal deaths, and medical care for injured people all suffer direct financial consequences. HWC frequently entails psychological consequences, such as stress and anxiety, which have a direct impact on people's physical health (Ogra, 2008). Migration to a new location owing to a fear of wildlife incurs both social and monetary costs. Several policies and programs have been established worldwide to alleviate these expenses. Giving financial support, i.e., compensation, relief, insurance of property and lives, and revenue sharing of PAs with local people are common techniques for promoting human and animal coexistence (Dickmen, 2010; Acharya, 2017).

In addition to policies, many programs have been undertaken to mitigate HWC in various nations. The activities and programs implemented based on conflict-associated species share certain commonalities. They include solar/electric fencing, crop rotation, capture and relocation, habitat management inside the forest area, an early warning system, trench construction, and predator-proof livestock huts. Such policies and programs, when properly implemented, should foster coexistence between humans and wildlife.

In Nepal, the Buffer Zone Management Regulation 1996 ensures the return of 30 to 50% of the income of PAs to the nearby community for their development activities. This policy was successful in connecting communities with PAs, obtaining local community support for conservation activities, and promoting the coexistence of people and wildlife (DNPWC, 2017). On the other hand, the Relief Directives for the Damages Caused by Wildlife 2012 is the most important mitigation policy applied in the mid-hill physiographic region of Nepal. This directive provides a relief fund of up to NRs 10,000 (equivalent to US$76) for crop damage, NRs 30,000 (equivalent to US$229) for livestock killing, NRs 20,000 (equivalent to US$152) for minor injury, and up to NRs 200000 (equivalent to US$ 1526) for serious injury to people. In the case of the death of a person, the government of Nepal provides a maximum of NRs 1 million (equivalent to US$7633) as relief to victimized families (MoFE, 2012). However, these mitigation measures are not always effective in improving human-wildlife co-existence, and the complexity of HWCevents has been increasing every year (Distefano, 2005; Karnth et al., 2018). Major barriers to ideal policy implementation in developing countries include timely payment of compensation; transparency in fund distribution; availability of sufficient funds, public awareness of the compensation scheme, accessibility of people to concerned authorities, damage evaluation; and the length of the process (Nyhus et al., 2005; Barau et al., 2013).

To date, the effectiveness of the Relief Directives for the Damages Caused by Wildlife (2012) has not been assessed, particularly in relation to the mid-hill physiography outside the PAs of Nepal. Therefore, my study tries to fill this knowledge gap and aims to recommend for its improvement.

6. Study area

The study was conducted in Nepal (26.36–30.45° N, 80.06– 88.2° E). A total of 192 species of mammals are found in Nepal (Thapa, 2014), encompassing about 3.5% of the world's mammalian fauna. Despite the small land area (147,181 km^2), Nepal has high altitudinal variations ranging from 70 m to 8848.8 m from mean sea level (Mt. Everest) (GON/MOFSC, 2014). The country is classified into five disparate physiographic zones, namely the High Himalayas (above 5000 m s l.), High Mountains (3000–5000 m m.s.l.), Middle Mountains (1000–3000 m.m.s.l), Siwaliks (500–1000 m m.s.l.) and Terai (below 500 m m.s.l.) (GON/MOFSC, 2014). With a rich biological diversity, due to the heterogeneous physiography, a total of 118 ecosystems have been reported in Nepal, including 112 forest ecosystems (Kunwar et al., 2022). There are 12 national parks, one wildlife reserve, one hunting reserve, and six conservation areas covering 23.23% of the total land area of the country. The total population of the country is 26.5 million, out of which 64% of people primarily depend on agriculture and animal husbandry to sustain their livelihood (CBS, 2011).

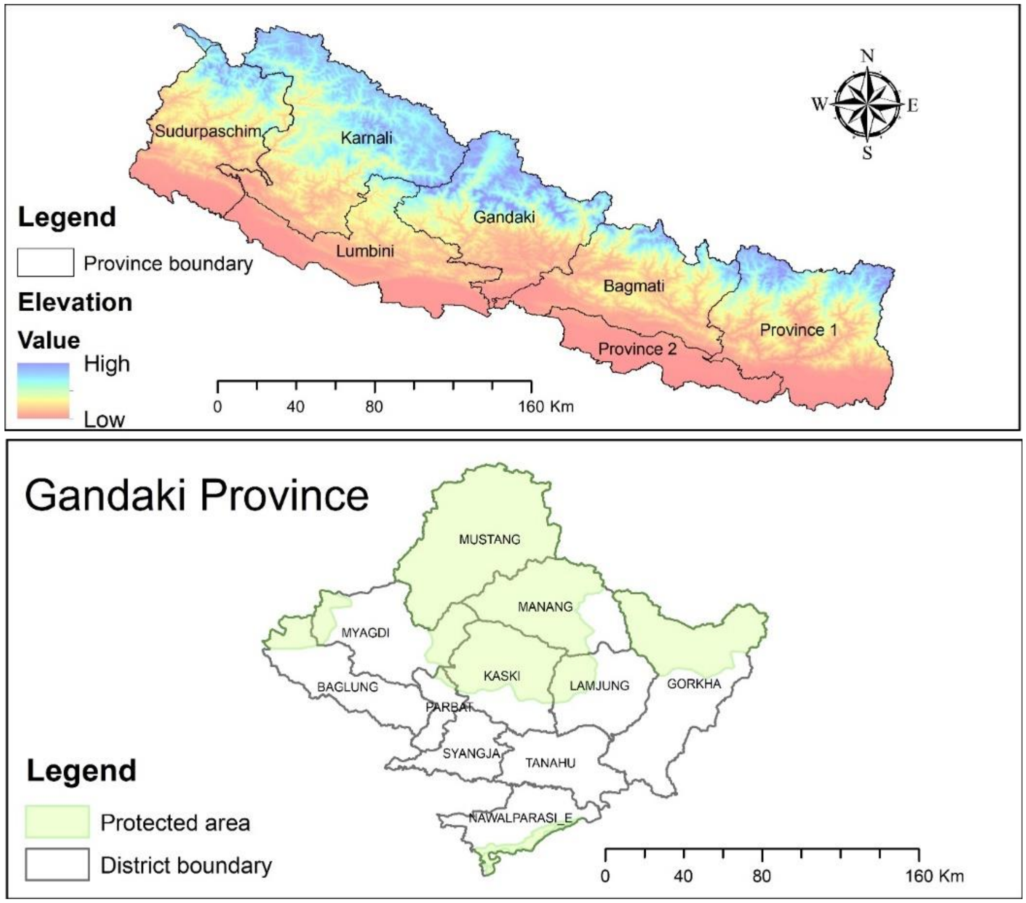


Figure 3: Map of study area, non-PA areas within Gandaki Province

Gandaki Province is one of the seven provinces with the higher level of biodiversity and the greater number of HWC. This province has a land area of 21,504 square kilometers and a population of 2.5 million people. Five districts, Parbat, Lamjung, Syangja, Tanahun, and Kaski (27˚55’ - 28˚26’ N, 83˚58’– 84˚25’ E) were selected as study areas. These districts have a human population of about 1.4 million, many of whom live in remote and isolated areas with poor access to markets and easy access to forest resources. These five districts cover an area of approximately 7,000 km^2 and represent the lowlands (70–1000 m asl), mid-hills (1000–3000 m asl) and high mountainous area (3000–5000 m asl) of central Nepal. The high mountainous part of Kaski and Lamjung districts shares 11% of the Annapurna Conservation Area (7,629 km^2), the largest PA in Nepal. The mid-hill region (also known as middle mountain) is characterized by sub-tropical and temperate bio-climates with a great variety of terrain types, ecosystems, and wildlife (Bhuju et al., 2007, Kunwar et al., 2010).

7. The research objectives, thesis structure and research questions

The objectives of this study include investigating the patterns, drivers, and impacts of human wildlife conflicts outside the PAs in the mid-hill region of Nepal in order to improve wildlife conservation and human-wildlife coexistence in a human dominated landscape. I study both the socioeconomic and ecological elements of HWC in this region. The key socioeconomic components are HWC trend analysis, the impact of HWC on local people's livelihoods, local perceptions of HWC, and different socioeconomic attributes of people linked with HWC. The key ecological factors include assessing the density of leopards and the number of prey species within community forests, the impact of land use change and climate change on the habitat, and the future dispersal of leopards.

The thesis includes six chapters:

Chapter 1: Introduction: provides the general theory of HWC and a literature review on the drivers and consequences of HWC at global and national scales, including the policies and practices adopted in Nepal for mitigation of HWC. I identified knowledge gaps and set the objectives and research questions for the study.

Chapter 2: Anthropogenic mortality of large mammals and trends of conflict over two decades in Nepal: encompasses patterns of anthropogenic mortality of wildlife and wildlife-caused human mortality in two decades (2000–2020) in Nepal, focusing on four megafaunas: elephant, rhino, tiger, and common leopard. I investigate the following research questions:

- What has been the trend of human-large mammal conflict over the last two decades in Nepal?
- What are the trends in human-caused wildlife mortality and wildlife-caused human mortality over the last two decades in Nepal?
- What are the major attributes and drivers associated with wildlife mortality over the last two decades in Nepal?

This chapter has been published in *Ecology and Evolution*. (*DOI: 10.1002/ece3.9381)*

Chapter 3: Human–wildlife conflicts in mid-hill regions outside Protected Areas of Nepal: describes the drivers, patterns, and impacts of human–wildlife conflict and mitigation strategies. The research questions include:

- What are the spatial and temporal patterns of HWC in the mid-hill physiographic region of Nepal under the community forest management system?
- What are the associations between different socio-demographic and ecological variables and HWC in a community forest management system?
- What are the impacts of HWC on the livelihoods of people?
- What is the impact of land-use change and restoration of community forests that has led to a change in the number of HWC events?

This chapter consists of two studies:

Study one, "Characterization and management of human-wildlife conflicts in the mid-hills outside protected areas of Gandaki province, Nepal" investigates the temporal, seasonal, and spatial distribution of human casualties from wildlife attacks in mid-hills of Nepal. This paper was published in PloS one, 16(11), e0260307. (DOI: https://doi.org/10.1371/journal.pone.0260307.

Study two, "Human wildlife conflict and impacts on livelihood: A study in a community forestry system in mid-hills of Nepal," analyzes the impact of the human wildlife conflict on the livelihood of local people, focusing mainly on the financial losses due to crop raiding and livestock depredation. This study has been published in Sustainability, *13*(23), 13170 (DOI: https://doi.org/10.3390/su132313170).

Chapter 4: Common leopards *(Panthera pardus)* and their prey interaction in relation to human-wildlife conflict in community forest regimes, mid-hills, and outside protected areas of Nepal: This chapter analyzes the density of common leopards and the abundance of their prey species within community forests in the mid-hills outside protected areas of Nepal. The chapter also includes a diet analysis of common leopards in this landscape. The research questions include:

- What is the density of the common leopard and the abundance of its prey species in community forests of the mid-hill region outside protected areas of Nepal?
- What are the impacts of the predator-prey ratio on the human-leopard conflict?
- What is the contribution of wild and domestic prey to the diet of the leopards in community forests in the mid-hills of Nepal, and what are its implications for human-leopard conflict?

Chapter 5: The Impact of Climate Change on habitat and distribution of Common leopards *(Panthera pardus)* and its implication on conservation and conflict in Nepal: This chapter explores the impacts of climate change on the habitat and distribution of the common leopard in Nepal. Research questions include:

- What is the present distribution status of the common leopard in Nepal?
- What would be the impacts of climate change on the habitat and future distribution of the common leopard?
- What are the implications of the changed future distribution pattern of common leopards in terms of leopard conservation and human leopard conflict management?

This chapter has been published in Heliyon (DOI: https://doi.org/10.1016/j.heliyon.2023.e12807).

Chapter 6: Conclusion and Policy Implications summarizes the findings of this thesis, provides an overview of management implications, and makes recommendations on mitigation strategies for HWC. The chapters of this thesis have been written in the format of journal publications. This results in some differences in format between chapters and some overlap of references between chapters. The references cited in the chapters are included with each chapter, and the citation styles on the articles also vary due to the mandatory requirement to follow the journal's format. Four articles from the thesis have been published in scientific journals.

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Chapter Two

Anthropogenic mortality of large mammals and trends of conflict over two decades in Nepal

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(Photo: RSS Nepal)

ABSTRACT

Wildlife conservation in human dominated landscapes faces increased challenges due to rising conflicts between humans and wildlife. I investigated the human and wildlife loss rates due to human-wildlife conflict between 2000 and 2020 in Nepal. I concentrated on Asian elephant (*Elephas maximus*), greater one-horned rhino (*Rhinoceros unicornis*), tiger (*Panthera tigirs*), and leopard (*Panthera pardus*) mortality, as well as human mortality caused by these species. Over the 21-year period, I recorded 1139 cases of wildlife mortality and 887 cases of human mortality.

Leopard mortality was the highest, followed by that of greater one-horned rhinos, tigers, and Asian elephants. Overall, the rate of wildlife mortality has been increasing over the years. Asian elephants were found to be more responsible for crop damage than greaterone-hornedrhino, while leopards were found to be more responsible for livestock depredation than tigers. The generalized linear model indicated that the mortality of wildlife in the districts is best predicted by the additive effect of human mortality, the proportion of agricultural land, and the literacy rate of the districts. Retaliatory wildlife mortality was the most challenging issue for wildlife conservation, especially for the large mammals. Findings from this study are important for mitigation of human wildlife conflicts, controlling retaliatory killing, and conserving these threatened large mammals.

1. INTRODUCTION

Loss of wildlife due to retaliatory killing by people is one of the most critical issues for large mammal conservation (Adhikari, Baral, Bhandari, Szydlowski, et al., 2022; Baral, Aryal, et al., 2022; Bhandari & Chalise, 2016; Collins & Kays, 2011; Eklund et al., 2020; Nielsen et al., 2004). In areas where humans and wildlife share common resources (Bhandari, Adhikari, Baral, Panthi, et al., 2022; Nyhus, 2016; Rutina et al., 2016; Xu et al., 2019), the competition for limited resources results in a scarcity of food for wildlife in their natural habitats (Baral, Adhikari, & Bhandari, 2022). This may cause wildlife to expand their range to nearby villages and cause crop-raiding, property damage, livestock depredation, and human attacks (Adhikari, Bhandari, Baral, Lamichhane, & Subedi, 2022; Baral, Sharma, Kunwar, et al., 2021). Such human wildlife conflicts (HWC) often lead to people's negative attitudes toward wildlife conservation (Adhikari, Baral, Bhandari, Kunwar, & Subedi, 2022; Baral, Aryal, et al., 2022; Bhandari & Chalise, 2016). People may retaliate these losses by killing the wildlife involved in such conflicts as a form of retaliation killing (Adhikari, Bhandari, Baral, Lamichhane, & Subedi, 2022; Baral, Aryal, et al., 2022; Baral, Sharma, Rimal, et al., 2021; Gubbi et al., 2014; Nyirenda et al., 2015). The loss of wildlife due to poaching and trading (Everatt et al., 2019; Rosen & Smith, 2010) as well as HWCrelated wildlife mortalities significantly contribute to the fall in their populations.

Human wildlife conflict is also accelerated due to an increment of human infrastructure development (such as road and building construction) in the wildlife habitats. Human settlements near wildlife habitats have resulted in a decrease in wildlife habitat size. Such encroachment of natural habitat and lack of conservation knowledge in the community (Nielsen et al., 2004; Pandey et al., 2016; Sijapati et al., 2021) has led to the population decline of several threatened species

(Baral & Heinen, 2007; Stclair et al., 2019). Conflict between humans and wildlife in Nepal is higher in lowland regions where most of the large herbivores and carnivores are present (Acharya et al., 2016; Baral, Aryal, et al., 2022; Bhandari, Aryal, Shrestha, 2019). However, the conflict between humans and large carnivores has been escalating in the mid-hill areas in recent days (Adhikari, Bhandari, Baral, Lamichhane, & Subedi, 2022; Baral, Aryal, et al., 2022; Bhandari, Aryal, & Shrestha, 2019). People's high degree of dependency on forest products and livestock has led to frequent encounters with wildlife in these areas (Baral, Sharma, Rimal, et al., 2021; Kutal et al., 2021).

In Nepal, four large mammals, Asian elephants (*Elephas maximus*) (hereafter elephants), greater one hornedrhino (*Rhinoceros unicornis*) (hereafter rhinos), tigers (*Panthera tigris*) and leopards (*Panthera pardus*), are more involved in conflicts with people, including property damage and human casualties (Acharya et al., 2016; Baral, Aryal, et al., 2022; Bhandari, Mawhinney, et al., 2019; DNPWC, 2017; Pant et al., 2016; Thapa, 2014a). Among the four species, elephants, rhinos, and tigers are distributed in lowland areas while leopards are distributed throughout the country (Baral, Aryal, et al., 2022; Bhandari, Mawhinney, et al., 2019). Elephants and rhinos are usually involved in crop raiding, whereas carnivores such as tigers and leopards are involved in livestock predation and attacks on humans (Bhandari et al., 2021; Bhattarai & Fischer, 2014; Gurung et al., 2008; Sijapati et al., 2021). The population of large mammals such as tigers, rhinos, and elephants are increasing in Nepal. The tiger population has increased from 121 in 2009 to 355 in 2022 (DNPWC and DFSC, 2022). Similarly, the number of rhinos also increased from 605 in 2015 to 752 in 2021 (DNPWC, 2021). The population of elephants and leopards has also been believed to be increasing in recent years, but the population census has not been assessed till date (DNPWC, 2017, 2021; DNPWC and DFSC, 2022; Ram et al., 2021). It is assumed that establishment of community forest programs and conservation awareness etc. could contribute to increasing population (Baral, Sharma, Kunwar, et al., 2021). Escalation of conflicts is inevitable in the scenario of an increasing number of large mammals (Mukeka et al., 2019). However, HWC has also increased due to encroachment of forest land, habitat fragmentation, and inefficient wildlife management practices in the regions outside protected areas (PAs) of Nepal (Baral, Sharma, Rimal, et al., 2021).

The government of Nepal has implemented various species-specific management strategies and a wildlife damage compensation scheme to minimize HWC. The HWC mitigation program was formerly started in PAs in 1996 and outside PAs in 2012 (Acharya et al., 2016; Bhattarai & Fischer, 2014). Despite the conservation efforts, new incidents of wildlife killing have been common over the years (Bhandari et al., 2019; Dhungana et al., 2018; Pant et al., 2016). Wildlife mortality is a prominent issue that has to be resolved for large mammal conservation in human-dominated landscapes (Baral Heinen, 2007; McGuinness & Taylor, 2014; Santiapillai et al., 1982, 2010; Zhang & Wang, 2003). Moreover, it is necessary to understand the patterns of human and wildlife mortality over a longer period in order to understand the trend and drivers of HWC, as such research provides foundational data for formulation and implementation of sustainable conservation strategies. Because large mammals are more likely to be involved in HWC events (Adhikari, Baral, Bhandari, Kunwar, & Subedi, 2022; Baral, Sharma, Rimal, et al., 2021), our study had two major goals: (1) to identify trends in human large mammal conflict over two decades, and (2) to examine major attributes associated with large mammal mortality over two decades. We hypothesized the increasing trend of human and large mammal casualties and the mortality of human to be a significant variable for predicting the mortality of large mammals.

2. MATERIALS AND METHODS

2.1 Data collection

The study was conducted in Nepal (26.36–30.45° N, 80.06– 88.2° E). A total of 192 species of mammals are found in Nepal (Thapa, 2014b), encompassing about 3.5% of the world's mammalian fauna. Our data collection was focused on records of the mortality of four large mammals: elephants, rhinos, tigers, and leopards, due to the prominent number of humans-wildlife conflicts associated with these four species. We also recorded the data regarding the mortality of human life and property damage (such as livestock loss and crop depredation) caused by these four species. Data were gathered from government reports [Department of National Parks and Wildlife Conservation (DNPWC), Department of Forest and Soil Conservation (DoFSC), Division Forest Offices (DFO), and Protected Areas (PAs)], technical reports, and newspapers published between 2000 and 2020 (See Data Availability Statement). During the collection of data, we recorded the nature of events (human mortality, wildlife mortality, livestock loss, and extensive crop loss), species involved in conflict, year, and location. Duplications and redundancies were crosschecked. Moreover, reliable records, such as the verified reports of government agencies, i.e., DNPWC, DoFSC, DFOs, and PAs were used for the purpose of validation, and the incomplete and unreliable records were omitted from the analysis.

2.2 Data analysis

We applied generalized linear models (GLM) with a Gaussian distribution to understand the influence of independent variables on wildlife mortality in 77 districts of Nepal (Dobson & Barnett, 2018; Hardin et al., 2007). The number of wildlife mortality (Wloss) in a particular district was set as a dependent variable, while seven in-dependent variables: (1) number of human losses within districts (Hloss), (2) proportion of agricultural land within districts (Pag), (3) literacy rate of people in the district (Lrate), (4) population density within district (Pden), (5) proportion of forest land within district (Pfr), (6) proportion of protected area within district (Ppa), and (7) density of livestock within district (Lden) were included in the analysis. All of the variables were included in further modeling because they had Pearson's correlations of $|r| < .7$. We used Akaike's Information Criterion; corrected for small sample sizes (AICc), to perform model selection. We selected the most parsimonious models based on a delta AIC < 2 and extracted the model averaged results to calculate parameter estimates using the MuMIn package (Barton & Barton, 2015) in R program. A total of 127 models with different combinations of seven independent variables were analyzed. Out of these models, seven models (Appendix 1) performed the best with a delta AIC value<2. We obtained model averaged coefficients using the seven best-fit models, and the significant predictor variables ($p < .05$) from the best-fit model were used to generate the probability of wildlife mortality over two decades. The Inverse Distance Weighing (IDW) function in ArcGIS was used to generate the heatmap (Al-Bakri et al., 2011; Kunwar et al., 2022). The IDW interpolator assumes that the local influence that each point possesses diminishes with distance, resulting in the decreasing influence of a variable with increasing distance from its sampled location (Shepard, 1968). It also attributes greater weight to the points that are closer to the processing cell than those that are further away. The interpolated surface, estimated through the moving average technique, generates values less than the local maximum and greater than the local minimum (Shepard, 1968; Wong, 2016). The in-point features were represented by 77 districts, and the field represented numerical values of wildlife loss. The exponent of distance, which controls the significance of surrounding points on the interpolated value, was set as 2 (the default value). We used variable search radius, whereas the maximum distance to limit the nearest search sample was also set to the default value (the length of the extent's diagonal). The procedure of interpolation was carried out using the spatial analysis technique within ArcGIS (ESRI, 2011). Finally, the heatmap was reclassified by assigning the values as low probability (0-0.40), medium probability (0.40-0.60), and high probability (0.60-1) of wildlife mortality.

3. RESULTS

We recorded 1139 ($\bar{x}$54.2/year, SD ± 14.3) HWC-related large mammal losses and 887 ($\bar{x}$42.2/year, SD ± 11.8) human losses between 2000 and 2020 in Nepal (Figure 1). Out of four species, leopard loss was the highest ($\bar{x}$42.3/year, SD ± 15.1), followed by rhinos ($\bar{x}$8.0/ year, SD ± 6.9), tigers ($\bar{x}$ 2.2/year, SD ± 1.2), and elephants ($\bar{x}$ 1.5/ year, SD ± 1.3) (Figure 2). During this period, leopards killed an average of 18.8 people (SD ±2.4) yearly, followed by elephants at 14.1 (SD ± 8.8), tigers at 5.8 (SD ± 2.3), and rhinos at 3.3 (SD ± 1.1) (Figure 3). Overall, the rate of wildlife mortality was higher compared with human mortality. Both the HWC related wildlife and human mortality have shown an increasing trend with time (wildlife mortality R^2 = 0.35, human mortality R^2 = 0.84) (Figure 1). The results showed a high correlation (r = .44) between wildlife and human mortality over the period of 21 years. We recorded 517 (SD ± 188.7) events of crop damage by the elephant, followed by the rhinos with 280 events (SD ± 39) yearly. Similarly, leopards contributed the highest livestock depredation (280 livestock/year, SD ± 103.3) followed by tigers (77 livestock/year, SD ± 28.9) (Figure 4).

The model with the highest AIC weight (0.24) to predict wildlife mortality was the model with the additive effect of three variables (number of human losses + proportion of agricultural land within district + literacy rate of district). The average of seven best fit--models (with delta

AICc < 2) (Appendix 1) found that the number of human losses and proportion of agricultural lands have significant positive associations with the number of wildlife mortality, whereas literacy rate had a significant negative association (Table 1). We found a high probability of wildlife loss in lowland districts such as Jhapa, Chitwan, Nawalparasi, Dang, Bardia, and Kanchanpur. Similarly, the mid-hill districts with a high probability of wildlife mortality were Kabhre, Kathmandu, Lalitpur, Bhaktapur, Tanahun, Kaski, Argakhachi, and Baitadi (Figure 5). Most of the mid-hill districts were under medium risk of wildlife mortality, whereas the high mountain and high Himalayan regions had a lower probability of wildlife mortality. The heat map depicted central Nepal as the most prominent zone for HWC related wildlife mortality (Figure 5).

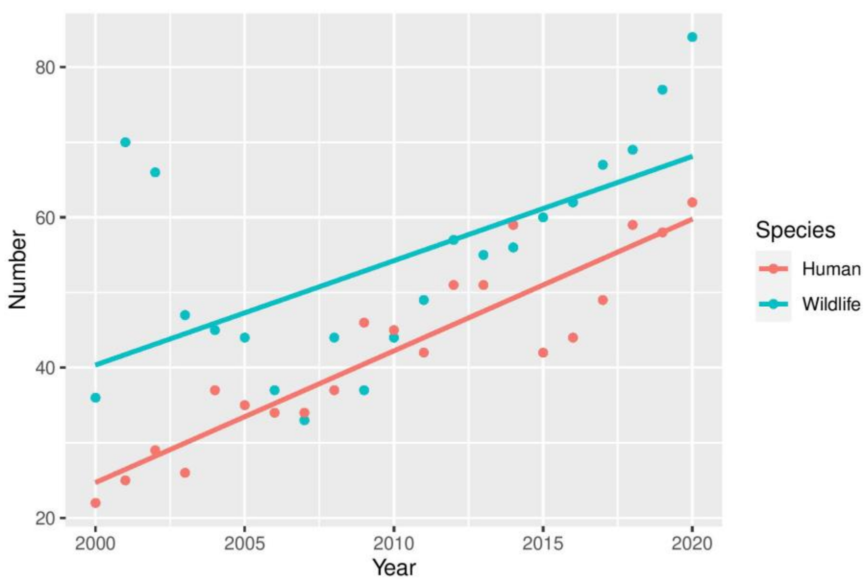

Figure 1: The trend of large mammal loss and human loss from large mammals between 2000 and 2020 in Nepal

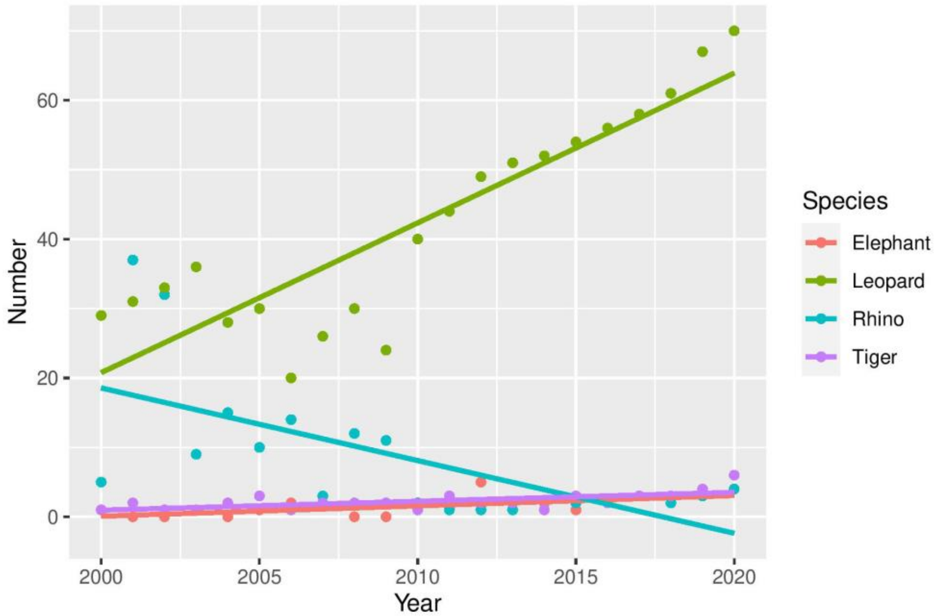

Figure 2: Patterns of large mammal loss due to human wildlife conflict between 2000 and 2020 in Nepal

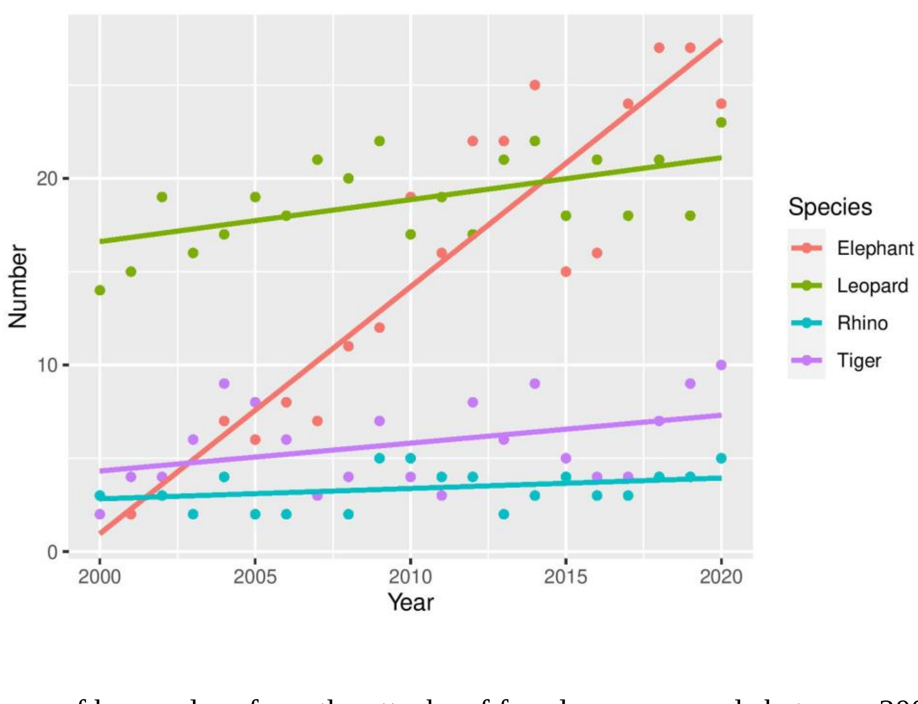

Figure 3: Patterns of human loss from the attacks of four large mammals between 2000 and 2020 in Nepal

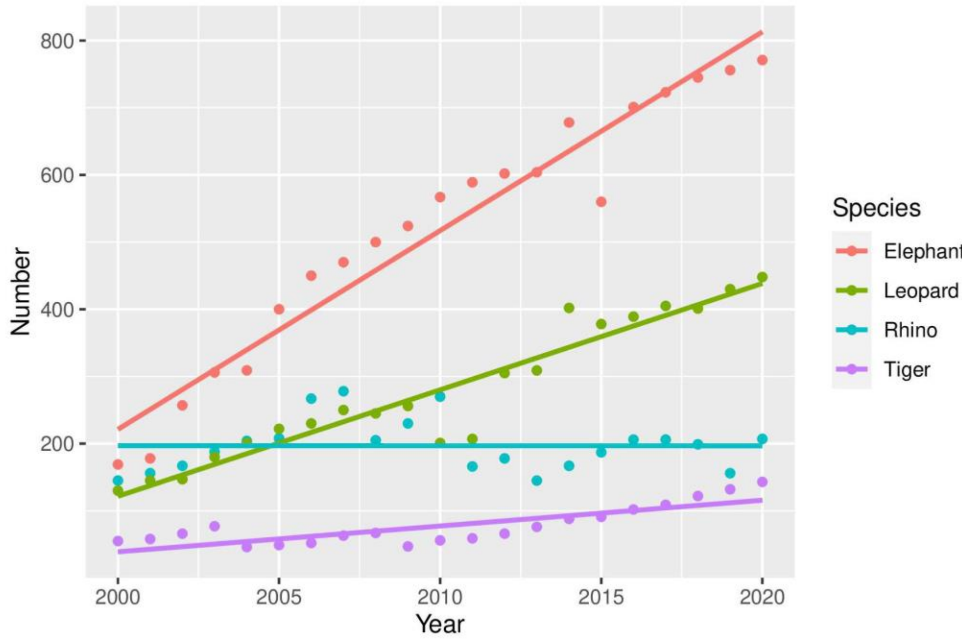

Figure 4: Total number of events of property damage (crop depredation by elephants and rhinoceros, and livestock predation by tigers and leopards) between 2000 and 2020.

Table 1: Model averaged coefficient for the seven best-fit models (delta AIC < 2), where: number of wildlife losses: (Wloss), number of human losses within districts: (Hloss), proportion of agricultural land within district: (Pag), literacy rate of people in district: (Lrate), population density within district: (Pden), proportion of forest land within district: (Pfr), proportion of protected area within district: (Ppa), livestock density within district: (Lden).

Variables	**Estimate**	**Std. Error**	**Adjusted SE**	***z* value**	**Pr(>|z|)**	***Significance* value**
(Intercept)	0.001373	0.027441	0.027908	0.049	0.96075	
Hloss	0.963708	0.033709	0.034248	28.139	<2e-16	***
Pag	0.079198	0.038371	0.038938	2.034	0.04196	*
Lrate	−0.101064	0.032002	0.032499	3.11	0.00187	**
Pden	0.053734	0.033577	0.034092	1.576	0.11499	
Pfr	0.033057	0.031325	0.03185	1.038	0.29932	
Ppa	−0.028436	0.029069	0.029566	0.962	0.33616	
Lden	−0.031387	0.052179	0.053071	0.591	0.55425	

Note: *p = .05, **p< .001, ***p< .0001.

4. DISCUSSION

Our results shed light on an important component of HWC and reveal that the HWC related wildlife mortality in Nepal is escalating, and is largely associated with human casualties, the proportion of agricultural area and the literacy rate of people within districts. The correlation between wildlife and human mortality indicates that retaliatory actions (from humans) play an important part in wildlife mortality.

