

**LANDSCAPE LEVEL MODELING OF ASIAN  
ELEPHANT (*Elephas maximus*) HABITAT, ITS  
POPULATION AND INTERACTION WITH HUMANS IN  
NEPAL**

**A THESIS**

Submitted by

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For the award of the Degree of

**DOCTOR OF PHILOSOPHY  
IN  
WILDLIFE SCIENCE**

Under the guidance of

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## DECLARATION

I hereby declare that the work conducted under the thesis titled "Landscape level modeling of Asian Elephant (*Elephas maximus*) habitat, its population and interaction with humans in Nepal" is a record of original research work, done by me and subsequently submitted for the award of the degree of Doctor of Philosophy in Wildlife Science to Saurashtra University, Rajkot. This research work has been carried out under the guidance and supervision of Dr. Bivash Pandav, Scientist-F, Wildlife Institute of India, Dr. Samrat Mondol, Scientist-E (WII), Dr. Naresh Subedi (NTNC), Dr. Baburam Lamichhane (NTNC) and Dr. Hem Sagar Baral (ZSL Nepal). The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, observation and understanding and the particulars given in it are true to the best of my knowledge.

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## CERTIFICATE

This is to certify that the thesis by "Landscape level modeling of Asian Elephant (*Elephas maximus*) habitat, its population and interaction with humans in Nepal" is an original and independent research work submitted to the Saurashtra University, Rajkot (Gujarat), for the award of the degree of Doctor of Philosophy in Wildlife Science.

Mr. Ashok Kumar Ram has put more than six semesters of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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I certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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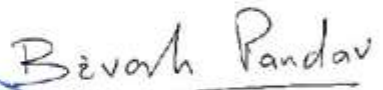
  
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## **Chapter 1: Introduction**

# Chapter 1: Introduction

## 1. 1. Background

Nepal is located in the cross border of two bio-geographical realms, viz. Palearctic and Oriental, with highly diverse flora and fauna (MoFSC, 2014). The country is also located at the lap of Mount Everest, the tallest mountain peak in the world, in the Himalayan region. It covers an area of 147,181 km<sup>2</sup>, which represents ~ 0.1% of the global landmass; provides home for ~3.2% world's known flora and 1.1 % of fauna respectively (MoFSC, 2014). The altitude ranges from 56 meters above sea level in Dhanusa (the southeastern alluvial plains) and rises up to 8,848 meters at the peak of Mount Everest. About 75% of people depend upon agriculture in Nepal, and most of them are subsistence farmers (Barrueto et al., 2018; CBS, 2014). Additionally, about 100-120 ethnic groups of people inhabit Nepal making it culturally diverse. It is geographically diverse as well, with five significant physiographic landscapes extending from east to west: High Himal, High Mountains, Middle Mountains, *Siwaliks*, and *Terai*, with various climates ranging from cold alpine semi-desert type in the trans-Himalayan zone to humid tropical type in the *Terai* lowlands (Figure 1.1) (MoFSC, 2014). Nepal has about 44.42% of land area under forest cover and 21% as agriculture, with 26 million people living in the country (CBS, 2014; DFRS, 2015).

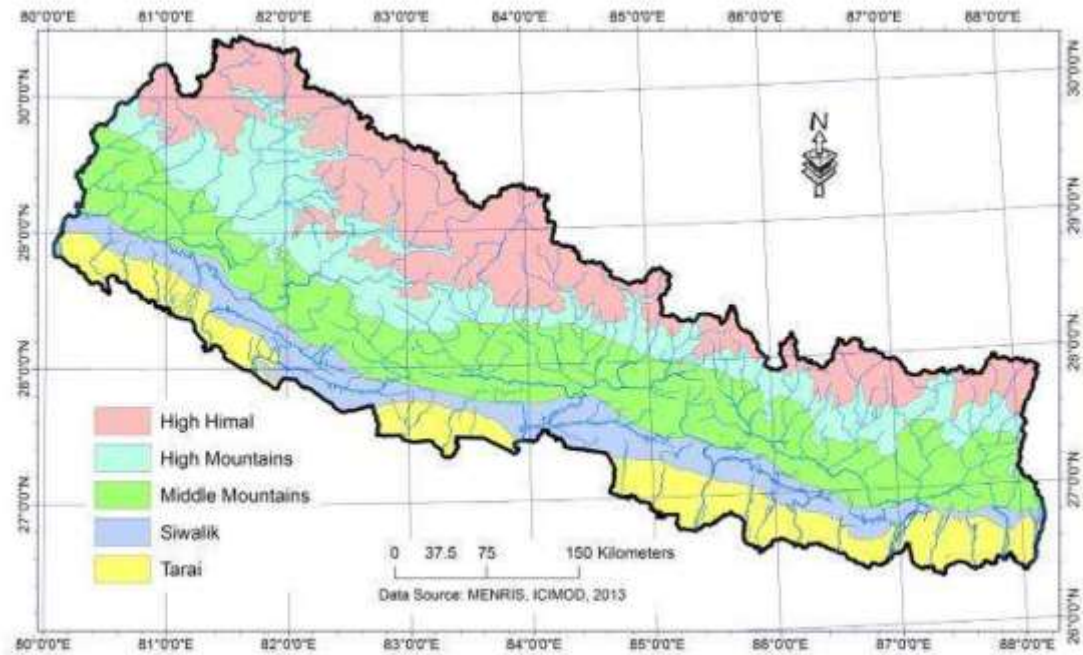


Figure 1.1. Physiographic regions of Nepal. (Map source, MOFSC,2014)

Our study area covers both the lowland *Terai* and *Chure/ Siwalik* area of Nepal, also known as Chure Terai Madhesh Landscape (CTML) of Nepal (Chaudhary and Subedi, 2019; Ram et al., 2021b). The *Terai* (low alluvial land) and *Chure* (also called Siwalik) are young mountain ranges bearing commercially valuable forests, which however, have suffered highest deforestation and degradation (0.44% per annum during 2001-2010). The CTML is habitat for major charismatic mega-fauna, including populations of Bengal tiger (*Panthera tigris*), one-horned Rhinoceros (*Rhinoceros unicornis*), Asian Elephant (*Elephas maximus*), gaur (*Bos gaurus*), and wild buffalo (*Bubalis bubalis*) among many other species of mammalian fauna.

## **1.2. Literature review**

### **1.2.1. Status and distribution:**

Asian elephant (*Elephas maximus*, Linnaeus, 1758 referred to as 'elephant' hereafter) is a globally endangered mega-herbivore (Williams et al., 2020). It is an umbrella species in the tropical and sub-tropical forests of Asia and plays an influential cultural role in various Asian societies (Jadhav and Barua, 2012; Menon et al., 1996; Sukumar, 2003a; Vasudev et al., 2020).

Once widely distributed in Asia, elephants are now confined to ca. 5% of their historical range in highly fragmented landscapes (Sukumar, 2006, Leimgruber et al., 2003). It was distributed over a large area extending from the Tigris-Euphrates basin, eastward through the Indian sub-continent and south-east Asia to the north of the Yangtze River in China; are recently concentrated to 13 range countries of the world (Joshi et al., 2009) with an estimated population of 45,000-52,000 in the wild and 16,000 in captivity (Sukumar, 2003). Elephants require larger areas to survive owing to their long-distance seasonal ranges (Goswami et al., 2017; Leimgruber et al., 2003). However, increasing habitat fragmentation brings them in frequent confrontation with humans. As a result, human-elephant conflict (HEC) worsens and had become a prominent cause of elephant population decline (Sukumar, 2006). Elephants have been observed from sea level to 3,000 m altitude in the Himalayan region (Williams et al., 2020). Elephants are habitat generalists, consuming a large number of plant species. They eat 5% of their body weight each day, which for adults range between 170 to 200 kg of food per day, and need 80 to 200 liters of water a day, which is used more for bathing (Sukumar, 2006). Elephants feed on plants by plucking grasses, forbs, and creepers, frequently uprooting

them; by stripping leaves, fruits, twigs, or bark from woody trees and shrubs; by breaking-off branches to facilitate consumption of edible parts; and by pushing over or uprooting trees and shrubs (Koirala et al., 2016; Sukumar, 1989). Additionally, elephants graze and browse on different plants and trees' delicate and palatable portions. The consequences of plant utilization by elephants vary; depending on the species selected (Douglas-Hamilton and Barnes, 1982), the levels of damage inflicted, the season when damage occurs, period of continuing damage, elephant densities (Owen-Smith and Chafota, 2012), and interactive effects of other factors such as fire, rainfall, and soil properties (Owen-Smith, 1988).

Before 1950s, Nepal's *Terai* areas were forested with a little to no human habitations (Dhakal and Thapa, 2017; Wegge et al., 1998). Malaria (life threatening infectious disease) eradication program of the Government and concurrent Government resettlement programs resulted in a rapid influx of people from the hills into the *Terai* region since 1950s. Many people of Nepalese origin residing in India and Myanmar also came back to Nepal to settle in *Terai* during the 1960s, resulting in loss of over 80% of forest cover/natural habitat into human-dominated landscape (Aryal et al., 2020; Laudari et al., 2020). Since then, elephants' habitat range in Nepal has been constantly fragmented into smaller areas due to encroachment, agricultural expansion, linear infrastructure development, and conurbation expansion near the forest at both sides of the national highway in Nepal each (Pradhan et al., 2007). Additionally, rapid development of linear-infrastructure including the Railways (currently under construction), expansion of Highways, power transmission lines, and irrigation canals have caused further obstruction to elephant movement. Previously, till about 1950s the forest of low land *Terai* was famous for its abundant wildlife, stretching across the

entire length of Nepal (Bajimaya, 2012). However, in the present, wildlife is primarily concentrated in the Protected Areas and sparsely distributed outside of the Protected Areas. Overtime, the elephant habitats in Nepal have continuously decreased due to range of developmental and socio-political pressures on the habitats (Ram, 2014). The government of Nepal (GoN) had promulgated National Parks and Wildlife Conservation Act during 1973 (NPWCA 1973) for conserving the endangered flora & fauna. Under its ambit, Protected Area network was established for conservation and management of this iconic and flagship megafauna (MoFSC, 2015). Further to this, the GoN recognized the importance of elephants and prioritized elephant conservation including that of the captive elephants by establishing National Parks; an elephant breeding center at the Chitwan National Park (CNP), and implementing the elephant conservation Action plan (2009-2018) (DNPWC, 2010; Yadav, 2002) for conservation and management of elephants.

Earlier, large groups of elephants reportedly occurred in the Protected Areas of Bardia National Park, Suklaphanta Wildlife Reserve, Parsa Wildlife Reserve, and Chitwan National Park. Additionally, there are records of splinter groups of elephants in Koshi Tappu Wildlife Reserve, Sunsari district, Morang, and Jhapa (Ram, 2014). Moreover, transboundary herds of elephants move from India to Nepal and vice-versa in the Eastern, Mid-western, and Far-western Nepal. Such large migratory herds concentrate close to Bahundangi VDC, Jhapa while relatively smaller herds usually occur in Jhapa through to the Udaypur districts (Shrestha, 2007). Across Nepal, elephants were found in four isolated populations with about 50-55 individuals during 1970s. This further increased to 127-145 individuals during 2008 (DNPWC, 2009; Flagstad et al., 2012; Kharel, 2002; Narendra M B Pradhan et al., 2011; Mukti

Narayan. Shrestha et al., 1985; Smith and Mishra, 1992; Yadav, 2002) (Figure 1.2, and 1.4).

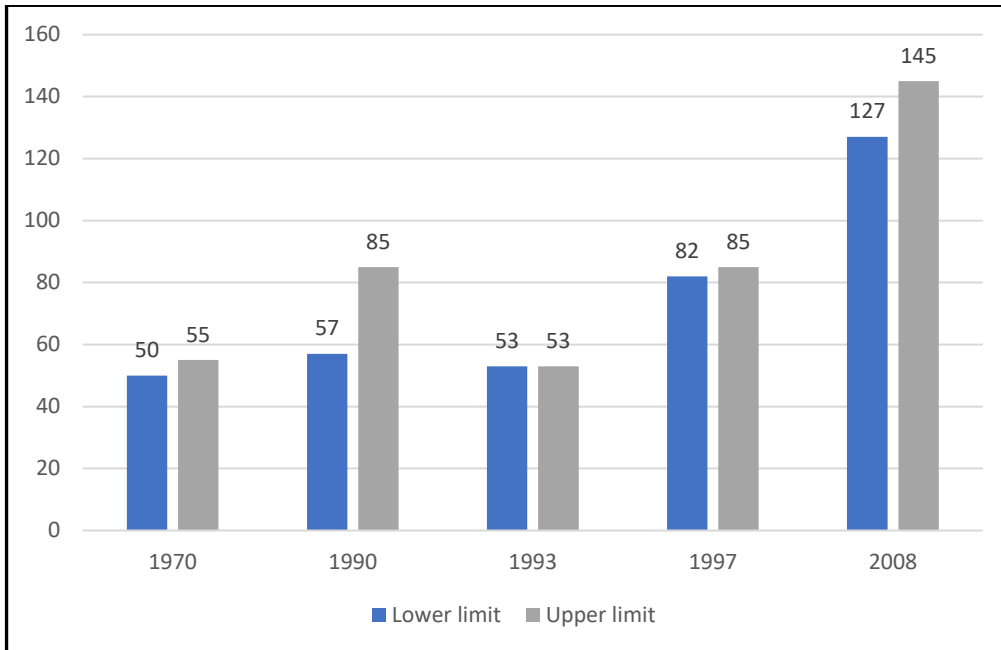


Figure 1.2: Elephant population (Kharel, 2002; Narendra M B Pradhan et al., 2011; Shrestha et al., 1985; Smith and Mishra, 1992; Yadav, 2002)

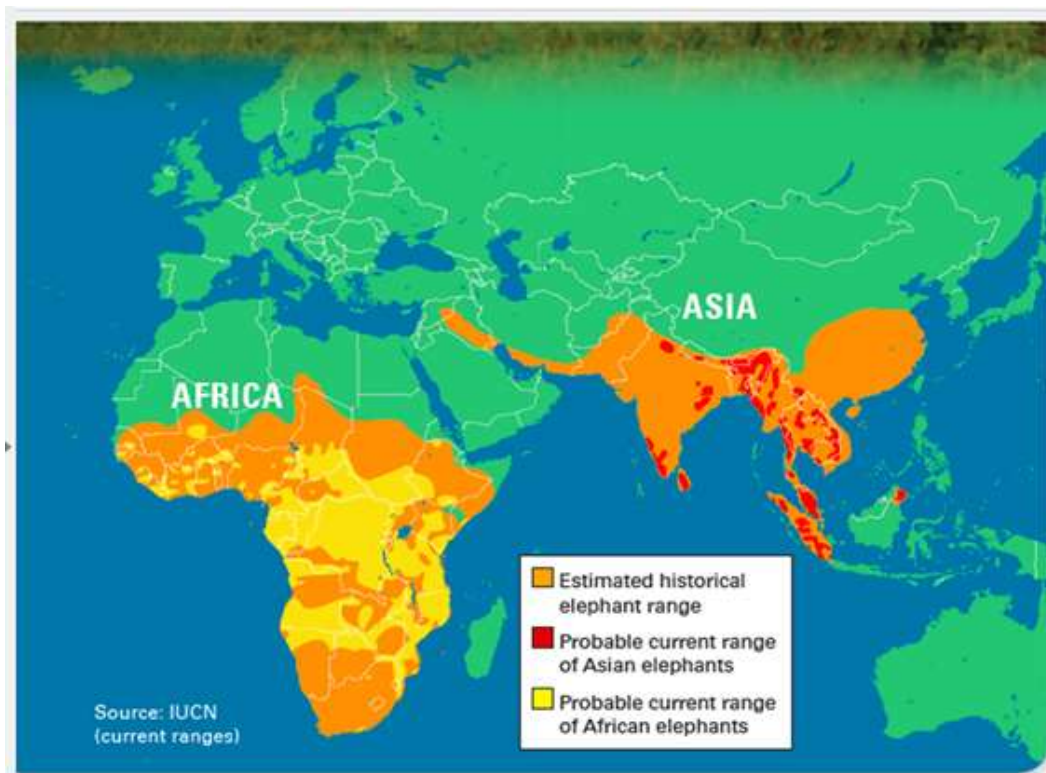


Figure 1.3: Global distribution of elephants

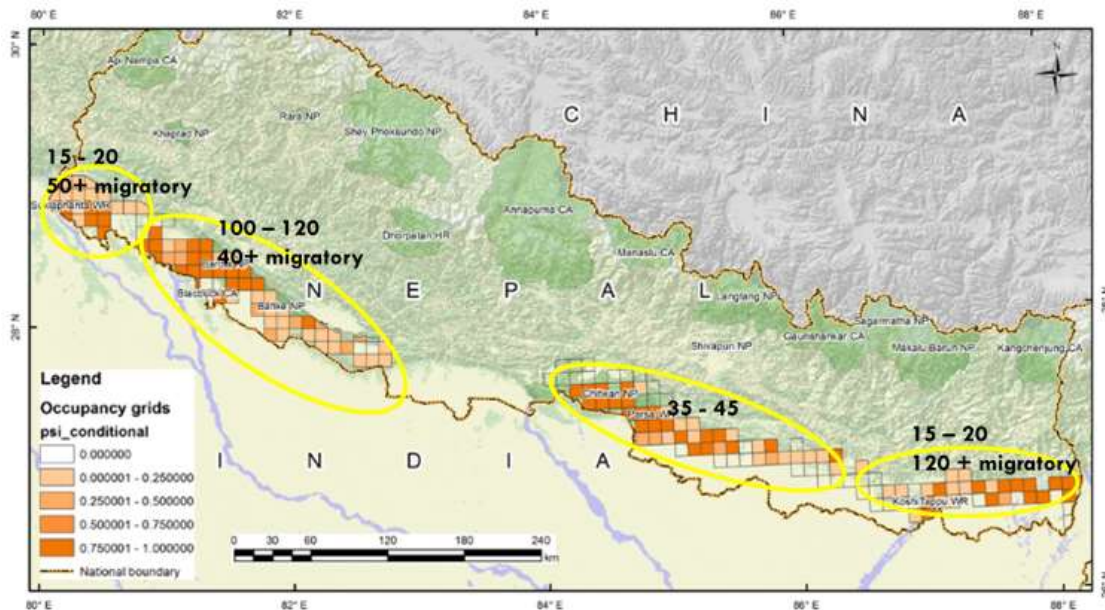


Figure 1.4. Elephant distribution in Nepal (Lamichhane et al 2018)

### 1.2.2. Habitat status

Globally 31% (4.06 billion hectares) of forests and 14.9% of protected areas are available for biodiversity conservation (FAO, 2020). In comparison, elephants occur in just 5% of the land area across the world (Leimgruber et al., 2003). While Nepal has secured 23.2% of the landmass as a Protected Areas (PAs) (MoFSC, 2015), elephants occur only in the Chure Terai Madhesh Landscape (CTML) habitat in the lowlands and Siwaliks. Encroachment, illegal harvesting of timbers, heavy grazing and invasive alien species have continuously threatened protected habitats (Ram, 2008; Subedi et al., 2017). About 29% of the forestland is managed as community forests, where local communities play a significant role in managing forests outside the PAs (Aryal et al., 2020; FAO, 2020). A study in central Nepal explored that  $<5^{\circ}$  slopes and  $<400\text{m}$  altitude is suitable habitat in the Parsa National Park, which supports 45 elephants (Sharma et al., 2019). Similarly,  $3194.8\text{ km}^2$  forest (of which 40% protected areas)

available as a suitable habitat for wild elephants in western Nepal, which provides home for 120-145 individual elephants (Sharma et al., 2020).

### **1.2.3. Habitat fragmentation:**

Forest fragmentation hinders wild animals' dispersing and migratory patterns (Fahrig, 2003; Fahrig et al., 2019). Habitat status assessment is also crucial for managing rare and endangered mega-fauna in the world (Padalia et al., 2019). There are few studies to refer to on forest loss and fragmentation in Nepal. Thus, the effect of forest loss and fragmentations on elephant populations at the landscape level in Nepal is lacking (Reddy et al., 2018; Singh et al., 2017; Uggupta and Singh, 2017).

### **1.2.4. Human elephant conflict.**

Human-wildlife conflict (HWC) is a negative interaction between humans and wildlife, when "wildlife impacts humans negatively (physically, economically, or psychologically), and where humans likewise negatively impact wildlife". Further, human-wildlife conflict (HWC) represents underlying disagreements among people, which need to be addressed to support human well-being and biodiversity conservation (Peterson et al., 2013). Human Wildlife conflict (HWC) is managed both by implementing active as well as a passive measures in the world and also in Nepal and backstopped by the ex-gratia payment provided as a compensation payments in relief to victims (Barua et al., 2013; Lewis et al., 2011; Redpath et al., 2013). Rhinoceros, tigers, leopards, wild buffaloes, snow leopards and Asian elephants are major mega-fauna involved in Nepal's human-wildlife conflict (HWC). Asian elephant (*Elephas maximus*) has been responsible for over 30% of total wildlife-related human attacks

(Acharya et al., 2017; Neupane et al., 2017a) and caused massive crop and property losses in Nepal. The conflict related to the Asian elephant has caused considerable damage to life, property, and produce, and the resulting conflict is known as Human-elephant conflict (HEC) (Amwata and Mganga, 2014). Globally 13 elephant range countries harbor ~ 50,000 elephants across Asia (Menon and Tiwari, 2019), and 34 range countries in Africa harbor ~400,000 individual elephants (Lindsay et al., 2017). Both Asian and African elephants suffer human-elephant conflict. India, Sri Lanka, Bangladesh and Nepal loses an average of 500, 81, 37, and 18 human lives due to human elephant conflict annually (Prakash et al., 2020) (Acharya et al., 2016). Now both the residential and trans-boundary migratory elephant populations seem increasing, which had also increased the number of conflicts (Ram and Achanrya 2020). Elephants used to migrate from Assam into eastern Nepal and also from the Protected Areas of Dudhuwa, Plilibhit, Katarniyaghat, and Nandaur wildlife sanctuaries of India to western Nepal (ten velde 1997, Lamichhane et al., 2017; Ram and Acharya, 2020). Human deaths, injuries, crop & property damages are major characteristics of human-elephant conflict (HEC). In Nepal, elephants have caused over 67% of conflict related human deaths, and 30% of total fatality cases were by leopards *Panthera pardus* (Acharya et al., 2016).