The incidence of casualties is particularly common in human-dominated areas due to shared use of resources (Acharya et al., 2016; Bhandari, Mawhinney, et al., 2019). Among different types of HWC, crop raiding, livestock loss, and human loss are the most prominent causes (Acharya et al., 2016; Baral, Sharma, Rimal, et al., 2021; Bhandari & Chalise, 2016). Similarly, wildlife killing as a retaliatory action against crop loss and livestock depredation is one of the major reasons for wildlife death (Baral, Aryal, et al., 2022; Bhandari and Chalise, 2016; Karanth et al., 2019; Mateo-Tomás et al., 2012). The correlation between the proportion of agricultural land and retaliatory killing of wildlife confirms such a trend. The greater the agriculture land near the forest, the greater the chance of crop and livestock loss by wildlife. Consequently, these species are highly victimized by local people, mostly farmers. Moreover, the lower literacy level of the people is also responsible for the higher rate of wildlife killing. Illiterate people may have lower awareness of the ecological value of wildlife and are more likely to retaliate when their livelihood is damaged by wildlife (Bhandari, Mawhinney, et al., 2019). Similarly, illiterate people usually sustain their lifestyle with a higher dependency on agricultural practices and livestock rearing activities in rural areas, which increases the possibility of their encounter with wildlife. This encounter likely results in casualties of wildlife due to retaliatory action of those people in response to livestock/property loss.

Our results showed that a majority of human losses were primarily attributed to the attacks by leopards in the mid-hill physiographic region of Nepal. A high number of human casualties due to leopard attacks was reported in the central mid-hills of Nepal, resulting in an average of 12 leopards being killed annually in retaliation between 2015 and 2019 in the same region (Baral et al., 2021). These higher conflicts between humans and leopards could be primarily associated with lower prey availability in the forest (Sharma et al., 2021). Leopards' primary prey species are ungulates (i.e., barking deer and wild boar), and their populations in the mid-hills have declined significantly in recent years (Baral et al., 2021, 2022). Moreover, people in mid-hill areas are mostly farmers with agro-pastoralism, with forest-dependent livelihood, and cattle herding practices, which can lead to increased leopard mortality due to retaliatory actions. At the same time, with the increasing human presence in and around the leopard's habitat for hunting, poaching, timber, and firewood collections, they also result in a higher rate of deliberate and fateful encounters between humans and leopards. Leopards generally inhabit mid-hill regions (between 500 and 3000 m), and their population will likely decrease in the near future due to habitat loss, loss of prey, and habitat fragmentation (Baral, Sharma, Rimal, et al., 2021; Bhandari et al., 2021; Bhandari, Mawhinney, et al., 2019; Sharma et al., 2021). Such a situation is concerning not only or leopards but also for overall wildlife conservation (Acharya et al., 2016; Baral et al., 2021; Bhandari, Mawhinney, et al., 2019; Pant et al., 2016).

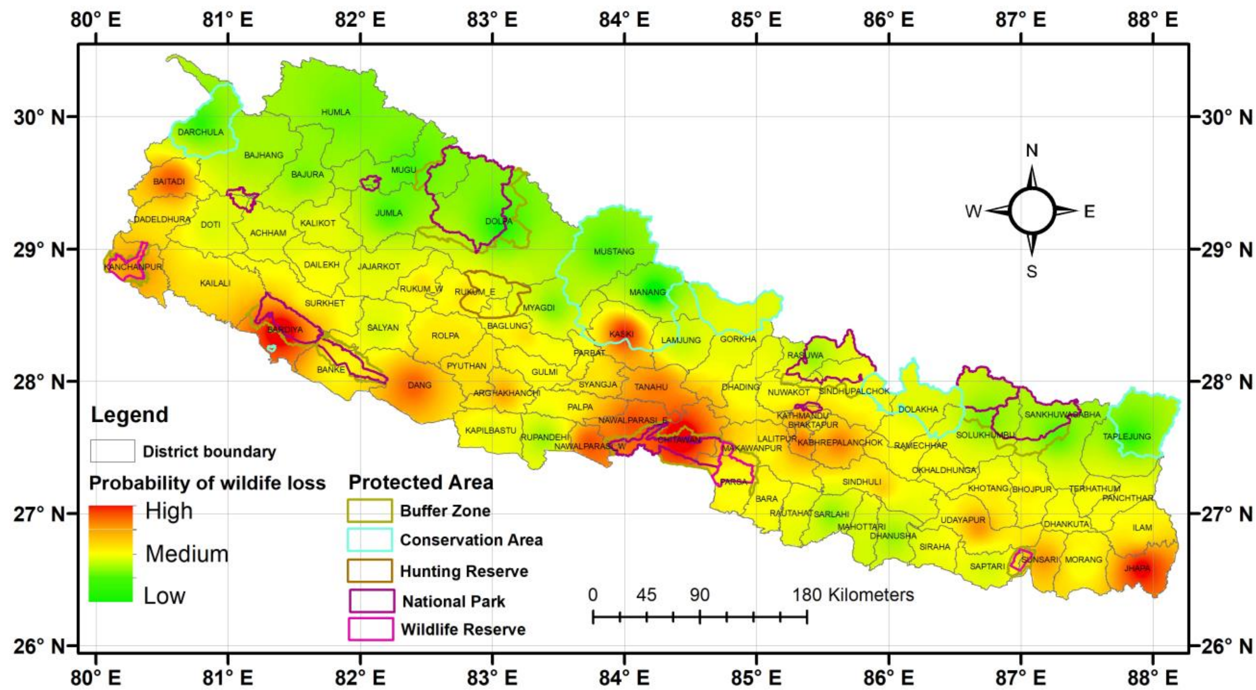

Figure 5: A map depicting the likelihood of wildlife loss based on model averaged coefficients of the best fit models. Green represents a low probability of wildlife loss (0-0.40), yellow a medium probability (0.40-0.60), and red a high probability (0.60-1).

Livestock depredation, human casualties, and poaching for pelts (Bhattarai et al., 2019; Bhattarai & Fischer, 2014; Eklund et al., 2020) are regarded as some of the major causes for tiger mortality. Human deaths from tiger attacks were significantly higher near PAs than in other areas (Bhattarai & Fischer, 2014; Dhungana et al., 2018; Gurung et al., 2008). The trend of human deaths due to tiger attacks in places such as Chitwan National Park (CNP) has increased significantly, from an average of one person per year prior to 1998 to seven people per year after 2000 (Gurung et al., 2008). Over 70% of the tiger population refuges in the CNP and Bardiya National Park (BNP) (Bhandari, Aryal, & Shrestha, 2019). However, in recent times, tigers have been recorded even in the mid-hill regions (Illam and Dadeldhura districts). This expansion of the range could be attributed to two major factors. First, the recent increase in the population of tigers could have potentially forced them to search for new habitats. Second, the restoration of north-south corridors and increased linkage between habitats in lowlands and uplands may have created a favorable scenario for tiger range expansion in the mid-hills region. With the increased population of tigers in recent days and the expansion of tiger range, more conflict incidences can be presumed to follow in coming days if proper habitat management techniques (prey restoration, habitat management, etc.) are not efficiently implemented.

According to our research, anthropogenic factors are also contributing to the mortality of elephants and rhinos. The human caused mortality of elephants is also gradually increasing in Nepal. The average mortality rate for the elephant was 1.5 per year during 2000–-2020. However, anthropogenic mortality of rhinos was found to be decreasing in recent years, with an average of eight rhinos killed per year during the study period. These species are also responsible for the killing of people. Elephant attacks killed 14.1 people on average per year, whereas rhino attacks killed 3.3 people. The incidence of human casualties attributed to elephant attacks has been surging rapidly in recent years (Ram et al., 2021). These large herbivores prefer feeding on diverse types of plant species as well as frequently visit human settlements and agricultural lands near protected areas to feed on crops. These incidences are quite common at CNP, BNP, Sukhaphanta National Park (SNP), and Koshi Tapu Wildlife Reserve (KWR) (Koirala et al., 2016; Short, 1981). This pattern of resource use near a human-dominated landscape can lead to HWCs and may result in both human and wildlife casualties (Bhandari, Adhikari, Baral, & Subedi, 2022; Martin et al., 2009). In addition, these mega herbivores using farms, roads, and human trails for their movement may also damage infrastructure and increase HWC (Bhandari, Adhikari, Baral, & Subedi, 2022; Shaffer et al., 2019). Similarly, loss of the natural habitat of these mega herbivores and fragmentation of biological corridor forests in southern Nepal, especially for elephants, has aided in the escalation of human-elephant conflicts (Yadav, 2007). Nepal's lowland forest or Chure hill forest contributes as a major corridor for elephant migration, where elephants migrate between Nepal and India (Dhakal & Thapa, 2019; Pant et al., 2016). In most of these areas, elephant migratory routes have been destroyed and converted into villages and agricultural land, leading to increased human and elephant conflict. Human killings by rhino attacks were relatively lower than elephants. This may be because rhino populations are concentrated in a few pocket areas within Nepal, such as CNP and BNP. Most of the victims in CNP between 2003 and 2013, including fatalities and losses of property, were mostly associated with the crop loss by rhino (Ruda &Kolejka, 2020). Large amounts of crop damage may be one of the major causes of the killing of rhino (Bhandari, Adhikari, Baral, & Subedi, 2022). Similarly, poaching could contribute to rhino mortality. However, there has been a decrease in poaching in recent years, but it has not stopped completely.

The heatmap created using the coefficients from the best fit models revealed that the southern lowland districts (i.e., Kanchanpur, Bardiya, Dang, Nawalparasi, Chitwan, Sunsari, and Jhapa) have the highest likelihood of loss for these large mammals. The fact that these habitats are home to all four large mammals may be one of the major factors contributing to the higher likelihood of wildlife mortality in this area. The higher percentage of agricultural lands in these districts and the greater number of human casualties could be considered additional factors. While several mid-hill districts (i.e., Baitadi, Argakhachi, Kaski, Tanahun, Kathmandu, and Lalitpur) had a higher likelihood of mortality, the majority of the mid-hills showed a medium probability of wildlife mortality. The loss of wildlife in the mid-hills is mostly represented by the events of leopard loss. Our study supported the findings of previous studies as high human leopard conflict is frequently reported from the mid-hill areas (Acharya et al., 2016; Adhikari, Baral, Bhandari, Kunwar, &

Subedi, 2022; Baral et al., 2021; Pant et al., 2016). On the contrary, the high Himalayan regions had a very low probability of wildlife loss, particularly because the studied species are largely absent in these areas.

On the basis of a secondary database of HWC on Nepal over two decades, our study illustrated the overall scenario of the human large mammal conflict with a focus on the attributes of anthropogenic mortality of four threatened species within Nepal. However, a large number of HWC events may go unreported to authorities and thus be absent from the database. Hence, the actual number and incidences of conflicts could be potentially higher than the reported cases. For example, tigers, leopards, elephants, and rhinos are among the protected wild species of Nepal. As killing those species is illegal, people may hide such information. Similarly, in some remote areas in Nepal, where there is limited access to communication, HWC incidents might not be reported to the authorities. Nevertheless, our study included vital HWC information for over two decades, gathered from reliable sources, therefore, these results represent the overall scenario of human-large mammal conflict in Nepal.

5. CONCLUSIONS

This study concluded that anthropogenic mortality of large mammals has been increasing in recent years, posing a challenge to the conservation of threatened species such as the tiger, elephant, rhino, and leopard. Managing human large mammal conflict and mitigating retaliatory killing of those species is particularly challenging due to retaliatory emotions associated with human casualties, livestock losses, and property damage. Mortality of large mammals increased with the number of human casualties and the proportion of agricultural land within the district, whereas it decreased in the districts with a higher literacy rate. In order to reduce the mortality of large mammals, potential retaliatory actions by local people should be strictly controlled. Similarly, habitat fragmentation should be controlled, and local people should be motivated to inform the conservation authorities in the event of conflict. Extension of conservation education and conflict mitigation programs among high wildlife mortality districts is imperative for sustained wildlife conservation. At the same time, the database on human casualties and wildlife loss should be upgraded at the local and national level and integrated into national and provincial level planning, particularly outside PAs.

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Chapter Three

Human-wildlife conflicts in mid-hill regions outside Protected Areas of Nepal

Summary

(Photo: Kedar Baral)

In Nepal, the mid-hill ecosystem is highly human dominated and people depend heavily on forest resources for their subsistence. Hence, interaction between wildlife and humans is unavoidable. On the other hand, the area is underrepresented in the Protected Area system, and as a result, wildlife conservation and of human-wildlife conflicts management are given lower priority by the government. This chapter discusses the causes, patterns, and consequences of human-wildlife conflict, as well as mitigating techniques for resolving these conflicts. The chapter contains two studies.

Study I: **Characterization and management of human-wildlife conflicts in mid-hills outside protected areas of Gandaki province, Nepal**

(Publised in PlosOne; DOI: https://doi.org/10.1371/journal.pone.0260307)

ABSTRACT

With the intent for better management human wildlife conflict (HWC) and wildlife conservation in mid-hills outside protected areas of Gandaki province, Nepal, I analyzed the patterns and drivers of HWC. Using data collected from literature, government records and questionnaire survey, we investigated temporal, seasonal and spatial distribution of human casualties caused by wildlife attacks. I also appraised the perception of local people towards wildlife conservation. I have recorded 77 cases (69 human injuries and 8 mortalities) during the period of nine year between 2011 and 2019. The number of wildlife attacks increased over this period. Wildlife attacks were more frequent in winter with 50% (42) of attacks occurred between September and December. Common leopard (*Panthera pardus*) and Himalayan black bear (*Ursus thibetanus laniger*) were the major species involved in these conflicts. Common leopard was the most feared species that caused highest number of human mortalities (87%, n = 67); the most severe type of HWC outcome. Forty-eight percent (n = 37) attacks were reported at human settlement areas followed by 27% attacks in agriculture land (n = 21) and 24% (n = 19) in forest. Generalized linear model analysis on spatial variables showed that the probability of human attacks increases with decreasing elevation ($\beta = -0.0021$, $Z = -1.762$, $p = 0.078$) and distance from the forest ($\beta = -0.608$, $Z = -0.789$, $p = 0.429$). We recommend to decrease habitat degradation / fragmentation, carry out habitat management program within forest to increase prey availability to decrease the wildlife invasion into human settlement area, and decrease dependency of people on forest resources by providing

alternative livelihood opportunities. Simplified relief fund distribution mechanism at local level also helps alleviate the impact of HWC. The knowledge obtained by this study and management measures are important for better human-wildlife co-existence.

1. INTRODUCTION

The Human-Wildlife Conflict (HWC) refers to the interactions between human and wild animals that results in negative consequences on livelihood and life of people and or wild animals [1]. HWC dates back to human prehistory. The earliest forms of HWC occurred in the form of predation of early hominoids by wild animals or vice-versa [2]. HWC occurs in different contexts involving a range of animal taxonomic groups [3-5]. It is a common issue in the Himalaya region where wildlife and people co-exist [6] and share the limited resources [5]. This region exhibits great propensity for HWC due to its rich biodiversity, heavy reliance of people on forests, cropland and animal husbandry for livelihoods [7, 8]. A high degree of dependency on forest ecosystems and prevalent poverty has led to unsustainable extraction of forest products and conversion of forests into agricultural land [9]. HWC incidences have increased as poaching, deforestation, habitat degradation and fragmentation and overexploitation are escalated [10] with increase in human population [11, 12].

The common forms of HWC in the Nepal Himalaya are crop raiding, property damage, livestock depredation and human-injuries and mortalities caused by wildlife attack [13, 14]. Among these types of HWCs, the latter two have the highest cost [15, 16]. Common leopard (*Panthera pardus*) causes the highest number of human attacks in Nepal, followed by wild elephants [6]. The occurrence of leopard attacking humans in Nepal is higher than that of any-where else within leopard distribution range [17]. Leopard attacks occurred in all regions outside the protected area system (PAs) and mid-hills of Nepal [18, 19] which have severely impacted the traditional agricultural and farming practices [20–22].

Most of the protected areas (PAs) in Nepal are established to conserve large mammals. HWC caused by the large mammals such as Asian elephants (*Elephas maximus*), greater one-horned rhinoceros (*Rhinoceros unicornis*) and tigers (*Panthera tigris*) has been increasing due to increase in their populations since the establishment and implementation of PAs [23, 24]. The increased competition among animals within PAs may have triggered the invasion of wildlife to areas outside PAs, resulting in frequent HWCs [7]. In the last five years, over two third of HWC incidences in Nepal occurred outside of PAs [25, 26]. Around 40% of the forest areas outside PAs have been managed under the community forestry programme [6]. Due to the successful implementation of community-based forestry program in the last three decades, degraded forests have been restored and recovered the wildlife population in mid-hills outside PAs, promoting free movement of wildlife [27–30]. Such situation has increased the encounter of local people with wildlife resulting in increased HWC.

The forest habitats including community forests outside PAs in mid-hills ecosystem of Nepal are surrounded by the large human population [21], and hence the landscapes are human dominated. HWC is mostly associated with the local livelihood [31, 32] since the dependency of people is very high on forest resources to sustain their life. The use of forest resources / area for summer grazing, herding, collection of plants and harvesting of forest products i.e., timber, fuel-wood from forests and forest fringes are still persistent among people of studied districts [33, 34]. HWCs occurred in human settlement outside PAs while people carrying out such activities [35–37]. However, the management of HWC at landscape level addressing the issues outside and inside PA are limited [38]. Hence, management of HWC outside PAs and decreasing dependency of people on forests resources are therefore urged [32].

The studies on the causes, and characteristics of HWC outside the PAs in mid-hills and central Nepal are scarce [15, 26]. Outside PAs of Nepal, HWC incidences are very frequent [37] and Himalayan black bear and leopard are the main wildlife species responsible for attacking human [39, 40]. Their ecology and interactions with human are poorly studied. Understanding the patterns and causes of Human-Wildlife interactions outside PAs of Nepal is most pertinent in formulating conservation policies to mitigate HWC and improving the local livelihood. In this study, we examine the extent and magnitude of HWC associated with casualties and injuries of wildlife and human, assess the spatio-temporal distribution of HWCs involving human casualties and recommend the strategies for future conservation planning.

2. METHODS

2.1 Study area and site description

Five districts, Parbat, Lamjung, Syangja, Tanahun and Kaski (hereafter referred to as PLSTK) (27˚55' - 28˚26' N, 83˚58'– 84˚25' E) were selected as study area (Figure 1). These districts have human population of about 1.4 million, many of whom live in remote and isolated areas with poor access to markets and easy access to forest resources. These five districts cover the area of approximately 7,000 km^2 and represent lowlands (60 to 1000 m asl), mid-hills (1000 to 3000 m asl) and high mountainous area (3000 m to 5000 m asl) of central Nepal. The high mountainous part of Kaski and Lamjung districts shares 11% of Annapurna Conservation Area (7,629 km^2), the largest PA of Nepal. The mid-hill region (also known as middle Mountain) is characterized by sub-tropical and temperate bio-climates with a great variety of terrain types, ecosystems and wildlife [41, 42]. Broad-leaved, coniferous and oak-laurel forests are common in mid-hills [43].

Over 50% of country's' population lives in hills and mountains [44]. The hills and mountains not only have the highest percentage of poverty (42%) on average, but it is also increasing [45].

Within the study sites, Devghat, Tanahun district represents the lowest elevation and tropical bio-climate (187 m asl) whereas the Lwang-Ghalel (~ 2500 m) of Kaski district, Chimkeswari (2325 m) of Tanahun, Panchmool (~ 2600 m) of Syangja district, Dahare-Deurali (~ 2600 m) of Parbat district and Bahundanda (~ 2600 m) of Lamjung district represent the highest elevations and temperate bio-climates. The study sites cover a big section of Chitwan Annapurna Landscape (CHAL) corridor. The CHAL represents north-south corridor and connects alpine high mountains in north to tropical lowlands in south through Gandaki watershed. The Gandaki watershed connects Marsyangdi (Lamjung), Madi (Tanahun), Setigandaki (Kaski) and Kaligandaki (Parbat and Syangja) sub-river basins. These sub-river basins boast high bio-diversity and supports rich natural, social and cultural heritage [43]. It is an important transit route for migratory birds and is home to endangered species such as common leopard, red panda *(Ailurus fulgens)* and Himalayan black bear [30, 46].

Total population of PLSTK districts is 1318848 [47], with population density 219 people per KM^2. Majority of the people (76.86%) live in the rural area and agriculture is the mainstay of local livelihood. Most of the rural settlements are close to the forest area and fuelwood is the major source of energy [48]. Other livelihood strategies include animal husbandry, summer grazing, and collection, use, and trade of forest products. The dominant ethnic groups Gurung and Magar comprised of about 35% of the total population of the area [47], are mountain dwellers, sheep herders, cattle grazers and trans-himalayan traders [34] who often confront with wildlife in the mountain rangelands [33, 49, 50].

2.2 Data collection

We received human ethics research approval 4000023041 from Massey University New Zealand for our research. Prior to fieldwork and interviews, we also received written consents from the division forest offices and oral consents from participating individuals. HWC data of the study districts were collected from both published articles and the government reports relevant to this study. HWC databases of PLSTK division forest offices between 2011 and 2019 were reviewed.

Data records only after 2010 were logged when the official recording of wildlife damage for compensation scheme was formally started. Information of 77 cases of human attacks (injury and death) was collected from the records of PLSTK division forest offices (DFO). Divisional forest officers were consulted to crosscheck the data and gather S1 File. Field visits were made to meet the victims and persons accompanying the victim, and to observe the sites of attack. We visited the sites of 12 attacks including all eight human deaths. Numbers of the field visits on the PLSTK districts were proportionately selected based on the total number of the conflict events in the districts. Since Tanahun district has high incidents of human-wildlife conflict, we visited all six sites (Nareshowartar, Purkot, Khahare, Bhansar, Samjur and Mirlung) of human death in Tanahun. Field observations of conflict sites and checklist surveys of the victims and accompanying people were carried out between March and December 2019 to verify the sites and conflicts, and to collect additional information regarding the perception of people and management options. We conducted 36 interviews with the victims of HWCs and another 21 interviews with the persons accompanying the victim during the attack, or immediate family member who was well aware of attack details. Personal details during the interview were maintained confidential and, in the analysis, process the name were omitted by recording a code to keep the interviewees anonymous. We used a semistructured checklist to conduct the interviews. Interviews were conducted in Nepali language with the help of a forest ranger and local assistants.

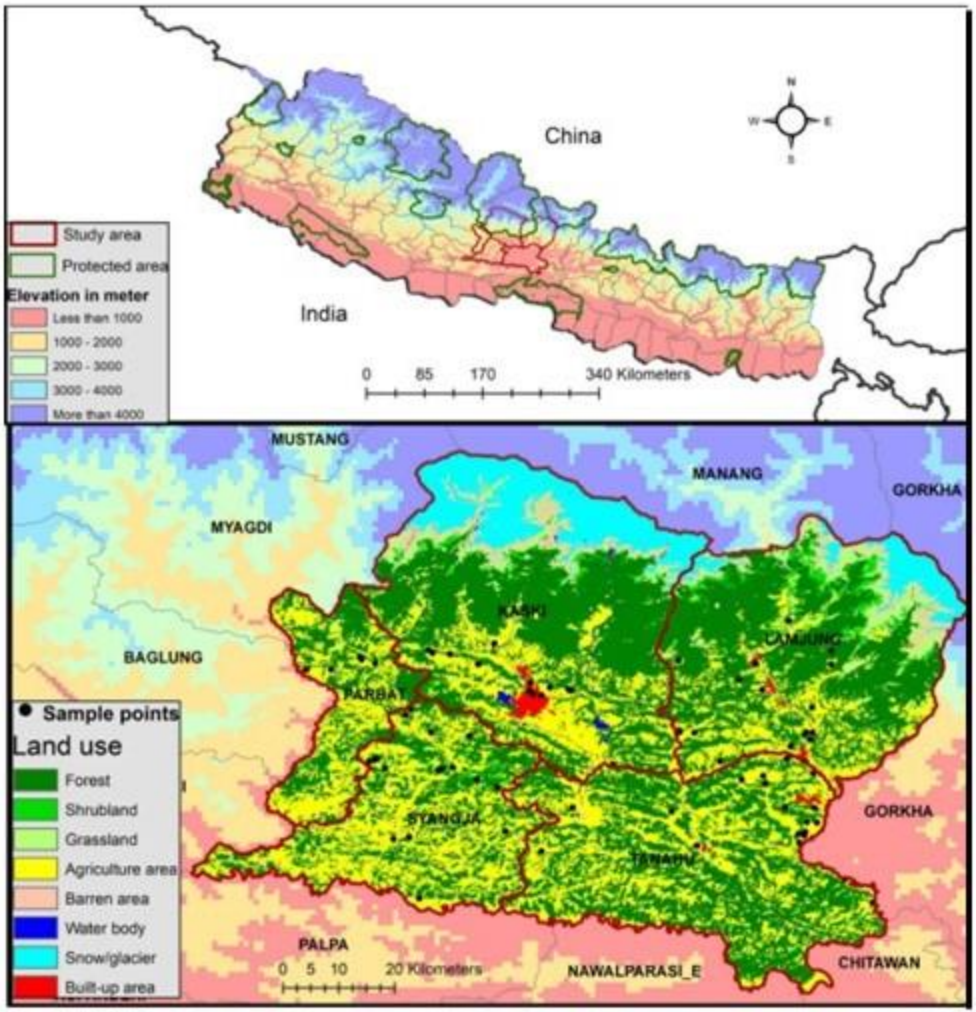

Figure 1: Location of study area showing the districts, elevation, land use and points of wildlife attacks. "Republished from [51] under a CC BY license, with permission from ICIMOD, original copyright 2010".

2.3 Data analysis

We collected four types of variables associated with human-wildlife attacks; species and number of wildlife involved in human attacks, temporal variables include year, month, season and time of attacks (0–4, 5–8, 9–12, 13–16, 17–20 and 21–24 hours), socio-demographic variables include the gender, occupation, and age group of the victims, and spatial variables include district, elevation, distance between point of attack and forest, and land use (forest, agricultural land, road and settlement) (S1 File). We classified attack locations according to land use as forests, agricultural fields, and settlement area. The distance from the casualties and nearest forest edge was measured in Google Earth in order to test whether the HWC is a function of distance. The data associated with demography and socio-economy was aggregated and decoded for confidentiality of the respondents.

We conducted multivariate logistic regression with the entire independent variables [total of 11 variables: temporal (year, month, season, time), socioeconomic (gender, occupation and age group of the victims), and spatial (district, elevation, distance between point of attack and forest), and land use (forest, agricultural land, road and settlement)] in the model to understand the relationship between predictive and explanatory variable (human death and injury due to wildlife attack). However, no single variable independently predicted the attacks in the analysis, and this could be a reason of the large volume of dataset, and the diverse nature of variables.

We conducted two different statistical approaches following Naha et al. [52]. Chi-square test of independence was used to understand the association between temporal (year, month, season and time), and socio-demographic variables (gender, age and occupation) with the wildlife attacks. We classified victims into four age groups, < 20, 21–40, 41–60 and > 61 years. The association between socio-demographic and temporal variables and the attacks were analyzed using Pearson chi-square test (Table 1). For the spatial dataset, we conducted a generalized linear model with binomial distribution to predict the effect of variables on the wildlife attacks following Acharya et al. [6]. We used a priori candidate model and ranked them based on Akaike Information Criterion (AIC) values. Those models with lowest AIC values were considered the appropriate for explaining the wildlife attacks (Table 2).

Table1: Association between socio-demographic, ecological variables and human wildlife conflict.

	Variables and sample number	**Coefficients**		
		Chi-square	**df**	***p* value**
Gender	Female (D = 3, I = 13)	0.594	1	*0.440*
	Male (D = 5, I = 56)			
Age	0–20 yrs (D = 6, I = 6)	24.118	3	*0.002*
	21–40 yrs (D = 0, I = 19)			
	41–60 yrs (D = 1, I = 32)			
	61–84 yrs (D = 1, I = 12)			
Occupation	Farmers (D = 2, I = 46)	19.587	2	*0.005*
	Forest product collectors and passersby (D = 0, I = 15)			
	Others (D = 6, I = 8)			

df = degree of freedom, D = death, I = injured.

A model with a ΔAIC (the difference between the two AIC values being compared) less than 2 is considered significantly better than the model it is being compared to. The number of attacks per year was summarized in terms of mean (M) and number of events with regard to different spatial, temporal and socio-economic variables were analyzed by using percentage. The variability was recorded in terms of SE and at confidence interval of 95%. Statistical analyses were undertaken in R statistical software (R Core Team 2016; Version 1.0.44).

3. RESULTS

3.1 Human wildlife conflict

Seven types of conflicts (crop raiding, livestock depredation, human attacks, traffic collision, disease transmission, property damage and mental distress) and associated 663 HWC cases were recorded in five study districts between 2011 and 2019, based on our review and field observations. Among the HWC types, livestock depredation and crop raiding were the most common. There were 77 (12%) cases pertaining to wildlife attacking to human, and these were used for further analyses (Figure 2). Out of these 77 cases, 67 (87%) cases were involved with Leopard and nine with Himalayan black bear.

Table 2: Akaike Information Criterion (AIC) scores of generalized linear models with binomial structure predicting human attacks by wildlife in Parbat, Lamjung, Syangja, Tanahun and Kaski (PLSTK) districts, Nepal.

Models	***df***	***AICc***	***ΔAIC***
District	5	49.2	0
District + Distance from forest	6	50.9	1.71
District + Elevation	6	51.2	2.02
District + Land use	8	51.4	2.21
Elevation	2	51.5	2.36
Elevation + Land use	5	52	2.83
District + Elevation + Land use	9	53.1	3.93
District + Distance from forest + Elevation	7	53.2	3.97
Null	1	53.4	4.24

ΔAIC is the difference between the AICc value of the best-supported model and successive models, and df= degree of freedom, Δ = delta.

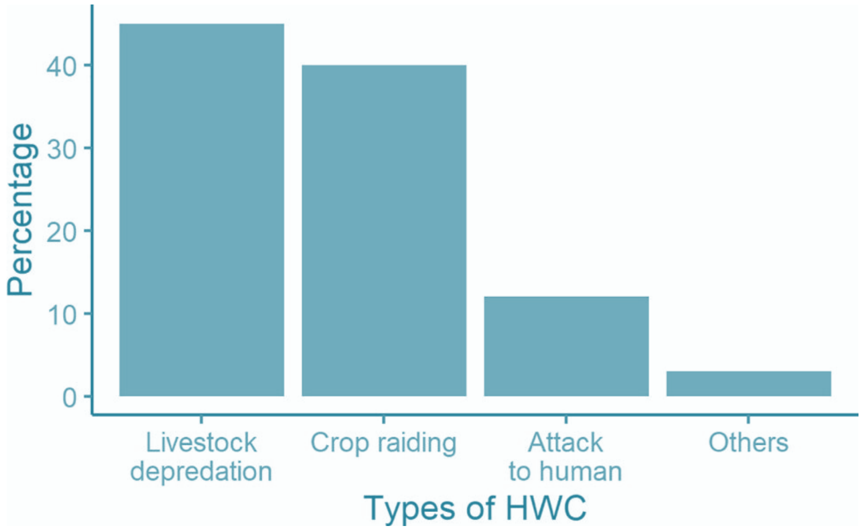

Figure 2: Types of HWC (Livestock depredation, crop raiding, attack to human and others) in PLSTK districts during 2011 to 2019.

3.2 Temporal variations of attacks

The mean number of humans attacks per year was 8.55±1.15 (injuries 7.66 ± 1.13 and the deaths 0.88 ± 0.84). Incidence of human attacks was increasing over the period of nine years, ($\chi 2 = 0.232$, df = 76, $p > 0.05$) (Figure 3). The frequency of human attacks varied with month and season ($\chi 2 = 152.08$, df = 76, $p < 0.001$, and $\chi 2 = 13.39$, df = 3, $p < 0.05$ respectively) with highest frequency of human attacks occurred in winter (December-March) and lowest in summer (July-August) (Figure 3). A high proportion of attacks (42%) occurred between September and December. The frequency of attacks varied with time of the day ($\chi 2 = 134.45$, df = 76, $p < 0.001$). The highest percentage of attacks (45% injuries and 62% killings), was recorded between 15.00 pm and 19.59 pm.

3.3 Socio-demographic characteristics of victims

Of the 77 victims, 79% (n = 61) were male and 21% (n = 16) were female. There was no difference in the proportion of male and female victims ($\chi 2 = 0.59$, df = 1, $p > 0.05$). Victims' ages ranged from 3 to 84 years at the time of attack. Most victims (42%, n = 33) were 41 to 60 years old followed by 24% (n = 19) 21 to 40 years old. The chi-square test showed a significant difference in occupation and age groups of the victims ($\chi2 = 19.58$, df = 2, $p < 0.05$) and ($\chi2 = 24.11$, df = 3, $p < 0.05$) respectively (Table 1).

3.4 Spatial pattern of human attacks

Between 2011 and 2019, eight people were killed and 69 were injured in five districts. All eight human deaths, six in Tanahun and two in Syangja were attacked by common leopard. Of the 77 human casualty cases, 6 human deaths and 16 injuries were reported from Tanahun followed by 18 injuries in Lamjung and 16 injuries and 2 deaths in Syangja. The lowest human injuries (n = 5) were recorded for Parbat district. Within the district, Bhanu municipality of Tanahun district was the most vulnerable to leopard attack and six children were killed within a period of two years between 2018 and 2019. Besides Leopard attack, Tanahun and Lamjung districts were also vulnerable to bear attacks (Table 2). Attacks by bear were mostly confined inside forest. The Chi-square test showed a significant difference in attacks among the districts ($\chi2 = 11.035$, df = 2, $p < 0.05$) and land use categories ($\chi2 = 10.04$, df = 2, $p < 0.05$). Higher number of events were happened in Tanahun district compared to other districts. On the other hand, significantly more attacks were held on human settlement areas.