HEC is a complex challenge, causing severe and widespread losses to local communities (Gross et al., 2018; Hoare, 2015; Redpath et al., 2015) and impacted all the aspects of livelihood components due to its multi-dimensional and multi-directional effects (Selier et al., 2016; von Rueden et al., 2015). HEC is influenced by seasonality migratory patterns, proximity to settlements and elephant group characteristics (Nyirenda, 2012; Pozo et al., 2017; Songhurst et al., 2016).

The HEC had extended beyond the boundaries of the Protected Areas (PAs) (Okello et al., 2015). HWC usually takes place in areas that are around 5 kilometers from the park boundary (Ruda et al., 2018). HEC primarily affects subsistence farmers, resulting in myriad socio-economic and political challenges. Such affected subsistence farmers resort to over-exploitation of natural resources such as elephants to avert food insecurity and hardships (Kalaba et al., 2013). Human-Elephant Conflict (Human fatality, injuries, crop & property damage) can be considered as a livelihood risk (Kahler and Gore, 2014) because of its impact on all types of livelihood capitals (human, social, financial, physical, and natural).

The nature and extent of human-elephant conflicts studied in Chitwan National Park and Parsa National Park complex (CNP & PNP) and its buffer zone in Nepal shows that crop damage and human casualties were more serious conflict issues among the other concerns of human–elephant conflict (Pant et al., 2015). Elephants do not recognize political boundaries set down by Governments and policymakers and thus, their ranges straddle across administrative boundaries even across countries (ten Velde, 1997). In Eastern Nepal, over 66 people were killed by elephants (Yadav, 2002), 40 were injured, and consequently, nine elephants were killed in retaliation during 2004–2013 (Ram, 2014a) in eastern Nepal. Due to disruption of corridors, elephant movement has been fraught with conflict-related issues across the four sub-populations throughout Nepal (Pradhan et al., 2007). Eastern elephant population migrated to Siraha and Udaypur districts of Nepal, and it was reported beyond the Kamala river before 2007 (Ram, 2014a; ten Velde, 1997). Moreover, elephant migration beyond the Kamala river (western boundary of Siraha) not recorded previously, has become a regular phenomenon (ten velde 1997). Elephants have been killed in retaliation in many places

including Sindhuli at Ranibas and Jhapa that are located beyond the boundaries of the Protected Areas (DFO, 2012). These incidences of retaliatory killing of elephants in areas outside of Protected Areas indicate ancestry migratory routes for elephants towards Sindhuli west to Sarlahi and towards the east to Udaypur. However, empirical assessment of habitat and connectivity are lacking.

### **1.3. Rationale:**

HEC, habitat loss, degradation, and fragmentation, retaliatory killings, poaching and illegal trades are the major threats for elephant survival around the globe and in Nepal as well. Very few studies on elephant habitat status (forest degradation and fragmentation), HEC, elephant distribution, population status and their habitat connectivity were carried out in Nepal. Thus, a comprehensive study on the landscape level covering the whole landscape of Chure Terai Madhesh Landscape (CTML), which is only a remnant habitat for elephants in Nepal is urgently required. Some of the earlier site-specific studies were carried out with different perspectives, but still related to elephants in Nepal (Acharya et al., 2017, 2016; Koirala et al., 2016; Lamichhane et al., 2017; Neupane et al., 2017b, 2017; Pant et al., 2015; Ruda et al., 2018). Considering these and the overall gaps, this study "Landscape-level modeling of Asian Elephant (*Elephas maximus*) habitat, its population and interaction with humans in Nepal" was conceived with the following objectives.

### **1.4. General objectives:**

The general objective of this study is "Landscape level modeling of Asian Elephant (*Elephas maximus*) habitat, its population and interaction with humans in Nepal" and specific objectives were

- Assessment of status and distribution of elephants across Nepal (focusing TAL Nepal)
- Tracking habitat loss and fragmentation in the elephant range of Nepal
- Assessment of human-elephant interactions (HEI) across Nepal using primary and secondary information

### **1.5. Research Questions.**

I have answered the following nine research questions within six chapters of this Thesis.

- a. How is the forest cover changing over time?
- b. How is the forest fragmentation affecting the four elephant ranges of Nepal?
- c. How much area is occupied by elephants across Nepal?
- d. What is the elephant population size in Nepal?
- e. What are the spatio-temporal patterns of elephant attacks on humans in Nepal?
- f. What are the factors responsible for elephants' attacks on humans?
- g. What are the significant landscape-level predictors of human-elephant conflicts in Nepal?
- h. What are the major human-elephant conflict (HEC) hotspots in the landscape?

### **1.6. Organizations of Chapters as per the specific objectives**

As per the gaps identified by Nepal's elephant conservation action plan (2009-2018) (DNPWC, 2010), I have selected my study on elephants' ecology and accomplished the three primary objectives, viz. status distribution, population, and human-elephant interaction in Nepal. I have completed my study in the following six different chapters.

## Chapter 1: Introduction

The 1<sup>st</sup> chapter provided broad background of species. Further, the historical status and distribution patterns were deliberated. Research gaps were highlighted, objectives and research questions were defined, and finally the existing information was condensed.

## Chapter 2: Tracking Forest loss and fragmentation in the Chure Terai Madhesh Landscape (CTML) of Nepal (*Ram et al. 2021*)

The 2<sup>nd</sup> chapter dealt with tracking of the historical forest cover across Nepal, the annual rate of forest loss, change in forest cover change for 90 years between 1930 and 2020, and also an evaluation of the habitat fragmentation in elephant ranges of Nepal.

## Chapter 3<sup>rd</sup>: Status and distribution of elephants in Nepal

The 3<sup>rd</sup> chapter dealt with the overall occupancy of elephants throughout the Nepal. Further, this chapter describes the current population of elephants in Nepal besides providing broad historic trends.

## Chapter 4: Patterns and determinants of elephant attacks on humans in Nepal (*Ram et al., 2021*)

The 4<sup>th</sup> chapter dealt with the patterns and determinants of elephant attacks on humans in Nepal. It further explored the spatio-temporal patterns of elephant attacks and their associated factors.

## Chapter 5: Landscape predictors of human-elephant conflict (HEC) in the Chure Terai Madhesh Landscape (CTML) of Nepal (*Ram et al., 2022*)

The 5<sup>th</sup> chapter examines the landscape predictors that affected the human-elephant conflict in Nepal and predicted the human-elephant conflict (HEC) hotspots in the different elephant regions of Nepal.

Chapter 6: Synthesis of chapters

The 6<sup>th</sup> chapter had synthesized all the chapters and created a link between all the chapters.

### **1.7. Study area**

The study area Chure-Terai-Madhesh landscape (CTML) is located between 26.4154<sup>0</sup> to 29.1134<sup>0</sup>N and 80.1259<sup>0</sup> to 88.0849<sup>0</sup>E. CTML covers the entire elephant distribution range in Nepal. The CTML spreads across 24 districts and covers an area of 42,456 km<sup>2</sup> (Figure 1.5). CTML comprises five physiographic units i.e., Chure hills (34.4%); Chure narrow gorges (2.2%); Dun/Inner Tarai (8.4%); Bhavar region (14.9%); and Tarai Madhesh (40%). Forty-eight percent of the landscape comprises agriculture and settlement; 47.16% forest, shrub-land, and grassland; and the rest 4.65% river and riverbed (GoN/PCTMCDB, 2017). CMTL is a part of the global biodiversity hotspot (Chaudhary et al., 2018) and provides essential environmental services such as groundwater recharge for more than half of Nepal's human population (~15 million) (CBS, 2014; Hamilton and Radford, 2007). The major habitat types are a) Himalayan subtropical broadleaved forests, b) Gangetic plains and moist deciduous forest, and c) Terai-Duar savannas and grassland. Apart from elephants, the study area is also a refuge for several endangered large mammals, including the tiger (*Panthera tigris*), greater one-horned rhinoceros (*Rhinoceros unicornis*), Gaur (*Bos gaurus*), and wild buffalo (*Bubalus bubalis arnee*). The annual rainfall ranges between 1,138 mm to 2,680 mm,

with over 80% of the rain occurring during monsoon months (DFRS, 2015). The altitudinal range lies between 60-1500 meters (Chaudhary et al., 2016). CTML is densely populated with an average human density of 392 persons/km<sup>2</sup> (CBS, 2014). Sixty percent of the people depend on subsistence agriculture and are involved in farm and off-farm based livelihood activities (Chaudhary and Subedi, 2019). Paddy (*Oryza sativa*), maize (*Zea mays*), wheat (*Triticum aestivum*), lentils (*Lens culinaris*) are some major food crops, where jackfruit (*Artocarpus heterophyllus*), mangoes (*Mangifera indica*), bananas (*Musa acuminata*) are some fruit crops farmed in the area (Neupane et al., 2017a). Large-scale linear infrastructure projects and mining activities are the major drivers of deforestation and habitat fragmentation in the landscape.

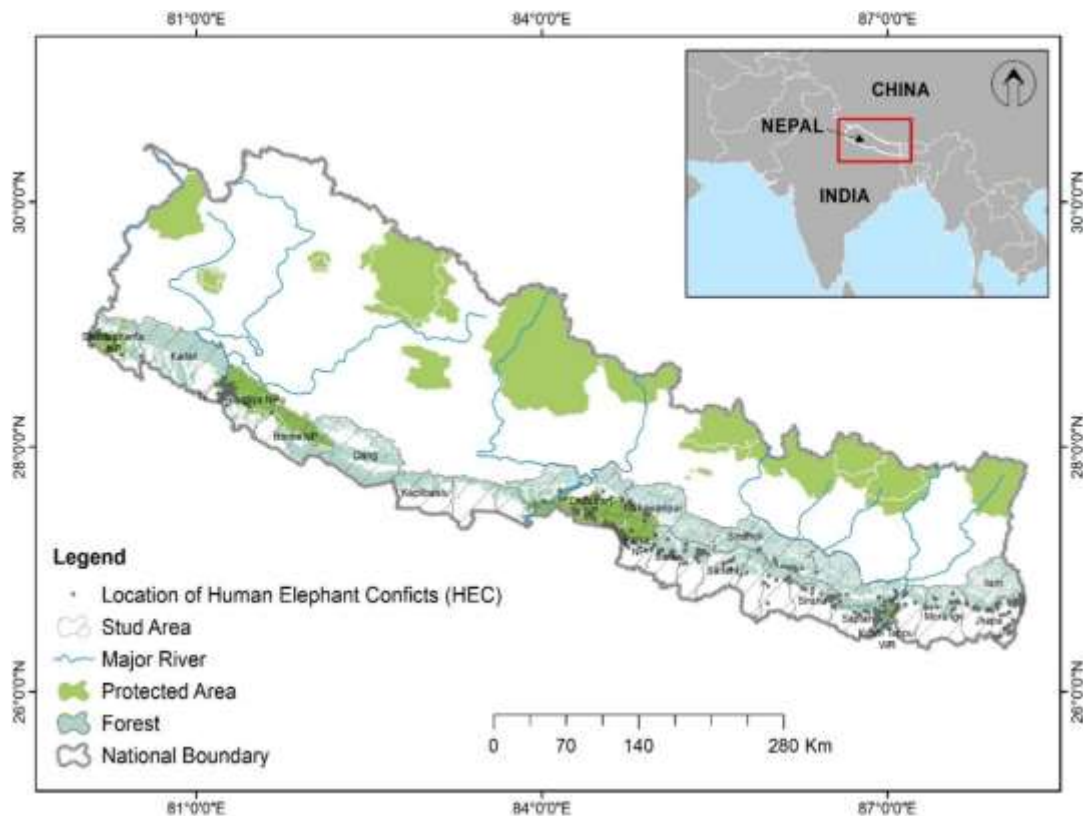


Figure 1.5: Study area, 24 district of Low land Terai and Siwaliks.

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## **Chapter 2:**

### **Tracking Forest loss and Fragmentation Between 1930 and 2020 in Asian elephant (*Elephas maximus*) range in Nepal**

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# **Tracking Forest loss and Fragmentation Between 1930 and 2020 in Asian elephant (*Elephas maximus*) range in Nepal**

### **2.1. Introduction:**

Deforestation and conversion of natural areas into human use impacts the earth's ecosystems and functions, and threatens biodiversity (Lambin et al., 2001; Lawler et al., 2014). The population of many wildlife species are declining globally, and about a million species are under threat of extinction primarily due to habitat loss/degradation, overexploitation, climate change, illegal wildlife trade, direct persecution, and conflict with humans (Anthony and Wasambo, 2009; Bongaarts, 2019; Pardini, 2018). Fragmentation is a significant factor leading to the loss of biodiversity in forested landscapes (Fahrig, 2003). Habitat fragmentation affects ecological patterns and processes by increasing the number of forest patches, reducing the patch size, interrupting connectivity within the ecological network (Collinge, 1996; Fahrig et al., 2019; Pierri-Daunt and Tanaka, 2014), and impacting several species (Bustamante et al., 2003). Habitat fragmentation could alter animal communities and trigger cascading effects on plants and ecosystem functions, including their carbon storage potential (Betts et al., 2017; Chaplin-Kramer et al., 2015; Symes et al., 2018). Continued fragmentation can lead to microclimatic changes in the edges, reduced core habitat, and eases the establishment of invasive species towards the forest interiors (Bustamante and Simonetti, 2005; Singh et al., 2017).

Effects of fragmentation on wide ranging large mammals like elephants is more severe and increases the extinction risks due to their needs for large and intact habitats (Ripple et al., 2017) (Cardillo et al., 2005) (Woodroffe et al., 2005). With the current rise in anthropogenic impacts and loss of wildlife habitats, shared heterogenous landscapes around protected areas have immense potential for long term conservation of large mammals (Goswami et al., 2014; Wittemyer et al., 2008).

Elephants are the largest living terrestrial mammals facing typical threats of large mammals such as habitat loss, poaching and conflict with communities(Shaffer et al., 2019). The increase in human population and expansion of agriculture had led to habitat loss and fragmentation, resulting in a significant decline in elephant populations across Asia and Africa(Desai and Riddle, 2015; Leimgruber et al., 2003; Thouless et al., 2016). Asian elephants are confined to 5% of the historic elephant range (Leimgruber et al., 2003). Elephants use large areas to meet their dietary and reproductive requirements (Koirala et al., 2016; Sukumar, 2006). Their home range size varies according to the forage availability and nature of the habitat (Baskaran, 1998; Branco et al., 2019; Fernando et al., 2008). Expanding human settlements and agriculture areas has reduced connectivity, caused the loss of habitats, and a rise in human impacts on elephants, resulting in frequent conflict ranging from crop damage to human casualty and persecution of elephants(Naha et al., 2020; Shaffer et al., 2019).

Nepal is one of the elephant range countries, with an estimated 200 elephants in Nepal and additional 150 elephants seasonally migrating from India(DNPWC, 2009; Ram and Acharya, 2020). The Chure Terai Madhesh Landscape (CTML) encompasses the entire elephant habitat in Nepal (Ram et al., 2021; ten Velde, 1997). Before the 1950s, the forest of CTML was reasonably intact (Wikramanayake et al., 2004) and had a wide distribution of elephants that reportedly occurred in high densities (Kharel, 2002; Shrestha et al., 1985; Smith and Mishra, 1992). A large tract of forests was converted into agriculture between 1950 and 1970, and wildlife was hunted down as agricultural pests with no legal protection (Gee, 1959). Nearly three hundred wild elephants were also captured (287 between 1800 and 1975) and turned into captivity for Royal hunting

expeditions, forest patrolling, transportation and national security (Shrestha et al., 1985). Deforestation led to the further decline of the elephant population.

In the CTML, the elephant ranges run east-west along the foothills of the Himalayas (ten Velde, 1997). Protected areas (national parks and wildlife reserves) and forests outside the protected network constitute significant elephant habitats in CTML. The landscape includes both government and community-managed forests. Different landscape-level conservation approaches, including the Terai Arc Landscape (TAL) program, were implemented for biodiversity conservation in the CTML region (MoFSC, 2015). However, CTML experienced significant habitat loss and fragmentation, contributing to the escalation of human-elephant conflict (HEC) (Subedi et al., 2021).

Despite increasing threats to the elephant conservation, landscape-specific information on the change in forest cover and habitat fragmentation is lacking for CTML and is urgently required for effective conservation planning for elephants. This study quantifies the change in forest cover for the last 90 years (1930-2020) using high-resolution imagery, estimating forest loss and habitat fragmentation in the CTML. We use the findings to relate habitat loss, fragmentation, and trends in HEC and discuss implications for elephant conservation in the human-dominated landscapes of Nepal and elsewhere. The findings will have implications for devising actionable strategies for elephant conservation and protecting existing forested habitats within human-dominated landscapes in Nepal.

## 2.2. Methods and materials

### 2.2.1 Study area

We divided our study area Chure-Terai-Madhesh landscape (CTML) (figure 1.5) into four regions (Eastern, Central, Western and Far-western) of similar size to assess the extent of forest loss (Table 2.1). Thus, elephants are distributed in four population clusters with limited connectivity viz. a) eastern population (Mechi River to Kamala River), b) central population (Kamala River to Narayani River), c) western population (Narayani River to Western boundary of Dang district), and d) far-western population (Eastern boundary of Banke district to Mahakali River) (Acharya et al., 2017; DNPWC, 2010) (Table 2.1).

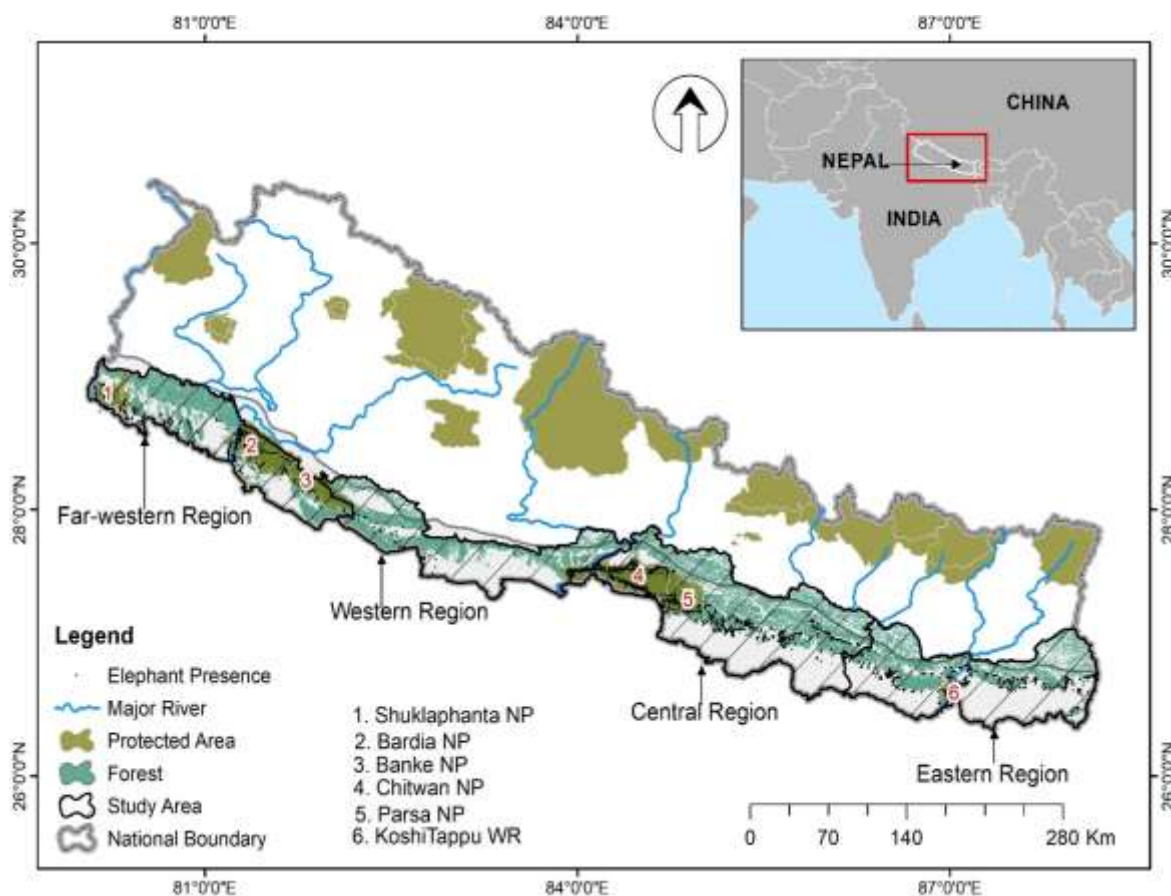


Figure 2.1: The geographical location of Nepal and the study area (Chure Terai Madhesh Landscape).

Table 2.1. Four different regions within Chure Terai Madhesh Landscape Nepal, area, forest cover and elephant population status. The elephant population was obtained from Ram & Acharya (2020).

SN	Region	Coverage (Districts)	Total Area (Km <sup>2</sup> )	% Forest cover	Elephant population
1	Eastern	Jhapa to Siraha	11,116.96	31.92	Residential: 27-35; ~100 migratory elephants each year from West Bengal, eastern India).
2	Central	Dhanusa to Chitwan	8,169.43	46.17	Residential: 45-53
3	Western	Nawalparasi to Dang	8,777.95	56.89	Migratory: 8-12
4	Far-Western	Banke to Kanchanpur	14,391.54	46.94	Residential: 80-125; ~45 migratory (from Uttarakhand and Uttar Pradesh, India migrated to far western habitats in Nepal )
	Total		42,455.88	44.92	

### 2.2.2. Derivation of forest cover

We analyzed forest cover change and fragmentation using both the patch and landscape metrics and considered forest fragmentation as habitat fragmentation (Wilcove et al., 1986). Natural Forests or plantations covering greater than 0.5 ha area were categorized as forest. (FAO, 2014). We used the hybrid classification techniques to combine high-resolution images, medium resolution images, and digitization of topographic maps. First of all, we prepared a forest cover map of the 1930s by digitizing greenwash areas shown on topographical maps prepared by Army Map Service, U.S. Army, Washington, surveyed during 1920–1940 (<http://legacy.lib.utexas.edu/maps/ams/india/>) at 1:250,000 scale. Due to the unavailability of multi-spectral satellite images of the study area before the 1970s, we

relied on the existing topographic maps to obtain forest cover of 1930 (Padalia et al., 2019; Sudhakar Reddy et al., 2016)

Kaim *et al.* (2014, 2016) found 5–10% inherent errors at various stages of land cover change analysis; while using historical data and topographic maps. The inaccuracy of forest cover mapping was minimized by visual interpretation and overlay analysis in the topographic maps. In addition, we resampled all the digital images at a 30-meter resolution to improve the mapping errors. (Kaim et al., 2016, 2014) reported the reliability of topographical maps to reconstruct forest cover. We also obtained the forest cover map of 1975 by on-screen digitization of Landsat 1 TM level 1 satellite images. We produced the forest cover maps of 2000 and 2020 from Landsat imagery scenes respective years with <10% cloud cover (Table 2.2; Figure. 2.2). All the Landsat data processing was conducted using the cloud-computing technology in the Google Earth Engine (GEE) platform (<https://earthengine.google.org/>). The GEE platform carried out a fast analysis using Google's computing infrastructure (Gorelick et al., 2017; Wang et al., 2019). We used the pre-processed Landsat imagery available through GEE to assess forest cover change across the study area (Huang et al., 2017).

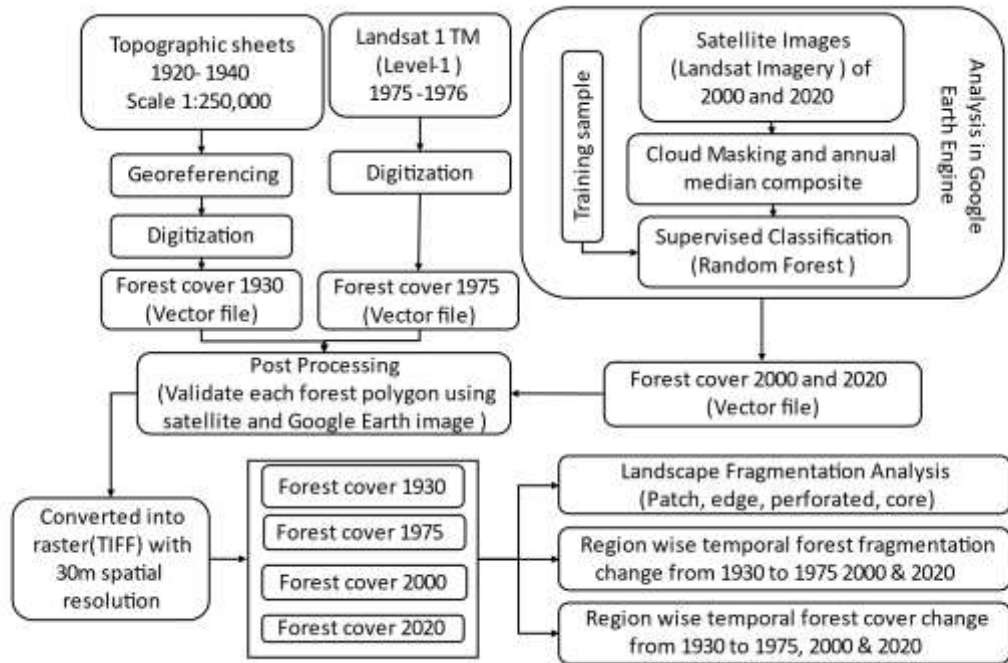


Figure 2.2: Overall methodological framework adopted for this study.

We used a cloud screening algorithm to remove cloud contaminated pixels from each Landsat image by applying quality assessment (QA) bands for 2000 and 2020. Then, we produced an annual composite by taking the median value from images from the target year (Midekisa et al., 2017). We delineated >1000 reference points for each period 2000 and 2020 respectively. We used supervised machine learning classifiers, i.e., Random Forest (RF), to classify remotely sensed data (Zurqani et al., 2018). Random Forest Classifier creates a set of decision trees from a randomly selected subset of the training set and aggregates the votes from different decision trees to classify the image (Rodriguez-Galiano et al., 2012). The classified image was downloaded as raster tiff files. The raster was converted into vector polygons and overlaid with high-resolution google earth images of respective years. The final forest cover map was obtained with the highest accuracy by post-processing (validating) the forest polygons

through onscreen digitization to match the forests visible in Google images (Zurqani et al., 2018).

*Table 2.2. Sources of data used in this study.*

SN	Data layer	Source	Spatial resolution (m)	Year
1	Topographic map	Army Map Service, U.S. Army, Washington	Scale 1:250,000 m (based on Aerial photo)	1920-1940
2	Landsat 1 TM	Earth Explorer (USGS)	60 m	1975-1976
3	Landsat 5 Surface Reflectance Tier 1	GEE dataset (USGS)	30 m	2000
4	Landsat 8 Surface Reflectance GEE dataset	GEE dataset (USGS)	30 m	2020
5	Administrative boundary	Department of Survey, Nepal	Scale 1:25,000 (Based on Aerial photo)	1996 – 1998

### **2.2.3. Data analysis**

#### ***2.2.3.1. Analysis of forest loss/gain***

Forest cover maps of the four different periods of 1930 (before malaria eradication), 1975 (the initial stage of PA system development), 2000 (well-established PA system) & 2020 (current scenario) were post-processed according to FAO forest definition. These layers were analyzed to understand changes in extent and location of forests using a post-classification change detection technique in Arc GIS 10.4.

We estimated the conversion of forests into the non-forest area on a grid overlay basis. We generated 5× 5 km<sup>2</sup> grids for forest cover change analysis following Padaliya et al (2019)(Padalia et al., 2019) and Reddy et al. (2018) (C. S. Reddy et al., 2018) for the time series assessment and analyzed spatial distribution trends of forest cover in these

grids from 1930–1975, 1975–2000, and 2000–2020 (Padalia et al., 2019; Reddy et al., 2013). We computed the forest cover area (distribution of transitions and persistence of forest) of four different periods in each grid using the zonal statistics tool of ArcGIS software (ESRI, 2016). Overall, forest cover change was calculated by combining all the grids and calculating the annual deforestation rate (percentage) using a compound-interest-rate formula (Puyravaud, 2003).

$r = \frac{1}{t_2 - t_1} \times \ln \frac{a_2}{a_1}$ , where  $a_1$  and  $a_2$  are the area covered by forest at times  $t_1$  and  $t_2$ . The region wise rate of deforestation was computed and presented.

We also overlaid the Human elephant conflict (HEC) locations (Locations of elephant attacks on humans) of last 20 years (between 2000 and 2020) over the forest cover map of 1930 & 2020 (Fig. 3d) to examine the relation of HEC with forest cover change. We took HEC data (elephant attacks on humans) from the published article Ram et al (2021) (Ram et al., 2021) .

### ***2.2.3.2. Modeling Forest fragmentation***

We carried out habitat fragmentation analysis in the four regions of CTML (Figure 2.1) and measured fragmentation in terms of core, perforated, edge, and patches. We used 30 m cell resolution for fragmentation analysis for four different periods. We used patch analyst (Elkie et al., 1999) to obtain the patch matrix for each region viz. patch density and size (number of patches, mean patch sizes, patch size standard deviation), edge metrics (edge density, mean patch edge), and shape index (mean shape Index, mean perimeter area ratio, mean patch fractal dimension), (Supplementary table S1).

Similarly, Landscape Fragmentation Tool (LFT V2.0, <http://clear.uconn.edu/tools/lft/lft2/>) was used to estimate landscape metrics (Vogt et al., 2007). The change of fragmentation during the 1930 to 2020 periods was carried out by cross-tabulating the fragmentation classes. Landscape Fragmentation Tool (LFT) classifies

forests at pixel-level into fragmentation classes: core 1, core 2, core 3, perforated, edge, and patch. Core forests are located far from the forest/non-forest boundary and surrounded by other forest areas. We considered the core forest as 100 m distance from the edge (Dutta et al., 2016). The core forests include three different types – 1) Core 1: forest patches area < 250 acres (1.012 km<sup>2</sup>), 2) Core 2: Medium core (forest patches area between 250–500 acres (1.01- 2.2 km<sup>2</sup>), and Core 3: large core (Forest patches area >500 acres (>2.2 km<sup>2</sup>) (Padalia et al., 2019). The peripheral forest was further classified into perforated (i) inner edge: forest pixels on the edge of small interior non-forest, and (ii) edge forest or outer edge: pixels that are between forest and large non-forest areas (Shapiro et al., 2016).

## **2.3. Results**

### **2.3.1. Temporal change of forest cover in CTML**

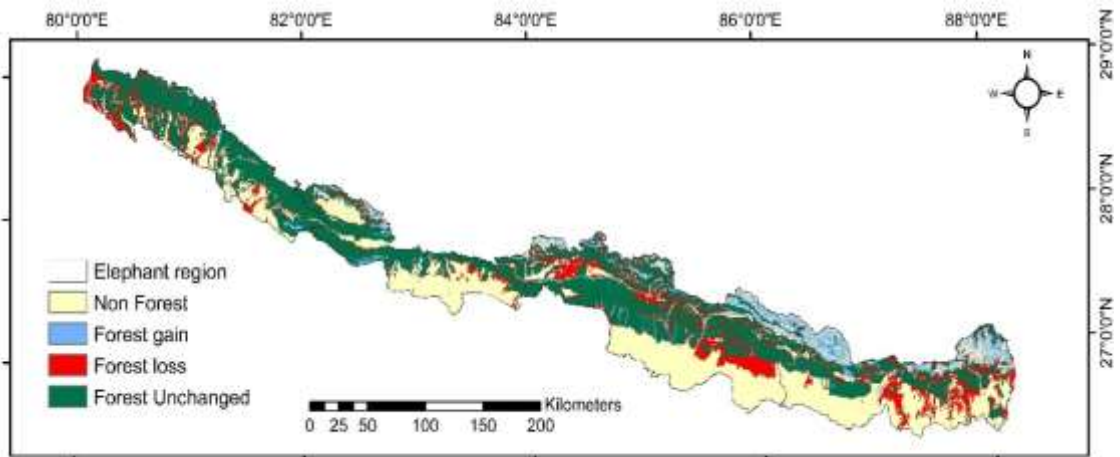
We estimated 24,315 km<sup>2</sup> of forest cover in 1930. The forest cover was reduced to 19,069 km<sup>2</sup> in 2020, with an annual rate of 0.27%. The deforestation rate (0.29%) was higher between 1930 and 1975. The highest rate of deforestation was documented in western region (0.33%) followed by eastern (0.29%), far western (0.28%) and central (0.16%) region between 1930 to 2020 (Table 2.3). In 2020, the far western region had the highest forest area (35.42%), followed by the western region (26.18%), central (19.78%), and eastern region (18.61%) of CTML (Table 2.3)

Table 2.3. Status of forest cover by area in 1930, 1975, 2000 and 2020 in Chure Terai Madhesh Landscape (CTML), Nepal. The total forest change percentage and annual rate of forest change (in parenthesis) is presented for four different time periods.

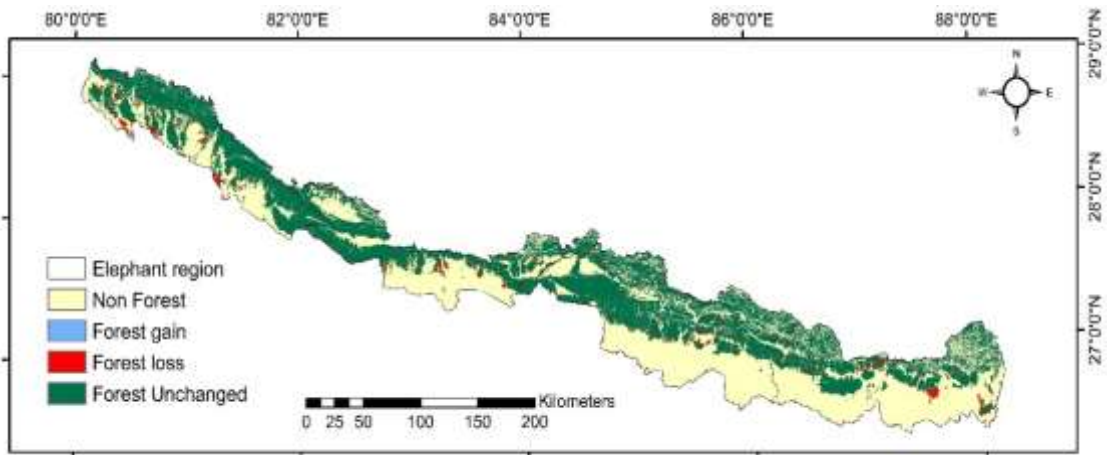
Region	Forest Area in different years (km <sup>2</sup> )				Percentage forest change (annual rate of forest change)			
	1930	1975	2000	2020	1930-1975	1975-2000	2000-2020	1930-2020
Eastern	4,607.92	4,084.94	3,781.68	3,548.48	-11.35 (-0.27)	-7.42 (-0.31)	6.57 (-0.32)	22.99 (-0.29)
Central	4,336.84	4,162.02	3,917.77	3,771.95	4.03 (-0.09)	5.87 (-0.24)	3.87 (-0.19)	13.03 (-0.16)
Western	6,703.66	5,590.97	5,186.52	4,993.85	16.60 (-0.40)	7.23 (-0.30)	3.86 (-0.19)	25.51 (-0.33)
Far western	8,667.14	7,482.98	7,167.34	6,754.86	13.66 (-0.33)	4.22 (-0.17)	6.11 (-0.30)	22.06 (-0.28)
<b>Total</b>	<b>24,315.56</b>	<b>21,320.92</b>	<b>20,053.32</b>	<b>19,069.14</b>	<b>12.32 (-0.29)</b>	<b>5.95 (-0.25)</b>	<b>5.16 (-0.25)</b>	<b>21.58 (-0.27)</b>

### 2.3.1. Spatial change in forest cover

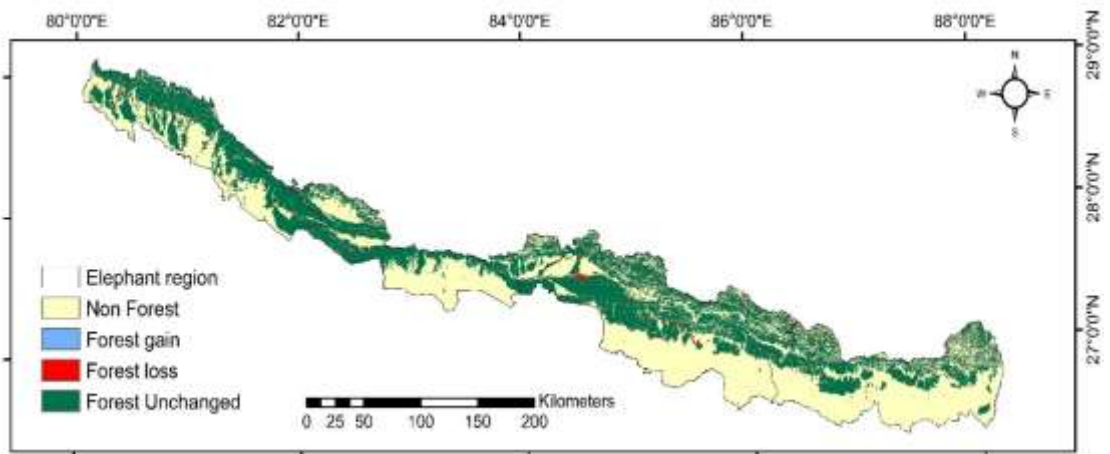
Altogether 1,592 grids of 5 x 5 km<sup>2</sup> were used to analyze the spatial patterns of forest cover change. Deforestation was documented in most of the grids (n=1505), and 75 grids lost entire forest area between 1930–2020. Increase in forest cover was observed in only 51 grids during the same period. The massive reduction in large forest patches (<20 Km<sup>2</sup>) was documented for 26 grids (Figure 2.3-a, b, c), (Supplementary table S2, Supplementary figure S5). We found ~ 60% of the elephant attacks on human (HEC) occurred in the area where forest was converted into the agriculture/settlements between 1930 and 2020 (Figure 2.3d).



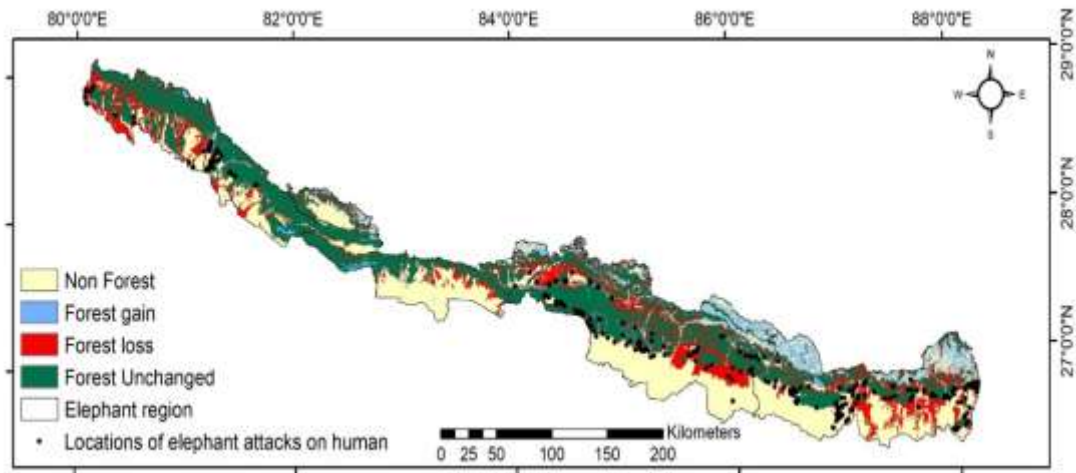
a.



b.



c.



d.

Figure 2.3: Forest cover change in the Asian elephant habitat (the Chure Terai Madhesh Landscape Nepal) during the time periods a) 1930–1975, b) 1975–2000, c) 2000–2020 and d) 1930–2020. In the map of d) 1930–2020, locations of elephant attacks on humans based on Ram et al. 2021<sup>[38]</sup> is also overlaid.

We calculated historical forest fragmentation for the last nine decades (1930–2020) and found that the total number of patches increased from 201 in 1930 to 28,559 in 2020. However, the highest decrease in mean patch size (121 km<sup>2</sup> in 1930 decreased to 0.7 km<sup>2</sup> in 2020) indicates that the forest has been fragmented into small patches. The mean perimeter ratio of the forest has been increased from 187 in 1930 to 1210 in 2020. The edge metrics showed that edge density increased from 548 (m/km<sup>2</sup>) to 3630 (m/km<sup>2</sup>), reduced mean patch edge to 2,426.63 ha from 66,271.31 ha. Similarly, the shape index suggested that the mean shape index (MSI) decreased sharply where the mean perimeter area ratio (MPAR) increased progressively (Table 2.4).

Table 2.4. Forest fragmentation status in the CTML, Nepal in different time periods.

SN	Landscape metrics	1930	1975	2000	2020
<b>1</b>	<b>Patch density and size</b>				
a	Nump --No of patches	201	22,602	26,727	28,559
b	MPS -- Mean Patch size (km <sup>2</sup> )	121	0.9	0.8	0.7
<b>2</b>	<b>Edge metrics</b>				
d	ED- Edge density (m/ km <sup>2</sup> )	548	2849	3263	3630
e	MPE-Mean patch edge	66,271.3	2,691.4	2,451.4	2,426.6
<b>3</b>	<b>Shape Index</b>				
f	MSI-Mean shape index	1.8	1.4	1.4	1.4
g	MPAR-Mean perimeter area ratio	187.4	1,274.4	1,245.5	1,210.8
h	MPFD-Mean patch fractal dimension	1.3	1.4	1.4	1.4

Between 1930 and 2020, 21.58% of the forest area was converted primarily into agriculture and settlements. The fragmentation analysis showed that the core forest (Core 3) size decreased by 43.08%, whereas, core 2 and core 1 size increased by 320.86% and 1107.33%. The patch area increased from 0.16 km<sup>2</sup> to 210.70 km<sup>2</sup> between 1930 to 2020. The edge area increased from 1,086.54 km<sup>2</sup> to 3269.72 km<sup>2</sup>, and the entire large core forests area (Core3) reduced significantly by 9,968.68 km<sup>2</sup> in 2020 (Table 2.5).

The Eastern region lost 22.99% of forest between 1930 and 2020. The core 3 decreased by 57.34%, whereas core 1 and core 2 increased simultaneously by 1019.26% and 409.08%. Similarly, the edge area increased by 219.91%. The central region lost 22.06% of the forest between 1930 and 2020; core 3 decreased by 46.36%, whereas core 1 and core 2 increased by 4254% and 648% respectively. The western region lost 13.03% of the forest, and core 3 forests were reduced by 30.88%, whereas core 1 and core 2 increased by 488% and 162% respectively. Finally, the far western region lost 5.51% of the forest, and the core 3 forest was reduced by 37.11%, whereas core 1 and core 2 increased by 663% and 145% respectively. The overall forest fragmentation result suggests that the highest fragmentation occurred in the eastern

region (in core 3), followed by the central, far western, and western region, where the core forest (core 3) was reduced by 57.34%, 46.36%, 37.11%, and 30.88% simultaneously (Table 2.5 and Table 2.6), (Figure 2.4; Supplementary figure S5).