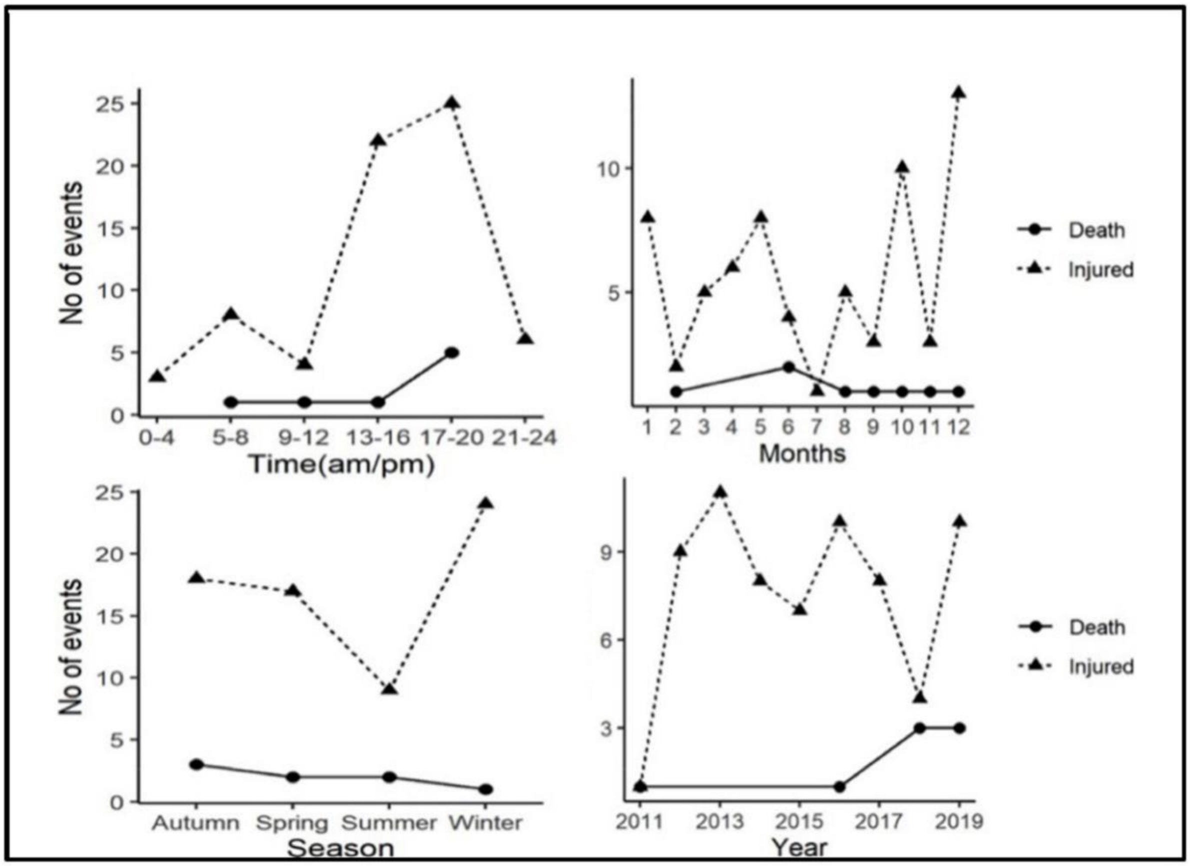

Figure 3. Temporal distribution of HWCs in PLSTK districts during 2011 to 2019 showing time month, season and year of the events.

In contrary, the leopard attacks were recorded mostly from nearby of settlement and agriculture lands. Forty-eight percent (n = 37) attacks were reported at human settlement areas. There were 27% attacks in agriculture land (n = 21) and 24% (n = 19) in forest (Figure 4). GLM analysis on spatial variables demonstrated district location as top important variable for predicting wildlife conflict followed by distance from forest (Table 2). The probability of human attacks increases with decrease in elevation (β = -0.0021, Z = -1.762, p = 0.078), and distance from the forest (β = -0.608, Z = -0.789, $p< 0.05$).

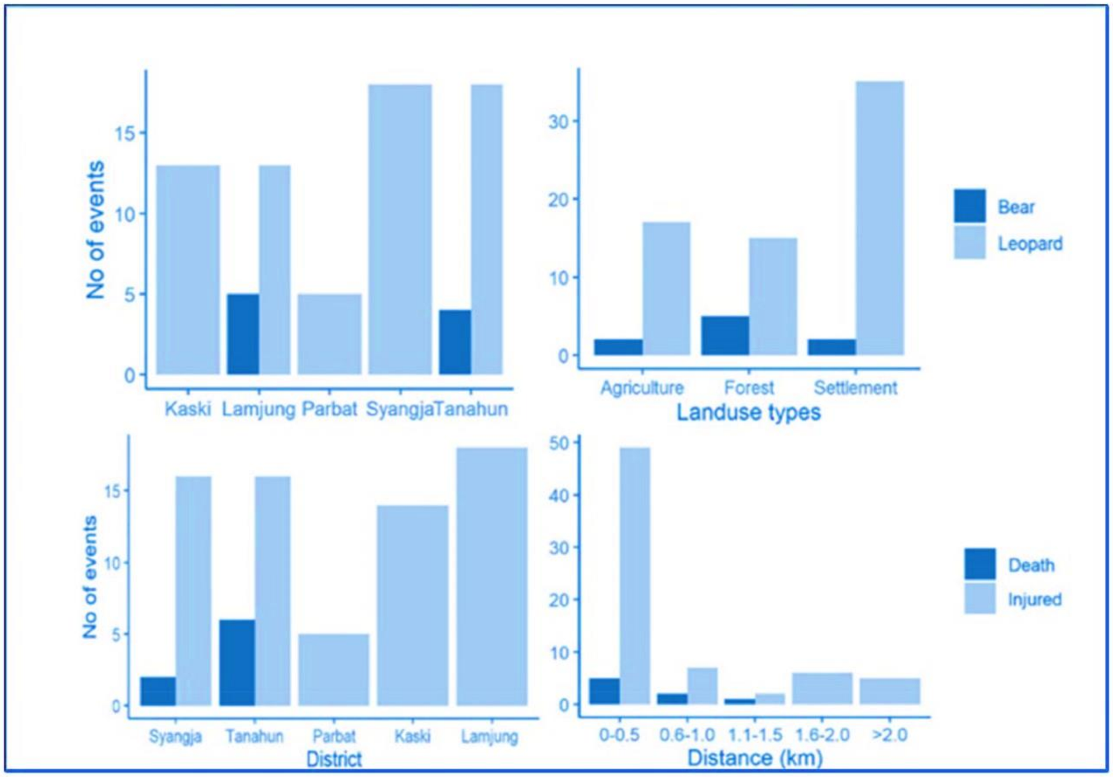

Figure 4. Spatial distribution of HWCs in PLSTK districts during 2011 to 2019 showing events by districts, land use type and distance of the event site from the forest.

4. DISCUSSION

4.1 Human attacks

DFO records of five districts (Parbat, Lamjung, Syangja, Tanahun and Kaski) shows that mainly two wild animals (leopard and Himalayan black bear) involved in attacking humans while there are 26 wildlife species causing human-wildlife conflicts and 13 triggering severe human attacks in Nepal [53–55]. Of these animals, leopard attacked 67 people and Himalayan black bear injured nine indicated that the leopard attacks were not accidental and severely threatened local people and their livelihood. The studies in other mountain areas of the world also found that Himalayan black bear and leopard are the major mammals responsible for human attacks [39, 40, 55–58]. Big mammals like elephant, tiger and leopard are potentially dangerous in causing property destruction and inflicting injuries to people elsewhere [59]. There were 441 leopard attacks in Nepal over a decade between 1994 and 2004 [58]. Over two third leopard attacks were recorded from human settlement areas and agriculture land. This shows that the human leopard conflict has been a serious issue in Nepal for a long time.

The average number of attacks per year was 8.55 (SE 1.15), including 7.66 (SE 1.13) injuries and 0.88 (SE 0.84) deaths. Similar finding of average seven injuries in a year was recorded in Chitwan district, central Nepal [23]. The records in our study area were less than that of Pauri Garhwal, India where the average injuries and death per year were 11 (SE 1.13) and 3 (SE 0.6) respectively [60]. The higher number of attacks in Pauri Garhwal is probably due to the higher population density (130/sq km) than our study area (110/Km^2). The Pauri district (area 5230/ Km^2) of India bordering the western Nepal has similar mid-hill types of physiography and sub-tropical climate. Similarly, the forest cover in Pauri is higher (64%) than our study area (32.5%), which may inhabit larger population of leopard.

Human attacks by Himalayan black bear are considered to be the most ubiquitous form of conflict in the mid-hills of Nepal [55]. All nine attacks by Himalayan black bear were recorded at Tanahun and Lamjung districts. Similarly, within the Panchase Protected Forest, which lies across three study districts (Kaski, Syangja and Parbat) four cases of human casualty were associated with Himalayan black bear [26]. Panchase is the area where the agro-pastoralism is still prevalent. Human casualty is common in mid-hills where the livelihood is agro-pastoralism. A study of Nepal Trust for Nature Conservation (NTNC) from 2005 to 2013 [57] catalogued six cases of Himalayan black bear attacks in Manaslu Conservation Area, Gorkha, Central Nepal. It indicates that the Himalayan black is also a major wildlife causing HWC in mid-hill physiographic region of Nepal.

4.2 Distribution of HWC

Our study area is among the areas of highly vulnerable to HWC. Despite the vulnerability, the human attacks in our five study districts were varied with magnitude. There were eight death reports, all from the leopard attacks and only occurred in two districts (six in Tanahun and two in Syangja). It might be due to the higher habitat destruction and less availability of prey species in forest in these districts. In Nepal, 75 out of 77 districts have been suffering from HWC, with Jhapa, Baitadi, Tanahun, Kaski, Arghakhanchi, Manang, Mustang districts being the most suffered [58]. Tanahun and Syangja districts truly represent the mid-hill physiography are found to be the most vulnerable for HWC. Tanahun district has the highest livestock holding size (3.72) compared to the rest districts [61]. There were 12 people killed by leopard in Kaski district between 1987 and 1989 [62] indicating the prevalent and persistent of HWC in mid-hills. Leopard is common in mid-hills [63]. Thapa [64] reported that 45 humans were attacked and 14 were killed by leopard in Chitwan Annapurna Landscape (CHAL) between 2006 and 2013. There were seven human injuries by leopard in 2009 in Chitwan district, central Nepal [23]. There were 20 confrontations of leopard in Kathmandu valley between 2010 and 2013 [37]. All these incidences revealed that the central Nepal and mid-hill districts are highly vulnerable to leopard attack [18].

The forest habitats of the mid-hills are surrounded by the large human population. Dense population along with local poverty of people trigger the human interference in wildlife habitat [65] and aggravate HWC at local scale. The hills and mountains have highest percentage of people under poverty (42.3%) and high emigration rate on average, and these have increasing trends [45].

Outmigration caused the lack of working manpower in agriculture land and farm-land resulting in abandonment of agriculture activities. Fallow land promotes the growth of shrubs and bushes connecting wildlife habitat with human settlements. These, in combination of prey shortage in the natural habitats, have facilitated the HWCs [45].

Forty-eight percent of the wildlife attacks (n = 37) reported were from human settlement areas followed by that from agriculture land 27% (n = 21) and forest 24% (n = 19), revealing that the most cases happened in anthropogenic landscapes. Generally, the probabilities of attacking by large carnivores are reported to increase with dense forest [66] but our results suggest that higher risk of human attacks by wildlife are in human settlements. Out of total 77 incidents, leopard attack sites were all in human settlement area and agriculture lands and 75% (n = 58) of these were found within one km distance from the nearest forest. Geographical features of the mid-hills with undulating landscape, presence of small creeks, trees and bushes within and nearby village may make favorable condition for leopard to interact with people. Furthermore, leopard is a generalist species and adapted to living in the forest fringes, nearby human habitations and moderate vegetation cover [60, 67] and avoid confronting with bigger carnivore mammals such as tigers [68]. Leopards tolerate proximity to humans better than bears, lions and tigers and often come into conflict with humans [69]. Tigersare found frequently at lowland Tarai region below 1000 m in Chitwan National Park (100 m– 815 m) and Bardia National Park (150 m–1400 m) [70] and hardly seen in middle mountains [71]. Increasing HWC in mid-hills is likely due to higher dependency of people on forest and the area being extensively extended outside protected area system. Due to the wider spread poverty in study area, people often visit forest area for collecting forest-based fruits, vegetables, nuts etc. [33] and poaching the wildlife to sustain their livelihood [54]. Studies showed that poaching of prey species and habitat degradations are rampant resulting in high number of HWCs in Nepal [6, 18, 64].

4.3 Temporal pattern of HWC

The frequency of human attacks varied with time, month, season and year. There were 52% attacks between 15.00 pm and 19.59 pm in study area, which contrasts with the pattern of leopard attack in Pauri Garhwal where the most attacks (53%) were reported during day time (08.00 am –16.00 pm) [52]. The leopard also attacks in early and late night [72]. We recorded 31% leopard attacks (n = 24) between 17.00 pm and 19.59 pm supporting the crepuscular nature of leopard. Fifty-six percent of human attacks happened in autumn and winter season. This was associated with the frequent movement of people for crop harvesting and forest product collection during this period. The increased human activities were reported as a primary reason of rising leopard attack in India also [73].

The second largest number of human attacks was associated with Himalayan black bear and the most of them were reported between October and February. Our result substantiated the earlier results [35, 74] which reported that the early winter is likely to have greater number of attacks by Himalayan black bear in the mid-hills. Attacks by Black bears during late August to September were recorded high in the Sichuan Province in China coincide with wild mush-room harvesting [75]. In India majority of the crop depredation by Himalayan black bear and conflict with people occurred in between August and September [76] which coincided the time of visitation by rural people for fodder, grasses and firewood [77]. Black bears hibernate at the end of autumn and on the pre-hibernation period they become more active, consume more grains and fruits and travel long distance in search of their preferred food [78], which may have resulted in higher confrontation of black bear with people.

4.4 Characteristics of victims

The middle-aged people (41–60 years old) were attacked more because they were more likely to engage in outdoor occupations. Generally male are engaged in outdoors, and they were found to be frequently attacked (61, compared to 16 of females) by wild animals. Farmers were the major victims of animal attack ($p < 0.05$). As leopard frequently range and refuge near human settlements, farmers in their settlement and farmland are often victimized [69]. Forest product collectors who venture several kilometers into the forests are also likely to encounter with wild animals.

4.5 Causes and impacts

Human attacks by wildlife were found increasing in recent years. There is an increasing trend in the number of human attacks due to wildlife interactions, even in the areas with no previously reported incidents [13, 14]. This trend was consistent to increasing forest cover and PAs management [26]. We reported an increasing forest cover (388 ha/yr) in the PLSTK districts between 1996 and 2016 [69]. Increasing forest cover was also recorded between 2000 and 2010 in CHAL districts [79, 80]. There were several reports of increasing HWCdue to the increase in forest cover [81], attributed by the successful community-based forest conservation programs in the mid-hills and free movement of wild animals to nearby agricultural lands [28, 82–84].

On the other hand, deforestation and forest degradation have led to frequent HWC [85]. In the mid-hills of Nepal, animal husbandry, forest product collection and agropastoralism create competition between local communities and wildlife for the use of natural resources. The situation was worsened as the land-use change resulted population decline of prey species, resulting in increased incidence of wild animal preying on livestock and escalated HWC [85]. Nowadays, because of the increasing urbanization and land use change [86], land abandonment and unattendance of agricultural lands transformed areas into shrub-land covered by invasive plant species [87]. These regenerating areas enabled wild animals to approach human settlement and result in HWC. Increasing HWC due to both increasing and decreasing forest cover is a conservation paradox. The majority of HWC occurred in nearby human-dominated landscapes highlights the need for proper management of areas outside PAs. Thus community-based forest conservation for the sustainable supply of forest products and improve prey population through wise use of lands is crucial in HWC management.

4.6 Human-wildlife conflict management

There are some strategies proposed and implemented to mitigate HWC in Nepal [88]. Control of habitat fragmentation and degradation of wildlife is the foremost one. Carrying out habitat management activities within forest to provide the necessary food, water and shelter to wildlife within forest area is also crucial to decrease the invasion of wildlife in villages. Decreasing dependency of people on forest resources by providing alternate livelihood options such as bee keeping, horticulture of citrus species, and cultivation of spices like turmeric and ginger etc. can help reduce HWC and improve the livelihood of rural communities. Compensation mechanism is a major strategy to promote the human wildlife co-existence. Government of Nepal has started to distribute the compensation / relief fund to the wildlife victimized people for their loss of property and life since 2012. However, its procedures are arduous and time consuming. Thus, a simple procedure of compensation and establishing it at local level will help more effectively mitigate the HWC impact. Removing bushes and invasive species around human settlements should be initiated to reduce wildlife attacks. Without taking into account of spatio-temporal variability and the fate of wildlife seem to be ineffective in mitigating conflicts on a long-term basis [56].

5. CONCLUSIONS

Based on the findings of present study, we conclude that patterns of wildlife attacks on humans are influenced by spatial and temporal factors. Leopard was the major wildlife causingHWC followed by black bear. The conflict ranged from crop raiding, livestock depredation, traffic collision, property damage, transmission of diseases and human attacks. Among them, human attack was the most critical expression of HWC and needs addressing sensitively to liaison the local support for wildlife conservation.

The wildlife attack to human has been increasing and majority of attacks occurred in and around human-dominated landscape, followed by forest. Control of habitat fragmentation, degradation and implementation of habitat management activities within forest are crucial to decrease the invasion of wildlife in human settlement area. Decreasing dependency of poor people on forest by providing alternative livelihood opportunity would helpful to decrease the encounter of wildlife with people. Moreover, simplifying the compensation system to the people victimized by wildlife is necessary to promote human wildlife co-existence.

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Study II: **Human Wildlife Conflict and Impacts on Livelihood: A Study in Community Forestry System in Mid-Hills of Nepal**

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ABSTRACT

Human wildlife conflict (HWC) impacts the livelihood of many rural communities world-wide. This study investigated the impact of HWC on people living near community forests (CF) in Nepal. Using databases provided by the Division of Forest Offices and data obtained from surveys between October 2019–March 2020, we quantified the financial loss of HWC to the local people. Between 2015 and 2019, 3315, or 27%, of the livestock owned by the survey respondents were killed by wild predators in the Kaski and Tanahun Districts. Chicken *(Gallus gallus)* was the most common prey taken (80%), followed by sheep *(Ovis aries)* and goats (*Capra hircus)* (15%), cows (Bos spp.) (2%), pigs (Sus *domesticus*) (2%), and buffalo *(Bubalus spp.)* (1%). Leopards *(Panthera pardus)* were the primary predators, followed by golden jackals *(Canis aureus)*, jungle cats (*Felis chaus)*, yellow-throated martens (*Martes flavigula)*, and Himalayan black bears *(Ursus thibetanus)*. The financial loss of livestock during this period was USD $115,656.00, equivalent to USD $142.61 per household. Crops were also damaged and eaten by wildlife, and 2165 crop-raiding events were recorded between 2015 and 2019. Rice (*Oryza sativa)*, followed by maize *(Zea mays)*, millet *(Panicum miliaceum),* and potatoes *(Solanum tuberosum)* were the main crops lost. Rhesus monkeys *(Macaca mulatta)* were the most common crop raiders, causing 74% of the damage, followed by Indian field mice *(Mus booduga)* (12%). From 2015 to 2019, crop losses equated to USD $83,424.00. Forest regeneration on abandoned agricultural land expanded wildlife habitats, enabling wild animals to come within reach of human settlements, which increased the

likelihood of HWC events. Although the success of the community forest restoration program resulted in increased forest-cover, marginally increasing biodiversity, the reduced distance between human settlements and wildlife habitat, compounded by a lack of natural prey, may have unwittingly exacerbated HWC in this region. We recommend surveying predator and prey populations in the forest habitat, and implementing a habitat management program to improve prey populations within the community forests. Meantime, we propose establishing a financial relief and insurance program for crop and livestock losses at the local community level to alleviate any financial difficulties to the local communities caused by HWC.

1. INTRODUCTION

Human wildlife conflict (HWC) occurs where wildlife and humans coexist and compete for limited resources [1–3]. HWC is more pronounced in areas with an ever-expanding human population, substantial habitat loss or modification, and, in some circumstances, where there has been an increase in forest-cover as a result of successful conservation actions [4,5]). Rural communities, whose livelihood totally depends on agricultural and livestock production, often suffer from economic losses when crops are raided, or livestock are killed by wild animals ([6–8]. Some wild animals, such as leopards *(Panthera pardus),* tigers *(Panthera tigris),* and Asian elephants (*Elephas maximus)*, not only kill livestock, damage people's property, and spread disease, they also occasionally kill and injure people [9,10]. These events, especially those that cost human life, can lead to retaliatory killing of wild animals, including those that are legally protected, endangered, or threatened [11–14]). Consequently, HWC affects both the livelihood of people and wildlife [15], and at the same time, jeopardizes wildlife conservation goals [16,17]. Therefore, implementing conservation plans to mitigate against HWC is critical for safeguarding the lives and livelihood of people and wildlife conservation.

Wildlife conservation formally started in Nepal in 1958 by the promulgation of the Wildlife Conservation Act 1958 [10]. In addition, the WWF (World Wildlife Fund for Nature), in collaboration with the Government of Nepal, launched the first Rhino conservation program in Chitwan Valley in 1967, with the aim to increase the population of the greater one-horn rhinoceros *(Rhinoceros unicornis),* whose population dramatically declined in 1950s [18]. Since then, the government of Nepal has prioritized the protection of several large mammalian species, including endangered tigers and Asian elephants, and their habitat [19]. The initiative was strengthened by creating the National Park and Wildlife Conservation Act (1973). The Government of Nepal also launched a community-based forest restoration program in 1976 to protect natural resources and prevent the unsustainable utilization of natural resources [20].

Community forests (CFs) under the forestry program were government-owned forests handed back to resident communities so that the forest and resources could be locally and sustainably managed. Community forests comprise 39% of the total forest-cover in Nepal, and provide goods and services to 50% of Nepal's population [21]. The CF program was created as part of a Master Plan for Forestry Sector (1988) and Forest Act 1993, and is now the largest forestry program in Nepal. This successful forest management program improved forest habitats and benefited wildlife populations significantly [14,22–25]. Unfortunately, we have also observed more HWC events [11,26,27] due to an increase in wildlife population within the community forests, which has led to an increased number of HWC encounters between people and wild animals [28].

In recent years, many people have migrated from rural areas and mountainous regions to urban environments [29], and have abandoned or neglected their farms [30]. Furthermore, scrub and bush has quickly regenerated on these abandoned farms, allowing wild animals to venture closer to human settlements, resulting in a higher frequency of HWCs [11,31,32]. With fewer farmers working the land in these rural areas, wild animals have taken to attacking unprotected livestock and raiding unsecured crops [33].

Despite an increase in the number of HWC incidents, little data has been collected on the socioeconomic impact of HWC in these areas. Understanding the impact of HWC on the socioeconomic status of local people is essential for designing and implementing effective mitigation plans [34]. Studies on the causes of HWC, to date, have primarily focused on habitat fragmentation and degradation [11]. The combined effects of improved forest-cover in the CF areas alongside the regeneration of abandoned farmland on HWC has not been investigated. This study aims to examine: (1) types of HWCs in Kaski and Tanahun Districts, which are mid-hill regions outside of the protected areas of Nepal; which animal species are involved in HWC events; (3) the socioeconomic impact of HWC on the local communities; (4) whether land-use change and restoration of community forest has led to change in the number of HWC events; and (5) recommended HWC mitigation strategies.

2. MATERIALS AND METHOD

2.1 Study Area

This study took place in the Chitwan-Annapurna Landscape (Figure 1), which is a corridor for large wildlife between Chitwan National Park in the south and the Annapurna Conservation Area in the north. Within this region, we selected the Kaski and Tanahun Districts (27.744–28.625 N and 83.703–84.562 E (Figure 1), which ranges from a low-level (200 m ASL) tropical climate through to a cooler temperate in the high mountains (8091 m ASL: Mount Annapurna). In total, this area covers 3563 km^2. The mid-hill region (also known as middle mountain) is characterized by diverse ecosystems and wildlife [35], flowering and medicinal plants [28], and significant cultural and religious diversity [30,36].

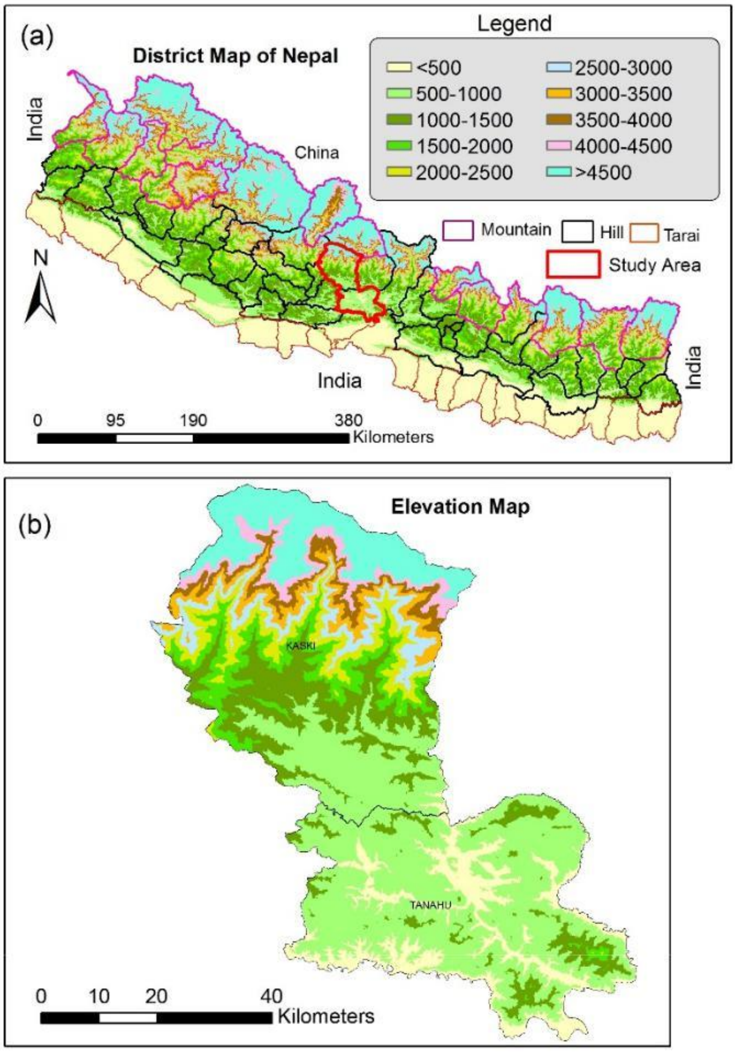


Figure 1. Location Map of study area (a) District map of Nepal with elevation (b) Elevation of Tanahu and Kaski districts

The forest-cover is 1764.42 km^2 (47%) [37], and is dominated by *Shorea robusta, Terminalia tomestosa, Schima wallichii*, and *Castanopsis indica*. The mid-hill region is also rich in wildlife biodiversity, including some species that have been associated with HWC incidences in the past, such as leopards *(P. pardus)*, golden jackals (*Canis aureus*), jungle cats (*Felis chaus*), wild boars (*Sus scrofa*), yellow-throated martens (*Martes flavigula*), barking deer (*Cervus vagianalis*), Indian civets (*Viverrazibetha*), Himalayan black bears (*Ursus thibetanus*), and Indian crested porcupines

(*Hystrix indica*). There are 815,400 people living in this area, of which, 64% are working in agriculture, forestry, and farming [38]. Thus, human pressure on the land and forest is immense.

2.2 Data Collection

There are 1122 registered Community Forests in the Kaski and Tanahun Districts. By consulting with the Division Forest Offices, we selected 40 community forests (20 in Kaski and 20 in the Tanahun District) that ranked high in the reported number of HWC events during 2015 to 2019. Collectively, there were 4120 households listed within the community forest operational plans as of March 2020. We randomly chose 811 (19.68%) households (400 from Kaski and 411 from Tanahun) as respondents for our survey, and visited each household to survey the household members. As women collected more resources from the forests and undertook more farming activities, including animal husbandry, than men, we mainly surveyed the women in each household. Moreover, most males were engaged in other jobs and businesses, and so, could not provide the information we were seeking. All interviewees accepted our request and provided written consent for participating in the survey. All personal data were kept anonymous and confidential by using a coding system. The surveys were conducted in the Nepali language with the help of a forest rangers and local assistants.

Table 1. Major information taken from the respondents during questionnaire survey

Demographic information	**Gender, Age, Family size**
Socio-economic information	Household income level, Occupation, Literacy level
Major crops cultivated	
Major livestock reared	
HWC related information	
A. Crop loss	
	Year-wise types and number of crops damaged by wildlife between 2015–2019
	Wild animal involved in these events
	Did you see which wild animal was involved in these events?
	If you didn't see, how did you identify which wildlife caused the loss?
	What is the current market price of this crop loss?
	Distance of crop loss site from nearest village (<1 km, 1–3 km, >3km)
	What mitigation measures have you been applying to decrease crop loss by wildlife?
B. Livestock depredation	
	Year-wise types and number of the livestock injured/killed by wildlife
	Wild animal involved in these events
	Did you see which wild animal was involved in these events?
	If you didn't see, how did you identify which wildlife caused the loss?
	What is the current market price of this livestock loss?
	Land-use type of event site (settlement, forest, cultivated land/open areas)
	What mitigation measures you have been applying to decrease livestock loss by wildlife?
C. Human attack	
	Year-wise human injury/death caused by wildlife between 2015–2019
	Wild animal involved in these events
	Did you see which wild animal was involved in these events?
	If you didn't see, how did you identify which wildlife caused the human attack?
	Land-use type of event site (settlement, forest, cultivated land/open areas)
	What mitigation measures you have been applying to decrease wildlife attack to humans?

We surveyed people with different education backgrounds, gender, ethnicity, and religion. We asked them demographic and socioeconomic information, and whether they, or anyone else in their household, had encountered any HWC related events between 2015 to 2019 (Table1)

We verified the data we collected from the households with that from the Division Forest Offices (DFO) of the Kaski and Tanahun Districts. In addition, supporting data on crop damage by wildlife was also collected from published articles and reports, and verified using the database from the DFO's in Kaski and Tanahun between 2015 and 2019. We asked the respondents to describe the type of HWC event they, or a member of their household, encountered and to identify which animal was involved. We placed a variety of photographs of the animals and their sign (e.g., footprints, scats) in front of the respondents so they could verify which animal species was/were involved in the HWC event(s). We also interviewed 21 policymakers at the district level, including the forest director, divisional forest officers, field-level forest officers, municipality chairs, and other elected representatives, regarding the mitigation measures implemented to avoid HWC-related issues. Finally, we reviewed Nepal's wildlife and HWC policies, i.e., Forest Act (2019), National Park and Wildlife Conservation Act (1973), the Relief Fund Distribution Directive for Victims of Wildlife (2012), and the Crop and Livestock Insurance Directive (2013), to understand and evaluate the impact of these policies on HWC mitigation and wildlife conservation.

2.3 Land-Use and Land-Cover Change

Land-cover (LC) data for this study were extracted using Landsat 5 TM (Thematic Mapper), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and 8 OLI (Operational Land Imager) images for 1998/1999, 2008, and 2018. These images were collected from United States Geological Survey (USGS) site https://earthexplorer.usgs.gov (accessed on 9 October 2021) (Table 2) on multiple dates. All images were geometrically, radiometrically, and topographically corrected and verified for their accuracy. Accuracy assessments were conducted using high resolution Google Earth Images, (http://earth.google.com) (accessed on 9 October 2021) of multiple dates, topographical maps published by Nepal's Survey Department (Government of Nepal, 1998, scale 1:25,000, 1: 50,000), and field data (GPS points) which were reference points provided by the household members collected during the surveys. For the analysis of land-cover change, we applied eight land-cover categories, as recommended by Anderson et al. [39]. Based on the secondary data from DFOs, the 21 key personnel, and the survey respondents themselves, we found that Bhanu Municipality in the Tanahun District was the most affected area of HWC events. Given this, we then compared the effects of land-use change of this municipality with HWC events in 1999, 2008, and 2018.

Table 2: Landsat data used in the study. TM = Landsat 5 Thematic Mapper; ETM+ = Landsat 7 Enhanced Thematic Mapper Plus; and OLI = Landsat 8, Operational Land Image.

Path/Row	***TM-1998***	***ETM+1999***	***TM-2008***	***OLI-2018***
142/040		13 December	26 October	7 November
142/041	17 February	13 December	26 October	7 November

2.4 Data Analysis

We quantified the annual crop/livestock production (as a percentage loss) of respondents. As, generally, more women regularly enter the forests and worked more on the land, we tested whether they were more likely to be affected by HWC events than men by using a chi-squared test. A chi-squared test was also used to test whether HWC events were becoming more frequent through the years. All analyses were performed within R (R Core Team, 2018) [40].

3. RESULTS

3.1 Demographic Information

Among the 811 respondents surveyed, 88% (n = 713) were women. The age of respondents ranged from 16 to 95 years old (median = 52 years), and the average family size was six individuals (range: 1 to 24 individuals). Eighty-six percent (700) of the respondents worked in the agricultural sector for their livelihood, followed by 9% (72) in business, and 5% (39) in other occupations. The literacy rate was relatively high for the area 78% (n = 729), and 70% (n = 564) of respondents were considered to have a medium economic status (based on Nepal's participatory wellbeing ranking).

3.2 Trends in HWC

Crop damage and livestock depredation data were collected from the surveys and databases provided by the Division Forest Offices (DFO) at Kaski and Tanahun. From the interviews, the respondents reported 2165 crop damage events and 3315 accounts of livestock being killed by wildlife from 2015 to 2019. This was vastly different from the DFO records, as only 938 HWC-related events were reported. The types of HWC events reported to the DFO were mainly livestock being killed or injured, wildlife being killed or injured, and people being killed or injured (Figure 2). Most, if not all, of the minor HWC events, e.g., crop losses, were not reported unless it was a significant loss. Not surprisingly, more women encountered HWC events than men ($\chi^2 = 4.2981$, df = 1, $p = 0.038$).

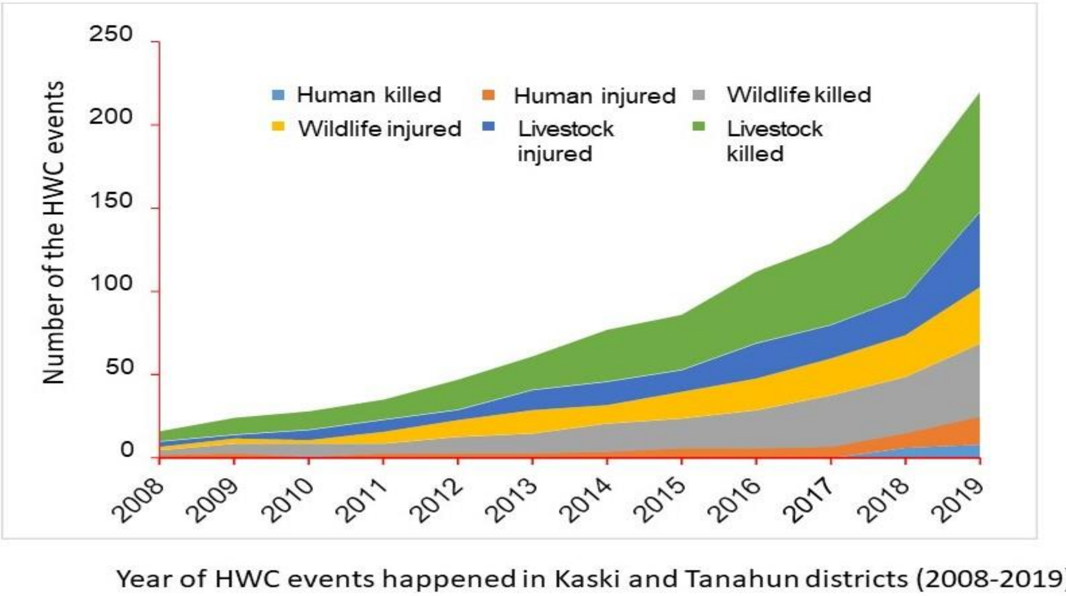


Figure 2: Number of wildlife attacks on livestock and humans, and number of wildlife killed by people (Data source: DFO, Kaski and Tanahun)

3.3 Livestock Predation

Data obtained from the interviews show that between2015–2019, of the 3315 livestock killed (27% of all livestock owned), the main predators involved in these attacks were leopards, golden jackals, jungle cats, yellow-throated martens, black kites (*Milvus migrans*), and Himalayan black bears. Chickens *(Gallus* spp.) were the most commonly killed livestock species (80%) by these predators, followed by sheep (*Ovis* spp.), goats *(Capra*spp.) (15%), cows (*Bos*spp.) (2%), pigs (*Sus*spp.) (2%), and buffalo (*Bubalusbubalis*) (1%). Leopards killed the widest range of livestock, i.e., domestic goats and sheep (62%), chickens (18%), cows (10%), pigs (6%), and buffalos (*Bubalus*) (3%) (Figure 3).