Elephant Habitat in Bardiya National Park

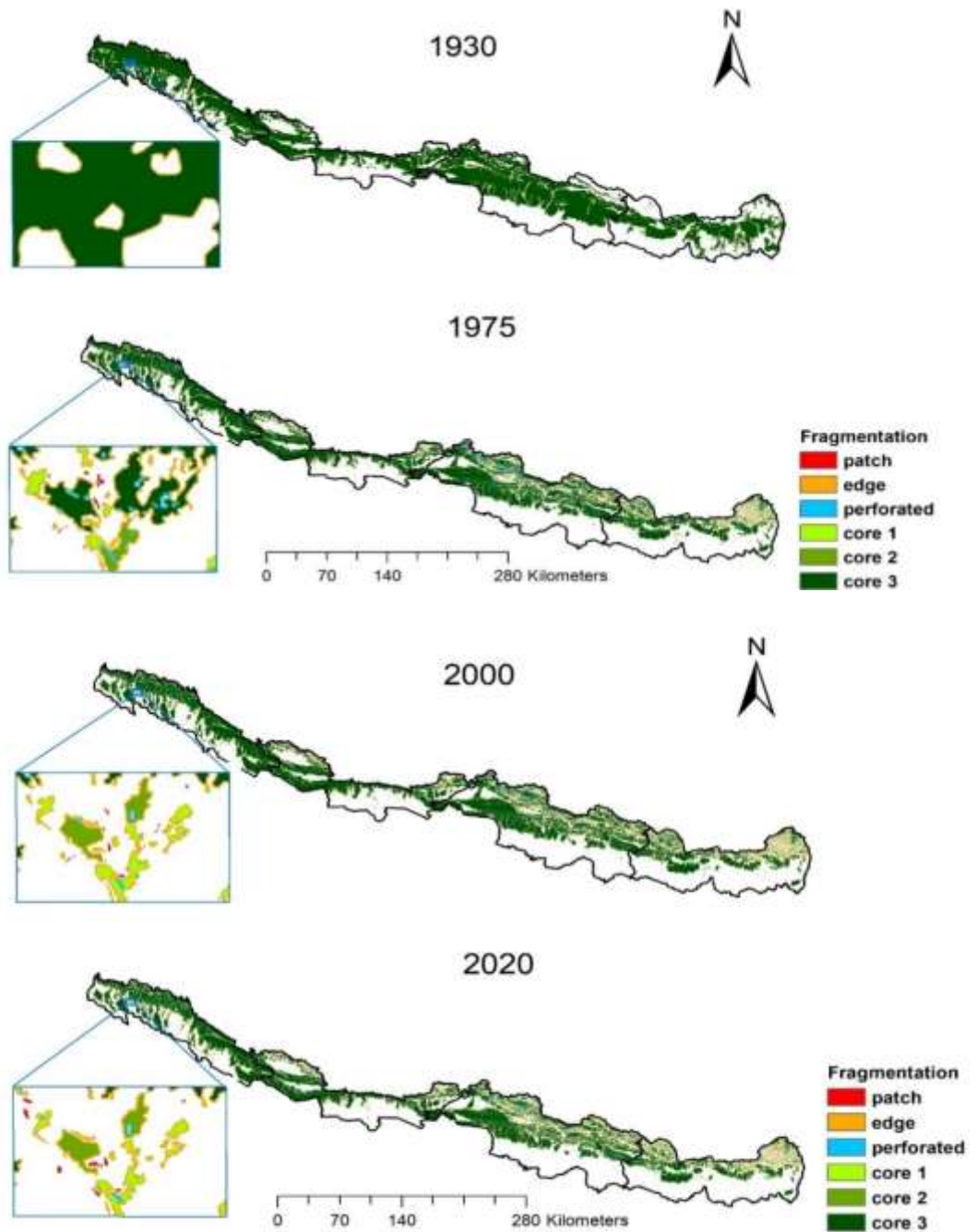


Figure 2.4: Habitat (forest) fragmentation of Asian elephants in the Chure Terai Madhesh Landscape, Nepal. Inset shows an enlarged view of habitat fragmentation in four different periods (1930, 1975, 2000 and 2020) at that particular location.

Table 2.5. Temporal Forest fragmentation (area in km<sup>2</sup>).

Fragmentation class	1930	1975	2000	2020	Change 1930-1975	% Change (1930-1975)	Change 1975-2000	% Change (1975-2000)	Change 2000-2020	% Change (2000-2020)	Change 1930-2020	% Change (1930-2020)	% Change (1975-2020)
Patch	0.16	157.11	165.69	210.85	156.95	*	8.58	5.46	45.16	27.26	210.7	*	34.21%
Edge	1086.55	2825.61	2910.84	3279.62	1739.06	160.05	85.23	3.02	368.78	12.67	2193.07	201.84	16.07%
Perforated	0.67	1876.53	1430.23	1693.21	1875.86	*	-446.3	-23.78	262.97	18.39	1692.54	*	-9.77%
Core1	42.18	422.32	474.32	509.25	380.14	901.23	52	12.31	34.93	7.36	467.07	1107.33	20.58%
Core2	49.34	157.51	182.84	207.65	108.17	219.23	25.34	16.08	24.81	13.57	158.31	320.86	31.83%
Core3	23136.67	15881.84	14889.4	13168.56	-7254.83	-31.36	-992.44	-6.25	-1720.84	-11.56	-9968.11	-43.08	-17.08%
Total	24315.56	21320.92	20053.32	19069.14	-2994.64	-12.32	-1267.6	-5.95	-984.19	-4.91	-5246.42	-21.58	-10.56%

\* The estimate is not reliable as forest cover within these categories were very small in 1930.

Table 2.6. Region-wise Forest fragmentation in Nepal.

Fragmentation class (Area in km <sup>2</sup> )	Eastern					Central					Western					Far western				
	1930	1975	2000	2020	1930-2020 %change	1930	1975	2000	2020	1930-2020 %change	1930	1975	2000	2020	1930-2020 % change	1930	1975	2000	2020	1930-2020 %change
Patch	0.01	69.68	333.42	93.36	-933500.00	0.14	49.51	224.21	75.1	-53542.86	0.000	22.21	192.38	23.4	*	0	15.71	215.33	18.99	*
Edge	297.17	863.34	1820.37	950.68	-219.91	322.23	1011.77	2802.83	1252.36	-288.65	219.920	463.55	1367.61	544.19	-147.45	247.23	486.95	1726.4	532.38	-115.34
Perforated	0.11	457.76	1360.58	423.75	-385127.27	0.11	826.08	3304.97	706.05	641763.64	0.240	268.44	1649.26	271.11	112862.50	0.21	324.25	2088.15	292.29	139085.71
Core1	15.89	162.51	8.48	177.85	-1019.26	4.28	133.75	22.79	186.38	-4254.67	13.200	59.21	14.89	77.71	-488.71	8.82	66.85	21.6	67.31	-663.15
Core2	15.2	65.74	6.7	77.38	-409.08	8.83	40.92	18.22	66.08	-648.36	9.990	22.44	18	26.24	-162.66	15.31	28.42	22.24	37.96	-147.94
Core3	4279.55	2465.92	252.14	1825.46	57.34	8331.55	5420.95	794.33	4468.89	46.36	4093.490	3326.18	675.62	2829.29	30.88	6432.07	4668.8	1112.8	4044.91	37.11
Total	4607.92	4084.94	3781.68	3548.48	22.99	8667.14	7482.98	7167.34	6754.86	22.06	4336.840	4162.02	3917.77	3771.95	13.03	6703.66	5590.97	5186.52	4993.85	25.51

## **2.4. Discussion**

### **2.4.1. Patterns of forest cover change and fragmentation**

Our study provides comprehensive information on forest cover change and fragmentation within the primary elephant habitat in Nepal between 1930 and 2020. We documented the loss of more than one-fifth of the forest area and extensive fragmentation during this period. Our results suggest that the elephant habitat remained intact during the 1930s. However, the rate of deforestation was higher between 1930 and 1975 due to the conversion of forests into agricultural land. Forest cover loss was the highest in the western region, where the elephant population is the lowest. The regions with higher coverage of protected areas (central and far-western parts) had a comparatively lower rate of deforestation. Protected areas establishment (~6,000 km<sup>2</sup>) and restoration through community-based conservation programs (~300 km<sup>2</sup>) may have contributed to reducing deforestation rates after 1975 in CTML (DFRS, 2015).

A previous study from entire south Asia documented a 29.62% forest cover loss between 1930 and 2014 with a 0.68% annual rate of deforestation (C. S. Reddy et al., 2018). The forest loss and rate of deforestation in CTML are lower than the average for South Asia (C. S. Reddy et al., 2018; Singh et al., 2017). (S. C. Reddy et al., 2018) also documented the annual rate of deforestation 0.49% for Nepal, which is higher than our results. Forests occupied 42.73 % of CTML in 2020, but forest cover was not evenly distributed throughout the landscape. A large part of the remaining forest occurs in the Chure region (>70% forested), where the rate of deforestation was comparatively lower (0.18%/year between 1995 and 2010) (Aulestia, 2019; DFRS, 2015). However, most of the flat and productive

land of the CTML was converted into agricultural land with a higher rate of deforestation (i.e., 0.40%/year) between 1991 & 2010 (DFRS, 2015). Among the four regions, the western part experienced the highest loss of forest cover (25.51%). The remaining forest cover (56%) and rate of deforestation (0.33) were found higher in the western region, where almost the entire forests lie outside of the protected areas. Despite massive forest clearance in Chitwan valley (Laurie, 1978) and other areas of central CTML, the rate of forest loss was only 0.16% per year. The establishment of Chitwan and Parsa National Parks and the intact forest remaining in the northern part of Bara and Rautahat may have contributed to lower deforestation rates in Central CTML (Rimal et al., 2018). The results indicate that Government should prioritize conservation efforts to restore elephants' movement through corridor restorations within the human-dominated landscapes outside protected areas.

Elephant habitat is more fragmented outside protected areas due to the high pressure of encroachment and developmental activities (Peh, 2010). These forests are also used more frequently by the local communities to meet their subsistence needs of livestock grazing and dependence on forest products (Acharya et al., 2016; Lamichhane et al., 2018). With increasing forest fragmentation, the elephants and other wildlife are also forced to live in smaller forest patches with spatial overlap with human activities (Carter et al., 2012). This situation increases the chances of confrontation between humans and elephants, often leading to fatal attacks (Choudhury, 2004; Ram et al., 2021). The eastern region had the highest forest fragmentation (57.3% of large core forest lost) within our study, where HEC incidents were also the highest (DNPWC 2020). The eastern region also bears a long

migratory route of a large herd of elephants (>100) and provides habitat for some residential elephants. Although the forest cover is not significant within Koshitappu Wildlife Reserve (KTWR), it still provides refugia and a corridor for elephants in the eastern region. While navigating through the highly fragmented forests, there is always a threat of elephants getting deflected due to haphazard drives and another form of human resistance resulting in elephants ending up in human-use areas off the forests, as corroborated by telemetry studies on elephants in the landscape.

Forest fragmentation results suggested that large forest patches have decreased rapidly, whereas forests in the medium and small core have increased massively. Similarly, the area of forests in the patch, perforated, and edge category has also increased during the last nine decades (1930-2020), which indicated the high rate of forest fragmentation in the CTML. Landscape metrics analysis also reveals the massive fragmentation of forests between 1930 and 2020, increasing the patch number and decreasing patch size (Table 2.5, 2.6 and Figure 2.4) (S. C. Reddy et al., 2018). Similar to Nepal, a massive decline in extensive core forests and an increase in fragmented patches has been documented in other elephant range countries India, Myanmar, Bangladesh, and Sri Lanka (Puyravaud, 2003; Puyravaud et al., 2019, 2010; Reddy et al., 2013). Fragmented forest patches should be connected through a combination of the weak and high-quality habitat to enable elephant connectivity throughout the landscape. The human pressure (illegal cattle grazing, resources extraction) and risks of invasive species (*Lantana camera*, *Chromolaena odorata*, *Parthenium hysterophorus*, *Mikania micrantha*, etc.) spread are high in smaller and perforated forest patches as well as forest edges (Sampson et al., 2018).

Our study focused on forest cover change within elephant range. Elephants are habitat generalists and roam across large areas which comprises of a matrix of forests, grasslands, wetlands and agriculture areas (Roever et al., 2012). Size of protected areas in Nepal are not large enough to sustain elephants throughout the year. The fragmented forest patches serve as refuge whereas crop fields around human settlements and periphery of protected areas act as attractants for elephants. Human-elephant conflict (HEC) intensifies along the periphery of these protected areas, forest patches. The ecotone habitats along the forest-agriculture matrix have high activity of humans leading to increased probability of human-elephant conflict (Ram et al., 2021). Out of 412 cases of elephant attacks on humans (HEC), 60% occurred at forest cover loss areas during 2000–2020 in Nepal (Ram et al., 2021) (Figure 3d). Human activity around riverine patches, water bodies also reduce access to such important resources for elephants. Apart from strengthening forest patches, wildlife corridors it is also important to grow unpalatable crops within ecotone habitats to reduce visitation by elephants. These changes in land use patterns have to be integrated with necessary management interventions to reduce human-elephant conflicts (Fahrig et al., 2019)(Liu et al., 2016). Large herbivores exhibit different strategies of habitat use with seasonal variation and spatial distribution of resources (Ripple et al., 2015). Studies on on habitat utilization pattern by elephants (Desai and Baskaran, 1996; Sukumar, 1989)shows the distribution of water resources (Smit et al., 2007a, 2007b), precipitation patterns (Birkett et al., 2012) and social factors (Wittemyer et al., 2008) influence their movement and spatial distribution. The intensity of conflict varies with distribution of resources, agricultural practices, human population, climatic conditions and connectively between habitats (Goswami et al., 2015; Neupane et al., 2019, 2017b; Wilson et al., 2015).

#### **2.4.2. Drivers of deforestation and fragmentation**

Several studies indicate loss of elephant habitats and fragmentation due to a combination of multiple factors such as agriculture and settlement expansion, encroachments, irrigation, infrastructure development hydropower projects, illegal logging, mining, commercial plantations (Nandy et al., 2011; Reddy et al., 2016, 2013; Sukumar, 1989). Additionally, expansion of oil palm plantation in Indonesia (Suba et al., 2017) and tea, paddy cultivation in north-east India has also contributed to habitat loss (Naha et al., 2019). However, in Nepal, forest conversion into farmlands through government policy was responsible for forest loss and fragmentation in the initial years (1930 – 1975), whereas encroachment and infrastructure development activities have continued the fragmentation at present and recent past and expansion of agriculture is a significant factor for conversion of elephant habitat in Nepal.

A large part of the forest was lost in CTML during the first 45 years (1930-1975) due to various socio-political changes and national policy of promoting forest conversion into agricultural land in Terai (Gee, 1959). Three significant changes were a) fall of Rana regime and political instability, b) Private forests nationalization act 1957 and its impacts c) Land resettlement policy. Rana rulers used to grant forest and other lands as 'Birta' (grant their families and close relatives as private property) and provide to government employees and other servicemen to use a share of a product as a 'Jagir.' As a result, the tiny forest remained under government control (Laudari et al., 2020). After the fall of the Rana Regime in 1951, state of political instability in the country caused massive deforestation and wildlife hunting (Gee, 1963). In the meantime, the government of Nepal nationalized

all the private forests by promulgating the "Private Forest nationalization Act, 1957" (Kanel and Acharya, 2008). As a result, owners of the private forests converted their forested land into farmlands to secure their land tenure (Dahal et al., 2017; Ranjit, 2019). Similarly, eradicating malaria in CTML during the 1950s and introducing a new settlement policy by the government promoted thousands of hill migrants to convert Terai forests into farmlands (Laurie, 1978). The human population in the CTML also increased many folds during this period, accelerating deforestation and forest degradation (Adhikari and Dhungana, 2010).

The deforestation rate was lower between 1975 and 2020. The primary reasons were a) establishment of protected area network, b) initiation of community participation in forest management c) well-established institutional setup for forest protection and management (Laudari et al., 2020). With decreasing deforestation and increasing forests and wildlife conservation efforts, wildlife populations, including the elephants, have also increased (~50 individuals in the 1970s to >200 in 2020; Shrestha et al. 1985; Ram & Acharya, 2020). However, the forest fragmentation continues in large parts of the forests outside of the protected areas. Large-ranging species like elephants are affected by this as they come into frequent clashes with humans while navigating seasonally through these highly fragmented forests in CTML.

This study indicates that the conservation of large-ranging species like elephants and tigers in CTML has been challenging as most of the remaining forests are highly fragmented, especially outside the protected areas. With planned and ongoing infrastructure development activities in CTML, forest fragmentation continues to increase. It shows the

importance of the landscape-level conservation approach and helps policymakers, protected area managers to restore corridor and connectivity by implementing metapopulation management of large mammals in Nepal and around the globe.

## **2.5. Conclusion**

Forest loss and fragmentation induced a severe threat to elephant conservation in Nepal. Such fragmentation brought both the elephants and humans along the forest's edge, where they interact with each other, often resulting in severe human-elephant conflict (HEC). Increasing the number of forest patches also increases the visibility of elephants in the migratory routes, increasing the poaching threats. Our research findings have implications for devising appropriate policies for conserving large mammals and their habitats in human-dominated landscapes in Nepal and beyond. Further understanding of the relationship between forest loss/fragmentation and human-elephant conflict is necessary. The particular focus of elephant conservation is necessary outside the protected areas and migration corridors where habitat is highly fragmented.

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(Photo credit: Buddi Binod Acharya)

### **Chapter 3:**

## **Status, Distribution and Habitat use by Asian elephants in Nepal**

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## **Status, Distribution and Habitat use by Asian elephants in Nepal**

### **3.1. Introduction:**

The Asian elephant evokes high cultural importance in subcontinent (Maria, 2014). Yet, habitat loss, fragmentation, poaching, and human–elephant conflict threaten Asian elephant conservation across the Globe (Jathanna et al., 2015). Asian elephants require a large area to fulfill their life-history requirements, often leading to conflicts with humans due to common resource demands (Hoare, 1999; Sukumar, 1991). Elephants are ecologically significant and protected by being listed as endangered (Williams et al., 2020) and a CITES appendix I species. The seasonal variability of resources availability could potentially influence the spatial distribution patterns of elephants, which exhibit different habitat selection strategies (Pradhan et al., 2008). Karanth et al., (2010) study showed that elephants face a high probability of local extinction and are distributed in fragmented populations, confined mainly to wildlife reserves (DeFries et al., 2010; Karanth et al., 2010).

Being an important and sensitive basic population parameter, numerous studies have examined elephant distribution and their habitat use patterns (Chamaillé-Jammes et al., 2007; Loarie et al., 2009) in both Asia and Africa. However, considering the recently observed phenomenon of high-level of flux in the distribution of elephants in certain parts of their range within Asia, repeated and periodic assessments of elephant distribution assumes greater importance. In particular, there is paucity of information on elephant occurrence and dynamics in Nepal (Lamichhane et al., 2017). Although, there are around 200 wild and 250 captive elephants (Ram and Acharya, 2020) estimated across the fragmented landscape of Chure Terai Madhesh

Landscape (CTML) (Narendra M B Pradhan et al., 2011), their current extent of distribution is important to assess. The existing literature from Asia on elephant habitat relationships suggests that elephants respond to both the temporal and spatial availability of resources *viz.* forage and water (Sukumar, 1989) and also profoundly respond to human disturbances (Desai and Baskaran, 1996). In Nepal, the elephants reportedly occur in Chure and Terai Madhesh Landscape (CTML) (Ram et al., 2021). The CTML landscape experiences high variations in water and forage distribution resulting in possible non-random elephant distribution. In general, the research efforts on elephant ecological aspects continue to be minimal across Nepal. For example, even the population assessment is restricted to small pockets of the Terai Arc Landscape, with focus on Protected Areas. Similarly, studies focusing on elephant distribution, habitat use, population size, density, and ecology (Flagstad et al., 2012; Narendra M B Pradhan et al., 2011; Pradhan and Wegge, 2007), were carried out often in small-scale and detailed information is lacking at the landscape-scale. This results in disjunct information and hinders framing landscape-level policies appropriate for elephant conservation. From elephant conservation perspective, forest loss, fragmentation, and human–elephant conflicts (crop raiding, property damage, human killings, and retaliatory killing of elephants) are major species management concerns in Nepal (Choudhury, 2004; Pradhan et al., 2011) that needs to be addressed and the scale of investigation of these aspects needs to be hierarchical and should ideally start with gaining a robust understanding on elephant spatial occurrence in the larger CTML complex.

Occupancy modeling estimates proportion of area occupied by a species at large spatial scales, which accounting for imperfect detection, which is considered fundamental in ecological studies (Mackenzie et al., 2006; Jathanna et al., 2015). In occupancy approach, participatory research surveys can also be incorporated and imperfect reporting can be modelled. Many studies have effectively used occupancy-based elephant distribution modeling with estimates that are

robust and thus, useful for the management (Buij et al, 2007; Jathanna et al, 2015). Considering the practical utility of occupancy-based approaches in assessing spatial distribution of elephants, especially in large landscapes that support relatively low number of elephants, we used single season occupancy modeling a.) to estimate proportion of area occupied by elephants, including seasonal use of agricultural land, and b) direct count method to estimate the elephant population. We hypothesized that detection probability is higher closer to settlement and detection would be positively related to the availability of water, terrain types and negatively associated with human population density.