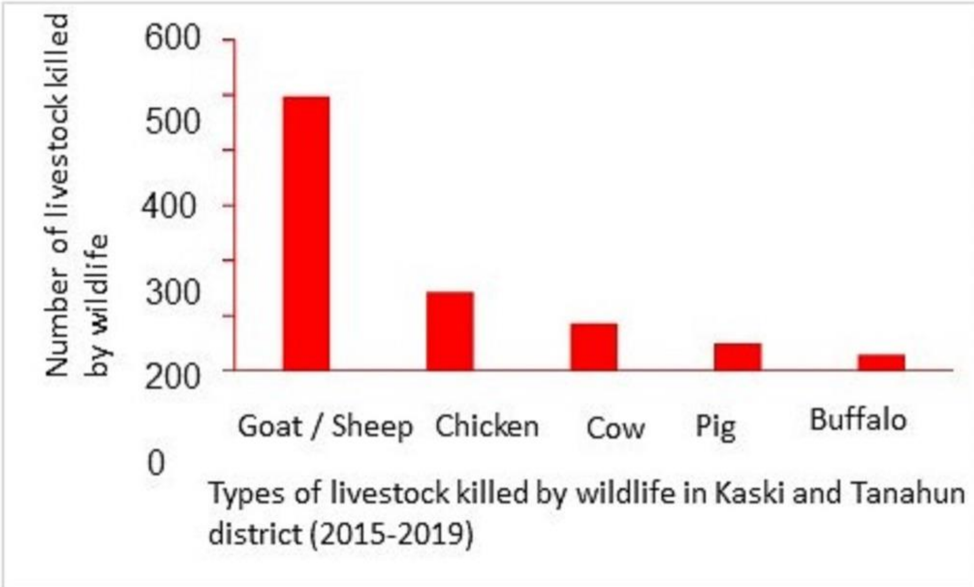


Figure 3: The variety and number of livestock killed by leopards in Kaski and Tanahun Districts between 2015–2019

Himalayan black bears also killed pigs, whereas the remaining four wildlife predators (golden jackals, jungle cats, yellow-throated martens, and black kites) were only recorded to kill chickens. Livestock losses amounted to 13,300,440 Nepalese rupees (USD $115,656.00), or an average of USD$142.61 per household between 2015–2019.This represents an average loss of income of 23% per household.

3.4 Crop Damage

The main crops grown in these districts were rice (*Oryza sativa*: 63%), corn (*Zea mays*: 20%), millet (*Pennisetum scrobiculatum*:9%), potato (*Solanum tuberosum*:5%), wheat (*Triticum aestivum*: 2%), and mustard (*Brassica juncea*1%). The survey respondents recorded 2165 crop-loss events between 2015–2019. Proportionately, somecrops, such as rice and corn, were severely impacted by wildlife (χ^2 =39,506, df=5, p<0.001).

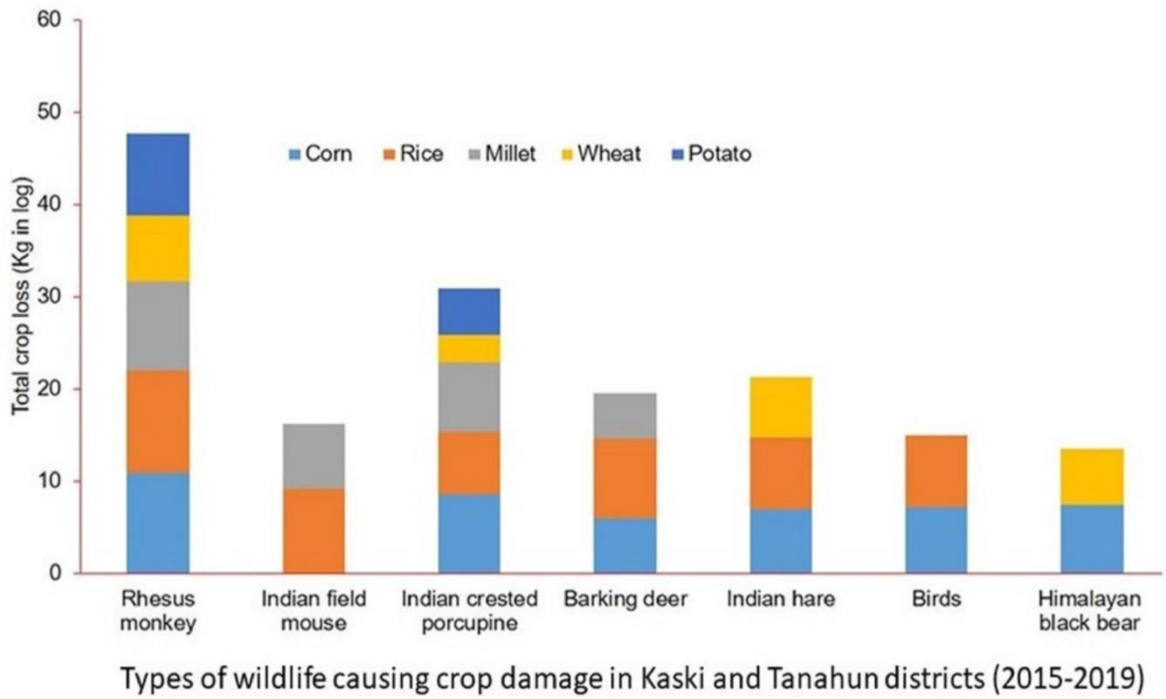


Figure 4: The amount of crop-loss in kilograms to different wildlife species within the Kaski and Tanahun Districts (data obtained from questionnaire surveys).

Collectively, crop losses amounted to NPR9, 844,032 (US$83,424.00), or an average of US $102.86 per household. Crop loss accounted for 17% of the total household income of the respondents. Rhesus monkeys (*Macaca mulatta*) caused the most crop damage (74%), followed by Indian field mice (*Mus booduga*) (12%) (Figure 4).

3.5 Land-Use Types and HWC

Most crop damage (78%) occurred within a 1 km radius of where people lived. Additionally, 64% of livestock attacks occurred near cattle sheds. Most livestock were attacked in the early evening or later at night. Some livestock (27%) were also attacked by predators when they were grazing within the community forests. The remaining predation events (9%) occurred on cultivated land or in open areas.

3.6 Land-Use Change, Community Forest, and HWC

Satellite imagery from 1998, 2008, and 2018 showed that the land-cover changed during this period, with cultivated land decreasing by 3.5%, and forested land increasing by 3%. In 1998, 43% of the land was forested (1593 km^2), whereas 32% (1170 km^2) was cultivated for agriculture (Figure 5; Supplementary file S1). In some areas, such as the municipality of Bhanu in the Tanahun District, cultivated land decreased from 1998 to 2018 by20.52% (from 94.0833 to 74.7785km^2) (Figure6). Of the 19.30 km^2 cultivated land lost, 15.75 km^2 was converted to forest, and the remaining 3.55 km^2 was either impacted by urbanization or reverted to barren areas or shrubland. Overall, the forest-cover increased by 18.23% (86.39 km^2 in 1998 to 102.14 km^2 in 2018) (Figure 6). Only a fraction of the forest land (0.96 km^2) was transformed into cultivated land (Figure 6) during the same period.

Figure 5: Land-cover map of study area in 1998, 2008, and 2018 in Kaski and Tanahun districts.

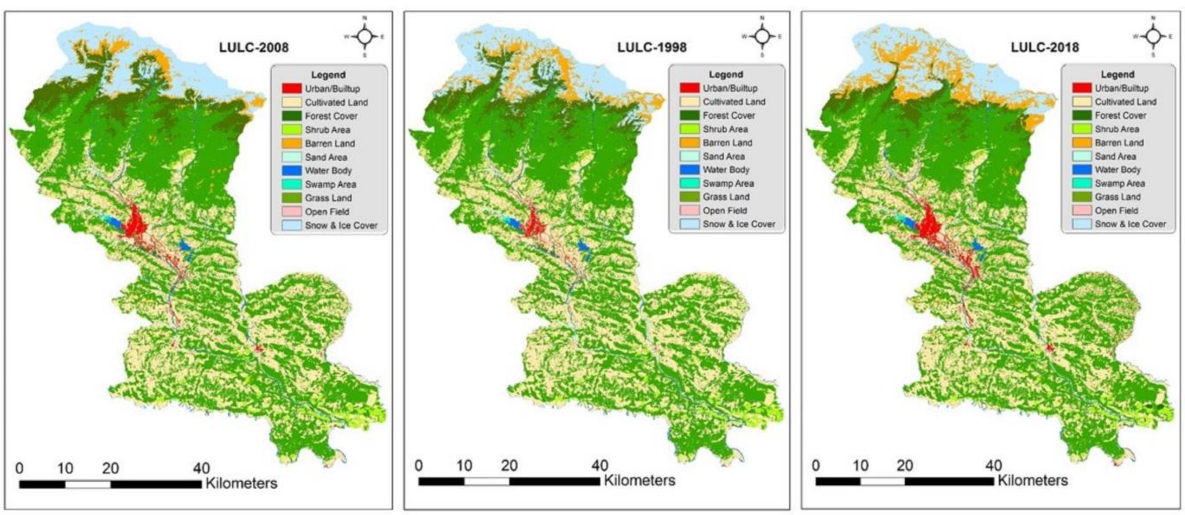
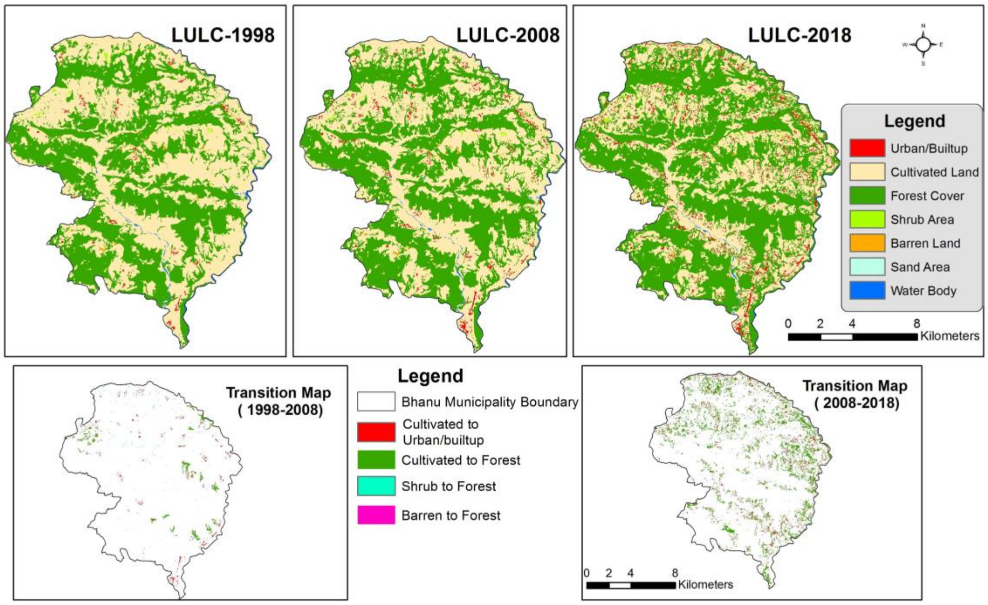


Figure 6: Land-cover transition map of Bhanu Municipality in 1998, 2008, and 2018.



4. DISCUSSION

Our survey recorded 2165 crop-loss events and 3315 domestic animals killed from 2015 to 2019. Yet, the DFO data base in the same area only had records of 938 HWC events between 2008 and 2019. The reasons for these discrepancies are: (1) records in the DFO database of HWC events only formally started in 2012, after the compensation/relief scheme to victims of HWC events was instigated by government of Nepal; and (2) many HWCe vents, such as crop-losses, were not reported because of the lengthy bureaucratic process to obtain the funds and the small amount of compensation on offer for any such losses. Some respondents possibly expressed exaggerated statements of their loss by wildlife pertaining to the number of livestock killed and amount of crop damaged in the hope that they may receive higher compensation packages from the authorities [7]. However, we verified their statements by cross checking the survey data with the DFO records, and verified the information provided independently by interviewing other family members.

The villagers of the Kaski and Tanahun Districts lost 27% of their livestock to wildlife predation from 2015 to 2019, representing 23% of their household income. Chickens, goats/sheep, and cows were the main species lost. Generally, the domestic animals were kept inherds, making the measy prey. Similar predation events were observed in India near the Kibber Wildlife Sanctuary, where local farmers lost 18% of their livestock to wildlife, representing 25% of their house hold income [41]. Leopards, golden jackals, yellow-throated martens, and black kites were the main predators that attacked and killed livestock, whereas rhesus monkeys were the main crop raiders. Leopards and rhesus monkeys are well-known pest species by the local communities within the middle mountains [8,32,42]. Leopards generally attack and kill the larger livestock species, e.g., cows and goats [32], whereas golden jackals and jungle cats target chickens. Due to their inquisitiveness, intelligence, and close proximity to people, rhesus monkeys also caused the highest amount of crop damage in the surrounding Shivapuri National Park [42], Langtang National Park [43] and Chitwan National Park [44] of Nepal. Primates are the dominant pest for crop damagein Africa as well [45].

Livestock depredation by wildlife often coincides with ineffective farming practices, such as little or no fencing, poorly constructed livestock shelters, and allowing livestock to roam in open pastureland or wander into the community forests where the predators naturally reside [32]. Thus, better husbandry practices, including constructing safe enclosures, better fencing, and stall feeding, would help deter and prevent many livestock predation events by wildlife [45,46].Most people within the Kaski and Tanahun Districts are poor,and only farm a few goats, sheep, and chickens:on average, most households had six animals [47]. Thus, losing any livestock to predators incurs significant hardship, and has major ramifications for their livelihoods (K.B. personal observation).

From 2015 to 2019, 67% of HWC incidences occurred outside the protected areas (PAs) where the large predators live [10]. While the Division Forest Offices have been conducting training and capacity-building programs for the local communities about forest management, they teach virtually nothing on wildlife or conservation management techniques. Hence, there is a lack of knowledge among the local people about living with and working around large predators [24]. The community forest user groups used the Community Forestry Development Directives 2001 endorsed by the Department of Forest and the Government of Nepal to formulate their Community Forest Operational Plan.However, the template does not provide any provisions for dealing with wildlife management within the CFs. So, none of the community forests had incorporated wildlife conservation practices into their operational plans. This is a significant gap for managing large predators outside the protected areas. Thus, provisions in these user-group directives are urgently needed to address this issue in order to reduce and mitigate further HWCs.

Out of Nepal's 77 districts, crop raiding is a significant problem in 69 districts [10,42,43]. In Kaski and Tanahun, the farmers lost 17% of their total income due to crop damage alone. Inadequate fencing and security means crop raiders can access crops with relative ease. Though fencing or electric wires and other security options act as good deterrents, they are too expensive to install and maintain for the majority of the local farmers. This is also true in many other developing nations [48]. For example, in Tanzania and India, many farmers lost income from crop raiding by wildlife because they could not afford to construct secure fencing systems. [48,49]. Increasingly, agricultural losses from wildlife are severely impacting economic and social well-being of farmers, which further exacerbates the financial hardships faced by local people [50].

Some of the reasons rhesus monkeys likely targeted the crops are: (I) a lack of fruit trees/food in the forest; (II) the ease of access to crops; (III) an increase in the monkey population [43]; and (IV) the forest regeneration on abandoned agricultural land, allowing the monkeys to move closer to farming areas. Previously, the natural forests contained abundant fruit trees, such as mango (*Mangifera indica*), guava (*Psidium guajava*), banana (*Musa sapientum*), gooseberry (*Ribes uva-crispa*), fig (*Ficus carica*), etc. [49], which would have provided sufficient food for the monkeys. However, many of the fruit trees have since been felled to make room for timber production [20,24]. The scarcity of wild fruits means the monkeys and some other herbivorous animals have now taken to invading the nearby farms to find a lternative foods. Hence, cultivating the fruittrees in the forest and its edge would create a good habitat for monkeys and herbivores, and, consequently, theywould be less likely to invade the cultivated land for food [45].

The Community Forestry programis generally regarded as a successful program, as the rural communities are now able to control, protect, and manage their own forest resources [11,22]. The program was implemented under the National Forestry Plan in 1975 to counter massive forest loss. The initial objectives of this program were to rehabilitate the degraded forest land and provide afforestation opportunities [51,52]. Through the active participation of the local communities, the forests have regenerated, and the forest-cover has increased. In the1990s, the target of the community forest program was fulfilling the needs of the local people for timber, fuelwood, grass, fodder, and medicinal herbs. Moreover, it empowered many women and disadvantaged groups to generate income, and manage and develop their capacity in forest resources management [52]. After 2000, the program focused on the livelihoods of the local people, good governance, and sustainable forest management [52]. However, the priority of the forestry policy was focused on growing production trees for timber harvesting, rather than on biodiversity conservation or enhancing species diversity and ecosystem function [52]. Hence, little consideration was given to the needs of the wild animals living within the forest. During this same period, there has also been a reduction in the amount of grassland available for wild herbivores to graze within forest land. This, along with a lack of prey availability in the natural forests, may have forced predators to seek alternative prey in nearby villages, resulting in increased HWC in this area.

Satellite maps show the expanding forest areas and a decrease in cultivated land. The National Forest Resources Inventory of Nepal 2015 shows an increase in tree-cover from 39.6 % to 44.76 % between 2005 and 2015 [37]. Of this forest area, 90% is conventional forest, and 4.38% is re-vegetated secondary forest on retired or abandoned agricultural land. The increase of trees on the abandoned agriculture land has happened ince people migrated to urban areas for education and employment opportunities [29,53–55]. One downside of this emigration is that fewer people are now working the arable land and watching over their livestock [56,57]. Furthermore, forest regeneration on abandoned land has created additional pathways and corridors [30], enabling wild animals to move even closer tohuman settlements, and increasing the likelihood of wildlife encounters with people, their crops/livestock, and property. Thus, the deforestation and degradation of natural habitats, combined with an increase in forestarea [11,58] and with regenerating scrub on abandoned farmland, all contributed towards increasing the probability of a HWC event [37].

The Ministry of Forest and Environment (Government of Nepal) has a Relief Distribution Directive for damages caused by wildlife which was endorsed in 2012 [59]. This scheme pays up to (NPRs) 10,000 Nepali Rupees (~USD $85.5) for crop damage, NPRs 30,000

(~USD$256.5) for livestock loss, NPRs 20,000 (~USD$171) for minor injuries to people, and up to NPRs 200,000 (~USD $1710) for serious injuries. In the event of a person being killed, the scheme provides a maximum of NPRs 1,000,000 (~USD $8547) to the family. DFO records in the Kaski and Tanahun Districts show that NPRs 22,653,600 (equivalent to USD$ 193,620) were paid out for crop, livestock losses, and human injury/death between 2015–2019 [60]. Though this scheme helped mitigate the impact of HWC, most respondents felt that the process of applying and obtaining these funds was overly bureaucratic, time-consuming, and complex. Unfortunately, there is no local relief fund, and all applications have to submit their claims to the federal government. Thus, only those people who incurred major losses submitted claims for HWC issues. Those who incurred smaller losses did not bother to submit claims. These losses, though small, still had a significant financial impact on the individual farmers.

The Ministry of Agriculture and Livestock (through the Government of Nepal) has implemented an insurance plan for the loss of agricultural crops and livestock loss. This insurance plan was established in 2013. Yet, of the 811 respondents interviewed, only 9% (n = 73) knew about this policy, and none of them had ever applied for insurance compensation. Thus, nobody had ever received any money from this policy for their crop and livestock losses because of wild animals. It is important that the local people are not only informed about these compensation plans and insurance policies, but that they receive assistance to submit and process the claims. Thus, it is important to make these systems accessible and easy to apply in order to alleviate the suffering and financial hardship oflocal people due to HWC. This would also greatly reduce the resentment and retaliatory actions of the local community towards the native wildlife, should an HWC event occur.

5. CONCLUSION

The local people in the Kaski and Tanahun Districts within the mid-hill area of Nepal are highly prone and susceptible to HWC. Land-use changes have enabled wild animals to move nearer to human settlements for food and resources, which increases the probability of wild life raiding their crops, attacking livestock, and injuring or killing people. Aholistic management plan that is balanced with clear administrative processes is required urgently in this region to address the issues of HWC. Such a plan requires the involvement of all the stakeholders, such as the local farmers/community, government officials, and wildlife scientists. Issues such as stock management (protecting and securing crops and livestock) can be done through grants for securing their crops and premises, training, and education. A generala wareness program on human safety and well-being, and wildlife conservation would be immensely beneficial, particularly for those people living near the community forest areas. Managing wildlife within the community forests is also essential so they have the necessary food, water, and shelter within forests. In addition, a management program should provide economic incentives for people to stay in the region and carry out agroforestry on their land, rather than migrate to urban areas. Finally, establishing a local relief fund and insurance program for crop and livestock loss to HWC, rather than using a national overly-bureaucratic mechanism, would give confidence to the local community should they ever incur future damages, and this would greatly improve the co-existence of people and wildlife.

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Chapter Four

Common leopards (*Panthera pardus*) and prey interactions in relation with human wildlife conflict in community forest regime, mid-hills, outside protected areas of Nepal

(Photo: Camera trap survey, 2020)

Summary

My previous chapters have identified the common leopard (*Panthera pardus*) as the predominant species involved in human-wildlife conflicts in the mid-hills of Nepal, outside of protected areas. This chapter focuses on the leopard population density and prey species abundance within community forests in this landscape. The chapter analyzes the availability of prey species of leopard, predator-prey interaction as well as their relationship to the human-leopard conflict in this physiography. In addition, the chapter discusses the prey selection and diet analyses of common leopards in this habitat. This chapter contains the following two studies:

Study I: Density of leopards and status of their prey in mid hills of Nepal: Implication on conservation conflict

ABSTRACT

Predator population density and prey availability have been regarded as two major drivers of human-wildlife conflict. The common leopard (*Panthera pardus*) is one of the large predators of the forests and grassland ecosystems that are often involved in conflicts with humans. Limited information is available about the density of leopards and the status of its prey species in the mid-hills of Nepal, where the leopard often attacks livestock and people. We investigated the density of leopards and the status of their prey species in high human-leopard conflict areas where leopards killed ten children between 2018 and 2020. About 200 livestock were depredated by leopards, and 14 leopards were killed in retaliation at the same time. This study was conducted between October and December 2020. We used 72 camera traps for 21 nights in community forests covering a 200 km^2 area. We recorded 14 leopards (4 male and 10 female), and the estimated leopard density was 16.3 ± 2.8 / 100 km2 (MARK) and 15.2 ± 2.6 / 100 km^2(DENSITY). Using the line transect method, we counted a total of 569 number of prey (livestock + wild) at the study site, among them the detection rate/km was lowest for wild ungulate prey species (barking deer and wild boar) (0.2), 2.0 for livestock and 3.21 for other wild prey species. Among all prey species, encounter rate of rhesus monkeys was found to be the highest and that of wild boars to be the lowest. Our study concluded that lower availabilityof wild ungulate prey, especially (barking deer and wild boar), may have contributed to the escalating incidence of livestock depredation, causing human-leopard conflict. Similarly, conservation of leopards' wild ungulateprey species through habitat restoration and implementation of a human-leopard conflict mitigation action plan are highly recommended to minimize conflict.

1. INTRODUCTION

The leopard is one of the most widely distributed predators among the felidae (Nowell and Jackson 1996; Jacobson et al., 2016; Sunquist and Sunquist 2017). Leopards are a generalist species and occupy a wide range of habitats, including tropical, temperate, alpine forest, and grasslands up to 5200 m above sea level (Nowell and Jackson, 1996; Stein et al., 2017). Worldwide, leopard populations have declined at an alarming rate, and its conservation status is vulnerable according to the IUCN Red Data (Stein et al., 2017). Leopards range from the lowlands (1000 m) to the high mountains (>4000 m) in Nepal. They are frequently sighted in fragmented and human dominated landscapes. Human-leopard conflict has been reported frequently at the forest edges throughout Nepal (Aryal and Kreigenhofer 2009; Acharya et al., 2016, Bhandari et al., 2019). Because of their wide distribution and ability to survive in the human dominated landscape, leopards are often involved in human-wildlife conflicts (HWC) (Jackson, 1984; Lovari et al., 2015). The leopard's survival rate as a top predator is dependent on wild prey populations (Oli 1994; Karanth et al., 2004). Prey scarcity has been shown to have a significant impact on litter size, mortality, home range, and dispersal (Fuller and Sievert 2001). Lack of natural prey due to anthropogenic impacts has been suggested as a driver for leopards to invade human settlements and prey on domestic animals (Lovari et al., 2015; Shehzad et al., 2015).

The mid-hill regions of Nepal are characterized by sub-tropical and temperate bio-climates with a great variety of terrain types, ecosystems, and wildlife (Baral et al., 2021a). This region is home to more than half of the country's human population (Kutal et al., 2021). Human population growth and urbanization in the mid hills have resulted in habitat fragmentation. The decline in biodiversity and prey abundance are responsible for increasing human-leopard conflicts (Achrya et al., 2016;

Baral et al., 2021a). Other factors, such as the lack of appropriate management of livestock and poultry farms, also contribute to increased human leopard conflict (Baral et al., 2021b). Moreover, frequent attacks on domestic livestock by leopards are thought to be a major problem in the mid-hills of Nepal. Increasing human-leopard conflicts in the mid-hill region can result in retaliatory kills of leopards, which can contribute to the further decline of leopard populations.

The mid-hill landscape outside Protected Areas (PAs) is highly human-dominated, and the forests in this landscape have been managed under the community forestry system. The majority of human-leopard conflicts happen outside PAs (DNPWC, 2017), and the limited studies of human-leopard interaction in this landscape are not sufficient to address this problem. The complexity of prey-predator relationships determining population density in a certain area needs a detailed understanding to gain profound knowledge about the sustainability of the prevailing ecosystem. To date, there are a handful of studies on the leopard and their prey status in Nepal, and they are mostly concentrated on the lowlands and around the PAs of Nepal. Understanding the leopard and their prey status in the human-dominated landscape helps answer what drives conflicts between humans and leopards and how to minimize those conflicts. We hypothesized higher density of leopard and lower prey abundance in the study area.

2. METHODS

2.1 Study site description

The study site comprises 200 km^2 of community forests in Bhanu Municipality (27° 26' to 28° 25' N and 84° 57' to 85° 34' E; alt. 450–800) in Tanahun district, Nepal (Figure 1). The human-leopard conflict in Tanahun district is chronic, with leopards killing 10 children (14 years old) between 2018 and 2020, with 6 children killed in Bhanu municipality alone. In the same period, 176 livestock were killed by leopards, and people killed 14 leopards in the district in retaliation. Concerning this issue, to date, there have been no studies carried out in this district about the causes of such tragic conflicts. The degraded forests were handed over to local communities in 1996 for better management and have since recovered significantly.

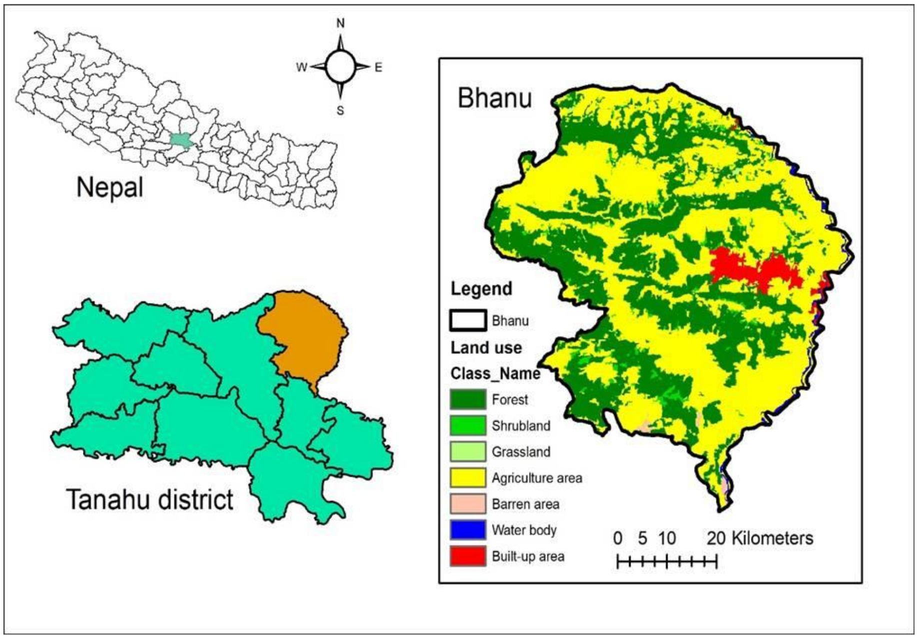

Figure 1: Map of study site locations, the Tanahun district of Nepal with the land use types of the study area.

My study site lies outside of the Protected Areas and represents the mid-hill physiography in central Nepal. The climate of the study area is sub-tropical, with an average annual rainfall of 1,761 mm (Sharma et al., 2021; Bhandari et al. 2022a). The minimum and maximum temperatures at the site are 6 and 41 degrees Celsius, respectively. Sixty-four percent of local people are dependent on agriculture and livestock as a primary source of income (DFO Tanahun 2019). The Tanahun district is home to 20 mammalian species, including large carnivores such as leopards, large Indian civets, and Asiatic black bears, as well as more than 200 species of birds (DFO

Tanahun 2019). The forests are dominated by *Shorea robusta* (Sal), followed by riparian *Dalbergia sissoo* (Sissoo), and *Acacia catechu* (Khayer) forests (Sharma et al., 2021; DFO Tanahun 2019).

2.2 Data collection:

Leopards are sexually dimorphic and have a rosette pattern, and therefore, camera traps can be applied to identify individuals and estimate the density of the leopard (Pocock 1975; Menon and Danial 2003; Balme et al., 2009; Harihar et al., 2009; Borah et al., 2014; Song et al., 2014; Devens et al., 2018). Camera trapping is one of the most cost-efficient, robust, and non-invasive wildlife survey methods (Karanth 1995; Karanth and Nichols 1998; Foster and Harmsen 2012). The capture-recapture method relies on individuals being identifiable (Karanth 1995; Wang and Macdonald 2009) and has been the predominant approach used in the study of felidae density.

In this study, camera traps were installed between October and December 2020. Due to the physiographic conditions, such as mountains, we created 2x2 km grid cells in our study site for a camera trap survey (Figure 2). As leopards preferred roads and trails (Van et al., 2018), we used existing jungle roads, walking trails, and river banks to install the camera traps within the grid cells. Altogether, traps were installed in 36 locations, and the distance between two locations was approximately at least one kilometer. At each location, two camera traps (the Model Panthera and the Slith Cam camera) were placed on either side of the road, trail, or bank, for a total of 72 camera traps used at the study site. The paired camera traps were installed about 2 to 5 m from the center of the road, trail, or bank. We followed published guidelines for camera trapping by Karanth (1995); Karanth and Nichols (1998); and Silver et al. (2004) to photograph both sides of the leopards for individual identification. Camera traps were typically fixed to trees or mounted on wooden posts at a height of 40-45 cm above ground. When activated, the camera traps take three photos with a 30-second interval before the next activation. All the camera traps were programmed to operate continuously for 24 hours over 21 nights. Each camera trap was monitored for performance every 5–7 days.

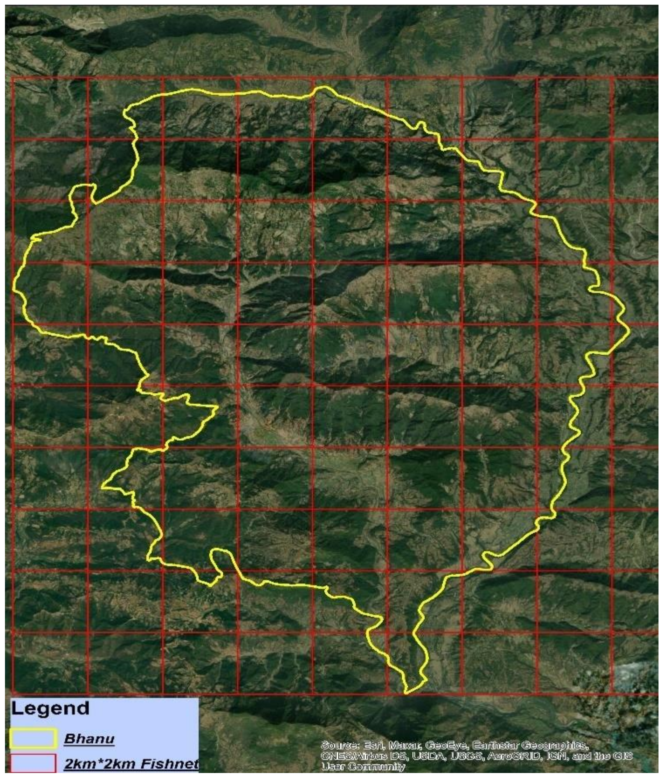

Figure 2: Grid design (2m*2m) map of camera trap in Bhanu municipality.

2.3 Data analysis

The leopards photographed were identified manually by comparing the shape, size, and topography of rosettes (Thapa et al., 2014) (Figure 3). The rosette patterns in the leopard coats are unique to individuals and distinguishable (Thapa 2020; Henschel and Ray 2003) when comparing one photo to another. Poor-quality photos with unclear visuals were not included in the analysis. We recorded the camera trap capture history of each individual. Abundance and density of the leopard were estimated using the software programs MARK (White and Burnham, 1999) and DENSITY (Efford et al., 2004). We assumed that the sampled population was demographically closed, as leopards are long-lived animals (Karanth, 1995; Borah et al., 2014) and our sampling period was relatively short.

To estimate the abundance in MARK, the captures and recaptures of leopards were described by a binary matrix. We used closed population models for the abundance estimates (White and Burnham 1999). We formally tested for population closure using Close Test (White and Burnham, 1999) and open Pradel models implemented in MARK. In the Pradel models, we compared the Akaike information criterion corrected for small sample size (AICc) scores between a model in which recruitment and survival were constrained to 0 and 1, respectively (representing population closure), and an open model in which these parameters were estimated based on observed data. The jackknife estimator (Otis et al., 1978) has been used in photographic-capture studies to estimate capture probability and size.

To estimate the density of the leopard using the DENSITY program (Efford et al., 2004), we used the maximum likelihood spatially explicit capture-recapture method (Borchers and Efford, 2008; Efford, 2009). We used two-fold approaches (leopard capture and camera trap history) (Efford 2009). We ranked all models using the sample size-adjusted Akaike's Information Criterion (AICc) and considered all models with ΔAICc< 2 as the best models. The final density estimates were calculated using model averaging techniques. We reported the unconditional variance estimates for the model average estimates.

Prey abundance data was obtained from a camera trap survey. The photographic captures with >30 minutes intervals were regarded as independent captures. To compute the abundance for each species, the total independent captures for each species were summed for all camera traps over all days and divided by the total number of camera trap days.

Following (Burnham, et al., 1979), we walked a total of 72 random transects during the morning, day, and evening (average transect length 1.44 km; range 0.7–2.7 km) to observe the potential available prey for leopards. While the transect lengths varied, the search effort (walking speed and pace) was thesame forall transects, so we could concentrate on seeing even the smallest species present. The transects were randomly laid out within all possible habitats of the leopard. For each prey species, the estimated encounter rate index was calculated as encounter rate = number of sightings/total distance traveled.

We used a one-way ANOVA to test the variation between leopard capture in a camera trap station and distance to human settlements (very close = 0–9 km, close = 1-2 km, and far = > 2 km). We also used ANOVA to test the differences between leopard photographs in three different habitats. We counted 1 photo if 2 or more were captured within 30 seconds of the camera triggering to reduce autocorrelations.

3. RESULTS

Our camera traps were operated for 1512 trap nights and captured a total of 52 photographs of leopards. Six photographs were discarded from analysis because they were of poor quality and could not help identify individual leopards. Out of 52 photographs, 46 leopard photographs were used for analysis. We identified 14 individual leopards (4 males and 10 females) (Annex 1) (Figure 3). The population size (CI) of leopards estimated by DENSITY was 15.2±2.6 /100km^2. The capture probability was 0.0526 per occasion and 0.6420 overall (Log likelihood = -77.003, Npar=

2, AIC = 158.006, AICc = 159.006). The estimated leopard population size using MARK was 16.3 ± 2.8 / 100 km2, and Mbh2 was the best fitted model (Table 1). Leopards were mostly photographed between 17:00 h and 04:00 h, and few pictures were taken during the daytime (8:00 h to 16: 00 h) (Figure. 4). We investigated that 14.8% of leopard photographs were taken in 1:00 h (Figure 4). The number of leopards photographed was significantly higher in 'very close' distance category (distance between camera trap station and human settlements), followed by 'close' and 'far' ($F = 1.7$, $df = 62$, $p = 0.05$).

Table 1: Model average for geographic closure for the leopard population in the study site from Program MARK. Models ranked according to the Akaike information criterion adjusted for small sample size (AICc). K is the number of parameters, ΔAICc is the difference between the AICc value of the best-supported model and successive models, and wi is the Akaike model weight. Data was collected from the camera traps at Bhanu Municipality between October and December 2020.

Model	**AICc**	**ΔAICc**	**wi**	**Model Likelihood**	**K**	**Deviance**	**-2log(L)**
{Mtbh2}	146.9013	0	0.95106	1	14	111.2485	117.1038
{Mt}	152.1831	7.3818	0.02373	0.025	14	118.6304	124.2857
{M0}	204.3369	58.9356	0	0	2	195.6566	201.3119
{Mh2}	205.3369	59.5356	0	0	2	195.6566	201.3119
{Mbh2}	206.8326	62.0313	0	0	3	195.1272	200.7825

Results generated from the camera trap revealed that the relative abundance of wild ungulates (barking deer and wild boar) was very low. Livestock has the highest density (6.71), indicating a significant presence of domesticated animals (Figure 5). This could be attributed to agricultural activities or human settlements. Rhesus monkey also demonstrates a relatively high density, suggesting a thriving population in the given area. On the other hand, several species exhibit lower densities, such as Golden jackal, CE mongoose, Barking deer, Wild boar, and Chinese Pangolin. These species might either have naturally lower population sizes or face environmental challenges impacting their numbers.

I counted a total of 569 number of preysat the study site. The detection rate/km was lowest for preferred wild prey species (barking deer and wild boar) (0.2), 2.0 for livestock and 3.21 for other wild prey species. Among the wild prey, the rhesus monkey was found to be the highest member (n = 195, encounter rate = 1.8), whereas the lowest encounter was for the wild boar (n = 4, encounter rate = 0.03). The goat had the highest detection rate (n = 120, encounter rate = 1.15) among domestic animals, followed by the cow (n = 41, encounter rate = 0.39).

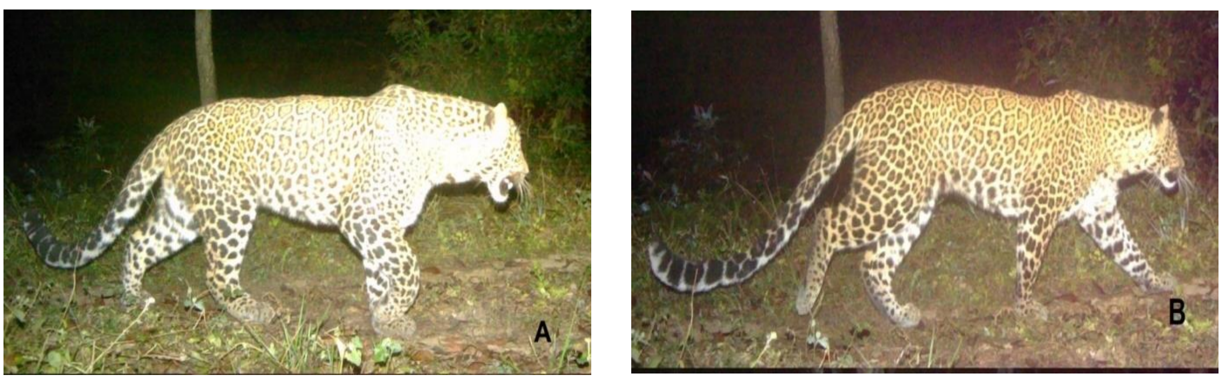

Figure 3: Photographs of two individual leopards, (A) and (B, C), showing differences in rosette patterns which allow for individual identification. Photos taken between October and December 2020 at Bhanu municipality Tanahun district of Nepal

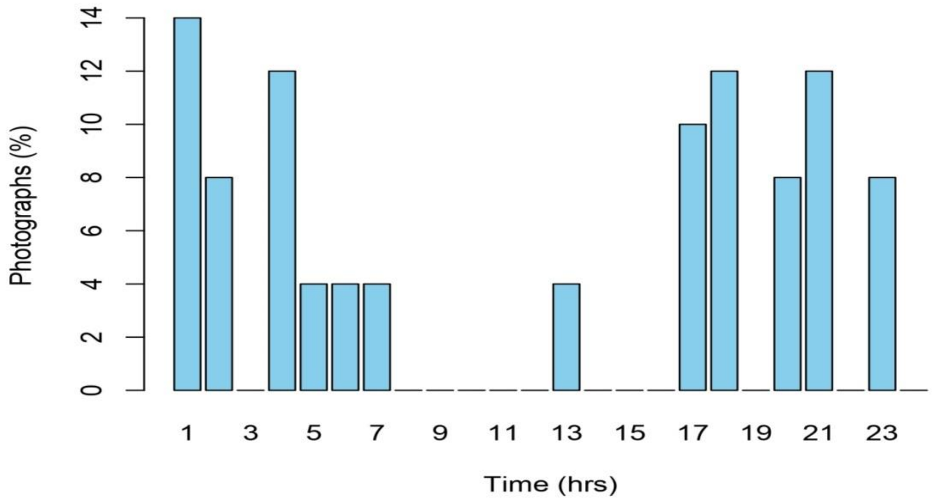

Figure 4: Leopard images captured at different time hours between October and December 2020. A total of 46 images were capture by the cameras.

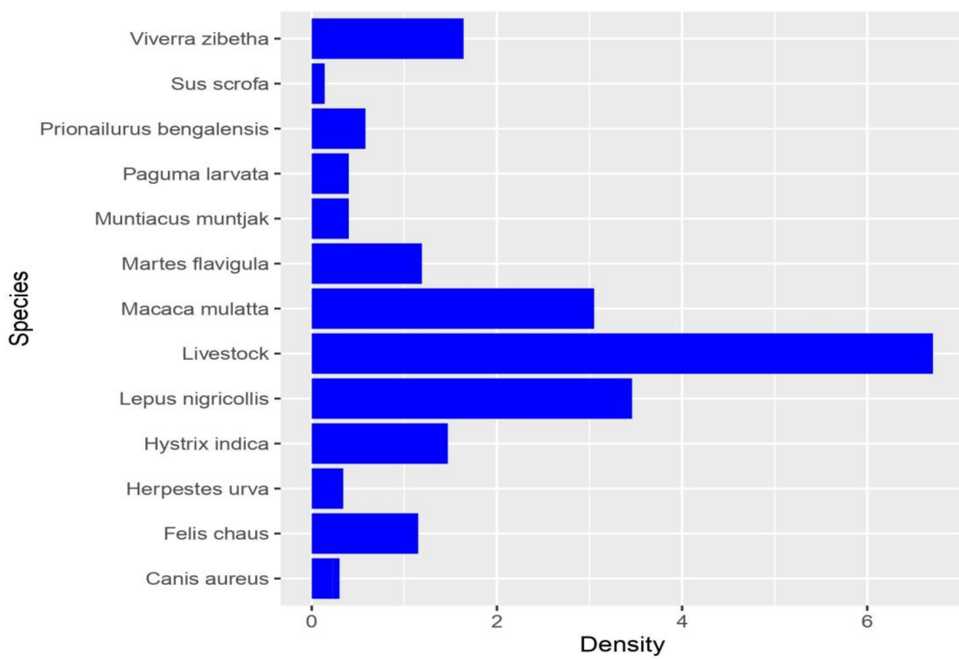

Figure 5: Relative Abundance of prey species and leopard generated from camera trap survey in the Bhanu Municipality between October and December 2020.

4. DISCUSSION

4.1 Leopard density

In Nepal, research on leopard density is limited. Our study estimated the highest density of leopards in the mid-hill regions of Nepal. However, leopard density in Nepal has been estimated at varying levels in different studies. A study by Thapa et al. (2014) estimated a density of 3.48–5.93 individuals per 100 km2 in the Bhabar region of the Terai Arc Landscape in Nepal. Another study by Pokheral and Wegge (2019) estimated nine different leopards in Suklaphanta National Park. These studies suggest that leopard density in Nepal is relatively low, with estimates varying across different regions and protected areas. However, it should be noted that these studies were conducted in limited areas of the country and may not accurately represent the overall leopard population in Nepal (Thapa et al., 2014; Thapa et al., 2020; Kandel et al., 2020).

The results of our study indicate that the density of leopards in the study area is notably higher in comparison to other regions, particularly in protected areas in India, such as Manas National Park in Assam, which had a density of 3.4 ± SE 0.82/100 km^2 (Borah et al., 2014), and Rajaji National Park, which had a density of 14.99 ± 6.9/100 km^2 (Harihar et al., 2009). However, the density in the study area was lower than that observed in the Limpopo Province of South Africa, where the density was 25 8.45/100 km2 (Devens et al., 2019). This elevated density in the study area may be attributed to the leopard's highly adaptable nature, which allows them to thrive in highly fragmented, human-modified environments, as well as their ability to coexist in human-dominated landscapes (Athreya et al., 2016a; Athreya et al., 2016b; Braczkowski et al., 2018). Furthermore, the presence of livestock in human-dominated landscapes, which serve as a source of prey for leopards (Kumbhojkar et al., 2020), may also have contributed to the high density. Additionally, the increase in livestock and poultry rearing in the surrounding areas may have prompted leopards to seek out food in human settlements (Hayward et al., 2006; Thapa, 2014). It is also noteworthy that leopards with cubs are frequently observed in urban areas such as Pokhara and Kathmandu, where there is a scarcity of forested areas (DFO Kaski 2020; DFO Kathmandu 2020).

Leopards are known for their broad diet, which includes a variety of prey such as small and large ungulates, small felids, primates, small mammals, and even livestock. This adaptability allows leopards to coexist with other small felids, such as the jungle cat and leopard cat (Baral et al., 2022). However, the relationship between leopard density and natural prey abundance is not straightforward, and can vary depending on the specific ecosystem and human activity in the area. Some studies suggest that leopard density may be higher in areas with lower natural prey availability. For example, a study in the Indian Himalayas found that leopard density was positively correlated with the availability of livestock and negatively correlated with the availability of natural ungulate prey (Athreya et al., 2016b). Similarly, a study in the Western Ghats of India found that leopard density was higher in areas with low natural prey availability and high human disturbance (Athreya et al., 2016a, b). On the other hand, other studies have found that leopard density is not necessarily related to natural prey availability. A study in the Kruger National Park, South Africa, found that leopard density was not significantly related to the abundance of natural prey (Funston et al., 2002). Additionally, a study in the Pantanal, Brazil, found that leopard density was positively correlated with the abundance of natural prey (Quintela et al., 2016). It is important to note that the relationship between leopard density and natural prey availability is complex, and can be influenced by a variety of factors, such as the availability of alternate food sources, human activity, and competition with other predators (Hayward et al., 2006; Ott et al., 2007; Aryal and Kreigenhofer, 2009; Athreya et al., 2016a). Since the leopard is the apex predator of the ecosystem in the middle hills of Nepal, it has no natural predators and no inter-specific competition, which could contribute to an increase in the leopard population in the mid hills of Nepal.

4.2 Prey status

In our study area, we observed a low rate of encounters with wild prey, particularly preferred prey species such as barking deer and wild boar. Among the documented prey species, the highest encounter rate was observed for the rhesus monkey. In contrast, the encounter rate of barking deer in our study site was significantly lower than that observed in other areas of Nepal, such as Chitwan National Park and Bardia National Park, where the encounter rate was 84.7 ± 7.9 individuals/km² (Wegge et al., 2009) and 31.73 ± 4.26 individuals/km² (Bhattarai and Kindlmann, 2013), respectively. Bhandari et al. (2020) also found a higher encounter rate of barking deer in Nepal's lowland regions. The limited availability of barking deer in our study site could be attributed to intensive poaching (Paudel et al., 2020), as wild ungulates are frequently hunted for meat and pelts. Habitat degradation is another possible factor that could have led to the low density of prey species in our study area. The fragmentation of forest cover and the increasing number of haphazardly constructed roads and electric transmission lines can severely affect the habitat connectivity of wildlife and contribute to the decline of ungulate populations (Taylor and Goldingay, 2010; Ascensao et al., 2019).

In addition to the limited availability of barking deer, our study also found limited numbers of wild boar at the study site. This could also be attributed to high levels of poaching in the area as wild boar are often targeted by hunters for their meat, which is considered a delicacy in many cultures (Sales & Kotrba, 2013). The poaching of wild boars can have a significant impact on the local population and can lead to a decline in numbers. Furthermore, wild boars are also known to damage crops, and this can lead to conflicts with local farmers (Pandey et al., 2016), which in turn lead to excessive hunting and poaching. Habitat degradation and fragmentation are also factors in wild boar population decline (Salazar et al., 2022). The loss of natural habitat can lead to a reduction in food sources and breeding sites, making it difficult for wild boars to survive in certain areas. In addition to this, wild boar populations are also affected by disease and competition with other wild and domestic animals. All of these factors combined can contribute to the limited availability of wild boar at the study site.

There are many factors that contribute to the decline of prey species. It is also noted that when there's a high level of anthropogenic activity and poor management, the illegal poaching of large herbivores increases (Paton et al.,2017). This leads to limited prey for leopards, which can cause them to turn to hunting livestock and even people. Previous research (Wegge et al. 2009, Bhattarai and Kindlmann 2013) has shown that leopards need a certain amount of prey (40 individuals per km^2) to survive, but the study found that there wasn't enough prey in the areas they looked at. This lack of prey may be contributing to recent conflicts between humans and leopards in the study area.

According to the study by Shrestha et al. (2010), the lack of proper wildlife management in community forestry programs may be a reason for the low availability of prey at the study site. The community forest program mainly focuses on planting trees, rather than preserving the entire ecosystem, which may have led to the modification of grasslands, habitats for wild herbivores, into forested areas, resulting in reduced prey populations (Duffey, 1974; Epaphras et al., 2008; Bhandari et al. 2020b). Additionally, the lack of management activities such as controlled burning and the construction of waterholes, which are necessary for growth, may have also contributed to the decline in prey populations. Climate change is also affecting water resources in and around forest areas, which is a serious threat to wildlife (Abbaspour et al., 2012). Furthermore, the construction of concrete tanks on water sources inside the forest and channeling the water to human settlements through pipes is reducing water availability in downstream areas, which is a serious threat to wildlife. The study site, Tanahu district, is one of the most vulnerable districts in Nepal in terms of forest fires (Matin et al., 2017), which results in the loss of large areas of forested habitat every year. In 2019, Tanahun recorded that around 87 ha of forest were burned by fire (DFO Tanahun, 2020). These fire incidents also had an adverse effect on the density of prey populations, killing a significant number of wildlife as well as deteriorating suitable habitats.

4.3 Human leopard conflict scenario

Human and leopard conflicts in the Tanahun district have increased significantly (Baral et al., 2021). The high leopard population and low prey availability could be the major drivers for human-leopard conflict. A limited availability of preferred prey species in the forest is likely to force leopards either to sustain themselves on less preferred wild prey, or to switch to domestic prey. On the other hand, old leopards that lack the ability to kill wild prey tend to roam near human settlements (Odden et al., 2014; Athreya et al., 2007) because livestock could be easier to capture. The increasing numbers of livestock and poultry in villages adjoining forests may also result in increased incidences of livestock predation by leopards. According to DFO Tanahun (2020), 176 livestock had been killed during 2018 and 2020. The increased predation of livestock and poultry by leopards increases the likelihood of a leopard encounter with a human. Ten people (< 14 years old) had been killed by a leopard attack during this period (DFO Tanahun 2020). Frequent predations on livestock and human casualties have led to the retaliatory killing of leopards by victims, which has caused the deaths of 14 leopards during the same period (2018–2020). In response to leopard attacks, twelve leopards that have injured or killed people have been translocated from Tanahun to similar bioclimatic areas, national parks, and other habitats to avoid further actions by both the leopard and humans.

The study suggests that a scarcity of prey and a high density of leopard populations in human-dominated areas are significant factors in conflicts between humans and leopards. However, the study has limitations, such as being based on data from a single season as historical information on leopard and prey density was not available. Additionally, using line transect sampling to assess prey availability may not be the most effective method, and more comprehensive methods for understanding density of prey species could be beneficial for further researches.

4. CONCLUSION

We concluded that the density of leopards was higher at our study site compared to other similar studies. This high density of leopards and low abundance of their preferred wild prey species could be associated with increasing human and leopard conflict in this region. Initiatives to increase wild prey populations and reduce habitat degradation could be an effective means of conserving leopards and protecting the well-being of local people in Nepal's mountain regions. Therefore, conservation of leopards' preferred prey species through habitat restoration and implementation of a human-leopard conflict mitigation action plan are highly recommended to minimize conflict. Moreover, long-term monitoring of both prey and predator density would be tremendously useful in understanding the relationship between leopard ecology, natural prey availability and human-leopard conflicts.

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Study II: **Prey selection by leopard (*Panthera pardus*) in mid hill regions of Nepal**

ABSTRACT

Information on prey selection and diet of the leopard (*Panthera pardus*) is important for leopard conservation. We investigated the prey species and the proportion of each species in the leopard diet in a human-dominated mid-hill region of Nepal. The analysis of 96 leopard scats collected between August 2020 and March 2021 revealed 15 prey species consumed by leopards, including small and medium-sized mammals and livestock. In addition to these prey species, plastic materials, bird feathers, and some unidentified items were also found in the leopard scats. Wild ungulates (barking deer, wild boar) constituted just 12% of the biomass killed, whereas livestock contributed 31% and other wild prey contributed 57%. Among all species, domestic goats contributed the highest relative biomass, followed by the jungle cat, dog, and large Indian civet. Similarly, the wild hare was found to have the highest proportion of relative individuals present in scat samples, followed by the jungle cat and the large Indian civet. A lower proportion of biomass from wild ungulates in the leopard's diet and a higher dependency of the leopard on domestic prey and other wild prey indicate a lack of medium-sized wild prey (ungulates) in leopard habitats. Therefore, conservation of wild prey species, especially medium-sized ungulates, is important for mitigating the leopard's dependency on livestock and human-leopard conflict in the future.

1. INTRODUCTION

Leopard (*Panthera pardus*) is one of the top predators of forest and grassland ecosystems (McDougal 1977) and is widely distributed in the Indian sub-continent (Santiapillai et al. 1982, Mondal et al. 2011, Thapa et al. 2011, Baral et al. 2022). Leopards are widely distributed in Nepal (Baral et al., 2023), with the mountainous regions of Nepal being one of the most highly suitable habitats for leopards, owing to their geographical features, diversity of prey species, and vegetation type. Leopards prefer tropical forests inside and outside the protected areas of Nepal. However, most of the leopard's distribution falls outside the protected areas, where the landscapes are dominated by human and anthropogenic activities (Thapa 2011, Bhandari et al. 2019). Leopards are known to adapt to human-dominated landscapes such as agricultural lands and patchy forests close to villages (Nowell and Jackson 1996; Mondal et al. 2011; Baral et al. 2022). Human population growth and urbanization in Nepal's mountain regions have reduced the natural habitats of leopards and their prey species, this may have caused leopards to expand their ranges into human-dominated habitats in search of prey.

Leopards are non-selective predators and are known to prey on a variety of species ranging from small to medium-sized mammals, birds, and livestock (Eisenberg and Lockhart 1972; Bothma and Le Riche 1986; Santiapillai et al. 1982; Johnsingh 1983; Rabinowitz 1989; Seidensticker et al. 1990; Karanth and Sunquist 1995; Sankar and Johnsingh 2002; Henschel et al. 2005; Andheria 2007; Ramesh et al. 2009). However, it seems likely that the species' morphology and solitary hunting strategy impose limitations on the prey it can capture most efficiently with minimal risk (Hayward et al. 2012). Leopards preferentially prey upon species within a weight range of 10–40 kg, with the most preferred weight range of prey at about 25 kg (Hayward et al., 2006). Moreover, it has also been suggested that, regardless of an ample supply of large prey, leopards rely more on small and medium-sized prey (Thapa, 2011; Bhattarai and Kindlmann, 2012). Karanth and Sunquist (1995) also suggested that, in the absence of large prey, leopards would prey on medium-sized prey. Moreover, with the increasing human encroachment on forest fringes, concerns have been expressed that leopards may switch diets to prey more on domestic animals and non-conventional prey, including small mammals and carnivores (Eisenberg and Lockhart 1972; Bothma and Le Riche 1986; Santiapillai et al. 1982).

The majority of large Felidae prefer ungulates as prey, and when wild ungulate abundance is low in their natural habitat, domestic species suffer (Treves and Karanth 2003; Karanth and Sunquist 1995; Sankar and Johnsingh 2002; Bhandari et al. 2017). When wild prey became scarce due to population decline or seasonal migrations, cases of livestock depredation were reported to increase (Zhang et al. 2013; Baker et al. 2008; Khorozyan et al. 2015). Leopards are known to frequently attack domestic animals such as dogs, goats, and other livestock (Goyal et al., 2007, Ramesh et al., 2009, Thapa et al., 2012, and Baral et al., 2022). Predation on livestock results in negative human-leopard interaction, which eventually leads to human-leopard conflicts (Bhandari et al., 2017; Nowell and Jackson, 1996; Inskip and Zimmerman, 2009).

The hunting behavior of large predators such as the leopard is a highly complex phenomenon that usually requires a detailed study of their dietary preferences. The study is especially important in human-dominated landscapes in order to understand the ecology of leopards in urban and semi-urban areas and explore the drivers of human-leopard conflict. Though there are some studies focused on the leopard's diet within the protected areas of Nepal (Aryal and Kreignhofer, 2009; Kandel et al., 2020), there is a lack of studies on the leopard's diet in the non-protected regions of Nepal. In this study, we examine the diversity and relative proportion of prey species in leopard scats in a human dominated non-protected area in the mid hill region of Nepal in order to understand the diet of leopard in such landscape. Through analyses on the portion and biomass of domestic and wild prey species in the diet of the leopard, I investigate the extent and likely cause of leopard predation on livestock.

2. METHODS

2.1 Study site

The study site is located in Bhanu municipality (27° 26' to 28° 25' N and 84° 57' to 85° 34' E; Alt. (450-800) of Tanahun district in the mid hill region, Nepal (Figure 1). The survey was conducted in the community forests. The community forests were established as a result of a set of policies and institutional innovations that began in the mid-1970s to involve local communities in forest management and biodiversity conservation, as well as to improve livelihoods (Acharya, 2002; Uprety et al., 2011). In the study area, forests of different sizes (from 3 to 300 ha) are managed by community forest user groups (Uprety et al. 2011). *Shorea robusta* (sal)-dominated forest and riparian forest are the dominant forest types in the study area. The riparian forests are found on sandy soils of the riverbanks. The dominant species is *Acacia catechu*, which is threatened in the area. Other common plant species include *Bombax ceiba, Dalbergia sissoo, Sapium insigne, Schima wallichii, Lagerstroemia parviflora, Bauhinia vahlii, Desmodium oojeinense,* and *Murraya koenigii* (Uprety et al. 2011). The study site is home to 20 mammalian species, including large carnivores such as common leopard (DFO 2019). The climate of the study area is sub-tropical and tropical, with a mean annual rainfall of 1,761 mm, a maximum temperature between 38 and 410C, and minimum temperature between 5 and 60 degrees Celsius, whereas rainfall distribution is monsoon-type between June and September (Uprety et al. 2011).

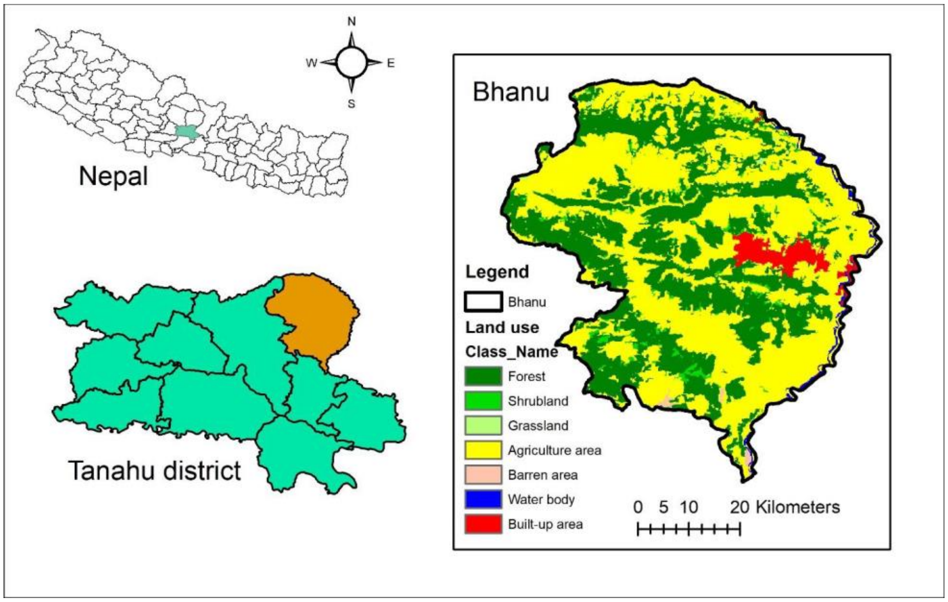

Figure 1: The study site location in the Tanahun, Nepal with the land use land cover map of the study area.

2.2 Scat identification and collection

We conducted our survey between August and December 2020 in habitats including forests, grasslands, riverbeds, and roads in order to collect a sufficient number of scats. An average of 1.8 km transect walk was conducted within 36 grids, covering a total of 64.8 km within the study area. All together, we collected 96 leopard scats. The scats of the leopards were identified based on their shape, size, and pugmark (Bhandari et al. 2015). The leopards' scats were much larger than those of other small cat species such as jungle cats and hyenas (Bhandari et al. 2015). The pugmarks of the leopard were supplementary evidence of leopard scat. Unidentified scats were discarded from the collection. The date of collection and GPS location were recorded for each sample before it was stored in zip-locked bags for further analysis.

2.3 Laboratory analysis

All scats were washed with cold water to remove the soil, leaves, and bones. They were then sun-dried for one day. The dried samples were labeled and stored in the paper bags for treatment. Following the method of Bhandari et al. (2020), we prepared slides imprinting the cuticle pattern of sample hairs of prey species found in leopard scats. A total of 20 hairs were picked randomly from each sample and soaked in a 1:1 alcohol and diethyl ether solution for 30 minutes. The hairs were then dried at room temperature. From these, five hairs were randomly selected and laid out in parallel lines on a slide that was painted with transparent nail polish to observe the cuticle pattern of the hairs. These hairs were then removed from the slide, and the imprint of the hair on the slide was observed through a compound stereoscopic microscope at 400X magnification.

The recorded cuticle images of the hairs extracted from the scat were then compared using a reference key for species confirmation. The reference images required for the comparison were also prepared following the aforementioned method. The hair sample and mean live weight of the prey species and small mammals and carnivores were obtained from the Pokhara Zoological Park, Kaski, operated by the Division Forest Office, Kaski, Nepal. We used the regression equations developed by Floyd et al. (1978) and Ackerman et al. (1984) to estimate the relative proportion of biomass of different prey species consumed by the leopard. The regression equations relate the average live weight of a prey animal consumed (x) to the weight of consumed prey represented by one field-collectible scat (Y):

$$Y = 1.98 + 0.035\,x$$

The term Y is the biomass of prey consumed (kg) to produce a single field collectable scat, and X is the average body weight of the prey species (in kg). Relative Biomass in scat (RBS) and Relative

Individual within scat (RIS) were calculated. Where A is the occurrence, B is the live weight of the prey species.

$$RBS = \frac{(A\times C)}{\sum(A\times C)} \text{ And } RIS = \frac{(D\div B)}{\sum(D\div B)}$$

We used the program SCATMAN to explore the prey selectivity of leopards (Link and Karanth 1994; Karanth and Sunquist 1995; Biswas and Sankar 2002). We also used Evlev's electivity index (Ei) to measure the relationship between the proportion of prey species found in the cats and the prey available in nature.

$$Ei = \frac{(ri - pi)}{(ri + pi)}$$

Where, ri represents the relative abundance of a prey in a leopard's diet and pi is the prey density. In this equation, Ei = ranges from -1 (total avoidance) to 1 (high preference).

Prey abundance data was obtained from a camera trap survey. The camera traps were deployed for a total of 21 days at 36 locations (756 trap days). The photographic captures with >30 minutes intervals were regarded as independent captures. To compute the abundance for each species, the total independent captures for each species were summed for all camera traps over all days and divided by the total number of camera trap days.

3. RESULT

We recorded 15 prey species among 96 leopard scats (Table 1). Plastic, bird feathers, and unidentified items were also recorded in the 4 scats. The number of prey species reached the asymptote at the sample size of 31 (Figure 2). Overall, goat contributed to the highest RBS followed by the jungle cat, dog, and large Indian civet (Table 1). 31% of the RBS came from livestock (Figure 3), with the goat contributing the most RBS among the livestock found in leopard scats, followed by the dog and domestic cat. Among the wild prey, RBS of wild ungulates (barking deer and wild boar) was just 12%, whereas RBS of other wild prey was 57% (Figure 3). Among the wild prey, jungle cats (13%) and large Indian civets (12%) had the highest RBS.

Table 1: Summary of the scat analysis of leopard in the mid hill of Nepal, total number scat= 96 (Where RBS=Relative Biomass within scat and RIS=Relative Individual within scat).

		A	**B**	**C**	**D**	**E**
Species	Composition	Occurrence %	Live weight "X"	Y = 1.98 + 0.035X	RBS %	RIS %
Capra aegagrus	18	8%	20	2.68	16%	5%
Felis chaus	30	14%	7	2.225	13%	12%
Canis lupus familiaris	21	10%	12	2.4	13%	7%
Viverrazibetha	27	**13%**	7	2.225	12%	11%
Canis aureus	12	6%	11	2.365	7%	4%
Muntiacusmuntjak	8	4%	18	2.61	7%	2%
Erethizondorsatum	12	6%	7	2.225	5%	5%
Sus scrofa	3	1%	38	3.31	5%	1%
Lepus europaeus	18	8%	1.5	2.0325	5%	19%
Felis bengalensis	12	6%	2.5	2.0675	4%	9%
Herpestes urva	12	6%	2	2.05	3%	10%
Martes flavigula	**9**	4%	3.5	2.1025	3%	5%
Macaca mulatta	6	3%	8	2.26	3%	2%
Pagumalarvata	**6**	3%	4	2.12	2%	3%
Felis catus	**6**	3%	2.5	2.0675	2%	4%

Similarly, wild ungulates had the lowest RIS (3%), whereas RIS for domestic prey and other wild prey was 16% and 81%, respectively (Figure 3). Among all species, wild hare had the highest proportion of RIS (19%), followed by jungle cats, large Indian civets, and crab-eating mongooses (Table 1).

Results generated from the camera trap revealed that the relative abundance of wild ungulates (barking deer and wild boar) was very low, whereas the abundance of monkeys was highest, followed by large Indian civets, jungle cats, and hares (Figure 4). Evlev's electivity index indicated a positive selection for leopard cats ($\chi 2 = 8.3$; $P < 00.05$), wild boars, and jungle cats and a negative selection for rhesus monkeys (preyed on less than expected, $\chi 2 = 22.1$; $P < 0.005$) (Figure 5).

We found that the majority of the scats (49%) were found on wide roads (>4 m in breadth), followed by narrow roads (1-4 m) (28%), trails (~1 m) (19%). Scats were found in mixed forests (34%), sal dominated forests (31%), shrubs (23%), and others (grassland, agriculture land, etc.) (12%).