## **3.2. Methods and materials.**

### **3.2.1. Study area**

Our study area Chure Terai Madhesh Landscape (CTML) encompasses the four elephant regions of (Eastern, Central, Western, and Far Western) Nepal (DFRS, 2015; Ram et al., 2021) and comprises of six National Parks (NP), one Wildlife Reserve (WR) of Nepal (CBS, 2014; MOFE, 2014). The study area covered the whole landscape of CTML and also included the Terai Arc Landscape (TAL) along with the eastern Terai landscape (Figure 3.1) (Chaudhary and Subedi, 2019; MoFSC, 2015).

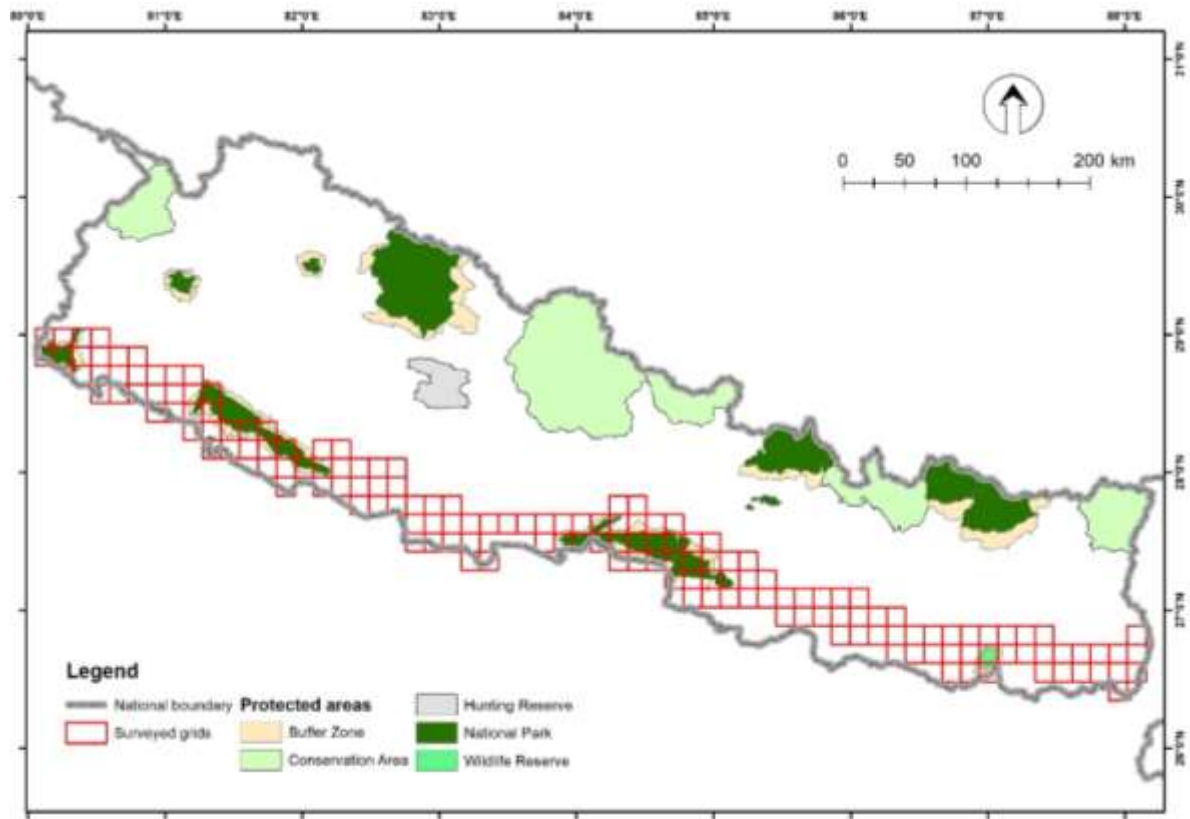


Figure 3.1: Study area (15\*15 Square km grids)

### 3.2.2. Methods used for estimating elephant distribution

#### 3.2.2.1. Survey design and sign survey:

We used a grid-based sampling approach to evaluate the effect of key factors influencing probability of occurrence of elephants in the study area (Lakshminarayanan et al., 2016b). Our parameter of interest was “true occupancy” or the “proportion of area occupied” by elephants in the CTML. Considering this, we divided our study area into  $15 \times 15$  km grids based on the average home range of an elephant herd (ca  $100 \text{ km}^2$  to  $800 \text{ km}^2$  in Sri Lanka and ca  $188 \text{ km}^2$  in Rajaji NP India) (Fernando et al., 2008; Jathanna et al., 2013; Williams et al., 2008). Further, we divided each  $15 \times 15$  km grid into four  $7.5 \times 7.5$ -km sub-grids

and conducted questionnaires surveys in sub-grids that contained a village (Figure 3.1). We surveyed the entire study area, CTML, to assess the total area occupied by elephants (Karanth et al., 2012; Lamichhane et al., 2017; Thapa et al., 2019). We used trained wildlife biologists and wildlife technicians (n = 14) with over five years of field experience in wildlife research and capable of identifying elephant sign surveys carried out the surveys. We surveyed (n=142) forested grids or adjoining grids of the forests out of (n=162). The remaining grids (n = 20), which were not surveyed due to inaccessibility or undulating steep, rugged terrain, were omitted from our study. We completed the occupancy surveys between November 2019 and March 2020, considering the seasons when variations in sign detection probabilities are not high. Since occupancy surveys use temporal or spatial replication to estimate detection probability, we used spatial replicates, and each replicate was sampled once (Kendall and White, 2009; Lakshminarayanan et al., 2016). We surveyed five transects, each having 9 km length (e.g., forest trails, forest roads, stream beds, etc.) from every grid and collected elephant presence signs (viz. dung, footprints, elephant trails, feeding signs, tree peeling, and felling signs along with the body rubbing mark) and covered 76% of the total area. We use a simple single-season occupancy framework (MacKenzie et al., 2002), treated each 1-km linear trails as replicates in the correlated detection framework (Hines et al., 2010) and collected elephant presence signs from each kilometer of walking distance in transects and recorded them along with the respective covariates, identified a priori. Before starting the field survey, we prepared a land-use map, identified the rivers and forest roads, other feeder roads, and forest trails in the map, and trained our technicians to collect the data. We have continuously monitored

the field surveys and checked the data quality (Lamichhane et al., 2017). We carried out sign surveys in the winter season (from November to February) when elephant signs are likely to persist for many days.

#### 3.2.2.2. ***Covariate's selection:***

The covariates were identified *a priori* based on elephant ecology and our general understanding of elephant behavior and conservation aspects. We used two types of covariates: a) sampling covariates of forest cover and terrain types of the sample site, (b) site covariates of extent of permanent water, extent of seasonal water, terrain, ruggedness index (TRI), Leaf Area Index, human population density, road length inside the grid, proximity to settlements, fragmentation (mean Perimeter area ratio), length of the roads and length of the stream. We derived the sample covariates from field data, and site covariates from the ArcGIS10.6 domain (Table 3.1). We tested for potential auto-correlations between these potential predictors and excluded correlated variables ( $r = >\pm 0.70$ ).

Table 3.1: Landscape predictors extracted from the ArcGIS domain using multiple sources.

Types of variables	Predictor variables	Codes	Units	Source /description of data (ArcGIS 10.6)
<b>Habitat (Fragmentation metrics)</b>	Mean Perimeter Area Ratio	MPAR	Meter/hectare	Classified satellite images of 2020 (Landsat 8, 30 m resolution)
<b>Habitat (Landscape variables)</b>	Extent of Forest cover	Forest	m <sup>2</sup>	„
	Proximity to settlement	ProxSet	m	„
	Leaf Area Index	LAI	m <sup>2</sup> /hac	
<b>Water</b>	Extent to seasonal water	SeaWat	m <sup>2</sup>	EC JRC/ Google Earth Engine
	Extent to permanent water	ParWat	m <sup>2</sup>	
	Length of the Stream	LS	m	Department of Survey, Nepal, digital topographic map
	Length of the road	LR	Km	Open street map
	Population density	PD	persons per km <sup>2</sup> .	GPWv411: Population Density (resolution - 1 km <sup>2</sup> )
<b>Elevation</b>	Digital Elevation Model	ELEV	m	SRTM Digital Elevation Data Version 4

### 3.2.2.3. Assessing elephant distribution using single season occupancy modeling:

We considered a 1-km search trail as spatial replicate and collected “detection-non-detection” data by covering around 45-km of walk effort in the transect. As far as possible, we invested an equal search effort of 45-km in each grid, thus maintaining spatial replicates. We constructed detection histories for each grid, where ‘1’ indicates species detection and ‘0’ indicates non-detection, and ‘-’ indicates a missing observation. We also prepared a detection history for each covariate; data recorded in each segment along the search trail were pooled to obtain a single average covariate score. We use occupancy( $\psi$ ) = sample unit occupied by the elephants,  $\theta^0$  = probability of elephant presence in the replicate given their absence in the previous segment,  $\theta^1$  = probability of elephant presence in the replicate given their presence in the previous segment and  $P_t$  = detection

probability of a sign conditional on elephant presence in the replicate (Lakshminarayanan et al., 2016a).

We calculated the naïve occupancy by dividing the number of grids with species present/total number of grids surveyed in program PRESENCE (2.13.17) (MacKenzie et al., 2002). A two-step process was followed to estimate the probability of detection and elephant occurrence (MacKenzie et al., 2002; Tyre et al., 2001). In the first step, we modeled detection probability ( $p$ ) keeping a constant covariate structure for occupancy model as  $\psi(\cdot)$ . We hypothesized that ground-based sample covariates, terrain types, and availability of forests influenced elephant detection in the study area. Further, we hypothesized that elephant signs detection would be affected by permanent and seasonal water availability, proximity to forest, and human footprints. In the second step, we modeled the occupancy probability ( $\psi$ ) or ( $\psi$ ), keeping the top detection model from step one as a stable structure for the detection model (Panthi et al., 2017; Singh et al., 2020). We constructed a set of 26 priori candidate models, each representing a different ecological hypothesis. These models included either single or additive effects of two or more covariates to investigate the influence of covariates on occurrence (Mackenzie and Bailey, 2004). Finally, we considered all possible combinations of occupancy and detection covariates but only reported models within 10 AIC of the top model that does not include uninformative parameters (Lamichhane et al., 2021).

The covariate models were compared and ranked using an information-theoretic approach, relying on Akaike Information Criterion (AIC) for testing relative model fits. Models with  $\Delta AIC < 2$  were taken as the best models (Burnham and Anderson, 2001). Due to the inherent advantage of model averaging (Burnham and Anderson, 2001), the final occupancy estimates and associated standard error were averaged across the model set. To infer the relative influence of covariates on occurrence, we summed the computed model weights of all the models containing the particular

covariate. Additionally, we used the estimated b-coefficients to assess the strength of association of each covariate with occupancy probability (Lamichhane et al., 2021; Paudel et al., 2021).

### **3.2.3. Elephant status assessment:**

Our objective of the population assessment was to get a ball-park estimate of population size. Given the large spatial scale of our study that covers the entire CTML, we reckoned that statistically robust and reliable elephant population estimation approaches (Jathanna et al, 2015) such as distance sampling, capture-recapture sampling and others based on statistical theory were not attempted and was clearly beyond the scope of this study. Elephant range countries in Asia use many conventional methods to estimate elephant population size, which includes the direct count (block count or total headcount without accounting for variable detectability and spatial variation in sampling), and sign-based dung density methods (which is statistically robust but for unresolved potential variations of dung decay and dung defecation rates) (Fernando et al., 2019; Karmacharya et al., 2011; Smith and Mishra, 1992; Sukumar, 1989; Varma et al., 2012; Vidya et al., 2005). In this study, due to the resource and time constraints and the overall scope of the work, we have used the conventional direct count (headcount) method duly acknowledging its limitations (Ram and Acharya, 2020; Smith and Mishra, 1992; Sukumar, 1989; Varma et al., 2012).

#### ***3.2.3.1. Field methods:***

We conducted stakeholder consultation, and critical informant survey to identify the elephant presence blocks and also organized 30 key informants' interviews to understand elephant distribution patterns throughout the study area and divided the study area in to five different blocks as per the presence mentioned in the stakeholder consultation and key informants survey. We carried out population count surveys for three different years that

include 2017, 2018, and 2019. We attempted to count all the individual elephant and herds inside the identified blocks and also counted elephants during the transect surveys carried out for assessing elephant occupancy. We followed elephant herds and tried counting them individually, and took photographs and videos of each and all individuals and herds. We covered at least 60% of the forest area during the transect survey and counted all the elephants detected. We had counted all the elephants, and age classified them following Varma et al (2012). Age-class definitions used were as follows: calf (0-1 year), juvenile (1-5 years), sub-adult (5-15 years), and adult (15+ years) (Sukumar, 1989; Varma et al., 2012) (figure 3.2 a, b).

#### **3.2.4. Data Analysis**

We entered the count data into the MS Excel spreadsheets. We counted elephants of 952 from all three years, and all the individuals and herds were photographed and visualized. We individually identified these photographs by using their phenotypic characters viz. types of the tusk (with tusks or without tusks, bent tusk, breached or sharp tusk, straight, convex or concave type tusk, sharp then tusk), notches and holes in the year, tail type (with tail or without tails), body size, etc. and their age groups were estimated as per the field keys.

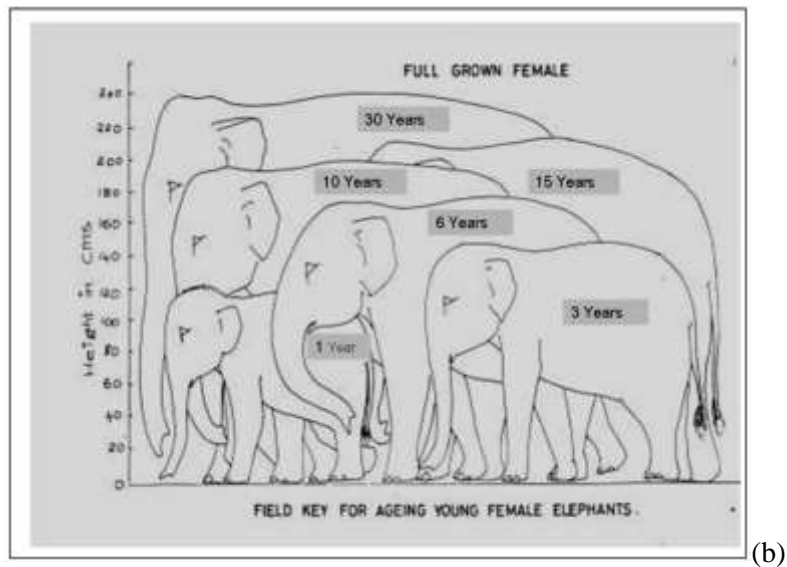
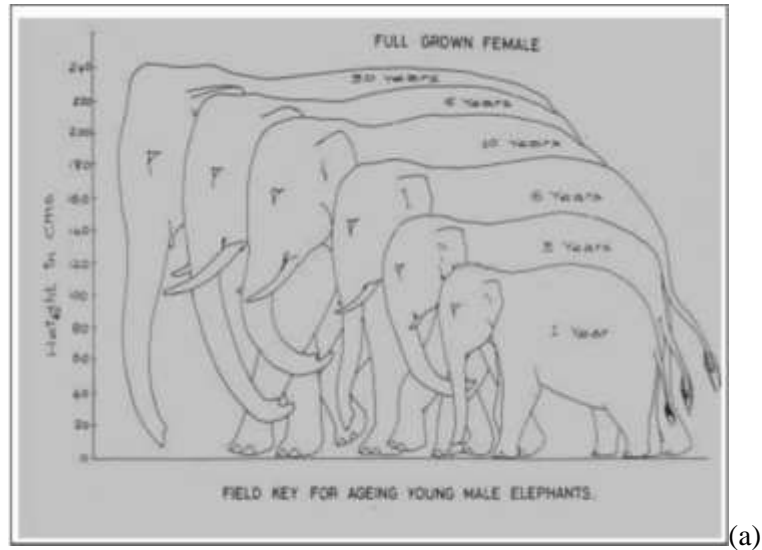


Figure 3.2 (a, b): Field keys used for age determinations (Varma et al., 2012)(Varma et al., 2012). We analyzed all the photographs and video clips to identify individual elephants to count, and the respective elephant's sex was identified. We matched all these data with the individual elephant count data during the transect survey, finalized the count results along with the respective age group and their sexes, and came up with a unique number of elephants.

### 3.3. Results

#### 3.3.1. Detection probability and estimated occupancy.

We surveyed a total of 6435-kilometers of potential elephant habitat aimed at detecting elephant signs from across 143 survey grids. During the surveys, we had detected elephant signs from 72 grids (with naïve occupancy 0.50). A model with constant occupancy estimated at naïve occupancy at 0.43 (SE = 0.06) across surveyed grid cells. Analysis of the elephant track surveys provided strong support for the hypothesis that detection probability is higher closer to settlement and with the area having higher forest fragmentation having higher value of mean perimeter area ratio (MPAR) (Table 3.2. and 3.3)

Table 3.2: Role of covariates in determining detection probability of elephant sign ( $P_t$ ) on 1 km long replicates, based on covariates for probability of occurrence of elephants from the global model.

Model	AIC	$\Delta$ AIC	AIC Wt (w)	Like lihood	k	-2*Log Likelihood
psi,th0(),th1(),p(Forest+ProxSetl+TRI+LAI+RoaddLn),th0pi()	2146.54	0	0.4248	1	10	2126.54
psi,th0(),th1(),p(Forest+ProxSetl+TRI+LAI),th0pi()	2146.6	0.06	0.4122	0.9704	9	2128.6
psi,th0(),th1(),p(Forest+ProxSetl+TRI),th0pi()	2149.23	2.69	0.1107	0.2605	8	2133.23
psi,th0(),th1(),p(Forest+ProxSetl+TRI+PopDen),th0pi()	2150.75	4.21	0.0518	0.1218	9	2132.75
psi,th0(),th1(),p(Forest+ProxSetl),th0pi()	2159.86	13.32	0.0005	0.0013	7	2145.86
psi,th0(),th1(),p(Forest),th0pi()	2169.03	22.49	0	0	6	2157.03
psi,th0(),th1(),p(Forest+MPAR),th0pi()	2170.66	24.12	0	0	7	2156.66
psi,th0(),th1(),p(.),th0pi()	2175.86	29.32	0	0	5	2165.86
psi,th0(),th1(),p(Terrain),th0pi()	2177.71	31.17	0	0	6	2165.71

Note: psi ( $\Psi$ ): model-averaged elephant occupancy;  $p$  = replicate-level detectability; AIC = Akaike's information criterion,  $\Delta$ AIC = difference in AIC value between the top model and the focal model; th0 ( $\theta^0$ ) = Pr (elephant presence in a replicate/grid occupied and which was absent in the previous replicate) and th1( $\theta^1$ ) = Pr (elephant presence in a replicate/ grid occupied and was present in the previous replicate);  $k$  = number of model parameters; Covariates: Forest: forest cover inside grids; ProxSetl = proximity to settlement across each grid; TRI = Mean Terrain ruggedness index averaged across each grid; LAI = mean leaf area index inside the grids, PopDen= averaged human population density in each grid; MPAR = Mean perimeter area ration (a measure of forest fragmentation in each grid), Terrain= Types of terrain (either undulating or flat) in the respective replicate; + = covariates modeled additively; (·) = parameters are held constant.

We fitted 26 ecological models (9 for detection and 17 for occupancy) based on occupancy-modelling framework using *a priori* covariates the potentially influenced elephant occupancy and detection probability. Results suggest that elephant detection was determined by presence of forests in the proximity to settlement, types of terrain, greenness of the vegetation, length of the road and availability of water with AIC weight ( $w = 0.42$ ; Table 3.2). Elephant occupancy was determined by the types of terrains in the respective habitat, availability of permanent water and human disturbances (based on population density) (Table 3.3).

Table 3.3: Role of covariates in determining probability of elephant occupancy.

Model	AIC	$\Delta$ AIC	AIC Wgt Model	Likelihood	No. of Parameters	-2 *Log Likelihood
psi,th0(Terrain+PopDen+PerWat),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2126.14	0	0.2156	1	16	2094.14
psi,th0(Terrain+PopDen+SeaWat),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2126.45	0.31	0.1847	0.8564	16	2094.45
psi,th0(Terrain+SeaWat+PerWat),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2127.08	0.94	0.1348	0.625	16	2095.08
psi,th0(Terrain+PopDen+PerWat),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat),th0pi()	2127.74	1.6	0.0969	0.4493	15	2097.74
psi,th0(Terrain+PopDen),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2128.57	2.43	0.064	0.2967	15	2098.57
psi,th0(Terrain+PopDen+RoadLn),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2128.92	2.78	0.0537	0.2491	16	2096.92
psi,th0(Terrain),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2129.27	3.13	0.0451	0.2091	14	2101.27
psi,th0(Terrain+TRI),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2129.28	3.14	0.0449	0.208	15	2099.28
psi,th0(Terrain+MPAR),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2130.38	4.24	0.0259	0.12	15	2100.38
psi,th0(Terrain+PopDen+StrmLn),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2130.38	4.24	0.0259	0.12	16	2098.38
psi,th0(Terrain+ProxSetl),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2130.4	4.26	0.0256	0.1188	15	2100.4
psi,th0(Terrain+PopDen+LAD),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2130.44	4.3	0.0251	0.1165	16	2098.44

psi,th0(PerWat),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2130.9	4.76	0.02	0.0926	14	2102.9
psi,th0(Terrain+Forest),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2131.26	5.12	0.0167	0.0773	15	2101.26
psi,th0(SeaWat),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2131.34	5.2	0.016	0.0743	14	2103.34
psi,th0(PopDen),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2134.91	8.77	0.0027	0.0125	14	2106.91
psi,th0(.),th1(),p(Forest+ProxSetl+TRI+LAI+RoadLn+StrmLn+PerWat+SeaWat),th0pi()	2135.03	8.89	0.0025	0.0117	13	2109.03

Note: psi ( $\Psi$ ): model-averaged elephant occupancy;  $p$  = replicate-level detectability; AIC = Akaike's information criterion,  $\Delta$ AIC = difference in AIC value between the top model and the focal model; th0 ( $\theta^0$ ) = Pr (elephant presence in a replicate/grid occupied and which was absent in the previous replicate) and th1 ( $\theta^1$ ) = Pr (elephant presence in a replicate/grid occupied and was present in the previous replicate);  $k$  = number of model parameters; Covariates: Forest: forest cover inside grids; PerWat = permanent water; SeaWat = Seasonal water, RoadLn = length of the road; StrmLn = Stream length; ProxSetl = proximity to settlement across each grid; TRI = Mean Terrain ruggedness index averaged across each grid; LAI = mean leaf area index inside the grids, PopDen = averaged human population density in each grid; MPAR = Mean perimeter area ration (a measure of forest fragmentation in each grid), Terrain = Types of terrain (either undulating or flat) in the respective replicate; + = covariates modeled additively; (·) = parameters are held constant.