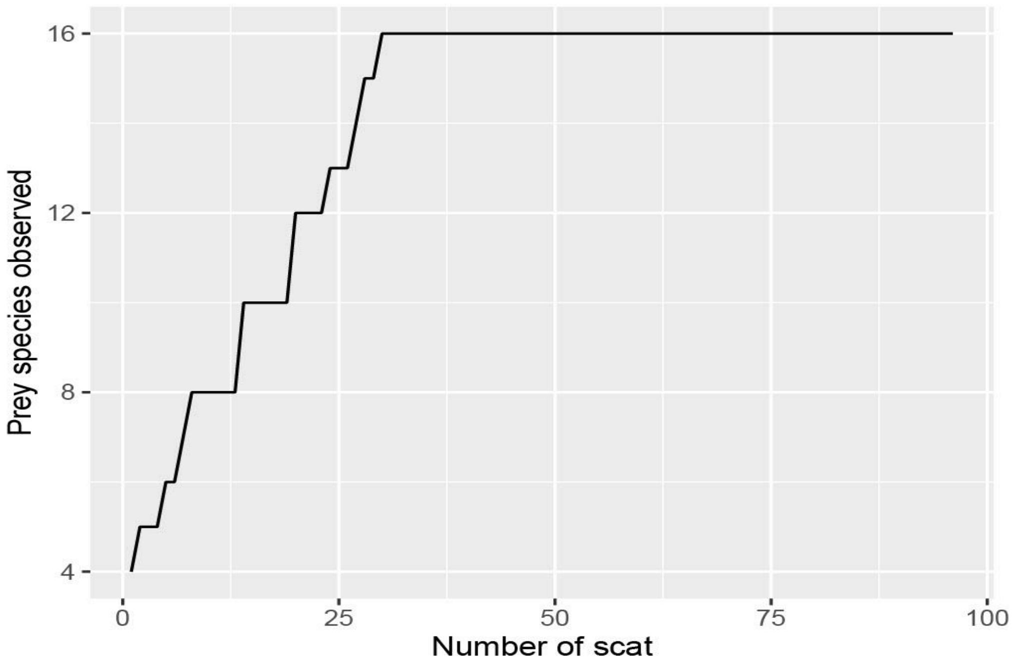

Figure 2: Total number of scats =96 is represented in X axis, whereas the number of species observed is represented in Y axis. The number of prey species reached the asymptote at the sample size of 31

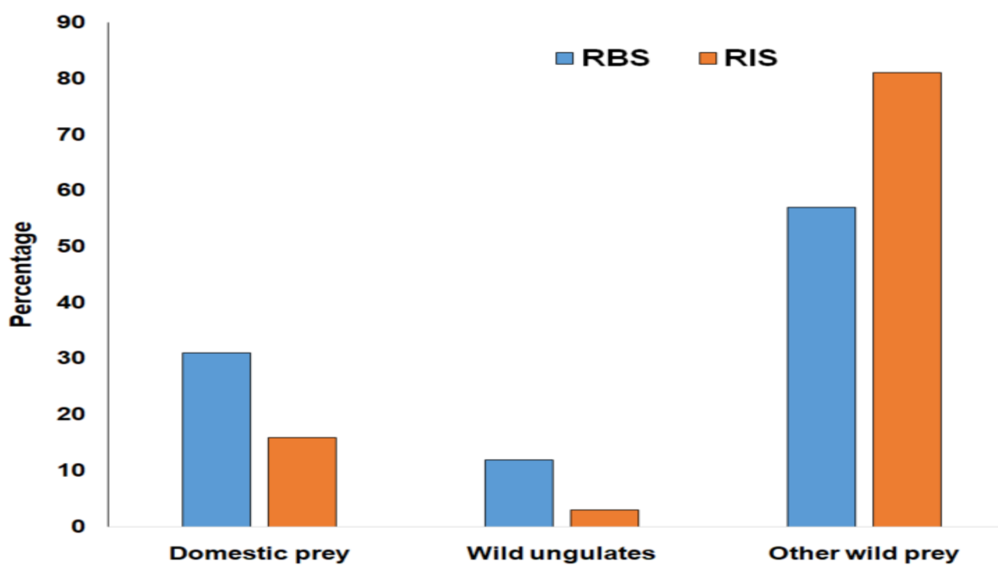

Figure 3: Percentage of relative biomass in scat (RBS) and relative individual in scat (RIS) of domestic prey, wild ungulates and other wild prey.

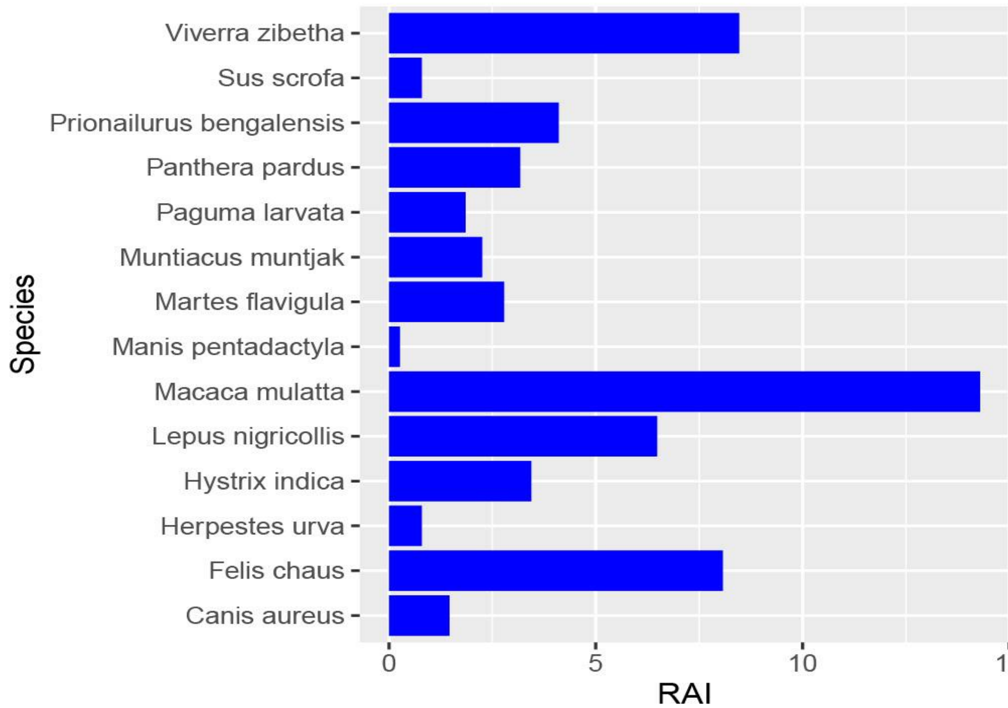

Figure 4: Relative Abundance of prey species and leopard generated from camera trap survey in the Bhanu Municipality between October and December 2020.

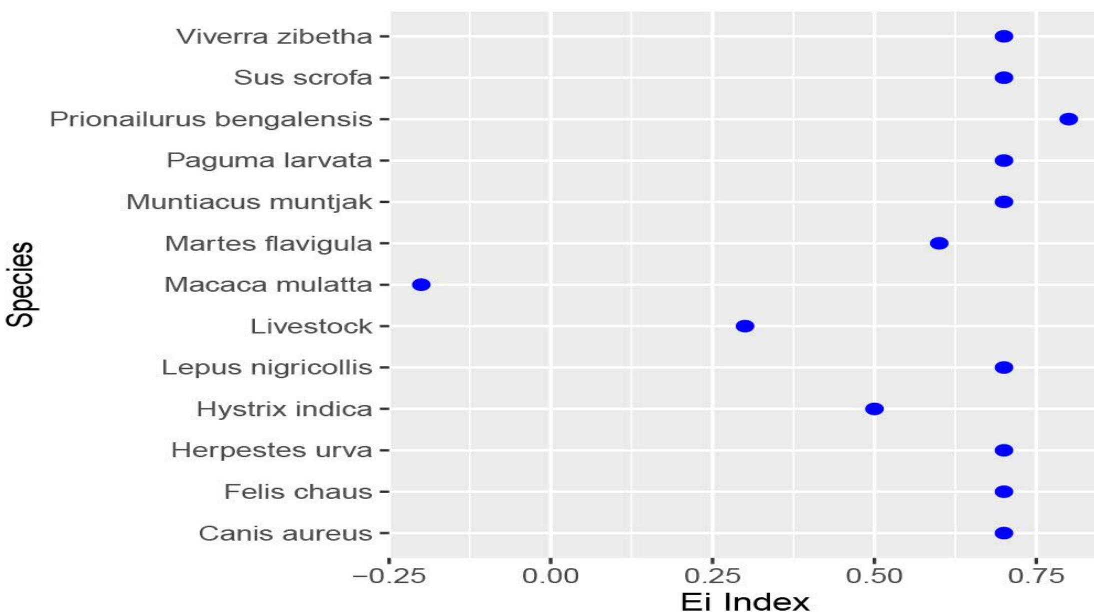

Figure 5. Evlev' selectivity index of the prey species based on leopard scat analysis. All species were positive selected except rhesus monkey.

4. DISCUSSION

We recorded 15 prey species in the leopard's diet, which is more than that found in other studies (Aryal and Kreignhofer, 2009; Thapa, 2011; Lovari et al., 2015). Hayward et al. (2006) suggested that leopards are known to have one of the most diverse diets among carnivores. A previous study recorded a high proportion (48%) of scat samples containing a single prey species (Mukherjee et al. 1994). In our study, however, not a single scat constituted of a single prey species. The larger prey diversity in scat and absence of single prey scats in our study could have been caused by the absence of large ungulates such as chital and sambar deer in our study area, thereby forcing leopards to prey upon multiple smaller preys, resulting in increased prey diversity in scats.

Relative biomass of wild prey in scat samples

Out of the wild prey species recorded in the scats of leopard, small carnivores (such as the jungle cat and the large Indian civet) comprised the majority of the relative biomass. However, these prey items are not conventionally a large part of the leopard's diet (Thapa 2014; Lovari et al. 2015; Kandel et al. 2020). Wild prey species such as wild boar and barking deer are commonly thought to be major prey species of leopards in Nepal's mountain region (Thapa 2014; Bhandari et al. 2020). However, in this study, these conventionally preferred prey species accounted for only 12% of total RBS. This might be due to the unavailability or low abundance of the ungulates (barking deer and wild boar) in the study area, forcing the leopards to shift a large proportion of their diet towards the subsistence prey such as other small wild mammals, which were more abundant in the study area.

Relative biomass of domestic prey in leopard scats

With 31% RBS, domestic prey constituted a substantial proportion of the total biomass. Livestock such as goats (16%) and dogs (13%) had the highest RBS out of the leopards' diet. The flexible hunting strategy has enabled the leopard to persist in close proximity to urban and highly anthropogenic areas (Pienarr 1969), as they are known to survive in human-dominated landscapes by modifying their foraging strategy and dietary habits (Gussingberg 1975; Chauhan and Goyal 2001). Human-dominated landscapes contain a variety of domestic prey (goats, sheep, dogs, cows, buffaloes, and poultry) in large numbers, which act as a substitute diet for leopards. Domestic livestock have been found to constitute a significant proportion of the leopard's diet in areas with high anthropogenic pressure (Athreya et al., 2016; Braczkowski et al., 2018; Kumbhoikar et al., 2021). A study conducted by Athreya et al. (2016) in a highly human-dominated landscape in western Maharashtra, India, reported 87% of the leopard's prey biomass to be domesticated animals, with 39% consisting of dogs alone. Compared to this study, the proportion of domestic animals in the leopard diet in our study area is lower. This discrepancy in result might be due to the fact that the study in India was conducted in a highly anthropogenic urban area, whereas our study was conducted in a semi-urban area with medium-high anthropogenic disturbance. Given the low abundance of ungulates in the wild and the higher overall availability of several small wild mammals (felid species, civet species, mongoose species, monkey, hare, porcupine, etc.) in our study area could be one of the reasons for the higher proportion of RBS (57%) of these small wild preys compared to RBS of the livestock and wild ungulates. Nevertheless, leopard diets were found to consist of a substantial proportion of livestock capable of generating frequent human-leopard interaction.

Influence of body weight on the prey preference

A significant portion, 31% of the RBS came from livestock (mostly goat and dogs), which have a mean weight above 10 kg. By comparing the weight of the prey with the leopard's body size, prey size is thought to play a significant role in the leopard's prey selection (Stander et al. 1997; Hrist 1969; Gilchrist 1991). Previous studies have reported the leopard’s preference for medium-sized prey species such as chital, wild boar, and hog deer (Stoen & Wegge 1996, Karki 2011; Bhattarai &Kindlmann 2012, Lovari et al. 2015; Bhandari et al. 2017). Other study results also signify that the leopard’s wide diet is in the range of preferred prey body weight of 10–40 kg (Hayward et al. 2006; Ramakrishan et al. 1999; Schaller 1972; Hart et al. 1996, Seidensticker et al. 1990; Karanth and Sunquist 1995; Sankar and Johnsingh 2002; Henschel et al. 2005; Andheria et al. 2007; Ramesh et al. 2009). Since the livestock (goat, dog) are usually of medium size (more than 10 kg) and are of comparable weight to the conventionally preferred preys (barking deer, wild boar), the preference of the leopard towards such domestic animals as a prey could be one of the possible reasons. Carnivores aim to minimize the time and effort used to find prey because it takes a substantial amount of energy to kill. A significant amount of energy is required to pursue and subdue a large prey, and this creates a 2-fold increase in the expenditure of energy (Carbone et al., 1999). Leopards may be targeting livestock near human settlements in their hunt for prey, as unguarded livestock is easier prey than wild ungulates.

Despite the fact that leopards are morphologically suited to medium-sized prey species, they may rely heavily on locally abundant small prey in harsh times when preferred or medium-sized prey is scarce (Aryal and Kreignhofer 2009; Zhirjakov 1990). However, there is little known about the role of alternative prey in the leopard diet (Shaw 1977). Due to the scarcity of their conventional prey at the study site and the significant energy required to find and kill them, leopards may have turned to preying on easily available small mammals and domestic animals. A study from Bailey (1993) suggested that leopards hunt alone at night on open habitats, whereas their predatory activity peaks at crepuscular and diurnal times (Henschel and Ray 2003). Such solitary hunting limits their options for the types of prey they can capture. Lions' large body mass and group hunting strategy allow them to forage on larger prey despite the threat of injury during the predation attempt and herd size (Hayward & Kerley, 2005). The solitary behavior of leopards may have restricted their ability to capture large domestic prey such as buffalo and cows. This may be one of the reasons that we found no representation of cows and buffalo among the livestock prey in the leopard diet but recorded a high proportion of smaller livestock such as goats and dogs among domestic prey.

Relative individual killed and Ivlev's electivity index

Small mammals such as India hare and jungle cat constituted the largest proportion of RIS, and are frequently being preyed upon by leopard compared to other preys. This may due to their high abundance and small body size. As leopard has to consume smaller bodied individuals to generate the same amount of energy when compared to preying higher mass species, which provide equal energy even with lower number of individuals killed. Numerous studies have reported instances of leopard preying upon other smaller carnivores (Stander et al. 1997; Pienarr 1969; Bailey 1993; Hamilton 1976). The preference of individuals is thought to be the major cause that governs the behavior of leopard preying upon other carnivores (Stander et al. 1997; Pienarr 1969; Hayward 2006) but the actual reason for this behavior is still vague and needs a detailed study (Palomares and caro 1999).

The abundance of monkeys in the study area is high but its proportion of relative biomass killed is comparatively low. Their arboreal nature and group vigilance may have helped themselves to stay protected from predators such as leopard (Zuberbuhler and Jenny 2002). Previous studies have also found that leopards only prey on primates when other prey are scarce (Seidensticker 1983, Hayward 2006). Despite of their abundant nature, this might be one of the reasons that monkeys were the only species with negative value in the Ivlev's electivity index.

Relation of leopard's diet with human leopard conflict

In regions like our study area, where natural prey abundance is low, leopards may increase their dependency on domestic livestock and even humans as alternative prey (Adhikari et al., 2022). Human-leopard conflict has become a growing concern, mainly due to the shift in the dietary pattern of leopards from wild prey to domestic prey (Athreya et al., 2011). Since the smaller wild prey might be unable to sustain the leopard's energy needs, the leopards are highly likely to search for prey in fringe areas with human settlements and agricultural areas. As a result, leopards in areas with high levels of human disturbance and limited natural prey availability are more likely to prey on domestic livestock and humans, resulting in increased conflict (Athreya et al., 2011). Hence, in order to promote a coexistence between humans and leopards, the negative interaction should be minimized, preferably by implementing sustainable conservation strategies for wild prey such as barking deer and wild boar.

5. CONCLUSION

Small carnivores (such as the jungle cat and large Indian civet) and livestock (goats and dogs) comprise the majority of the leopards' diet in Nepal's mid-hill region. The high dependency of leopards on small mammals and livestock will likely to increase negative human leopard interactions. Furthermore, the substantial proportion of livestock and small mammals consumed by leopards indicates a low abundance of medium-sized wild prey, especially conventionally preferred ungulate species such as barking deer and wild boar. Effective management strategies, such as wild ungulates conservation through habitat restoration techniques can help to create sustainable prey resource for effective conservation of leopards. Similarly, awareness and wildlife relief/compensation scheme can reduce conflict between humans and leopards in these areas, thereby promoting coexistence of people and leopards.

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Chapter Five

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

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(Photo: Sagar Giri)

ABSTRACT

Climate change is projected to create alterations in species distributions over the planet. The common leopard (*Panthera pardus*) serves an important ecological function as a member of

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

INTRODUCTION

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

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

Studying correlations between climatic conditions and the current ranges of species can help predict the future distribution of these species [24,26]. With the help of the Inter governmental Panelon Climate Change (IPCC), the climate modeling community created the Shared Socioe conomic Pathways (SSPs). A group of scenarios (SSP1-2.6, SSP 2-4.5, SSP 4-6.0, and SSP5-8.5) were developed to show a range of different climate change outcomes by the end of the century. Shared socioeconomic paths (SSPs) are narratives that outline many socioeconomic possibilities related to the population, urbanization, and GDP of a country (per capita). SSPs, which provide predictions of expected global socioeconomic patterns until the year 2100, are frequently used to develop scenarios for green housegas emissions (GHG) under different climate policies [27,28]. Temperature, rainfall, and humidity are all dynamic bioclimatic factors that are linked to species distribution and play an essential role in determining appropriate habitats [29,30].

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

Big carnivores perform an important ecological function and their extinction can trigger trophic cascades, resulting inarisein herbivore populations and habitat deterioration or alteration [36, 37]. The common leopard, as an apex predator of the mid-hill ecosystem of Nepal, performs a similar function [38-41]. Despite their importance, little is known about how climate change may affect their distribution. Research on the impacts of climate change on predators such as common leopards and their suitable habitat under climate change scenarios in the Himalayan area is crucial for future conservation [42] as well as predicting their interaction and conflict with humans [39,43]. Assessment of current suitable habitat according to the landuse categories could also provide important insights regarding range of species distribution and its potential association with conflict [44]. Such information is importantfor formulating and implementing sound conservation strategies, taking into account human as well as wildlife well-being [45]. The goals of this study were to learn about the current distribution ranges of common leopard from a climatic standpoint and to find out its implications for conservation of common leopard and its interaction and conflict with humans. The study also aimed to analyze the key climatic variables that regulate or restrict its dispersion. Under the assumption that climate change modifies common leopard habitats in Nepal, the current work seeks to generate a distributional maps of common leopard habitats and estimate the expected habitat shift in future climate change scenarios.

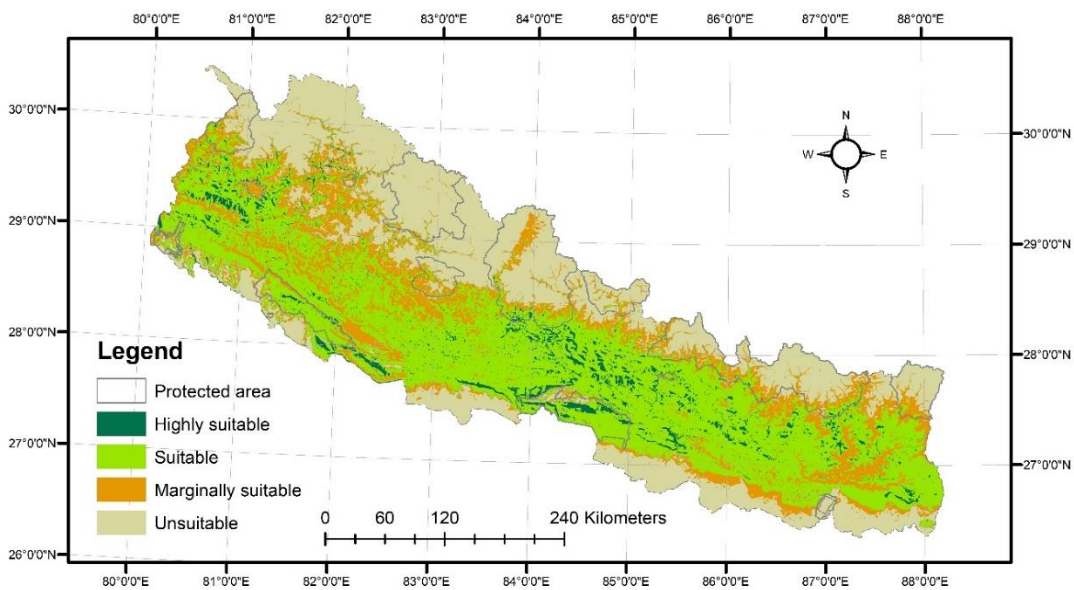

Figure 1: Present distribution of common leopard in Nepal, with blue boundary representing protected areas and the dark green color representing the highlysuitableareas, thegreencolorrepresentssuitable area, coral color represents marginally suitable area and peach color represent sunsuitable areas.

METHODS

Study area

This study was conducted in Nepal and used location data of common leopards collected throughout the country. Nepal lies in the central Himalaya region (28.3949°N, 84.1240°E) (Figure1). Despite the small land area (147,181km^2), Nepal has high altitudinal variations ranging from 70 m to 8848.8 m from mean sea level (Mt. Everest) [46]. The country is classified into five disparate physiographic zones, namely the High Himalayas (above5000msl.), High Mountains (3000–5000mm.s.l.), Middle Mountains (1000–3000mm.s.l.), Siwaliks (500–1000mm.s.l.) and Terai (below 500 mm.s.l.) [46] (Table1). With a rich biological diversity, due to the heterogonous physiography, a total of 118 ecosystems have been reported in Nepal, including 112 forest ecosystems (Majupuria and Majupuria, 2006; [46-49]. There are 12 national parks, one wildlife reserve, one hunting reserve and six conservation areas covering 23.23% of the total land area of the country. The total population of the country is 26.5 million, out of which 64% of people primarily depend on agriculture and animal husbandry to sustain their livelihood [50].

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

Data collection

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

We downloaded 19 bioclimatic variables (Table 2) × of current and future climate conditions (2050 and 2070) from Worldclim (https://www.worldclim.org/) [52] at a spatial resolution of 30 arc seconds (1 km *1 km). To model response of leopard to future climatic scenarios, we used bioclimatic variables from Models for Interdisciplinary Research on Climate (MIROC), specifically MIROC6, as it is the most recent upgrade to MIROC5 [53], and even has greater overall reproducibility of mean climate and internal variability compared to the previous version [54]. Though there are uncertainties in prediction of global climate change models [55, 56], the MIROC5 global circulation model (GCM) has consistently predicted rainfall for the Indian subcontinent [57] and has simulated extreme and summer precipitation better than other GCMs for the South Asian region [58]. Moreover, the temperature distribution and variations in the Indian subcontinent area can also be captured using MIROC5 [59]. For this reason, we acquired MIROC6 based bioclimatic variables for two scenarios (SSP2-4.5 and SSP5-8.5) for the years 2050 and 2070 for the analysis. SSP2-4.5 denotes an intermediate level of greenhouse gas emissions, in which CO2 emissions will decline after 2050 but not reach net zero by 2100. SSP5-8.5, on the other hand, has extremely high GHG emissions and triples CO2 emissions by 2075. Because SSP2-4.5 is considered to be a moderate and very plausible scenario [60], and SSP5-8.5 is the most extreme scenario but also the best match to the cumulative emissions from 2005 to 2020, we utilized these two specific scenarios [61]. Slope, aspect, and elevation were calculated using a 30 m resolution digital elevation model (DEM) acquired from the USGS website (https://www.usgs.gov/). We used all 19 bioclimatic variables and three topographic variables for the study. All the variables were downloaded at 1 km 1 km to match the spatial resolution.

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

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

(Source: GoN/MoFSC, 2014)

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

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

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

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

Modeling the distribution of leopard

To reduce spatial autocorrelation and type I error, the georeferenced location data were spatially filtered, and any location with a distance of less than 1k m to the closest location was removed. Out of 343 occurrence records of the common leopard, 206 presence points were retained after filtering. In order to reduce the multicollinearity among the variables, a variance inflation factor (VIF) test was conducted in Rsoftware [62] by systematically excluding the variables with VIF>5. Among the 19 environmental variables, i.e., isothermality, aspect, precipitation of driest month, mean diurnal range, precipitation of coldest quarter, slope, precipitation seasonality, annual precipitation, mean temperature of driest quarter, and elevation, were retained to be used for further analysis in Maxent after accounting for correlation amongvariables.

For is study, Maxent SDM was used for modeling the distribution of leopards. The optimal MaxEnt model was chosen by using maximum training sensitivity plus specificity threshold and the 10-fold cross-validation approach to build binary maps. A total of 48 alternative models were examined for this, with multiple combinations of six feature classes (H,L,LQ,LQH,LQHP, and LQHPT,where L Linear, Q Quadratic, H Hinge, P Product, T Threshold) and eight regularization multiplier (RM) values (0.5–4, 0.5). The maximum number of iterations was set to1000, and 70% of the presence points were used to train the model, with the remaining data used to test it [63].

The jackknife test was used to evaluate the dominant environmental variables and their permutation importance for the generation of a model [64]. Also, the response curves were created to scrutinize the association between environmental variables and habitat suitability.

Assessment of accuracy was conducted by both threshold-independent and threshold dependent methods. In the threshold independent method, the AUC-ROC value was used, which ranges from 0 to 1. AUC 0.7 indicates poor model performance, 0.7–0.9 indicates average model performance, and 0.9 indicates excellent model performance [65]. For the threshold dependent model, true skill statistics (TSS) were evaluated, which utilize the maximum sum of sensitivity and specificity. The TSS Sensitivity Specificity 1, which has a range from 0 to 1, in which 1 indicates perfect fit and 0 represents random performance. Using the R software [62], the final TSS was obtained by averaging the TSS of models generated from 10 replications.

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

RESULTS

Present distribution of commonleopard

At present, from a climatic perspective, out of the total area of Nepal, 4% of land was found to be highly suitable for common leopard, where as 43% resulted a ssuitable, 19% as marginally suitable and 34% wasdeemedun suitable (Figure 1). The majority of the area in the high Himalayas (93% of this region) was deemed unsuitable for the common leopard. The largest proportion (45%) oft he High Mountain region was classified as marginally suitable. 79% of total land within the middle mountains and 75% of total land of the Siwalik region was suitable for the common leopard, where as the Terai constituted mostly unsuitable habitat (69%). Out of four habitat classes, 13% of highly suitable habitat, 10% of suitable habitat, and 21% of marginally suitable habitat were inside protected areas (PAs), and a large portion of the climatically suitable habitat were in non-protected areas (Figure 2).

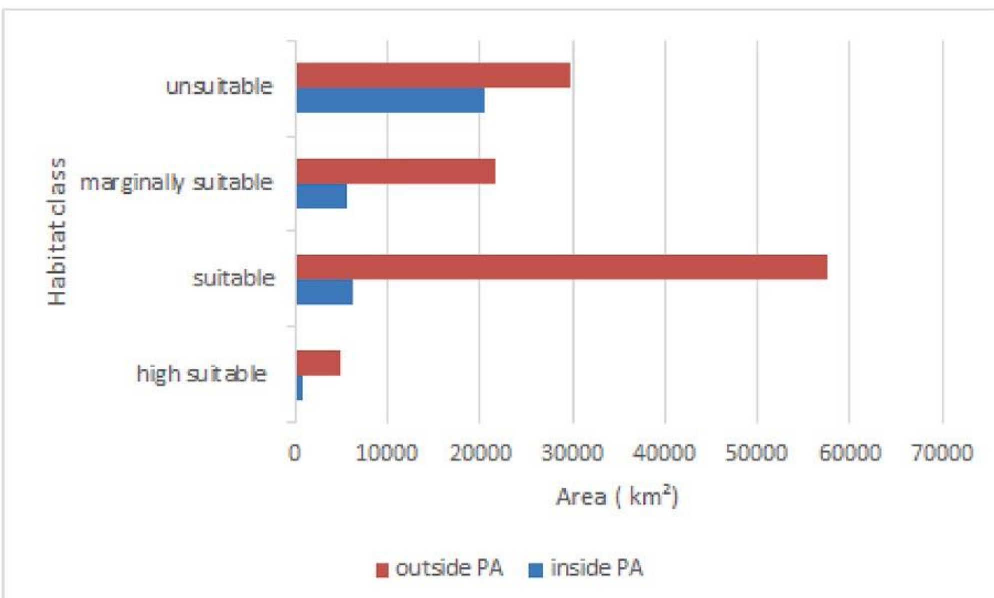

Figure 2: Two categories of protected areas and non-protected areas in Nepal (Xaxis) and four habitat class (Yaxis) for common leopard. Most of the suitable habitat encompassed in non-protected regions (outside PA).

Forest land covered the majority of the highly suitable habitat (58%), followed by agriculture land (35%). Similarly, suitable habitat consists of 60 % forest land and 34% agriculture area. The majority of marginally suitable habitats was forest (59%) followed by agriculture (24%) and grassland (8%), while the majority of unsuitable habitats constituted snow and glacier (24%), grassland (22%), and barren land (21%) (Figure3).

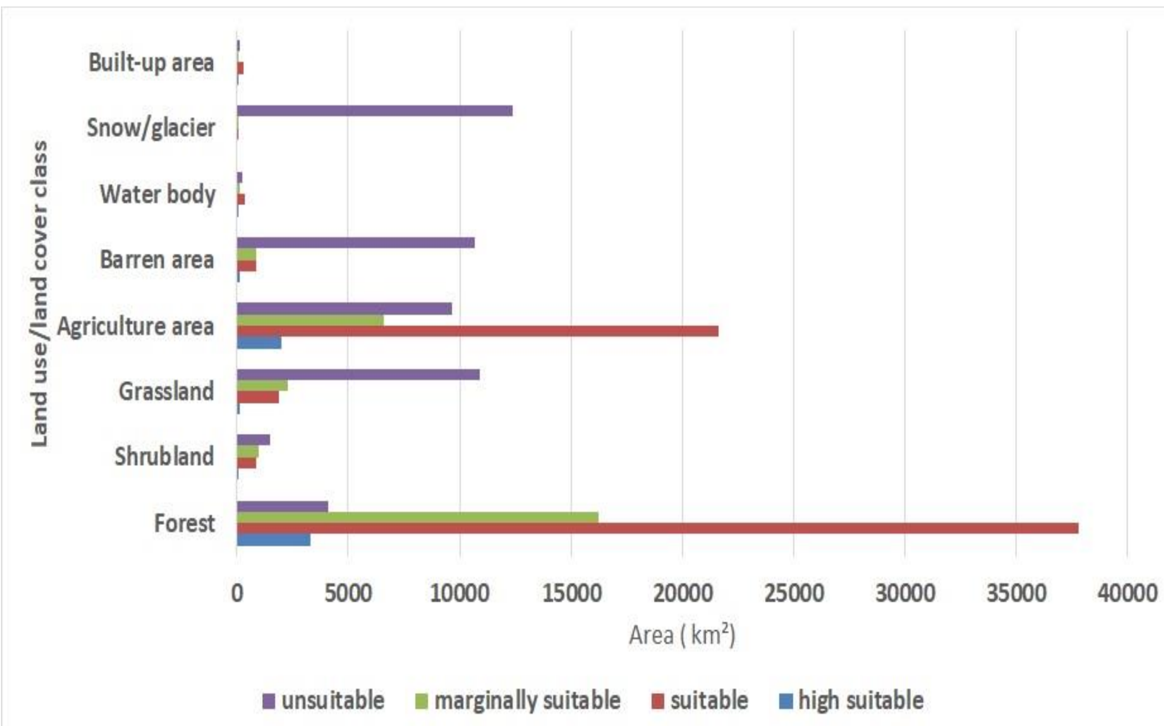

Figure 3: Eight categories of land use (Y axis) and corresponding distribution of suitable habitat among four habitat class (X axis).

Importance of variables and response curves of important variable

Out of 10 variables used in the model, the jackknife test (Figure 4) of regularized training gain indicated that elevation, mean temperature of driest quarter, annual precipitation, and precipitation seasonality were the variables affecting habitat suitability for leopards.

Response curves (Figure5) indicate that common leopards prefer elevations around 1000m. There is a gradual decrease in the probability of occurrence with lower or higher elevations. It also indicated that common leopards prefer the mean temperature of the driest quarter range from 10 to15°Celsius. Annual precipitation above 3500mm and a precipitation seasonality value of 70 (which indicates a low coefficient of variationin precipitation) was found to be the most suitable for common leopard.

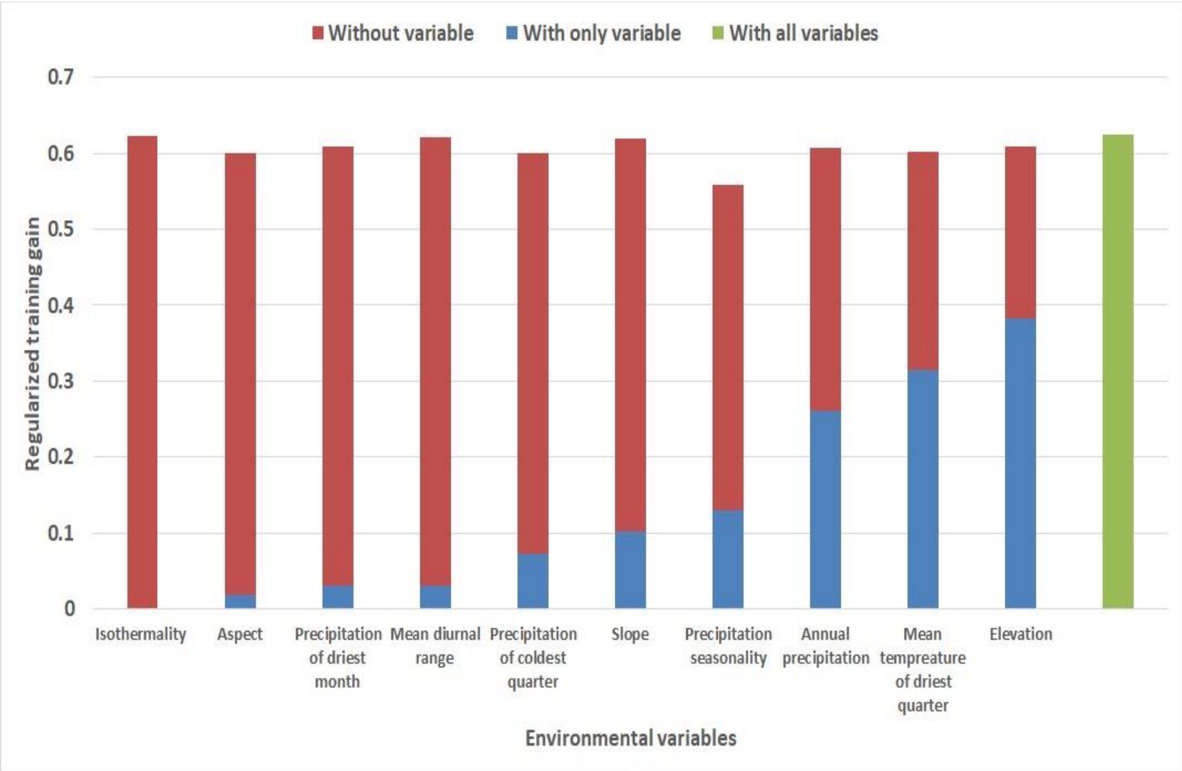

Figure 4**:** Jackknife regularized training gain for assessing the importance of variables for predicting the distribution of common leopard. The X axis includes 10 variables and the Y axis depicts the value of regularized training gain. Th ered colorrepresents values of training gain without variable, blue represents with only variable and green with all variables.

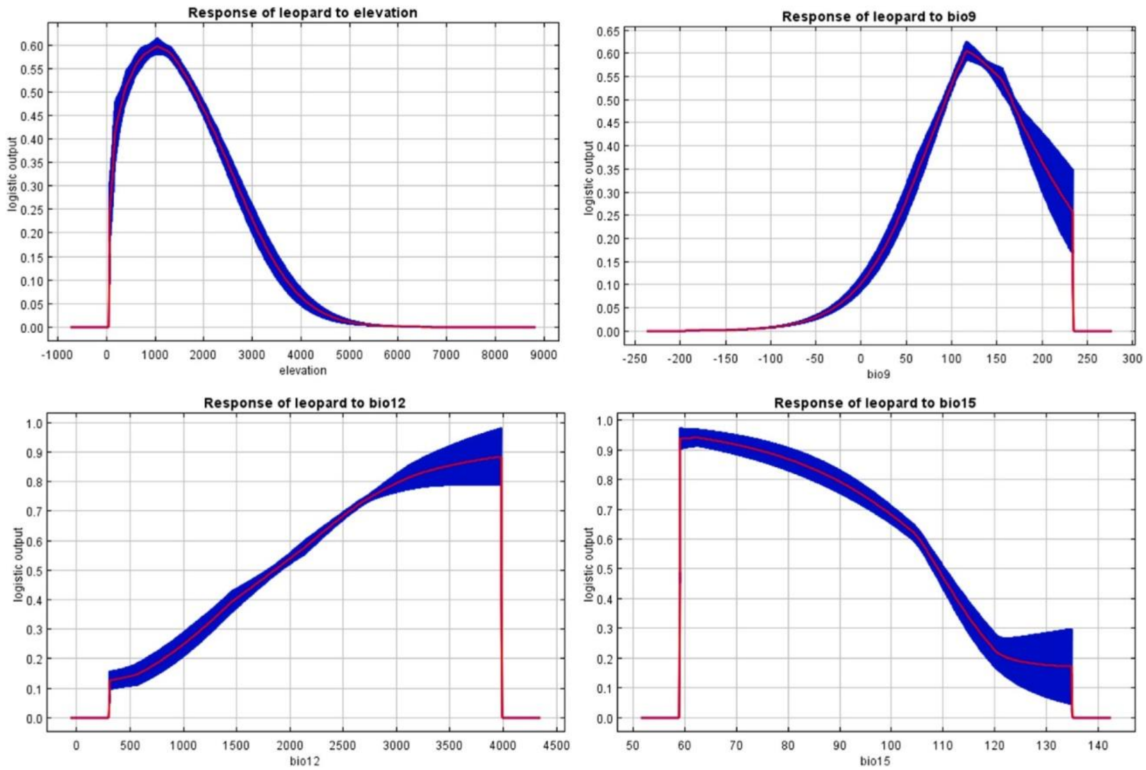

Figure 5: The response curve of four most important variables governing habitat suitability of common leopard. Bio9 indicates mean temperature of driest quarter (suitability peaks at around 10–15 °C), bio 12 indicates annual precipitation (suitability peaks at higher precipitation >3500 mm), and bio 15 represents precipitation seasonality (suitability peaks around the value < 70).

Future distribution of common leopard in Nepal

At both SSP2-4.5 and SSP5-8.5 scenarios, suitable and highly suitable habitat werere latively more stable than marginally suitable and unsuitable habitat (Figures 6 and 7). The unsuitable habitat decreased by 7% in the SSP 2-4.5 scenario, while the marginally suitable habitat increased by 10% by 2070. Similarly, in the SSP5-8.5 scenario, unsuitable habitat decreased by 6%, whereas marginally suitable habitat increased by 9% by the year 2070. In both scenarios, there are fairly similar trends of change in the highly suitable and suitable habitat categories across all physiographic zones (Figure 8).

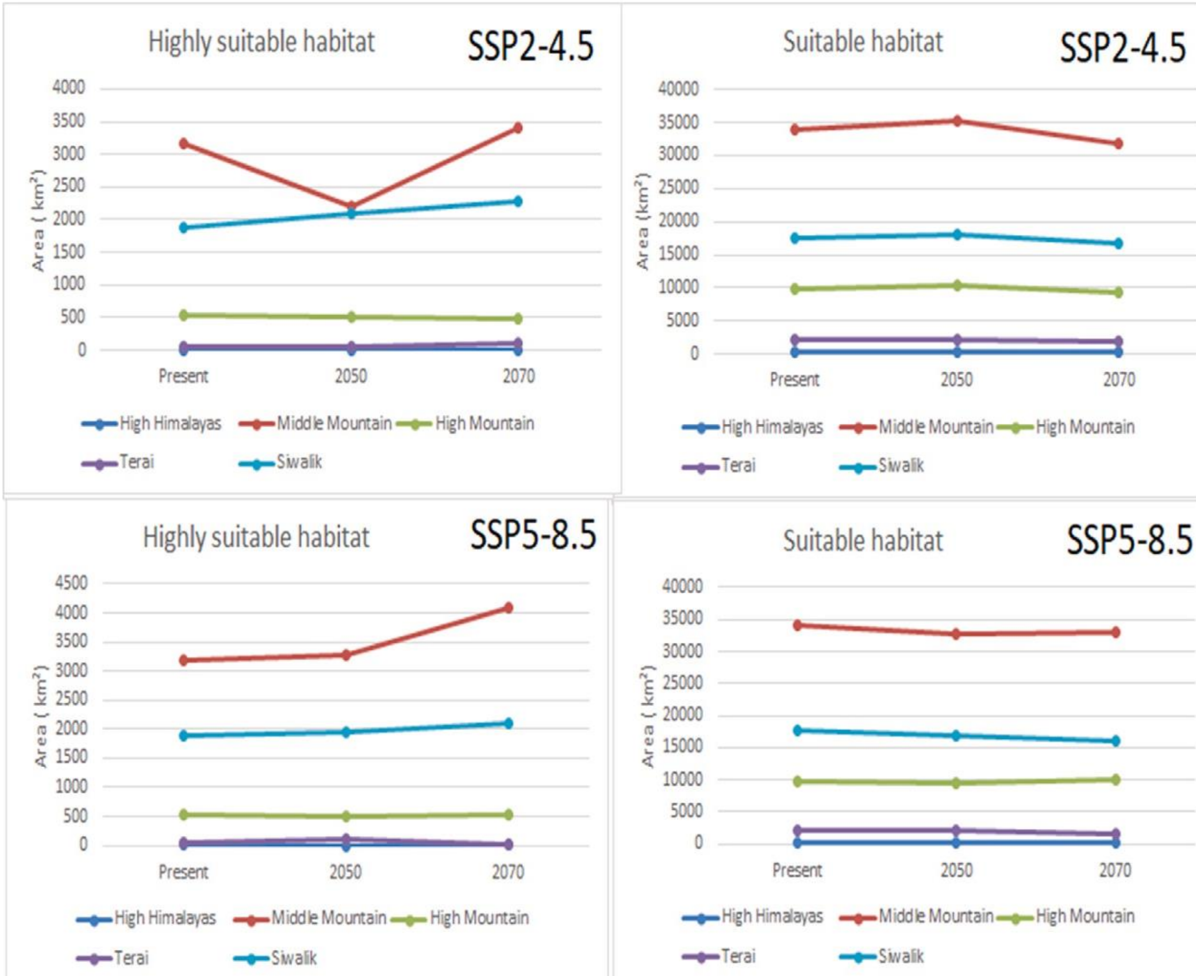

Figure 6: Areas corresponding to two categories (Highly suitable and Suitable) habitat for common leopard in under present condition and two climate change scenarios (SSP2-4.5 and SSP5-8.5) for the year 2050 and 2070. The x axis represents area, y axis represents the year and the lines represent the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

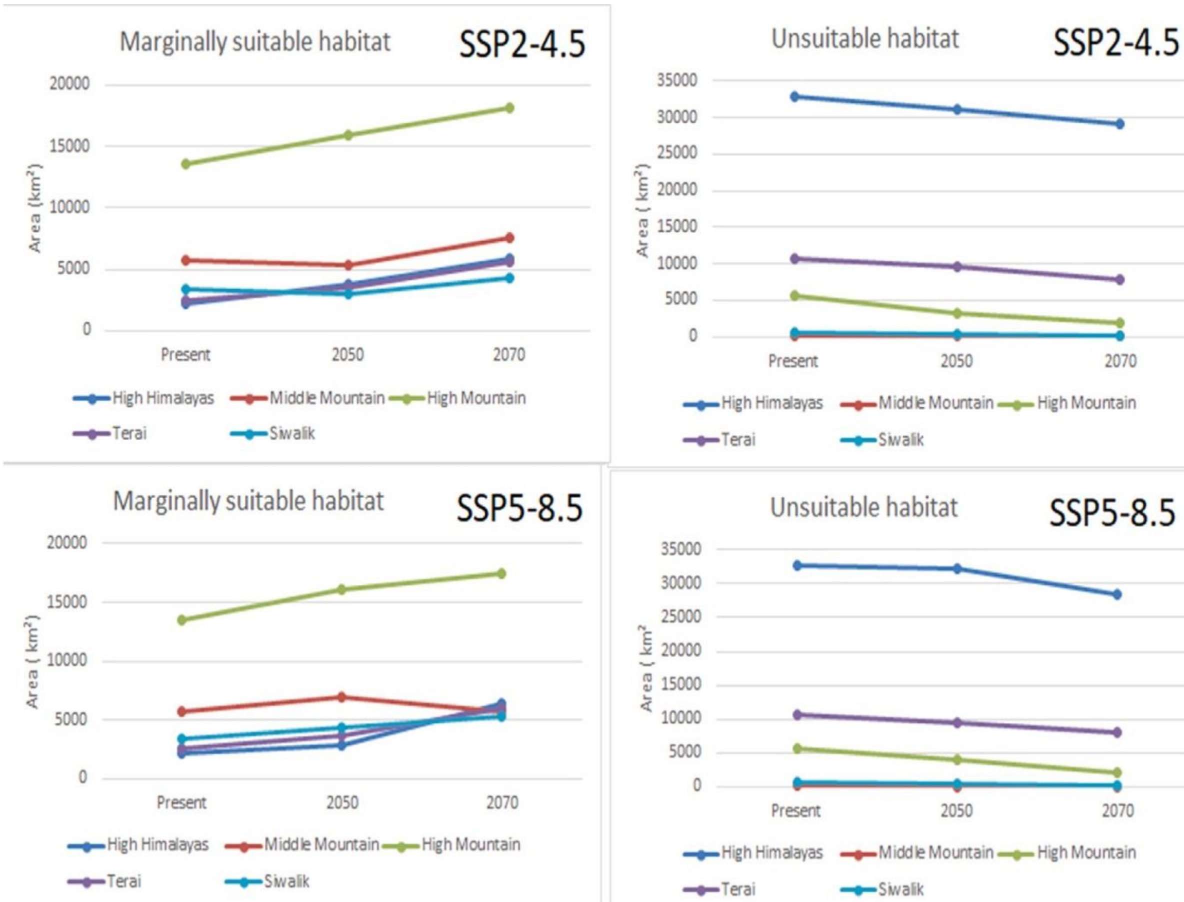

Figure 7**:** Areas corresponding to two categories (Marginally suitable and Unsuitable) habitat for common leopard in underpresent condition and two climate change scenarios (SSP2-4.5 and SSP5-8.5) for the year 2050 and 2070. The x axis represents area, y axis represents the year and the lines represent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

Accuracy assessment of themodel

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

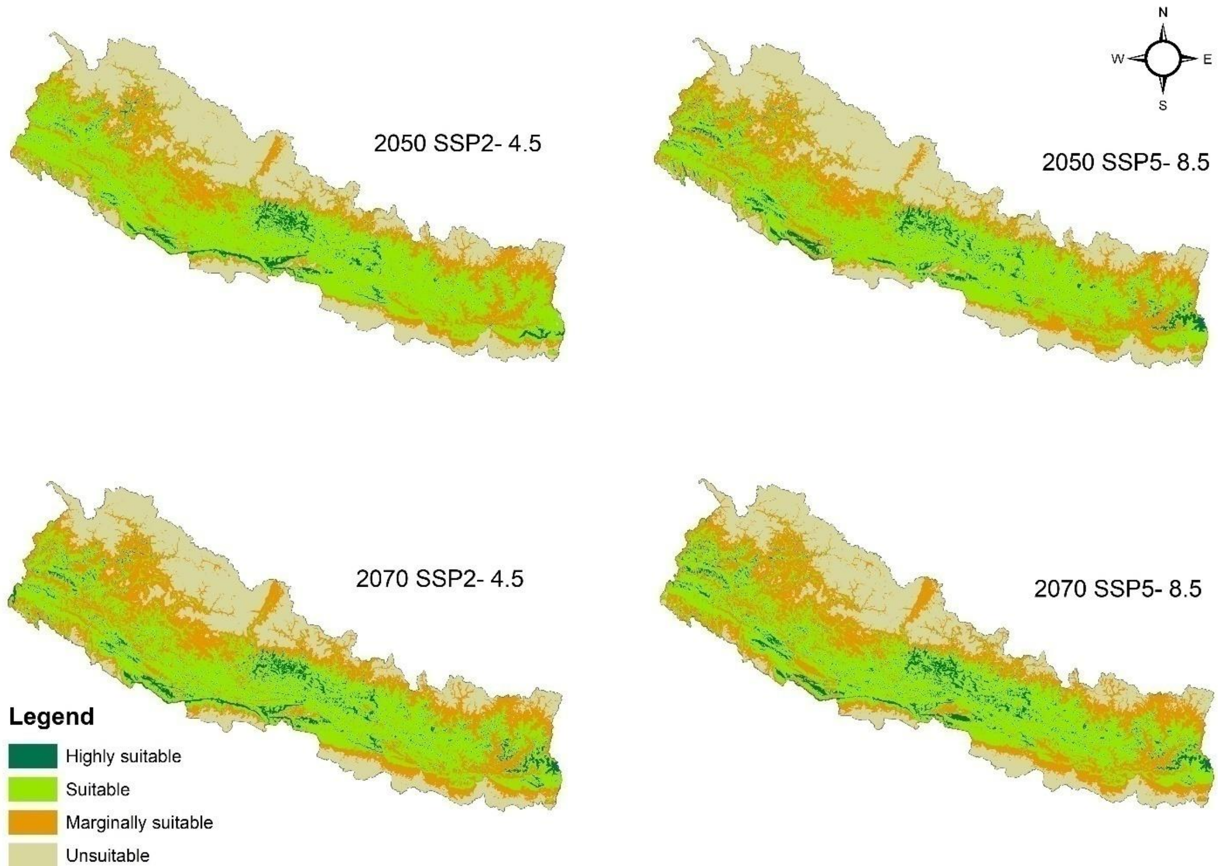

Figure 8: Future distribution (2050 and 2070) of common leopard in Nepal in SSP2-4.5 and SSP5-8.5 scenarios, where the darker color represents the highly suitable areas and the lighter color represents low suitable areas.

DISCUSSION

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

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

Our data showed that at present context, the agricultural land is the second most suitable habitat for leopards, followed by the forest areas. This may be due to the increase in a gricultural land abandonment in Nepal [73]. Abandonment of agricultural practices is due to emigration of people from the villages in mountain areas to cities and flatlands for jobs and other better life style opportunities [71, 74–76]. Forest succession in such abandoned agricultural lands has extended the habitat of wildlife. Human leopard conflicts in human-dominated landscapes may increase as the common leopard habitat expands into agricultural land [77].

A high proportion of the high Himalayas is unsuitable for common leopards, where as a large proportion of the high mountain regions is marginally suitable for common leopard habitat.

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

In the context of Nepal, winter is the driest quarter with the least amount of precipitation [83,84]. The majority of parts of the mid hills of Nepal experience a mean temperature of 10–15°Celsius in the winter season. The response curves generated in our study also indicated that habitat suitability peaked at 10–15°Celsius. Our study indicated high habitat suitability for leopards in areas where average annual rainfall is more than 3500mm. Areas with low precipitation seasonality; coefficient of variation in precipitation (less than70) were discovered to be more favorable for common leopard distribution. As a result, the higher annual precipitation value and low variation in precipitation provide suitable habitat for the common leopard. The districts of Tanahun, Kaski, Syanjga, Kathmandu, Argakahchi, Parbat, Ilam, and Dhankuta, with an annual average rainfall of 3500–4425 mm (DHM, 2018), represent good leopard habitat in the mid-hills of Nepal. These areas have a high level of human-leopard conflicts [72], indicating high leopard density.

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

CONCLUSION AND IMPLICATION ON CONSERVATION AND HUMAN WILDLIFE CONFLICT

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

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Chapter Six:

Conclusion and Recommendation

6.1 Human-wildlife conflict

Human-wildlife conflict (HWC) is a global problem that has become more severe both inside and outside of protected areas (PAs) (Distefano, 2005; Carter et al., 2012). Both humans and wildlife can be the cause of conflict (Mekonen 2020; Treves & Santiago 2020). The main conflicts brought on by wildlife are damage to crops, livestock casualties, and human fatalities, whereas the main conflicts caused by humans include poaching and retaliation (Pandey et al., 2015; Pant et al., 2016). HWC is a serious issue that impacts both human livelihoods and the conservation of rare and endangered wildlife species (Acharya et al., 2016; Baral et al., 2021).

I investigated the overall patterns of HWC in Nepal in the last two decades (2000–2022), especially conflicts between people and four large mammals: Asian elephants *(Elephas maximus)*, rhinoceroses (*Rhinoceros unicornis*), tigers (*Panthera tigris*), and common leopards (*Panthera pardus)* (Chapter Two). I recorded 1139 cases of mortality from these four species and 887 cases of human mortality caused by these four species during this period. Leopard mortality was the highest, followed by that of greater one-horned rhinos, tigers, and Asian elephants. Both cases of wildlife and human losses have been increasing over the last two decades. The loss of these megafauna is highly correlated with the human losses caused by these species. It shows that retaliatory wildlife loss was the most challenging issue for wildlife conservation, especially for the conservation of large mammals. The proportion of agricultural land was positively correlated with the frequency of HWC in our study areas, whereas the literacy rate of people was negatively correlated with both wildlife and human loss. Some potential remedial actions include: a) effective management of these megafauna and reduction of habitat fragmentation; b) designing and executing appropriate conflict mitigation initiatives; c) controlling the retaliatory killing of wildlife by raising awareness and strictly enforcing the law; and d) upgrading the HWC database and incorporating it into national and provincial level planning, particularly outside PAs.

6.2 Drivers of HWC in mid-hills, outside PAs of Nepal

6.2.1 Spatial and temporal factors responsible for HWC

The Himalayan black bear (*Ursus thibetanus laniger*) and the common leopard (*Panthera pardus*) were the main animals involved in conflicts in the mid-hill region of Nepal (Chapter Three, Study-I), and the number of wildlife attacks has been going up from 2011 to 2021.Both spatial and temporal factors influence the patterns of wildlife attacks on people. Wildlife attacks increased during the winter months of September through December. The highest percentage of attacks occurred between the hours of 15:00 and 20:00. Most wildlife attacks were recorded in human settlements, followed by agricultural land and forest areas. The likelihood of wildlife attacking people increases with decreasing elevation of the place, decreasing distance to the nearest forest area, and increasing reliance of people on forest resources.

In order to mitigate the HWC and conserve wildlife in Nepal's mid-hill region outside PAs, it requires reducing habitat degradation and fragmentation and increasing prey availability in community forests (CFs). Additionally, alternative means of livelihood such as eco-tourism, the cultivation of cash crops, beekeeping, etc. should be made available to people in order to lessen their dependency on forest resources and, as a result, reduce conflicts between humans and wildlife.

6.2.2 Socio-economic factors associated with HWC

Among the many social (age, sex, occupation) and economic (poor, middle, and rich) variables I tested, two variables, occupation and age, affected the incidents of HWC. The number of victims of HWC incidents was significantly higher among farmers and people under the age of 20 (Chapter Three, Study-I). Farmers are largely reliant on forests for forage and grass for animals, as well as fuelwood and medicinal plants for human use. Farmers usually cultivate land adjacent to forest areas. Due to these factors, farmers are more likely to encounter wildlife more frequently. On the other hand, children under the age of 20 tend to spend more time outdoors in natural places containing wildlife, such as forests, farms, and rivers. They may not have enough supervision and lack knowledge and education about the risks involved with encounters with wildlife. These elements can cumulatively raise the likelihood of children being attacked by wildlife.

I recommend implementing a broad public education campaign, especially for those who live close to CFs areas, and school teaching programs for children focusing on the knowledge of the behavior of various wildlife and the precautions that should be taken to ensure human safety and wellbeing. Additionally, offering off-farm livelihood opportunities to the people residing near forest areas, for example, ecotourism activities, handcraft production, small businesses, etc., would assist in lessening their reliance on the forest and the likelihood that they may come into contact with wildlife.

6.2.3 Land use change and HWC

Satellite image analysis of my study area revealed a 20.52% reduction in cultivated land between 1998 and 2018. Out of the lost cultivated land, 81.6% had been converted to forest, primarily in the adjacent village and residential area. By contrast, only 1.02 percent of forest land has been turned into cropland (Chapter Three, Study-II). The change of agriculture land to forest is mostly due to the abandonment of farmlands caused by the emigration of labor forces from the mid-hill regions to the cities and flat areas (Katuwal et al., 2018). Furthermore, forest regeneration on abandoned land has created additional pathways and corridors, enabling wild animals to move closer to human settlements, increasing the likelihood of wildlife encounters with people, their crops or livestock, and property. My study reveals that 78% of crop damage events, 64% of livestock depredation events, and 48% of human casualty events brought on by wildlife occurred in and around residential areas. Additionally, between 2018 and 2019, ten children were killed by leopards in their home / yard in the Tanahun district. Thus, villages and residential areas have become the hotspots of the HWC in the mid-hill region of Nepal.

Most of the studies to date have claimed that forest loss and fragmentation are the major causes of HWC (Chartier et al., 2011; Acharya et al., 2017; Scanes et al., 2018; Bloomfield et al., 2020). My study represents a contrasting scenario. The regeneration of the shrubs and forest on abandoned agricultural land near villages has led to an increase in HWC. This finding adds a new dimension to the conservation and management of habitats. Therefore, I recommend implementing an incentive-based agroforestry program to discourage villagers from abandoning the agriculture land. Additionally, providing the necessary facilities, i.e., roads, drinking water, education, and employment opportunities at the village level, would be helpful to control the emigration of people from their villages.

6.2.4 Predator-Prey Interaction and Human-Wildlife Conflict

The common leopard density in the CFs of the mid-hills of Nepal from our study is 16.4 per 100 sq km, and this is one of the highest densities of this species ever noted in Nepal. On the other hand, I recorded the lowest detection rate ($0.2/km^2$) of wild ungulates (typical wild prey species, such as barking deer and wild boar), followed by livestock ($2.0/km^2$) and other wild prey species ($3.21/km^2$). (Chapter Four, Study I)

From the analysis of leopard scats, 15 prey species were recorded in the leopards' diet, including wild prey (ungulates, birds, and small mammals) and livestock (Chapter Four, Study II). Goats contributed the highest relative biomass, followed by jungle cats, dogs, and large Indian civets. The highest relative number of individuals of prey in leopard sats was wild hare, followed by jungle cat and large Indian civet. I found that 12 percent of the prey items recorded in leopard scats were from wild ungulates or conventional prey species (barking deer and wild boar), 31% from livestock, and 57% from other wild prey species. The high percentage of livestock in the leopard diet indicates a challenging issue of HWC in the mid-hills of Nepal.

Decreased natural prey availability, particularly that of wild ungulates, may have forced leopards to move into human settlements in quest of food and increased the incidence of human-leopard conflict. Furthermore, due to the timber-oriented forest management, wildlife's habitat management activities within CFs for both leopard and prey species were lacking. Hence, I recommend carrying out habitat management for wild prey species, such as grassland management, waterhole construction, forest fire control, and control of poaching, for restoring prey populations in CFs and minimizing predation on livestock in the future. For the conservation of leopards, it is equally important to control habitat fragmentation within CFs, mainly the construction of roads and other unplanned infrastructures. The actions to control habitat fragmentation and prey population restoration should be included in the operational plan of community forests in order to reduce human-leopard conflicts and conserve leopard and its prey populations in CFs outside of the protected area in Nepal's mid-hills.

6.2.5 Climate change and its impacts on the distribution of the common leopard and implications for human-wildlife conflict

My study reveals that at present, 79% and 75% of the mid-hill and Siwalik physiographic regions, respectively, are suitable for leopards, and most of these areas lie outside protected areas (Chapter Five). My analyses expose that the very suitable and suitable areas will mostly remain unchanged under the scenario of climate change. However, the marginally suitable areas, which are primarily in the high mountain region, will significantly increase, indicating a shift in the habitat of leopards towards higher elevation areas as a result of climate change. Such predicted expansion of leopard habitat would potentially decrease the extinction risk of leopards. However, if new habitats are not well managed, the events of human-leopard conflict may escalate. As a result, I recommend effective management of habitats and prey species in such areas to ensure the long-term sustainability of leopard conservation and to reduce future conflicts between humans and leopards.

6.2.6 Inadequate policy and practices of the Community Forestry Program regarding wildlife conservation and resultant human-wildlife conflict

CF, the largest program in the forestry sector in Nepal, was launched based on the forest Act and regulations for the restoration of forests outside PA. Based on the analysis of past and present policies and practices on the CF program, I found that forest law, regulation, and guidelines did not incorporate all necessary provisions to address wildlife conservation and HWC mitigation outside PAs (Chapter Three, Study II). Consequently, community forest operation plans (CFOPs) prepared based on these acts and regulations do not integrate plans and activities for wildlife conservation and HWC management.

CF program significantly restored the degraded mid-hills and helped regain the forest cover and growing stock in Nepal (Pokharel et al., 2005; Gurung et al.,2013; Niraula et al., 2013). It also contributed to habitat expansion for many wildlife species (Acharya 2002; Mikkola 2002). CFs are providing biological corridors and connectivity for free movement of wildlife in forests and fringes (Acharya *et al.*, 2016). However, the poor wildlife management practices within CF have been triggering events of crop damage, livestock depredation, human attack by wildlife, and retaliatory killing of wildlife by people (Acharya 2018; Baral et al., 2021b; Baral et al., 2022). Over two-thirds of the HWC events in the last five years occurred outside the PAs (MoFE, 2020), ramifying that the areas outside the PAs particularly the CFs are highly affected by HWC and urgently need to implement the activities of wildlife conservation and HWC management (Adhikari *et al.*, 2018). Conversely, the mid-hill region of Nepal is least represented in the PA system (GoN/MoFSC, 2014) and receives poor wildlife management practices. Consequently, this landscape has been a hotspot for the HWC in recent years.

Two significant laws, the Forest Act and the National Park and Wildlife Conservation Act, were developed that clearly defined their priorities and operational scope in Nepal. The National Park and Wildlife Conservation Act of 1973 and its regulations gave priority to wildlife conservation within PAs and buffer zones only, whereas the previous Forest Act of 1993, the current Forest Act of 2019 and associated regulations are highly focused on the management of forests outside of PAs. Following these acts, the Ministry ofForest and Environment (MoFE) established two distinct departments, the Department of Forest (DOF) and the Department of National Parks and Wildlife

Conservation (DNPWC), with the respective responsibilities of managing forests outside of PAs and conserving wildlife inside of PAs. Such a separated and designated legal and institutional framework appears to be one of the main reasons for prioritizing forest (mainly timber) management over wildlife conservation and HWC mitigation in CFs outside of PAs.

Therefore, the existing forest law, forest regulations, and guidelines pertaining to the CF should be revised in order to include the necessary provisions for wildlife conservation and HWC mitigation. Furthermore, CFs, with the support of the Division Forest Office, should carry out research on habitat assessment, carrying capacity, and prey-predator ratio to be used in the planning of future management actions. Nation-wide studies are required to understand the impacts of current CF management practices on the conservation of wildlife. Such information is important for future conservation planning.

On the other hand, an individual CF is a small unit of forest and cannot sustain the population of top predators such as the leopard. Hence, a landscape approach to connecting the patchy CFs in the mid-hill region would benefit wildlife conservation and HWC mitigation in the long run. Establishing more PAs in mid-hill physiography to represent more ecosystems in this region in the conservation system is also crucial.

6.3 Impacts of HWC in mid-hills, outside PAs of Nepal

6.3.1 HWC and its impact on human life

HWC incidents have been rising steadily over the past 20 years and have had a remarkable negative effect on people's lives (Chapter Two). I recorded 887 ($\bar{x}$42.2/year, SD ± 11.8) human loss incidents during the 21-year period. Leopard caused the highest human death rate, followed by elephant, tiger, and rhino. The bulk of leopard-caused human deaths occurred in Nepal's mid-hill physiographic region. Between 2015 and 2019, there were 67 instances of leopard attacks in five districts in the mid-hills, and 10 people died as a result (Chapter Two, Study-I). Similarly, from 2011 to 2021, leopards killed 23 children in Baitadi, a mid-hill district. This may be mostly due to decreased prey availability in the forest and habitat loss or fragmentation. On the other hand, increasing bushes and forests on abandoned farmland near villages gives wildlife easy access to human settlements (Sharma et al., 2021; Baral et al., 2021) and increases the chance of human-leopard conflicts.

In light of these findings, I have come to the conclusion that controlling habitat degradation and fragmentation in forest habitat and educating local people about wildlife conservation, including knowledge on their behavior, are required actions to reduce human fatalities brought on by wildlife. Moreover, it is equally crucial to identify and map major HWC hotspots outside PA, together with designing and executing conflict mitigation initiatives (including prey restoration, enhancing education and awareness among local people, establishing repellent devices and early warning systems, supporting the construction of a protective enclosure for livestock to safeguard it from wildlife attack, etc.) for the future mitigation of the conflicts. Updating the sub-national and national-level databases on HWC is also necessary for future conservation planning.

6.3.2 HWC and its impact on livelihood of people

HWCs have significantly impacted the livelihood of rural people around the community forests of the mid-hill region, outside the protected area of Nepal. During 2015 to 2019, 27% of the livestock owned by local people were killed by predators, mainly by common leopards (*Panthera pardus*), golden jackals *(Canis aureus*) *and* jungle cats (*Felis chaus*), which is 23% of household income

(Chapter Three, Study II). On average, every household lost USD $142.61 per year during the period of 2015–2019 from livestock predation by wildlife. For the same period, local people lost 24 percent of their crops due to damage caused by Rhesus monkeys (*Macaca mulatta*) Indian field mice (*Mus booduga*) and other wildlife. Crop losses averaged USD $102.86 per household, accounting for 17% of household income.

Wildlife raiding of crops and killing of livestock are caused by two factors: Firstly, the diminishing natural prey species and habitat degradation inside forest areas Secondly, due to the higher migration rate of people from the rural to urban area, agricultural lands have been abandoned and converted to bushes and forests. This has increased the accessibility of wild animals to villages, resulting in more HWC incidents.

Hence, it is crucial to carry out habitat management actions (mainly grassland management, waterhole construction, and forest fire control) within CF areas in order to supply food, water, and shelter required by wildlife and effectively reduce HWC. It is equally important to provide subsidies to the residents of nearby forest areas for protecting and securing crops and livestock. Establishing a local relief distribution fund and linking crops and cattle to insurance mechanisms will help improve the coexistence of people and wildlife. In the abandoned agricultural areas, incentive-based agroforestry projects such as intercropping fast growing timber species (*Alnus nepalensis, Melia azedarach,* etc.) and medicinal plants (*Cinnamomum tamala*, *Azadirachta indica, etc.*) with cash crops (tea, coffee, cardamom, zinger, turmeric, etc.) would help to reduce future HWC and regulate people's emigration.

6.3.3 HWC and related wildlife mortality

Anthropogenic mortality of large mammals, including Asian elephants (*Elephas maximus*), rhinoceroses (*Rhinoceros unicornis*), tigers (*Panthera tigris*), and common leopards (*Panthera pardus),* increased in Nepal during the period of 2000–2020, posing a challenge to the conservation of these threatened species. Among the four species, leopard loss was the highest ($\bar{x}$ 42.3/year, SD ± 15.1), followed by rhinos ($\bar{x}$ 8.0/year, SD± 6.9), tigers ($\bar{x}$ 2.2/year, SD± 1.2) and elephants ($\bar{x}$1.5/year, SD ± 1.3). The killing of leopards showed an exponential increase, and the killing of tigers and elephants has increased steadily. On the other hand, incidents of rhino killing decreased. Mortality of large mammals was significantly increased with the increase in the number of human casualties caused by wildlife and the proportion of agricultural land within the district, whereas it decreased in districts with an increased literacy rate (Chapter Two). Retaliatory killing of wildlife is significantly associated with the antagonistic emotions of people generated by wildlife-caused human loss.

I recommend that retaliatory killings of wildlife be strictly regulated by a program of education and training for the people. This can be accomplished by implementing awareness programs, workshops, and seminars that educate the local populace on the significance of wildlife conservation and the potential negative effects of retaliatory actions. Implementing a participatory conservation program in collaboration with local people and benefiting them through the implementation of an ecotourism program would encourage locals to participate in wildlife conservation activities. In addition, governments, local communities, wildlife conservation organizations, and individuals must collaborate to reduce the killing of wildlife and create a safe environment for both humans and wildlife. Furthermore, relevant laws should be strictly enforced to ensure that those responsible for wildlife killing are accountable. Since leopards are at a greater risk of retaliatory killing, I recommend developing and implementing a Leopard Conservation Action Plan based on a thorough examination of the species' status, ecology, and future range under the climate change scenario. Similar to the data on the impact of HWC on humans outside of PAs, the management of data on wildlife mortality was inadequate, particularly outside of PAs. The database on both human mortality and wildlife loss should be upgraded at the local and national levels and included in national and provincial conservation planning, especially outside of PAs.

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Annex-1: Photo plates

Photo 1: Interviewing with local people

Photo 2: Fixing the camera traps in community forests of Tanahun district

Photo 3: Picture of leopard captured by camera traps in community forests of Tanahun district

Photo 4: Picture taken during the field visit of Professor Weihong in community forests of Tanahun district. In the background atraditional cage made by local people to trap man-eater leopard.