### 3.3.2. Beta estimates model

Table 3.5: Beta estimates elucidating the role of the covariates in explaining occupancy and detection probability.

Variabe	Estimate	SE	
psi.Terrain	-0.47063	0.178441	Occupancy
psi.PopDen	0.085901	0.066943	Occupancy
psi.PerWat	0.216201	0.10312	Occupancy
psi.SeaWat	0.229838	0.106577	Occupancy
P[1-1].ForestSamp	0.919459	0.236696	Detection
P[1-1].ProxSet	0.641081	0.166118	Detection
P[1-1].TRI	0.018883	0.262819	Detection
P[1-1].LAI	-0.66366	0.227805	Detection
P[1-1].Road	-0.17094	0.205152	Detection
P[1-1].StreamLn	-0.52497	0.148053	Detection
P[1-1].PerWat	-0.80338	0.172905	Detection
P[1-1].SeaWat	0.434682	0.22774	Detection

Our model suggested that the overall elephant distribution was determined by the terrain type, population density, availability of water and forest cover. Where terrain types were negatively

associated with the distribution of elephants and forest cover, availability of permanent water and seasonal water is positively associated with the elephant distribution in Chure Terai Madhesh Landscape (CTML).

### 3.3.3. Spatial distribution:

The overall spatial occupancy map suggests that elephants in Nepal are distributed in two populations ie. Eastern population (Jhapa district to Chitwan) and Western population (west Kapilbastu to Kanchapur district). The two population seems distinctly separated from each other but genetic connectivity is yet to be confirmed (figure 3.3)

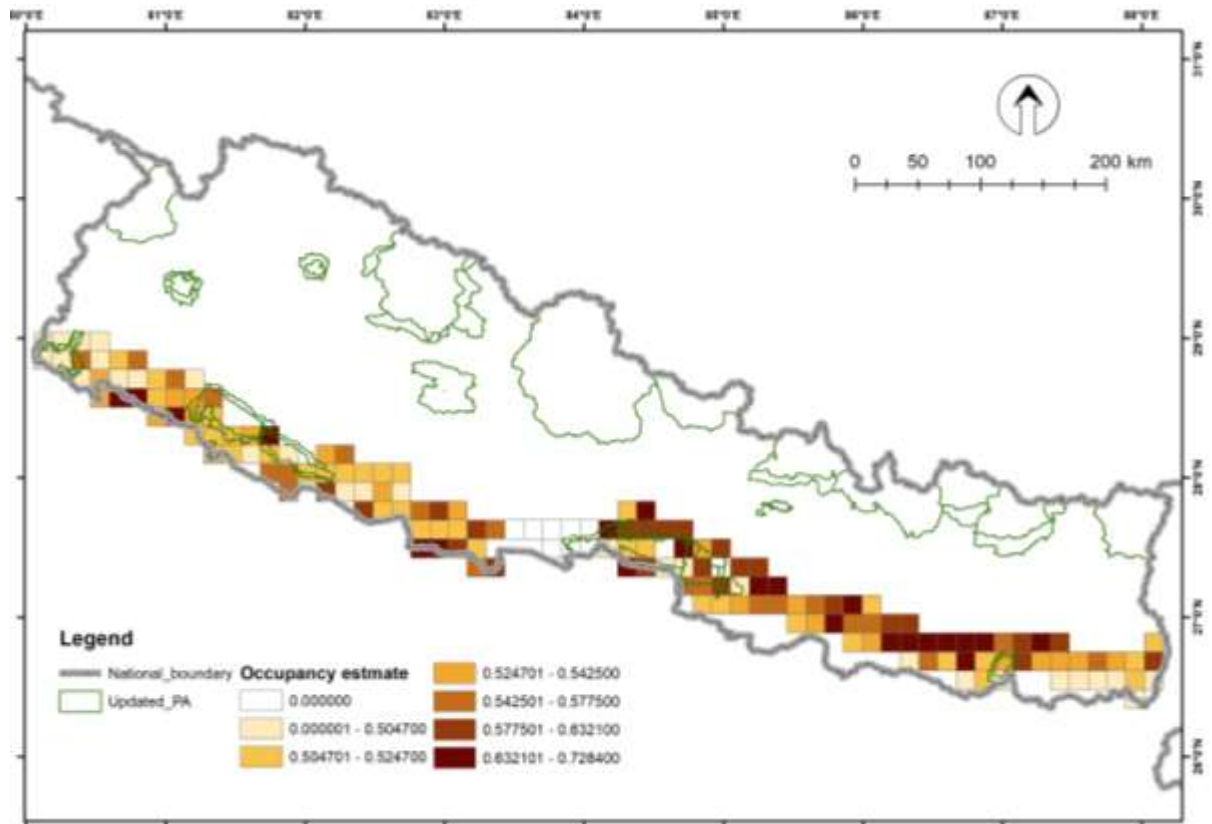


Figure 3.3: Grid wise occupancy estimates of elephants in the study area.

### 3.3.4. Elephant status in Nepal.

We counted 203-227 individual elephants (Figure 3.4) elephants in six different clusters (Table 3.4) using block count method. We counted each and every individual as per their phenotypic characteristics and identified individually with the help of photographs, video footages etc.

Table 3.4: Region-wide population status of elephants in 2020.

Locations	Adult Male	Adult Female	Sub adult Male	Sub adult female	Infants	Total
Jhapa	2	8	3	5	2	19-19
Koshi	1					16-16
Sindhuli_Sarlahi	1		7			8-8
Chitwan_Parsa Complex	7-9	14-17	4	7	8	42-45
Banke-Bardiya Complex	12-15	40-45	13	19	16-21	96-113
Shuklaphanta Complex	1	8-12	5	3	5	22-26
Total	27-32	66-78	32	34	31-36	203-227

We have also compared the recent elephant status with the previous guestimates (Smith and Mishra 1992, ten velde 1997, Kharel 2002, Pradhan 2007, DNPWC 2009 and Pradhan 2011) and found that elephant population is increasing (figure 3.4)

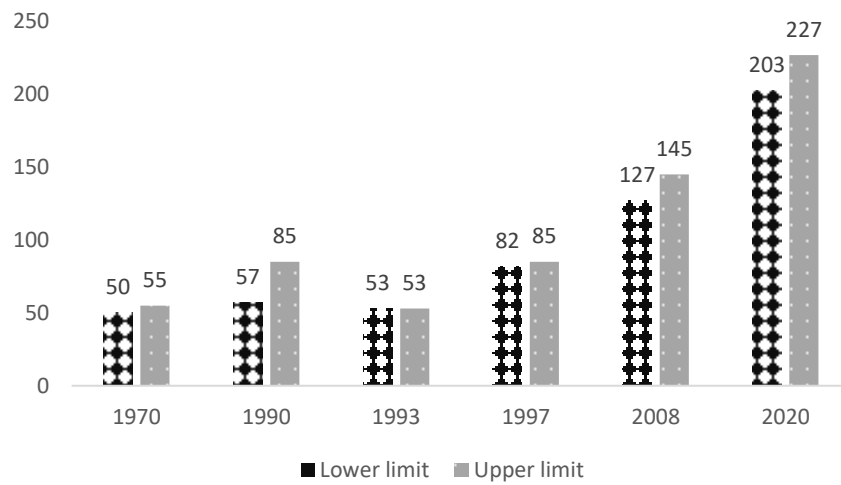


Figure 3.4: Increasing trends of Asian elephant's population in Nepal.

The age and sex structure of elephants suggested that female population is higher in comparison to male. The infants, subadults population also increasing, which is a best sign for elephant survival in Nepal (figure 3.5)

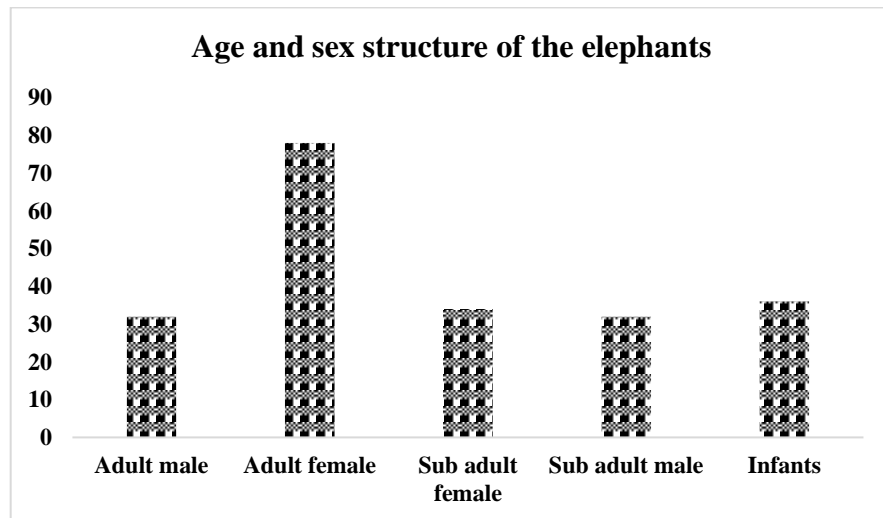


Figure 3.5: Age and sex composition of elephants in Nepal.

### **3.4 Discussion:**

#### **Role of covariates in determining elephant distribution:**

Elephant distribution and corresponding habitat use are influenced by their home range size, dispersal patterns, types of herds (either solitary, sub adult bulls' group or clans) and seasons (Krishnan et al., 2019; Sukumar, 1991). We carried out this study during the dry season when the resource availability is usually limited and water is availability is restricted to some places in the Siwalik foot hills. The CTML is the last remnant habitat available for elephants in Nepal, which too is highly fragmented (Ram et al., 2021; Reddy et al., 2018). Elephants are dispersing through the Siwalik foothills in this landscape but their habitat is connected in eastern and western part but surprisingly disconnected in the central part.

Based on our assessment, elephants occupied about 51% of the of the total CTML (21652 km<sup>2</sup>). The additive effects of the covariates, i.e., terrain types, population density, and water availability best explain the observed variations in elephant occupancy across CTML. Similarly, forest cover, proximity to forest, terrain types, the greenness of the vegetation, and road network explained variations in detection probability. Our modeling approach and the results justify the use of “correlated detection models” of occupancy for elephants (Hines et al., 2010; Lamichhane et al., 2021). The naïve occupancy was only 0.51 while the modeled occupancy was (0.43), which justifies use of occupancy modeling approach (Lamichhane et al., 2021) with a best performing spatial replicate occupancy model rather than standard occupancy model.

Overall, the study suggests that elephants were variably distributed in the landscape with significant clustering around the Protected Areas. Only few individuals and sub-adult groups were using habitat/forest outside the protected areas in the dry season. The extent of water either permanent water or seasonal water were the best predictor positively associated with the probability of occupancy, where permanent water is negatively associated with detection probability and the seasonal water is positively associated with the detection probability of elephants, because seasonal water is available in the large area (in rainy season) and elephants were fond of dispersing as per the availability of water, hence the estimated detection probability is higher(Sukumar, 1989). Similarly, forest cover is also found the best predictor of habitat use by elephants, because elephants usually use daytime for resting inside the forest and they used evening time for crop raiding, so detection probability was higher at the forest edge (Table 3.5).

### **Beta estimates model**

Beta estimates model suggested that terrain, population density, availability of permanent water and seasonal water facilitates the occupancy and detection probability and detection probability of elephants in the study area (Table 3.5).

### **3.4.3 Role of covariates in estimating detection probability of elephants**

This study provides only preliminary insights of detection probability as the data was collected for only single season. Forest cover, proximity to settlement and availability of water were the best predictors associated with the detection probability of elephants. Overall, result shows that detection probability (0.12) was very less and the estimated

occupancy was 0.43. The detection probability was less because of a) dry season (animals were restricted to the permanent water source which is only limited inside the protected areas) b) elephant population is also small (200-227) which clustered in to four different habitats and very less migration took place due to severe fragmentation and connectivity breach, though only sub adults or loner were dispersing long distances, which resulted the fewer detection of elephants in the CTML. Our study provides preliminary insights into the detection probability due to single season and required a multiple season study for detail assessment of elephants distribution (Jathanna et al., 2015; Rangarajan et al., 2010).

#### **3.4.4. Spatial occurrence of elephants in the landscape.**

The top model in the candidate set used for analyzing the spatial distribution of elephants in the landscape showed that elephants were distributed in two different habitats rather than four isolated clusters (Acharya et al., 2016; DNPWC, 2009; Pradhan et al., 2011; ten Velde, 1997) (Figure 3.3). Eastern landscape is relatively more occupied by elephants in comparison to the western elephants and there is a clear obstruction seen in the dispersal route of elephants in western Nepal (Figure 3.3). It might be due to large expansion of Butwal city and densely populated area of western Nawalparasi, Rupandehi and East Kapilbastu.

Elephants from the western side of Nepal dispersed from Kanchanpur to the west of Kapilbastu via Bardiya, Banke, and Dang district using the Kamdi corridor and Sohelba Wildlife sanctuary, India. These elephants were limited to west Kapilbastu near the Gugauli area, which is very close to the Indian border and visited these areas by using the

Sohelba wildlife sanctuary of India. The western elephant had used both the habitat of India and Nepal throughout the western landscape while migrating east-west. Probably, the Nandaaur elephant population migrated into western Nepal (viz. Shuklaphanta and Bardiya National Park) through Dudhuwa National Park and Katarniaghat Wildlife Sanctuary in India (this needs to be thoroughly investigated though). The eastern elephant population migrated from Jhapa to Chitwan Parsa complex, where the western elephants were dispersing from Shuklaphanta kanchanpur to the western part of the Kapilbastu (Figure 3.3).

### **3.4.5. Elephant populations**

Well-maintained historic records clearly showed that elephants were distributed all over lowland Nepal when Charkoshe-Jhadi forest was contiguous stretching from East to the West in Nepal (Bajimaya, 2012). Over decades and centuries, people have converted large tracts of elephant habitats into agriculture, which primarily increased after World War II (Sukumar 1989). Forest clearance had further increased following eradication of Malaria in Nepal and fueled by hill people resettlement program in the lowland *Terai* (Laudari et al., 2019). This program had altered 40% of the total forest area in comparison to 1930 in 2000 (Reddy et al 2014). This has led to the decline in number of major megafaunas including rhinoceros (*Rhinoceros unicornis*), tiger (*Panthera tigris*) and elephants which further increased throughout the *Terai* area because sport hunting of mega animals was also in place.

Our population assessment indicates that there are about 227 elephants (Figure 3.4) occurring in the wild across Nepal. Government of Nepal had 104 captive elephants tamed in seven elephants stable and one Elephant breeding center, where 106 elephants are kept in private elephant stable which were used for tourism business in Nepal.

### **3.4.Conclusions**

Initially, elephant population in Nepal was very small (~50 individuals) till 1970s, and subsequently increased to 227 during 2020 with a sex ratio of adult 1: 2.4 (Figure 3.4 & 3.5). Elephants occupied ~50% part of the CTML landscape, while naïve occupancy approach indicated that only 12% was occupied highlighting the importance of choosing occupancy approach. Low detection was possibly due to population size being small with minimal movement between elephant groups. Elephants were distributed in two subpopulations ie. Eastern population (Bahundangi to Chitwan Parsa complex) and Western population (West Kapilbastu to Kanchanpur). Elephants were dispersing in the East-West orientation through the Chure Siwalik foot hills, which are highly fragmented and need renewed focus on restoring corridors and connectivity for the long-term survival of this charismatic species.

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**Chapter 4:**  
**Patterns and determinants of Elephant attacks on humans  
in Nepal**

## **Chapter 4:**

# **Patterns and determinants of Elephant attacks on humans in Nepal**

### **4.1. Introduction:**

Asian elephant (*Elephas maximus*, referred to as 'elephant' hereafter; Figure 1) is a globally endangered megaherbivore (Williams et al., 2020). It is an umbrella species in tropical and subtropical forests of Asia and has an influential cultural role in various Asian societies (Jadhav and Barua, 2012; Menon et al., 1996; Sukumar, 2003; Vasudev et al., 2020). Once widely distributed in Asia, elephants are now confined to ca. 5% of their historical range in highly fragmented landscapes (Sukumar, 2006). In addition, the rapid development of linear-infrastructures including railways, highways, electric transmission lines, and irrigation canals, caused further obstruction to elephant movement. Elephants require large areas to survive with long-distance seasonal activities (Goswami, 2017; Leimgruber et al., 2003). However, increasing habitat fragmentation brings them in frequent confrontation with humans. As a result, human-elephant conflict (HEC) worsens and has become a prominent cause of elephant population decline (Sukumar, 2006). Attack on humans is the extreme form of HEC. Other effects on local people from HEC include loss of crops, damage to property, and safety threats (Dickman, 2010; Gross et al., 2021). A large number of elephants are also killed in retaliation.

Nepal is a typical example of an elephant range country with a small but growing population of >200 elephants in a highly fragmented landscape (Ram and Acharya, 2020). Increasing encroachment and forest conversion in the southern lowlands of the Terai and Chure (Himalayan foothills) region have destroyed the traditional migratory routes of the elephants (Ram, 2014). Whereas, some residential solitary bulls living in protected areas are habituated to visiting

agricultural sites for a higher-quality diet causing a high amount of damage (Koirala et al., 2016). Elephants cause the highest number of human deaths among the wildlife species in Nepal. Thus, HEC is a severe issue throughout lowland Nepal (Acharya et al., 2016).

Few studies on human-elephant conflict have been carried out in Nepal, focusing on crop and property damage (Graham et al., 2016; Gross et al., 2021; Neupane et al., 2013; Pant et al., 2016). However, detailed studies of elephant attacks on humans are still lacking. This study attempts to document the Spatio-temporal pattern of elephant attacks on humans in Nepal, the characteristics of the victims and attacking elephants, determine factors associated with the attacks, and identify human and elephant behavior contributing to victims' deaths when attacked. We tested hypotheses 1) human activities are responsible for elephant attacks on humans; 2) elephant attacks are higher in the proximity to forests, 3) elephant attacks were higher inside protected areas; and 4) solitary bulls elephants are responsible for attacks on humans. The study results have long-term implications for the conservation and management of elephants in Nepal's human-dominated landscape and beyond.

## **4.2. Material and Methods:**

### **4.2.1. Study area**

The study was conducted across the Terai and Chure region of Nepal, covering 46,000 km<sup>2</sup> of elephant range in 24 districts (Figure 2). The Terai and Chure region is densely populated with 391.5 persons/km<sup>2</sup> (CBS, 2012). About 51% of the total population of Nepal resides in the region, with agriculture and livestock farming as the primary occupation. About 42% of the study area is forested, providing habitats and migration corridors for the elephants (DFRS, 2015). However, significant cities, industrial sites, and highways fragment the forested areas. The forests in the

region were intact till the 1950s, but afterward, it was under continuous human pressure from the expansion of agriculture, settlements, and built-up areas.

The study area comprises various habitats, including highly productive alluvial floodplain grasslands, riverine forests, and climax Sal (*Shorea robusta*) forest supporting many rare and globally threatened species, including tiger (*Panthera tigris*), dhole (*Cuon alpinus*), greater one-horned rhinoceros (*Rhinoceros unicornis*). The study area has a sub-tropical climate characterized by hot and humid summers (mid-March/mid-June), intense monsoons (mid-June/mid-September), and dry autumns/winters (mid-September/mid-March) (Lamichhane et al., 2018). The maximum temperature varies from 35–40°C during summer and 14–16°C in winter (Jackson, 1994). The mean annual rainfall ranges between 1,138 and 2,680 mm, with over 80% of the rain occurring during the three monsoon months (Lamichhane et al., 2018). Elephants in Nepal are found in four population clusters, i.e. eastern (Koshi to Jhapa), central (Chitwan to Mahottari), western (Bardiya to Dang), and far-western (Kanchanpur & Kailali). Elephants frequently migrate the Nepal-India border through forest connectivity in the East (northern part of West Bengal), West (Uttarakhand), and some places in the South (Bihar and Uttar Pradesh).

#### **4.2.2. Elephant attacks data collection**

We compiled all available data of elephant attacks on humans (death and injury) from the Divisional Forest Offices (DFO) and Protected Area (PA) offices across the study area for the period 2000 to June 2020. These records are well maintained in the respective DFO and PA offices for providing monetary relief to the elephant-affected families. In addition, the official records obtained details of the victims and nature of the elephant attack (eg. name, age, sex, address, date of incidence). Each paper was verified by reaching every attack location with the help of the victim's spouses, relatives, or neighbors who knew the attack events and places. We also conducted

30 stakeholder consultation meetings to gather information on human killings, livelihoods, elephant visiting patterns, and perceptions of elephants.