Photo 5: Transect walking to access the abundance of prey species in community forests of Tanahun district

Photo 6: Collection of leopard's scats in community forests of Tanahun district

Annex-2: Human ethics approval letter

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Date: 25 July 2020

Dear Kedar Baral

Re: Ethics Notification - 4000023041 - **Human wildlife conflict: drives, consequences and mitigation strategies**

Thank you for your notification which you have assessed as Low Risk.

Your project has been recorded in our system which is reported in the Annual Report of the Massey University Human Ethics Committee.

The low risk notification for this project is valid for a maximum of three years.

If situations subsequently occur which cause you to reconsider your ethical analysis, please contact a Research Ethics Administrator.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:

"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named in this document are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact Professor Craig Johnson, Director - Ethics, telephone 06 3569099 ext 85271, email humanethics@massey.ac.nz."

Please note, if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to complete the application form again, answering "yes" to the publication question to provide more information for one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 350 5573; 06 350 5575 F 06 355 7973
E humanethics@massey.ac.nz W http://humanethics.massey.ac.nz

Annex-3: Supplementary materials

Chapter 2: Anthropogenic mortality of large mammals and trends of conflict over two decades in Nepal

Seven best fit models (with delta AIC < 2) out of 127 models ran in the analysis, where, number of wildlife losses: (Wloss), number of human losses within districts: (Hloss), proportion of agricultural land within district: (Pag), literacy rate of people in the district: (Lrate), population density within district: (Pden), proportion of forest land within district: (Pfr), proportion of protected area within district: (Ppa), density of livestock within district: (Lden).

Models	**df**	**logLik**	**AICc**	**delta**	**weight**
Wloss~Hloss + Pag + Lrate	5	−127.33	265.5	0	0.24
Wloss~Hloss + Pag + Pden + Lrate	6	−126.35	265.91	0.41	0.19
Wloss~Hloss + Pag + Pfr + Pden + Lrate	7	−125.55	266.73	1.23	0.13
Wloss~Hloss + Pden + Lrate	5	−127.99	266.83	1.33	0.12
Wloss~Hloss + Pag + Pfr + Pden + Lden	6	−126.82	266.84	1.34	0.12
Wloss~Hloss + Pag + Pfr + Pfr + Lrate	6	−126.9	267	1.5	0.11
Wloss~Hloss + Pag + Pfr + Lden + Lrate	6	−127.13	267.47	1.97	0.09

Chapter 3

Study I: Characterization and management of human-wildlife conflicts in mid-hills outside protected areas of Gandaki province, Nepal

Data and associated variables used for the study regarding attack of wildlife to human

HWC	Wildlife	Location	attack_ pointX	attack_ pointY	District	Elevation	distance_fr omforest	Landuse	Year	Mont h	Season	Time	Ethnicit y	Age	Occupation	Gender
Death	Leopard	Palung	248897	3104146	Tanahun	651	0.1	Settlement	2018	11	Autumn	16.3	Dalit	7	Student	Female
Death	Leopard	Bhansar	247609	3101694	Tanahun	655	0.1	Settlement	2019	6	Spring	7	B/C	8	Student	Female
Death	Leopard	Bhansar4	247204	3099834	Tanahun	510	0.2	Settlement	2018	12	Autumn	18.3	Ethnic	8	Student	Male
Death	Leopard	bhansar3	246272	3099623	Tanahun	519	0.2	Settlement	2019	8	Summer	17.3	B/C	3	Student	Male
Death	Leopard	Bhansar5	249230	3101527	Tanahun	538	0.2	Settlement	2018	2	Winter	19	Ethnic	7	Student	Male
Death	Leopard	Bangsing	774415	3122221	Syangja	1646	0.7	Forest	2011	6	Spring	14.3	Dalit	76	Farmer	Female
Death	Leopard	Waling	772130	3099124	Syangja	742	1.1	Forest	2016	9	Summer	9	Ethnic	58	Farmer	Male
Death	Leopard	Purkot	248844	3110319	Tanahun	567	0.7	Settlement	2019	10	Autumn	17.45	Dalit	7	Student	Male
Injured	Leopard	arva 2	210845	3126054	Kaski	963	0.1	Forest	2014	12	Winter	18.45	B/C	52	Business	Male
Injured	Snake	Serachaur	780365	3132257	Kaski	1284	0.1	Settlement	2018	4	Spring	15	Ethnic	62	Business	Male
Injured	Leopard	Jita	234094	3112800	Lamjung	624	0.1	Forest	2016	9	Summer	5	B/C	41	Farmer	Male
Injured	Leopard	Bhoteodar	247639	3117412	Lamjung	857	0.1	Forest	2017	10	Autumn	18.3	B/C	45	Farmer	Male
Injured	Bear	Pasagaun	227923	3130912	Lamjung	1642	0.1	Forest	2014	12	Autumn	14.5	Ethnic	64	Farmer	Male
Injured	Leopard	Karputar	227845	3118174	Lamjung	495	0.1	Settlement	2019	5	Spring	20	Dalit	37	Farmer	Male
Injured	Leopard	Karputar	230183	3117975	Lamjung	672	0.1	Settlement	2019	5	Spring	21	B/C	34	Business	Male
Injured	Leopard	Baglungp ani	237417	3127338	Lamjung	1442	0.1	Settlement	2016	1	Winter	23	Dalit	84	Farmer	Male

Injured	Leopard	Setidoban	777682	3118248	Syangja	1194	0.1	Agriculture land	2016	12	Winter	14	B/C	52	Farmer	Male
Injured	Leopard	sundarbazar	244670	3113009	Tanahun	684	0.1	Forest	2018	10	Autumn	12.5	Ethnic	59	Farmer	Male
Injured	Leopard	Syamgha	226205	3104003	Tanahun	462	0.1	Road	2016	1	Winter	17	Ethnic	37	Business	Male
Injured	Bear	Bhansar	247609	3101694	Tanahun	655	0.1	Settlement	2019	4	Spring	7	B/C	52	Farmer	Male
Injured	Leopard	Paudur2	777619	3132404	Kaski	1603	0.15	Agriculture land	2017	10	Autumn	6	B/C	53	Farmer	Male
Injured	Bear	Bahundada	252087	3129648	Lamjung	1226	0.15	Road	2012	12	Winter	20	Dalit	46	Farmer	Male
Injured	Leopard	Kahun	207496	3126587	Kaski	1192	0.2	Forest	2012	3	Winter	15.3	B/C	45	Business	Male
Injured	Leopard	Lekhnath	217129	3112655	Kaski	624	0.2	Road	2018	12	Autumn	6.45	B/C	36	Farmer	Female
Injured	Leopard	Arva	210470	3126106	Kaski	1042	0.2	Settlement	2012	6	Spring	17	B/C	5	Student	Female
Injured	Leopard	Paudur	776921	3132860	Kaski	1733	0.2	Settlement	2019	10	Autumn	1	Ethnic	54	Business	Male
Injured	Bear	bahundada	252138	3132095	Lamjung	2526	0.2	Agriculture land	2014	10	Autumn	17.3	Ethnic	58	Farmer	Male
Injured	Leopard	Bhoteodar	247828	3117645	Lamjung	952	0.2	Forest	2013	5	Spring	19.45	Dalit	62	Farmer	Male
Injured	Bear	Besisahar	241062	3125416	Lamjung	1191	0.2	Forest	2018	4	Spring	15.5	Ethnic	50	Farmer	Male
Injured	Leopard	Bhoteodar	248497	3116378	Lamjung	582	0.2	Road	2012	3	Winter	19.3	B/C	37	Business	Male
Injured	Leopard	Sundarbzar	245310	3115227	Lamjung	637	0.2	Settlement	2014	2	Winter	6.45	B/C	53	Farmer	Male
Injured	Leopard	Chapakot	776487	3088571	Syangja	452	0.2	Forest	2014	11	Autumn	14	Dalit	70	Farmer	Female
Injured	Leopard	Fedikhola	783802	3117750	Syangja	1046	0.2	Settlement	2015	12	Winter	11	Dalit	75	Farmer	Male
Injured	Leopard	Abukjhaireni	257805	3087054	Tanahun	306	0.2	Road	2014	5	Spring	10	Ethnic	40	Business	Female
Injured	Bear	Mirlung3	241203	3108729	Tanahun	686	0.2	Road	2016	12	Autumn	19.3	B/C	45	Farmer	Male
Injured	Leopard	Bhanu7	244250	3104408	Tanahun	923	0.2	Settlement	2013	4	Spring	18.45	B/C	54	Farmer	Male
Injured	Leopard	Pang	757740	3128995	Parbat	1101	0.25	Settlement	2016	6	Spring	21.45	B/C	57	Farmer	Female
Injured	Leopard	Rambach	774646	3099496	Syangja	793	0.25	Settlement	2017	9	Autumn	2.3	B/C	37	Farmer	Female

Injured	Leopard	Kaskikot	784856	3130509	Kaski	1593	0.3	Settlement	2015	1	Winter	13	B/C	56	Farmer	Male
Injured	Bear	Bahundada	245615	3137589	Lamjung	1209	0.3	Agriculture land	2013	10	Autumn	7.3	Ethnic	40	Farmer	Male
Injured	Leopard	Harinas	789860	3100899	Syangja	1298	0.3	Settlement	2019	5	Spring	16	B/C	68	Farmer	Male
Injured	Leopard	Pelkachaur	779438	310668	Syangja	1464	0.3	Settlement	2017	8	Summer	7.15	Ethnic	54	Farmer	Male
Injured	Bear	Mirlung	240860	3110033	Tanahun	929	0.3	Forest	2013	4	Spring	13	Ethnic	45	Farmer	Male
Injured	Leopard	Khjairenitar	210545	3105091	Tanahun	647	0.3	Road	2016	3	Winter	15.3	B/C	29	Student	Male
Injured	Leopard	Khansar 2	247325	3099946	Tanahun	519	0.4	Settlement	2019	8	Summer	18	B/C	5	Student	Male
Injured	Leopard	Kolma	788363	3108667	Syangja	1548	0.45	Settlement	2015	10	Autumn	13	B/C	45	Farmer	Female
Injured	Leopard	Bhoteodar	248866	3117557	Lamjung	616	0.5	Agriculture land	2016	1	Winter	5	B/C	39	Farmer	Male
Injured	Leopard	Paundi	247352	3112630	Lamjung	573	0.5	Forest	2013	5	Spring	15.3	B/C	45	Farmer	Female
Injured	Leopard	Paundi	247721	3112393	Lamjung	514	0.5	Road	2012	1	Winter	19	Ethnic	48	Farmer	Male
Injured	Leopard	Bansing	773554	3121279	Syangja	1240	0.5	Forest	2012	3	Winter	17	Ethnic	52	Farmer	Male
Injured	Leopard	Tanahusur	245250	3113583	Tanahun	590	0.5	Forest	2015	11	Autumn	16.3	B/C	48	Farmer	Male
Injured	Leopard	Anbu 2	253481	3091352	Tanahun	364	0.5	Road	2014	8	Summer	14	B/C	13	Student	Male
Injured	Leopard	Vyns	230103	3097823	Tanahun	369	0.5	Settlement	2017	8	Summer	8	B/C	34	Business	Male
Injured	Bear	Sanjur	237472	3109484	Tanahun	1111	0.5	Settlement	2019	2	Winter	23	B/C	65	Farmer	Male
Injured	Leopard	Bagar	793207	3127445	Kaski	920	0.6	Settlement	2015	1	Winter	15.3	B/C	36	Business	Male
Injured	Leopard	Bhansar 8	246324	3098033	Tanahun	712	0.6	Settlement	2011	11	Autumn	19.3	B/C	45	Farmer	Male
Injured	Leopard	Kaule	785118	3110086	Syangja	1134	0.75	Settlement	2015	10	Autumn	13	B/C	59	Farmer	Male
Injured	Leopard	Simpani	240085	3130144	Lamjung	1247	1	Settlement	2013	6	Spring	18	Ethnic	35	Business	Male
Injured	Leopard	Arunodaya	205424	3097421	Tanahun	919	1	Forest	2014	3	Winter	17	Ethnic	65	Farmer	Male
Injured	Leopard	Lahachok	787308	3134331	Kaski	1169	1.2	Settlement	2013	12	Winter	19	Ethnic	12	Student	Male

Injured	Leopard	Chiti	248887	3122111	Lamjung	1053	1.3	Settlement	2012	7	Summer	2	B/C	35	Business	Male
Injured	Leopard	Bhadrakali	206097	3125218	Kaski	873	1.6	Road	2015	9	Summer	18.15	Dalit	25	Student	Male
Injured	Leopard	Gairapatan	793071	3125955	Kaski	895	1.6	Settlement	2016	5	Spring	19.3	Dalit	5	Business	Female
Injured	Leopard	Putali bazar	781296	3111999	Syangja	838	1.7	Agriculture land	2018	5	Spring	14	B/C	62	Farmer	Male
Injured	Leopard	Sataun3	779657	3111750	Syangja	1131	1.9	Forest	2017	1	Winter	17	B/C	24	Student	Male
Injured	Leopard	Sataun2	779048	3111581	Syangja	1174	1.9	Forest	2017	1	Winter	17	B/C	56	Farmer	Male
Injured	Leopard	Rapakot	770553	3111658	Syangja	1496	2	Forest	2013	12	Winter	16	B/C	67	Farmer	Male
Injured	Leopard	Chipledhunga	793609	3125608	Kaski	877	2.1	Settlement	2016	6	Summer	15	Ethnic	47	Business	Female
Injured	Leopard	Ranipauwa	793704	3125412	Kaski	876	2.2	Settlement	2017	12	Autumn	8	Ethnic	36	Business	Female
Injured	Leopard	Aruchaur	768779	3113065	Syangja	1368	2.5	Agriculture land	2013	12	Winter	14.3	B/C	52	Farmer	Male
Injured	Leopard	Aruchour	769203	3113438	Syangja	1542	2.5	Agriculture land	2013	12	Winter	14	B/C	37	Farmer	Male
Injured	Leopard	Rapakotpakhapani	768012	3112887	Syangja	1542	2.5	Forest	2013	12	Winter	12	B/C	45	Farmer	Female
Injured	Leopard	Bajung 2	766115	3131373	Parbat	1503	0.15	Agriculture land	2012	4	Spring	13	B/C	52	Farmer	Male
Injured	Leopard	Bajung	766370	3130991	Parbat	1504	0.2	Agriculture land	2012	4	Spring	13	B/C	63	Farmer	Male
Injured	Leopard	Patichaur	768568	3130356	Parbat	888	0.35	Settlement	2019	8	Summer	15.3	Ethnic	56	Farmer	Male
Injured	Leopard	Khurkot	761621	3129125	Parbat	1527	0.6	Settlement	2019	10	Autumn	19	B/C	34	Farmer	Male
Injured	Leopard	Bhansar	247199	3099298	Tanahun	504	0.6	Settlement	2019	10	Autumn	18	Dalit	11	Student	Female

Study II: **Human Wildlife Conflict and Impacts on Livelihood: A Study in Community Forestry System in Mid-Hills of Nepal**

Land use and land cover change in Kaski and Tanahun District since 1998 to 2018.

LC category (Sq Km)	1998	2008	2018	Change between 1998 to 2018	Change %
Urban/Built-up	35.67	53.88	75.64	39.97	112%
Cultivated Land	1,169.87	1,156.64	1129.25	-40.62	-3.47%
Forest Cover	1,592.59	1,618.66	1636.84	44.25	2.78%
Grass land / shrub land	329.63	361.78	240.09	-89.54	-27.16%
Barren Land	151.47	108.41	202.85	51.38	33.92
Water Body	62.47	64.39	62.95	0.48	0.77%

Change in land use type within the period of 1998, 2008 and 2018 in Bhanu municipality of Tanahun district (Sq.km)

LULC	1998	2008	2018
Urban	0.9054	2.4678	5.4098
Cultivated	94.0833	91.9592	74.7785
Forest	86.3874	87.4405	102.1382
Shrub	0.702	0.2736	0.8748
Barren	0.9873	0.9099	0.5076
Sand	0.0171	0.2826	0.0054
Water	1.5669	1.3176	0.9459
	184.6494	184.6512	184.6602

Conversion of land use type from one category to another from 1998 to 2008 in Bhanu municipality of Tanahundistrict (Sq km)

		2008						
	LULC	**urban**	**cultivated**	**Forest**	**shrub**	**Barren**	**Sand**	**Water**
1998	Urban	0.8991	0.0054			0.0009		
	Cultivated	1.4067	91.5812	1.0288		0.0144	0.0045	0.0441
	Forest	0.1071	0.1053	86.1408		0.0063		0.027
	Shrub	0.0072	0.1773	0.2412	0.2736			0.0027
	Barren	0.0135	0.054	0.0288		0.0063		0.0027
	Sand						0.0171	
	Water	0.0324	0.0324				0.261	1.2411
	Total	**2.466**	**91.9556**	**87.4396**	**0.2736**	**0.0279**	**0.2826**	**1.3176**

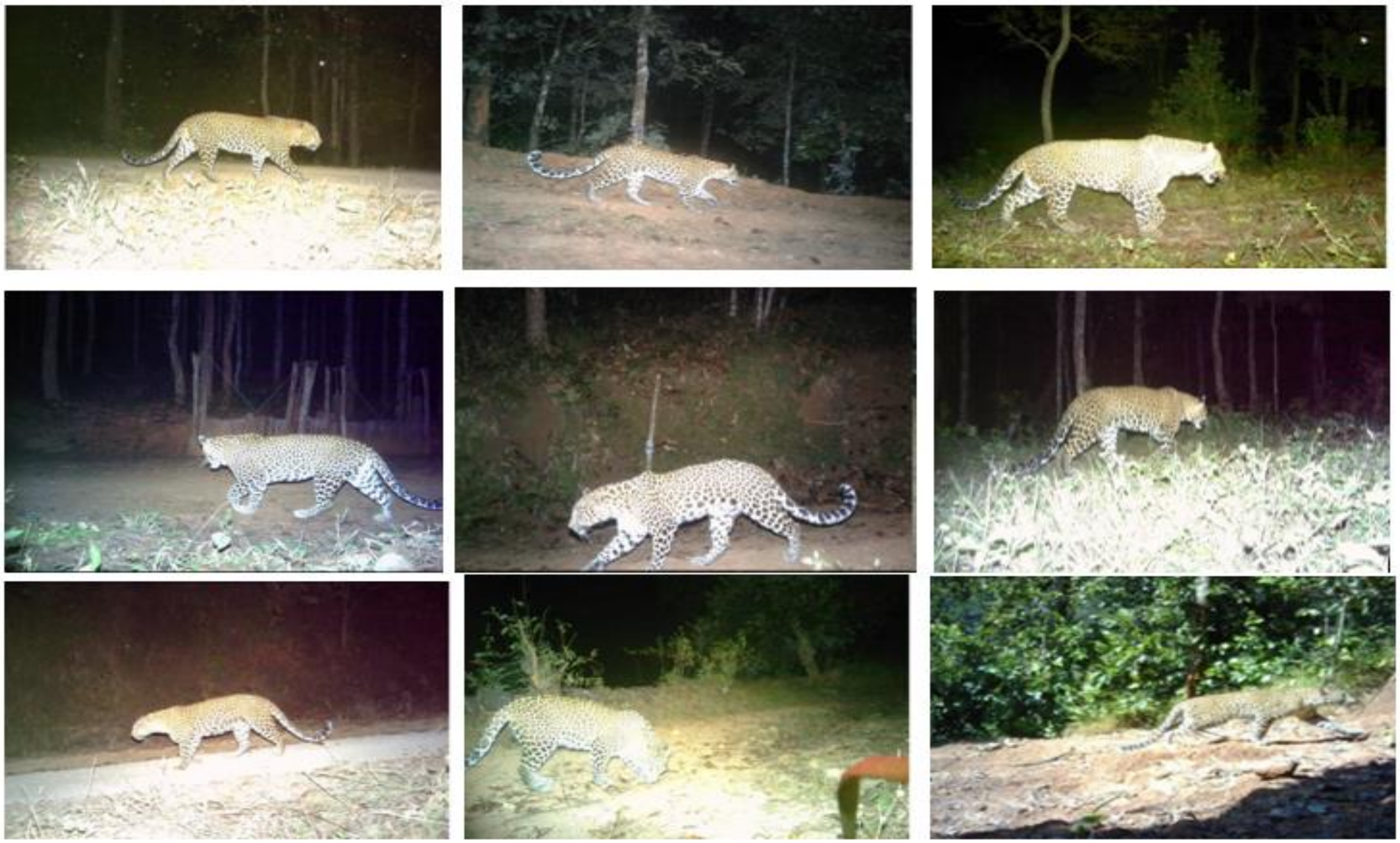
Conversion of land use type from one category to another from 2008 to 2018 in Bhanu municipality of Tanahun district (Sq km)

		2018						
	LULC	Urban	Cultivated	Forest	Shrub	Barren	Sand	Water
2008	Urban	2.4552	0.0009	0.0117				
	Cultivated	2.6225	73.6076	14.974	0.6876	0.0243	0.0009	0.0324
	Forest	0.2898	0.9603	86.1571	0.0117	0.018		0.0027
	Shrub	0.0018	0.1008	0.0252	0.1458	0.4644		
	Barren	0.0288	0.0621	0.2925	0.0288		0.0009	0.0324
	Sand		0.0063	0.2673			0.0036	0.0054
	Water	0.0108	0.0324	0.3996	0.0009	0.0009		0.873
	Total	5.4089	74.7704	102.1274	0.8748	0.5076	0.0054	0.9459
		5.4089	74.7704	102.1274	0.8748	0.5076	0.0054	0.9459

Chapter 4

Study I: **Density of leopards and status of their prey in mid hills of Nepal: Implication on conservation conflict**

Leopard's photographs during the cameara trap survey at the study site.



Study II: Prey selection by leopard (*Panthera pardus*) in mid hill regions of Nepal

The result of the scatman software

estimated species	observed	expected
ldboar	1.4	1.02
ngDeer	3.8	3.59
Icivet	12.7	10.45
Pcivet	2.8	1.96
Hare	5.7	8.33
ngoose	5.7	0.86
Martin	4.2	4.94
monkey	2.8	20.82
Lcat	5.7	1.84
Jcat	14	7.19
Jackal	5.7	0.05
Dumsi	5.7	9.15

CV(SCATRATE)=10%

species	Chi squared	Unadjusted p-value	Adjusted p-value	standard error
ldboar	0.143	0.7053	0.7109	0.0004
ngDeer	0.0126	0.9107	0.9152	0.0003
Icivet	0.5678	0.4511	0.5566	0.0053
Pcivet	0.3705	0.5427	0.5743	0.0019
Hare	0.9417	0.3318	0.4118	0.0042
ngoose	27.688	0	0	0
Martin	0.1194	0.7297	0.8242	0.0038
monkey	22.1785	0	0.0069	0.0021
Lcat	8.3387	0.0039	0.0064	0.0003
Jcat	7.1979	0.0073	0.1285	0.0078
Jackal	587.4103	0	0	0
Dumsi	1.4928	0.2218	0.3073	0.0049
Composite	647.7227	0	0	0

CV(SCATRATE)=20%

species	Chi squared	Unadjusted p-value	Adjusted p-value	standard error
ldboar	0.143	0.7053	0.7156	0.0007
ngDeer	0.0126	0.9107	0.9189	0.0005
Icivet	0.5678	0.4511	0.5936	0.0066
Pcivet	0.3705	0.5427	0.59	0.0028
Hare	0.9417	0.3318	0.4529	0.0059
ngoose	27.688	0	0	0
Martin	0.1194	0.7297	0.8266	0.0038
monkey	22.1785	0	0.0092	0.0015
Lcat	8.3387	0.0039	0.0081	0.0003
Jcat	7.1979	0.0073	0.1451	0.0092
Jackal	587.4103	0	0	0
Dumsi	1.4928	0.2218	0.3612	0.0067
Composite	647.7227	0	0	0

CV(SCATRATE)=30%

species	Chi squared	Unadjusted p-value	Adjusted p-value	standard error
ldboar	0.143	0.7053	0.7229	0.0011
ngDeer	0.0126	0.9107	0.925	0.0008
Icivet	0.5678	0.4511	0.6336	0.007
Pcivet	0.3705	0.5427	0.6038	0.0035
Hare	0.9417	0.3318	0.5125	0.0077
ngoose	27.688	0	0	0
Martin	0.1194	0.7297	0.8467	0.004
monkey	22.1785	0	0.0217	0.0034
Lcat	8.3387	0.0039	0.0169	0.002
Jcat	7.1979	0.0073	0.1647	0.0095
Jackal	587.4103	0	0	0
Dumsi	1.4928	0.2218	0.4251	0.0092
Composite	647.7227	0	0	0

CV(SCATRATE)=40%

species	Chi squared	Unadjusted p-value	Adjusted p-value	standard error
ldboar	0.143	0.7053	0.7362	0.002
ngDeer	0.0126	0.9107	0.9309	0.001
Icivet	0.5678	0.4511	0.667	0.008
Pcivet	0.3705	0.5427	0.6227	0.0042
Hare	0.9417	0.3318	0.5544	0.0091
ngoose	27.688	0	0	0
Martin	0.1194	0.7297	0.8513	0.004
monkey	22.1785	0	0.0565	0.0065
Lcat	8.3387	0.0039	0.0211	0.0022
Jcat	7.1979	0.0073	0.1819	0.0104
Jackal	587.4103	0	0	0
Dumsi	1.4928	0.2218	0.4855	0.0109
Composite	647.7227	0	0	0

Chapter 5: Impact of climate change on distribution of common leopard (*Panthera pardus)* and its implication on conservation and conflict in Nepal

X and Y coordinates of the 206 presence points of leopard within whole country.

SN	Species	X	Y
1	leopard	88.14699	26.64929
2	leopard	88.06173	27.00558
3	leopard	88.01746	26.5597
4	leopard	88.00389	26.63257
5	leopard	87.98456	27.01772
6	leopard	87.98178	26.91243
7	leopard	87.83445	26.61644
8	leopard	87.768	27.13126
9	leopard	87.6078	27.51521
10	leopard	87.32911	26.97463
11	leopard	87.26615	26.80484
12	leopard	87.2355	27.35996
13	leopard	87.03275	26.62224
14	leopard	86.9155	26.61482
15	leopard	85.67001	27.57214
16	leopard	85.6503	27.52063
17	leopard	85.61736	27.64711
18	leopard	85.5706	27.64331
19	leopard	85.42254	27.69384
20	leopard	85.39778	27.63952
21	leopard	85.38554	27.65179
22	leopard	85.37892	27.72128
23	leopard	85.36417	27.74534
24	leopard	85.35969	27.64187
25	leopard	85.33004	27.77121
26	leopard	85.32915	27.68155
27	leopard	85.32808	27.57386
28	leopard	85.30338	27.78829
29	leopard	85.29131	27.68921
30	leopard	85.28547	27.6707
31	leopard	85.28065	27.79998
32	leopard	85.25282	27.66033
33	leopard	85.22884	27.66664
34	leopard	85.22646	28.07772
35	leopard	85.00134	27.4606
36	leopard	84.82092	27.48158

37	leopard	84.772	28.06386
38	leopard	84.66196	27.99892
39	leopard	84.43253	28.14207
40	leopard	84.43118	28.01728
41	leopard	84.4195	27.95019
42	leopard	84.41877	28.00159
43	leopard	84.40894	28.13247
44	leopard	84.39923	28.26685
45	leopard	84.38268	27.97295
46	leopard	84.37955	28.23268
47	leopard	84.3646	28.22804
48	leopard	84.36239	27.71026
49	leopard	84.35699	27.55339
50	leopard	84.31206	27.7023
51	leopard	84.27889	27.96535
52	leopard	84.26667	28.31252
53	leopard	84.24233	27.74501
54	leopard	84.23923	28.04182
55	leopard	84.23787	28.09191
56	leopard	84.16892	28.20838
57	leopard	84.14572	28.31368
58	leopard	84.14014	28.15137
59	leopard	84.1107	28.43861
60	leopard	84.10513	28.15344
61	leopard	84.08506	28.09182
62	leopard	84.03923	28.38822
63	leopard	84.01645	27.62098
64	leopard	84.00466	28.11028
65	leopard	84.00309	28.44565
66	leopard	83.957	28.19975
67	leopard	83.87181	28.37858
68	leopard	83.82183	28.44819
69	leopard	83.80289	28.30948
70	leopard	83.76266	28.23066
71	leopard	83.71833	28.27888
72	leopard	83.62141	28.64732
73	leopard	83.68718	28.22445
74	leopard	83.65234	28.15925
75	leopard	83.62144	28.50036
76	leopard	83.64244	28.38212
77	leopard	84.36937	28.4781
78	leopard	83.5492	27.91654
79	leopard	83.51601	28.35277

80	leopard	83.50891	28.32959
81	leopard	83.46069	28.35606
82	leopard	83.42456	27.69651
83	leopard	83.41551	27.95275
84	leopard	83.35408	27.99501
85	leopard	83.27921	28.0015
86	leopard	83.26108	28.04964
87	leopard	83.14504	27.96392
88	leopard	83.14175	28.1368
89	leopard	83.12175	27.98552
90	leopard	83.09053	28.48894
91	leopard	83.06008	27.83393
92	leopard	83.05699	27.97254
93	leopard	83.01275	27.99251
94	leopard	82.52188	28.01507
95	leopard	82.51527	27.81185
96	leopard	82.28737	28.15581
97	leopard	82.23234	28.73572
98	leopard	81.83074	28.8874
99	leopard	81.70427	28.23048
100	leopard	81.64821	28.35999
101	leopard	81.47409	28.43051
102	leopard	81.22764	28.74701
103	leopard	81.16171	28.52925
104	leopard	80.67697	28.79884
105	leopard	80.5086	29.21094
106	leopard	80.50112	29.41073
107	leopard	80.50112	29.41073
108	leopard	80.40553	29.39037
109	leopard	80.40188	29.34518
110	leopard	80.38609	29.38572
111	leopard	80.3504	29.39897
112	leopard	80.35038	29.47405
113	leopard	80.32301	29.48874
114	leopard	80.31255	28.89228
115	leopard	81.78382	28.42851
116	leopard	81.93776	28.30892
117	leopard	82.37317	28.47081
118	leopard	82.09082	28.00791
119	leopard	81.12927	28.78381
120	leopard	81.32353	28.8486
121	leopard	80.32995	29.11879
122	leopard	80.93936	29.26772

123	leopard	81.59559	29.27308
124	leopard	81.23382	29.57325
125	leopard	80.75173	29.8067
126	leopard	82.10997	29.51141
127	leopard	87.4743	26.69833
128	leopard	86.57904	27.229
129	leopard	86.49135	27.47957
130	leopard	86.12649	26.94215
131	leopard	86.59408	26.79716
132	leopard	85.66099	27.06198
133	leopard	85.76486	27.00309
134	leopard	85.91832	27.4515
135	leopard	85.85891	27.48395
136	leopard	85.87324	27.91891
137	leopard	85.65423	27.95577
138	leopard	85.70787	27.76373
139	leopard	85.21891	27.07396
140	leopard	85.04214	27.15309
141	leopard	86.17275	27.69254
142	leopard	86.15395	27.80277
143	leopard	82.72119	28.62708
144	leopard	82.62848	28.30414
145	leopard	82.50542	28.87106
146	leopard	80.68326	29.68626
147	leopard	80.65884	29.94094
148	leopard	81.27984	29.76312
149	leopard	82.02358	29.78403
150	leopard	80.45681	28.70895
151	leopard	80.14263	28.88951
152	leopard	80.61717	29.57041
153	leopard	81.35847	29.13617
154	leopard	81.36525	29.42803
155	leopard	80.81181	29.02336
156	leopard	83.23669	28.59109
157	leopard	84.88026	28.25232
158	leopard	84.88258	27.92608
159	leopard	85.16459	27.88664
160	leopard	84.8704	27.78511
161	leopard	84.83709	27.66268
162	leopard	82.9516	28.31252
163	leopard	82.79666	28.07428
164	leopard	82.79738	27.90088
165	leopard	81.60811	28.61516

166	leopard	87.91535	27.45576
167	leopard	87.78779	27.57816
168	leopard	87.64695	27.22102
169	leopard	86.88954	27.06613
170	leopard	87.67639	26.87469
171	leopard	87.6675	26.65732
172	leopard	87.52201	27.13678
173	leopard	87.45713	27.30263
174	leopard	87.33427	27.60034
175	leopard	87.32865	27.77736
176	leopard	86.71955	27.67278
177	leopard	86.93286	27.44482
178	leopard	87.57911	27.63919
179	leopard	86.04321	27.23137
180	leopard	86.33057	27.13855
181	leopard	86.72605	27.33706
182	leopard	86.2612	27.42339
183	leopard	86.08932	27.54674
184	leopard	85.90374	27.69138
185	leopard	82.91295	28.93131
186	leopard	84.28425	28.54854
187	leopard	83.64083	28.71484
188	leopard	82.06502	29.23032
189	leopard	82.27267	29.37697
190	leopard	80.89617	29.8611
191	leopard	83.77646	27.9851
192	leopard	83.8696	28.09061
193	leopard	83.88521	27.98532
194	leopard	83.87333	27.84698
195	leopard	83.68416	27.6175
196	leopard	83.55167	27.8723
197	leopard	83.31151	27.73272
198	leopard	82.02874	28.6415
199	leopard	80.83135	28.62024
200	leopard	81.94121	28.10986
201	leopard	81.79258	28.30809
202	leopard	81.54642	28.28901
203	leopard	81.40166	28.625
204	leopard	84.40562	27.41006
205	leopard	83.88689	27.47808
206	leopard	83.92255	28.28748

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Name and title of main supervisor:	Associate Professor Weihong Ji, PhD
In which chapter is the manuscript/published work?	Chapter 2
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Please provide the full reference of the research output:

Title: Anthropogenic mortality of large mammals and trends of conflict over two decades in Nepal
This chapter has been published in Ecology and Evolution. (DOI: 10.1002/ece3.9381)

○ **The manuscript is currently under review for publication**

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Title : Characterization and management of human-wildlife conflicts in the mid-hills outside protected areas of Gandaki province, Nepal
This paper was published in PloS one, 16(11), e0260307. (DOI: https://doi.org/10.1371/journal.pone.0260307.

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  Please provide the full reference of the research output:

  Title : Human wildlife conflict and impacts on livelihood: A study in a community forestry system in mid-hills of Nepal. This study has been published in Sustainability, 13(23), 13170 (DOI: https://doi.org/10.3390/su132313170)

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(●) **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Title : The Impact of Climate Change on habitat and distribution of Common leopards (Panthera pardus) and its implication on conservation and conflict in Nepal
This chapter has been published in Heliyon (DOI: https://doi.org/10.1016/j.heliyon.2023.e12807).

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Please provide the full reference of the research output:

● **The manuscript is currently under review for publication**

Please provide the name of the journal:

Title : Prey selection by leopard (Panthera pardus) in mid hill regions of Nepal
This manuscript is currently under review on Ecology and Evolution

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