#### **4.2.3. Victim household questionnaire survey**

We conducted structured questionnaire surveys of all affected households (n=412) in the study area. On consent, either the head of the family or another adult member was interviewed. GPS location of each family was recorded. Before an interview, we requested verbal consent from the respondents. The questionnaire included the demographic background of the interviewee and the victim (age, sex, ethnicity, family size), socio-economic status (education, marital status, house type, income source, occupation, land tenure, etc.), victim behavior/activity during attack (place of attack, drunk, activities while attacked, methods used for chasing elephant) characteristics of shooting an elephant (type of elephant, musth, tusker) and habitat characteristics (land use type) (Table 4.1).

#### **4.2.4. Data analysis**

We entered all the questionnaire survey data in MS Excel and prepared descriptive summaries using the pivot table function (Dan Clark, 2020). We then performed data analyses in the R statistical package v. 4.0.2 (R Development Core Team, 2020). We used the chi-square test of independence to compare the frequency of attacks (death and injury) between seasons, months, ethnicity, age group, sex, and occupation of the victim (Babu Ram Lamichhane et al., 2018). We categorized victims into five categories based on ethnicity, upper-caste Hindus including Brahmin Chhetri Thakuri (BCT), Dalit or underprivileged group, Janajati (ethnic groups such as *Gurung*, *Magar*, *Newar*, *Tamang*, *Rai*, *Limbu*, *Tharu*, *Bote*, *Darai*, *Rajbansi*, etc.), Madhesi, and Muslim. Similarly, we grouped the victims into five age categories, i.e., <15, 15–24, 25–44, 45–64, 65+

years following (United Nations, 1982). The education level of the victims was categorized into illiterate (who cannot read and write), literate (who can read/write but have not attended formal school), Primary (completed primary school), and Secondary or above. The victim's housing was categorized into the cemented house, corrugated galvanized iron (CGI) sheet roof house, tiled roof house, and thatched cottage.

We carried out binomial logistic regression by constructing a Generalized Linear Mixed Model (GLMM) (Zuur et al., 2010) to determine the factors associated with fatalities in elephant attacks. In the GLMM, fatalities on elephant attacks were used as a dependent variable by coding the human fatality=1 and injury=0. Fourteen explanatory variables representing elephant characteristics, human characteristics, and site characteristics were defined (Table 4.1). Elephant behavior included social features (solitary bulls or herd elephants), and the elephant was in musth. The human elements had the age and sex of the victim, education, activities of the victim during elephant attack, location of the episode, type of house of victims. Human behavior or response towards elephants (chasing fire, explosives, or guns) was also included. Site characteristics included the place of attack, migration route of elephants, and proximity to the forest. We extracted the victim location's habitat and environmental variables (Naha et al., 2019) (Table 4.1) using the Google earth engine platform (Buchholtz et al., 2020; Gorelick et al., 2017) and Arc-GIS v 10.5 (ESRI, 2016; Wang et al., 2018).

We ranked models by the small-sampled corrected Akaike's Information Criteria (AICc, lower AICc value indicates higher model ranking) using multi-model inference in the 'MuMIn' package in R (Barton, 2020). The final model was obtained by averaging the top candidate models supporting the data equally well ( $AICc \leq 2$ , (Burnham and Anderson, 2001).

*Table 4.1. Variables used in binomial logistic regression and their type/source. The human casualty in elephant attack was the dependent variable, and the independent variables included elephant characteristics, human characteristics, and environmental and habitat characteristics.*

Variables	Type of variable	Categories/values	Data source
<b>Elephant characteristics</b>			
Herd type/size	Categorical	Solitary adult bulls, Sub-adult male, Sub-adult male group, Herd without calves, Female with calves	Questionnaire survey
Musth	Binomial	1, 0, NA (1 – Yes, 0 – No, NA – Don’t know)	Questionnaire survey
<b>Human characteristics</b>			
Response to elephant	Categorical	Shouting, Fire cracker, stones,	Questionnaire survey
Alcohol use	Binomial	1,0, NA (1 - Drunk, 0 - not drunk, NA – Don’t know)	Questionnaire survey
Victim sex and age	Categorical	Sex (Male, Female) Age (<15, 15 – 24, 25 – 44, 45 – 64, 65+),	Questionnaire survey
Victim ethnicity	Categorical	1. BCT (Brahmin, Chhetri and Thakuri); 2. Janjati (Ethnic communities of hills & Terai like Gurung, Magar, Tamang, Newar etc.); 3. Indigenous Terai (Tharu, Bote, Darai, Mushahar); 4. Dalit (under-privileged casts of Kami, Damai, Sarki etc.); 5. Madhesi and 6. Mushlim	Questionnaire survey
Education	Categorical	Illiterate, literate, primary, Secondary or above	Questionnaire survey
Activity of the victim at the time of incident	Categorical	Chasing elephants, resting at home, guarding crops, travelling on foot,	Questionnaire survey
House type	Categorical	Concrete, CGI sheet, tile house, thatch house	Questionnaire survey
<b>Environmental and habitat characteristics</b>			
Proximity to forest	Numeric		GIS & questionnaire survey
Season	Categorical	Winter, summer, monsoon	Questionnaire survey
Land-use type	Categorical	Farmland, settlements, forests/grassland	GIS

### 4.3. Results

#### 4.3.1. Victim characteristics

There were 412 records (274 fatalities and 138 injuries) of elephant attacks on humans. Males were attacked more frequently than females. Ethnic or *Janajati* people were the most affected group, followed by BCT, *Dalit*, *Madhesi*, and Muslim. The age of the victims of elephant attacks ranged from 7 months to 80 years old, but most of them (71%) were adults between 25- and 64-year (Table 4.1) A quarter of elephant attacks occurred while people chased elephants, and half took place around settlements or homes (Table 4.2. & 4.3). Most of the people attacked (88.8%) had a low level of education (illiterate, literate or primary education only). Two-thirds of the victims of elephant attacks were living in the thatched house. Majority of affected janjati and Bahun chhetri (BCT) were residing close to the forest boundary and they have affected mostly, however muslims are found less affected because there population in this territory was very less and therefore, less people were found affected by human elephant conflict.



*Table 4.2 Characteristics of victims attacked by elephants in Nepal's Terai and Chure region of Nepal between 2000 and June 2020.*

Victim characteristics	Incident type		Total
	Death	Injury	
<b>Sex</b>			
Female	116	38	154
Male	158	100	258
<b>Caste/ethnicity</b>			
BCT	74	49	123
Dalit	46	20	66
Janajati	115	50	165
Madhesi	36	15	51
Muslim	3	4	7
<b>Age</b>			
<15	19	7	26
15-24	39	23	62
25-44	101	61	162
45-64	92	39	131
65+	23	8	31
<b>Education</b>			
Illiterate	141	63	204
Literate	44	36	80
Primary	55	27	82
Secondary or above	34	12	46
<b>Housing</b>			
Cemented house	28	22	50
CGI sheet roof house	31	27	58
Tiled roof house	28	9	37
Thatched house	187	80	267
<b>Total</b>	<b>274</b>	<b>138</b>	<b>412</b>

*Table 4.3. Victim activity and location of elephant attacks in the Terai and Chure region of Nepal during 2000– June 2020.*

Activity of the victim	Location of attack			Total
	Crop field	Forest	Home/ settlement	
Chasing elephants	11	22	70	103
Travelling	1	30	50	81
Sleeping or working at home	-	-	66	66
Fetching forest products	-	65	-	65
Guarding crops	36	1	2	39
Livestock grazing	2	23	1	26
Open defecation	-	-	21	21
Other	1	7	3	11
<b>Total</b>	<b>51</b>	<b>148</b>	<b>213</b>	<b>412</b>

#### **4.3.2. Elephant characteristics**

Most of the elephant attacks on humans (85.2%, n=412) were caused by solitary adult bulls on musth or group of sub-adult males and rest of the attacks were caused by the elephants in herd or females separated from the herd (Table 4.4).

*Table 4.4. Characteristics of the elephants involved in attacks on humans in Nepal's Terai and Chure region between 2000 and June 2020.*

Elephant characteristics	Attacks on humans		Total
	Death	Injury	
<b>Group type</b>			
Adult males	213	103	316
Adult females	6	13	19
Mixed group herd	17	11	28
Sub-adult male group	27	8	35
Unknown	11	3	14
<b>Adult/sub-adult bull elephant</b>			
Yes	240	111	351
No	24	24	48
Don't know	10	3	13
<b>Elephant in musth</b>			
Yes	131	76	207
No	71	36	107
Don't know	72	26	98
<b>Total</b>	<b>274</b>	<b>138</b>	<b>412</b>

#### **4.3.3. Temporal and spatial distribution of elephant attacks on humans**

Elephant attacks on humans differed significantly across months ( $\chi^2= 76.272$ ,  $df = 11$ ,  $p<0.001$ ) with a peak in the post-monsoon season (September to December) (Figure 4.1a). Number of attacks were higher outside protected areas (Figure 4.1a) but the difference was not significant ( $t = -1.0751$ ,

df = 19.296, p = 0.2956). Linear regression showed a gradual increase of elephant attacks on humans (Figure 3b). The average annual attacks were 11 ( $\pm 8.5$  SD) during 2000–2010 and increased to 29 attacks ( $\pm 11.2$  SD) during 2011–June 2020.

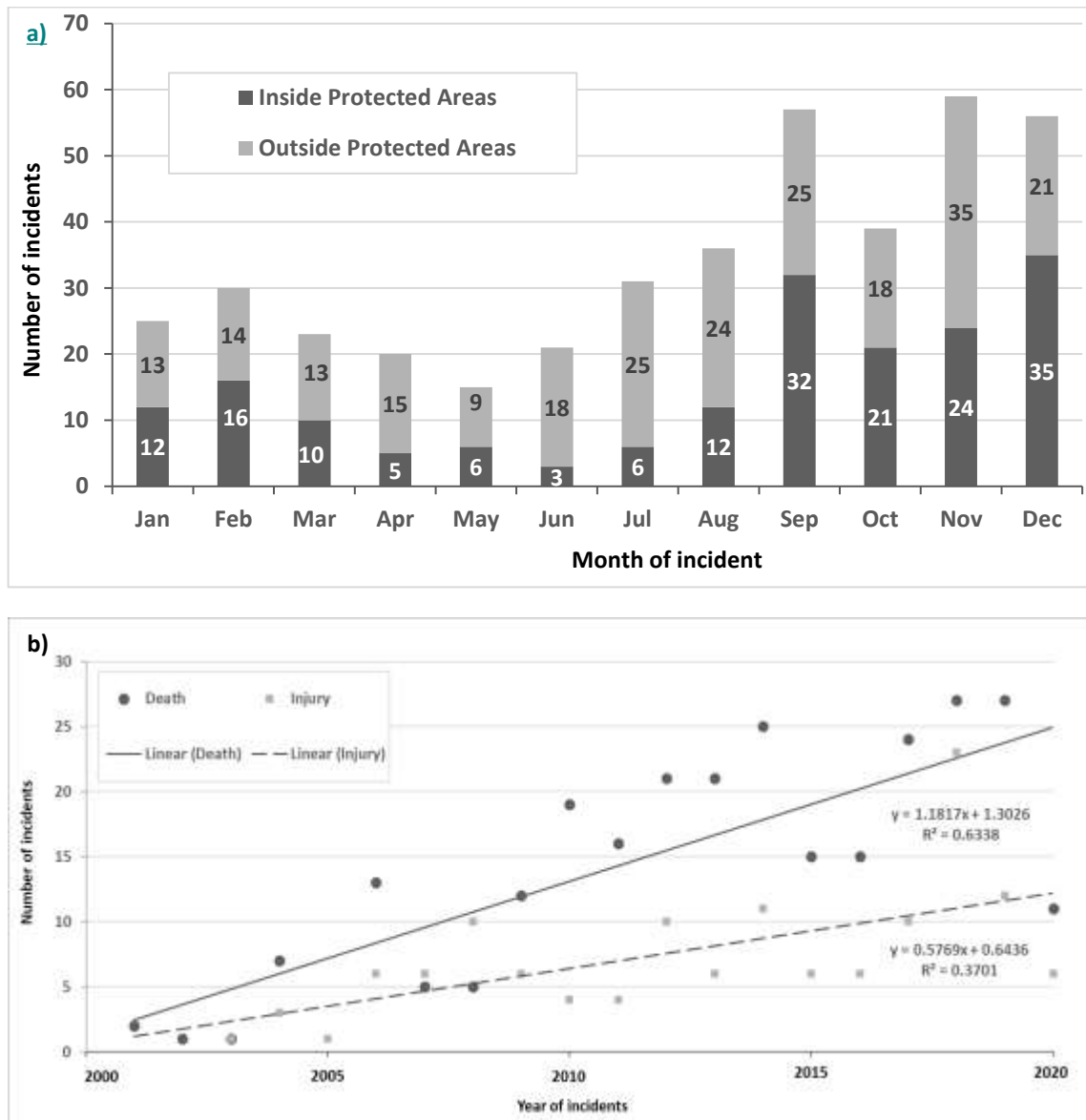


Figure 4.1. Temporal distribution of elephant attacks on humans (death and injuries) in Nepal during 2000 and June 2020 a) over the months, and b) years.

In the forested areas, elephant attacks on humans were at peak in the afternoon (4-5pm), whereas, in settlement areas, elephant attacks peaked in the evening (7-9 pm) (Figure 4.2b).

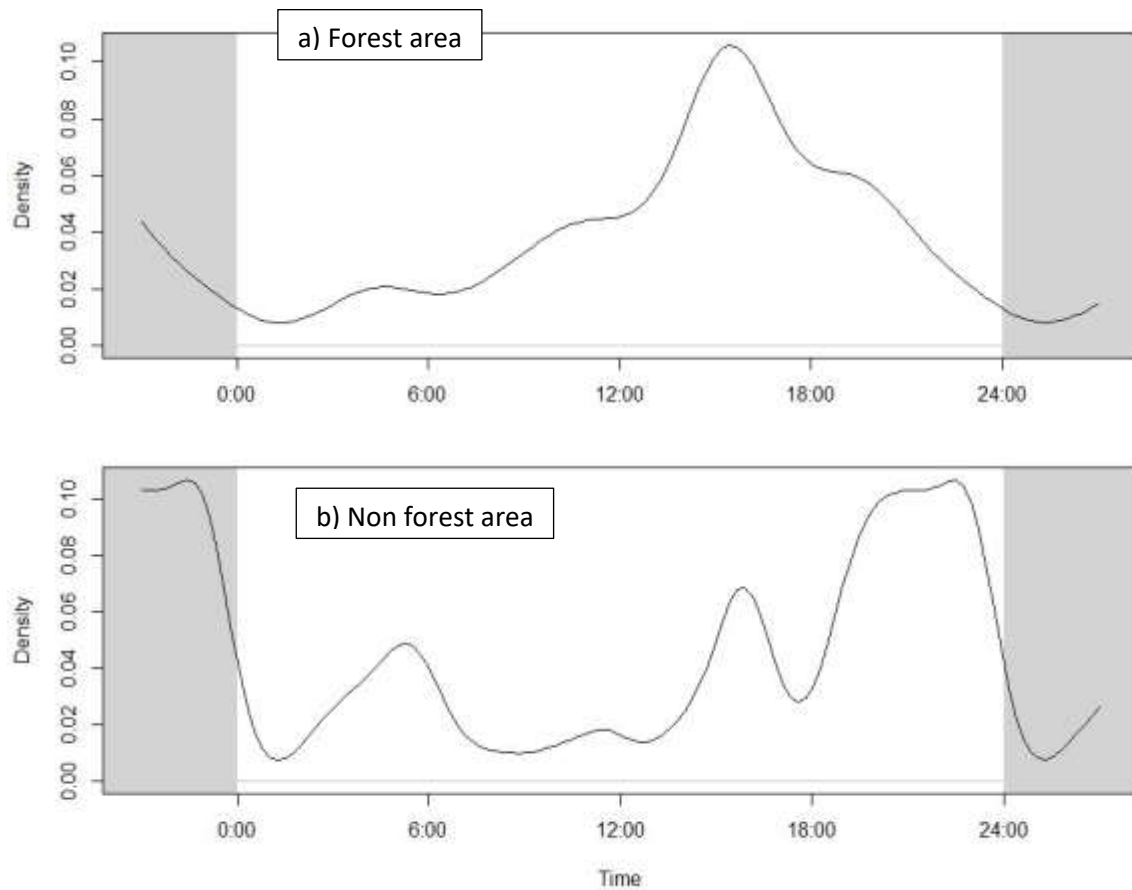


Figure 4.2. Elephant attacks on humans at a different time of day in a) forested areas and b) settlement and agriculture areas outside forests.

The number of attacks on humans differed significantly among the districts ( $\chi^2=338.49$ ,  $df = 19$ ,  $p$ -value  $< 0.01$ ) with the highest number of incidents ( $n=66$ ) from Jhapa and Bardiya districts (Figure 4.3). Most elephant attacks (67%) occurred within 500 m from the forest edge (Figure 4.4).

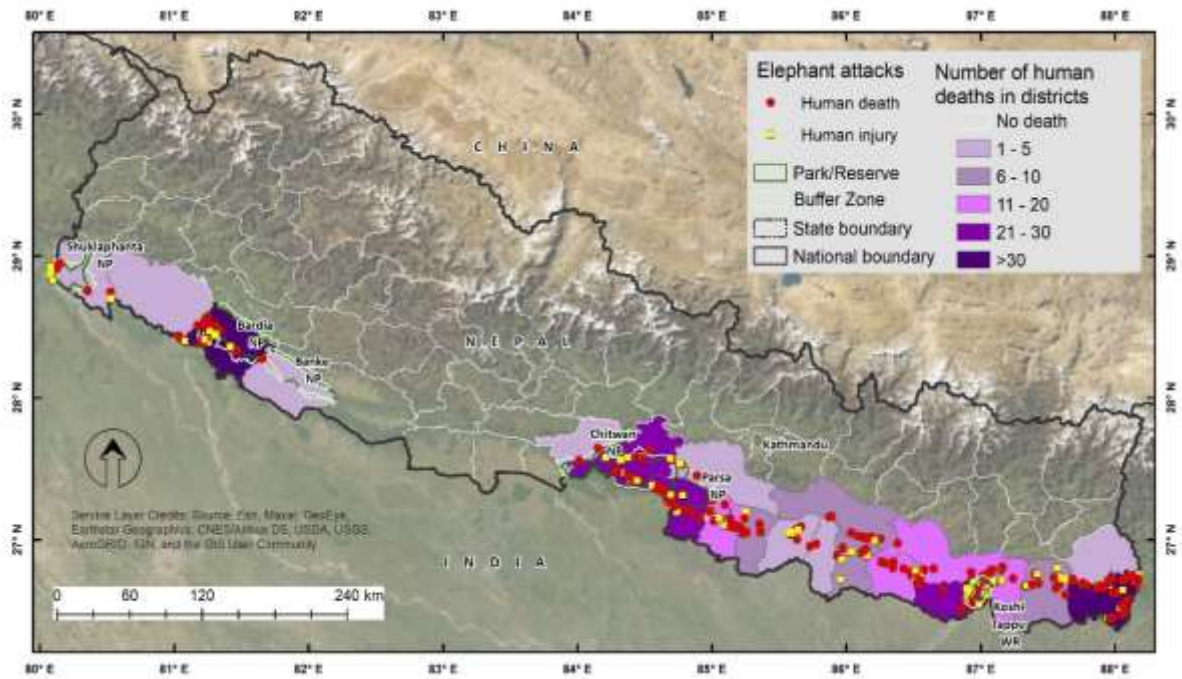


Figure 4.3. Spatial distribution of elephant attacks on humans in Nepal.

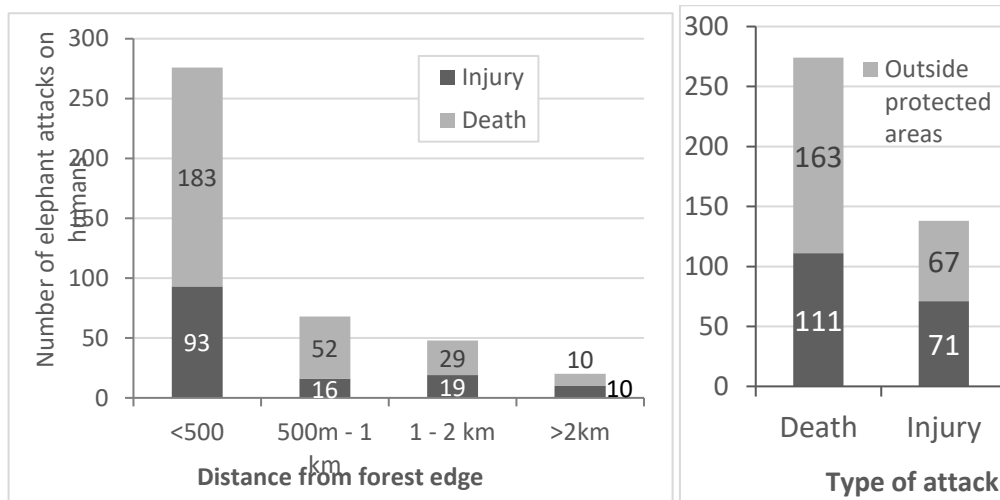


Figure 4.4. Spatial distribution of elephant attacks on humans in Nepal with respect to distance from forest edge (left) and inside/outside of the protected areas (right).

#### 4.3.4. Factors associated with human fatality

People who were drunk and chased elephants using fire crackers were more vulnerable to fatalities while chasing elephants using fire was negatively associated with deaths (Table 4.5).

*Table 4.5. Factors associated with human fatalities on elephant attacks in Nepal.*

Parameters	Estimate	Std. Error	Adjusted SE	z value	Pr(> z )	Significance
(Intercept)	0.652	0.795	0.798	0.818	0.413	
Crackers_Drums	1.095	0.508	0.511	2.142	0.032	*
Drunk	1.124	0.380	0.382	2.938	0.003	**
Fire_chasing	-1.715	0.576	0.579	2.961	0.003	**
House_typeCGI	0.063	0.588	0.592	0.107	0.915	
House_typethatched	0.795	0.504	0.508	1.566	0.117	
House_typetiled	1.585	0.828	0.833	1.903	0.057	.
Place_attackForest	-0.914	0.530	0.533	1.715	0.086	.
Place_attackHome/settlement	-0.272	0.522	0.526	0.518	0.605	
prox_forest	-0.001	0.000	0.000	1.919	0.055	.
Age	0.013	0.010	0.010	1.219	0.223	
Ele_Musth	-0.294	0.358	0.360	0.816	0.414	

Significance codes: <0.001 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

#### 4.4. Discussion

Our study presents the most comprehensive analysis of Nepal's elephant attacks on humans. Elephants attacked an average of 20 humans per year, with two-thirds resulting in fatalities in the Terai and Chure region. We documented the increasing trend of Elephant attacks on humans over the years. The human response towards elephants was a significant factor in elephant attacks, supporting our first hypothesis. A higher number of attacks by elephants on humans occurred in

the proximity of the forest (66.99 % attacks in <500m from forest edge), supporting our second hypothesis. In contrast to our third hypothesis, more people were attacked outside the protected areas. Over 76% of the attacks on humans were caused by the solitary bulls supporting our third hypothesis.

#### **4.4.1. Characteristics of the victims of elephant attack**

Elephants attacked males more frequently than females, which can be associated with the high mobility of males and their involvement in chasing the elephants (Sarker et al., 2015). For instance, the majority of the males were attacked while chasing elephants or traveling, whereas females were attacked more frequently while fetching forest products or working at home (Supplementary information S1). Most of the attacks on humans occurred close to forests where socio-economically marginalized people reside (Neupane et al., 2017a; Pant et al., 2016). Marginalized communities lived at the peripheral edge of the woods or society. Such gatherings were denied in mainstream economic, political, cultural, and social activities due to their living conditions, lifestyles, or exclusion. These people have less access to government resources and are excluded socio-economically. Among these communities, most of the attacked persons were illiterate, living in a thatched house, an indicator of poor social and economic condition (Neupane et al., 2013). People living in the thatched cottage often keep their grain storage close to where they sleep due to limited space in the house. It increases the chances of elephant damage in their home and risks of elephant attack (Naha et al. 2019). Neupane et al. (2013) documented a low level of education and awareness about elephants as an essential determinant of the elephant attacks on humans. A high proportion of attacks on *Janajati* (ethnic) people can be associated with local liquor production, consumption, and selling for their livelihood (Parajuli, 2015; Lamichhane et al., 2018b). Such liquor also attracts elephants (Naha et al., 2019), primarily the solitary bulls,

increasing the chances of encountering humans. Thus, people living in the settlements near the forest edge, especially on the elephant migration routes, are vulnerable to elephant attacks (Jadhav and Barua, 2012; ten Velde, 1997). This study's findings indicate a need to devise strategies and actions to stop elephants entering into the settlements and help poor and socially marginalized communities secure their livelihoods (Gross et al., 2021).

#### **4.4.2. Characteristics of elephants attacking humans**

Mixed herd elephants rarely attacked humans (<5% of the incidents), although they are involved in crop-raiding during migration through agricultural areas or settlements (Naha et al., 2020). Solitary adult bull elephants caused most attacks on humans in Nepal (Acharya et al., 2016), but it varied among elephant individuals. A few individual bulls, who repeatedly visited human settlements and agriculture areas, were involved in most of the attacks. Similar findings of attacks on humans by solitary bulls are reported from some parts of Bangladesh (Sarker et al., 2015). With frequent interactions with humans, these bulls become familiar with human behavior and lose the natural fear (Fernando et al., 2008). However, they are also harassed by people most of the time while raiding crops or grain stores. These irritating actions of humans make them more aggressive, resulting in violent attacks (Sampson et al., 2019). We identified 37 such bulls causing three-quarters of all attacks on humans in the last twenty years; some of them caused a disproportionately higher number of attacks (up to 36). Such individuals can be termed “problem individuals” (Lamichhane et al., 2017; Swan et al. 2018). Thus, human-elephant conflict management should prioritize managing such problem elephants (Fernando et al., 2008).

### **4.4.3. Temporal patterns of elephant attacks**

Documented records of elephant attacks on humans in Nepal go back to the 1970s (B.N. Uprety 2020, Pers. Comm.) with irregular forms until the late 1990s (Smith and Mishra, 1992). In our study, we only included data between 2000 and June 2020. The wild elephant population has gradually increased in Nepal from 52–53 individuals during the 1990s (Smith and Mishra, 1992) to 107–145 individuals in 2007 (DNPWC, 2009) and >200 individuals in 2020 (Ram and Acharya, 2020). The human population growth rate in the Terai and Chure region (1.72%) is also higher compared to the national average (1.35%; (CBS, 2014). Consequently, deforestation is also higher in this region, especially in the Chure (0.18% annually) (DFRS, 2015). The remaining forests are also becoming increasingly fragmented with planned and ongoing large-scale infrastructure development such as roads, railways, canals, industries, airports, and urban areas forming barriers to elephant migration (MOFSC, 2015). Overlap in forest use by elephants and humans is increasing, resulting in high human-elephant interactions (Acharya et al. 2017; Lamichhane et al., 2018a; Mariki et al., 2015; Mukeka et al., 2019).

Elephant attacks on humans occurred throughout the year but peaked during September–December, coinciding with the rice harvesting. Lamichhane et al. (2018a) also show that elephants use both forested and human-dominated areas, but human-dominated locations vary seasonally, with a peak in the autumn. Pre-monsoon (March–June) had the lowest level of attacks as agricultural areas are devoid of crops, and elephants are concentrated primarily in the forests feeding on climbers, tree barks, and new grass (Koirala et al., 2016; Lamichhane et al., 2018a).

Elephant attacks in forested areas peaked during the afternoon (~16:00) when human activity (Figure 4.2), mainly cattle grazing and fodder and forest resource collection, is high inside the forests. The elephants generally rest during the mid-day hot period and start becoming active with

decreasing afternoon temperatures (after 15:00) (Thapa et al., 2019). This increases the chance of interaction between elephants and humans. Close to sunset (~18:00), most people return home from the forest while elephants remain inside the forest, decreasing the chances of interaction between them. However, elephant attacks again increase in the evening (19:00–21:00) when elephants enter the settlements or agricultural fields, and people come in the confrontation while chasing elephants away. Changing people's behavior through conservation education, restoration of the elephant movement corridors and bottlenecks, devising elephant and people-friendly land-use policies will contribute to human-elephant co-existence.

#### **4.4.4. Spatial pattern of elephant attacks**

Two-thirds of elephant attacks on humans occurred within 500 meters from the forest edge. People living in proximity of forests are vulnerable to elephant attacks because 1) chances of encountering elephants is high at close distance to forest, 2) generally economically marginalized communities live in these areas with lack of proper housing (thatched houses), and 3) low level of education and awareness. A similar finding of a higher number of attacks by wildlife close to the forest or park boundary (<1 km) and an inverse relationship between the distance from the forest edge and wildlife attacks is reported in other studies (Gurung et al., 2008; Lamichhane et al., 2018b; Pant et al., 2016).

A higher number of elephant attacks outside protected areas (59.5%) in our study is consistent with Acharya et al. (2016). Similar results with higher conflict incidents outside protected areas have been reported from northeast India (Choudhury, 2004). Elephants require large areas to fulfill their needs of large quantities of forage, water, and finding mates. Thus their home ranges surpass the protected areas. People living close to protected areas are aware of elephant behavior and respond accordingly (Lamichhane et al., 2019). Beyond protected areas, human response towards elephants

is more aggressive due to a low level of awareness, resulting in a high number of human casualties and retaliatory killing of elephants (25 out of 33 retaliatory killings in past 20 years, unpublished data compiled by the first author).

The elephant attacks on humans were concentrated in four pockets, Jhapa, Koshi, Chitwan Parsa, and Bardiya. Despite the smaller population of elephants (~35) in eastern Nepal, the number of attacks on humans is relatively higher (43% of total attacks in Nepal). The reason for such a high casualty in eastern Nepal, especially in the Jhapa district of the south-eastern border of Nepal, is because of 1) the highly fragmented habitats outside of the protected areas, 2) the historic migration route of elephants from West Bengal, India straddling the national boundary, and 3) provoking human actions towards elephants. Historically, ~100 elephants migrated annually from West Bengal (India) entering Nepal from the eastern border during September–October, and May–June (Mallick, 2012). While migrating, they often confronted people as they were forced to travel through settlements and agricultural land. Many of their historic migration routes were encroached by people (Choudhury, 2004). A fence installed in the Bahundangi area (Jhapa district) at the Eastern border of Nepal has contributed to reducing human-elephant conflict in the fenced areas (Naha et al., 2019). However, the elephant continues their movement in Nepal from the south of the fenced area (NTNC, 2019). Some elephants, especially males, break the fence and continue their activity up to Koshi Tappu Wildlife Reserve (KTWR) and westwards.

A quarter of all elephant attacks on humans in Nepal occurred in KTWR and its periphery. KTWR acts as a stepping stone for the elephant population in eastern Nepal. The KTWR (173 km<sup>2</sup>) is much smaller than the home range of elephants (188 – 400 km<sup>2</sup>, Williams et al., 2008; Alfred et al., 2012; Williams, Krausman and Asir, 2015). With the high dependency of communities on the reserve for

grazing, fodder, firewood, and fishing, elephants and people come in frequent confrontation. The situation is further aggravated in the densely populated agricultural areas in the reserve's periphery.

The human casualty was recorded throughout Central (Nawalparasi East) and Eastern Terai. In the Chitwan-Parsa Complex in central Nepal, 27.4% of the elephant attacks were recorded, mainly from Chitwan, Parsa, and Bara districts. There is a gap in elephant distribution between the central population (Nawalparasi East) and the western population (Bardiya), with only a sporadic presence in Banke, Dang and Kapilvastu districts (Lamichhane et al. 2018a). The largest elephant population (>100) in Nepal exists primarily in Bardiya NP in western Nepal, where 16.7% of total elephant attacks on humans occurred. Elephants in the population of the west also migrate through the Chure foothills west of Bardiya, reaching up to Shuklaphanta NP, causing some attacks on humans (ten Velde, 1997).

#### **4.4.5. Factors associated with the human fatality**

Our results of two-third of elephant attacks resulting in a fatality are consistent with Acharya et al. (2016). Human behavior and responses towards elephants were the significant factors to cause elephant attacks on humans. Aggressive human behavior towards elephants with intolerance was the primary determinant of human fatality in elephant attacks (Nelson et al., 2003). People were primarily killed while chasing wild elephants using fire crackers and other high sound and light objects. Increased risk of elephant attacks on humans while hunting elephants with fire crackers can be associated with the irritation caused by unnatural and intense sound. Sometimes, the hackers cause injury to elephants making them more aggressive towards humans, ultimately increasing the chances of fatalities. Drunk people were more vulnerable to deaths if elephants were attacked (Neupane et al., 2017b). The negative association of fatalities while chasing elephants using fire torch indicates that it is a safe and effective method for pushing elephants outside the village.

## 4.5. Conclusions

Human casualties from elephants have increased with its multifaced impact on human-elephant coexistence in Nepal. First, elephant attacks were concentrated near forests, affecting socio-economically marginalized communities. Most of the attacks on humans were caused by solitary bull elephants. Third, the human response towards elephants was a significant factor associated with the elephant attacks on humans. The chances of elephant attacks and human fatalities increase when drunk people are chasing elephants. Local people and the Government of Nepal (GON) have adopted various preventive and curative measures such as fences in hotspots, problem animal management, and relief support for victims/families to reduce both human casualties and elephant retaliation. These measures should be continued, and additional activities such as integrated settlement, safe housing for socio-economically marginalized communities, and community grain houses in the payment could be promoted to reduce the confrontation between elephants and humans. Revising the 'elephant conservation action plan and strategy for Nepal' and its practical implementation will promote human-elephant co-existence HECx and sustain the increasing elephant populations of Nepal



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**Chapter 5:**  
**Landscape predictors of Human-Elephant Conflicts in Chure**  
**Terai Madhesh Landscape of Nepal.**

## **Chapter 5:**

# **Landscape predictors of Human-Elephant Conflicts in Chure Terai Madhesh Landscape of Nepal.**

### **5.1 Introduction**

Habitat loss, fragmentation, overexploitation of resources, and climate change are major anthropogenic drivers causing the purported 6th mass extinction on the earth (Mishra et al., 2020; Reid et al., 2005; Wagler, 2017). Greater than a million species faced extinction threats due to human impacts (Bongaarts, 2019). Because of high mobility, large resource requirements, and highly prized body parts, large mammals are particularly vulnerable to local and regional extinctions (Hoare, 1999; Liu et al., 2017; Sukumar, 1989). In addition to species extinctions, paradoxically, pervasive human impacts on the planet had also triggered human-wildlife conflict (HWC). Human-wildlife conflicts have a disproportionately higher effect on large mammals. Fragmentation can increase the perimeter to area ratio and improve the interface with local communities (Daskin and Pringle, 2016; Naha et al., 2020a; Tilman et al., 2017).

Asian Elephant (*Elephas maximus* Linnaeus, 1758; hereafter referred to as "elephant") is an umbrella species native to mainland Asia (Sukumar, 2003). Once distributed widely across Asia, the elephants are now confined in ~ 5% of their historical range ((Leimgruber et al., 2003) within 13 countries with an estimated population of <50,000 (Williams et al., 2020). While elephants have cultural reverence in South Asia, in SE Asia, they are hunted for ivory and meat (Williams et al., 2020). Despite their essential natural

and cultural role, elephants face high extinction risk and are categorized as endangered in the IUCN Red List (Williams et al., 2020)

The intensity of human-elephant conflicts (HEC) varies widely across Africa and Asia due to various ecological and socio-economic factors, including food availability, size of protected areas, agricultural practices, human density, seasonal variations of climate and socio-cultural beliefs (de Boer et al., 2015; Shaffer et al., 2019). Nevertheless, human-elephant conflict (HEC) is a pervasive threat to human-elephant coexistence within shared landscapes (Acharya et al., 2017; Lamichhane et al., 2018; Naha et al., 2020b). Crop, property damage, and occasional attacks on humans might reduce societal tolerance and provoke retaliatory killings impacting the elephant populations (Karanth et al., 2013).

Human elephant conflict (HEC) resulted in many human deaths and injuries, threatening the survival of Asian elephants throughout their range (Fernando et al., 2005; Sukumar, 2003, 1989). HEC varied as per their nature and extent (Dickman, 2010; Neupane et al., 2017; Ranjeewaa, Ashoka D.G. Pastorinib et al., 2017; Shaffer et al., 2019), and landscape features are also responsible for escalating human-elephant conflict (HEC) (Naha et al., 2019). Nepal has a small population of wild Asian elephants estimated to be ~230 individuals (Ram and Acharya, 2020a). These individuals form a part of the meta-population network of elephants across the *Terai Arc* region, encompassing the neighboring countries of India, Bhutan, Bangladesh, and Myanmar (MoFSC, 2015). Therefore, the HEC can potentially undermine elephant conservation efforts, threaten the survival of elephants outside protected areas and consequently reduce habitat viability (Ram et al., 2021b).

Forest cover is a primary determinant of elephant distribution. Thus, understanding the impact of forest loss and fragmentation is crucial for elephant conservation (Padalia et al., 2019). About 21.5% of elephant habitat was lost between 1930 and 2020, with a more significant (12.3%) forest cover loss between 1930 and 1975. Only 19,069 km<sup>2</sup> forest cover is available as an elephant habitat in Nepal and is reduced annually by 0.27%. During the last century, the continued fragmentation had fragmented elephant populations. It made them insular, with long-term ramifications for elephant conservation and human-elephant conflict (HEC) (Ram et al., 2021b). HEC has resulted in ~272 human deaths and a large amount of crop and property damages along with the ~ five elephants retaliation each year (Ram et al., 2021b), and gradually elephant poaching is also experienced in the Chure Madhesh Landscape (CTML) (Singh et al., 2019). The elephant habitat suffers from massive human encroachment, linear infrastructure development such as Madan Bhandari highway, Nijgadh Kathmandu fast track construction, and the proposed and ongoing railway constructions inside the forest (Mandal, 2020; Nefej, 2019). However, the CTML elephant population occurs as a meta-population. The meta-population, which hinges on continued elephant dispersal and mobility between patches, is threatened by infrastructure expansion (Bhattarai, 2019; Mandal, 2020; ten Velde, 1997).

Presently, there is considerable movement of large mammals in the CTML, including the elephant, tiger (*Panthera tigris*), rhino (*Rhinoceros unicornis*), and others (Archary and Ram, 2017; Service, 2021; Sharma et al., 2019). In the CTML, the elephant habitat is interspersed with humans, and thus, the interactions between the two species are

frequent. Some of those interactions turn negative, resulting in HEC (Ram and Acharya, 2020b). Elephants are among the less researched megaherbivore species in the CTML with a significant knowledge gap, including HEC. The HEC situations are dynamic; assessments have to be periodic to evolve contemporary strategies appropriate for the management. In this study, we examined a) landscape features associated with the HEC, and b) mapped conflict hotspots by modeling the probability of HEC with the hypothesis that a) Human elephant conflict (HEC) is associated with demography (ethnicity, education, family size) of the respondent and season of the conflict, b) Fragmentation configures human-elephant conflict in the landscape level, c) Availability of water is associated with human-elephant conflict in the landscape level.

## **5.2 Methods and materials**

### **5.2.1 Study area**

The study area Chure Terai Madhesh Landscape (CTML) (Figure 1.5)

### **5.2.2 Data collection**

#### ***5.2.2.1 Human elephant conflict (HEC) data***

The farmers who experienced elephant-related losses started reporting HEC incidents after implementing Buffer Zone programs (1998 or later), which provided relief to victims in the form of ex-gratia. Following an endorsement of the relief guidelines by the Government of Nepal during the year 2009, human-wildlife conflict data reported by victims were maintained systematically (Lamichhane et al. 2018). Therefore, we compiled all available data of human-elephant conflict (Human death, injury, crop, and property damage) from the Divisional Forest Offices (DFO) and Protected Area (PAs) offices across the CTML for twenty years (July 2001

to June 2020). The data includes the victim's name and address, date, type of loss, wildlife causing the loss, amount claimed and received. We also verified the information of HEC from annual reports of PAs, divisional forest offices, Department of National Parks & Wildlife conservation (DNPWC), and stakeholder consultation meetings (n=30).

#### ***5.2.2.2 Victim household questionnaire survey***

We identified five major HEC hotspots in the stakeholder consultation meetings and surveyed 10.3% of households (HH), selected randomly (n=1,116) of the total household (HH) using a structured interview with questionnaires. Upon receiving their consent, we interviewed either the head of the family or another adult member (age >18 years). The interviews were also recorded electronically, along with filling the questionnaire. We included demographic background, respondent's details, spatial and temporal information on the incidents, age, sex, literacy, address with GPS location, date/time of incidents along with the socio-economic status, and habitat characteristics of the respondent (Karanth et al., 2013; Lamichhane et al., 2018; Mukeka et al., 2019) (Supplementary information S9).

#### ***5.2.2.3 Landscape and habitat metrics***

We stratified the study area into 5 km<sup>2</sup> grids (n=1,407) using Arc GIS 10.5 to identify spatial factors at coarser scales (Naha et al., 2019, 2020a; Ram et al., 2021b). Next, we derived 12 landscape predictor variables for each cell for predicting human-elephant conflicts (HEC), in three different categories viz. a) fragmentation metrics (mean perimeter area ratio, effective mesh size, landscape heterogeneity) (S1, Table1); b) habitat characteristics (area of open forest, distance to protected areas, distance to forest area, area of permanent water, area of seasonal water, stream length, elevation); and c) human footprint (population density, length of road) (Naha et al., 2020a) (Table 5.1). Finally, we generated the binary and a counting statistic for the exact number of HEC events (treating each human fatality, injuries, crop, and property damage

as a single event) for each cell as a response variable for predicting the spatial HEC risk analysis (Naha et al., 2019, 2020b, 2020a).

Table 5.1: Landscape predictor variables

Types of variables	Predictor variables	Codes	Units	Range	Source /Description of data
<b>Habitat (Fragmentation metrics)</b>	Mean Perimeter Area Ratio	MPAR	Meter/hectare	0 – 0.34	Classified satellite images of 2020 (Landsat 8, 30 m resolution)
	Effective mesh size	MESH	Hectare	0 – 2,500	„
	Landscape Heterogeneity	SHDI	Numerical (ratio)	0 – 0.6900	„
<b>Habitat (Landscape variables)</b>	Area of Open Forest	AOF	m <sup>2</sup>	0 – 8,231,400	„
	Distance to Protected areas	DPA	meter (m)	0 – 107,477	„
	Distance to Forest Area	DFA	meter (m)	0 – 30,953.8	„
	Digital Elevation Model	DEM	M	100 – 3,602	SRTM Digital Elevation Data Version 4
	Area of seasonal water	ASW	m <sup>2</sup>	0 – 11,849,442	EC JRC/ Google Earth Engine
	Area of permanent water	APW	m <sup>2</sup>	0 – 1,937,874	EC JRC/ Google Earth Engine
	Length of the Stream	LS	M	0 – 197,724	Department of Survey, Nepal, digital topographic map
<b>Human footprint</b>	Length of the road	LR	Km	0 – 99.87	Open street map
	Population density	PD	persons per km <sup>2</sup>	0 – 12389.8	GPWv411: Population Density (resolution – 1 km <sup>2</sup> )

### 5.3 Data analysis

We carried out data analyses in the R statistical package v. 4.0.2 (R Core Team, 2020). We used the Pearson Chi-square test of independence (statistical significance  $\alpha = 0.05$ ) (Franke et al., 2012; Rao, 2002) to compare the association between frequency of elephant attacks and education of the respondent, ethnicity of the respondents, seasons of conflict, types of houses and family size. We used binary and count statistics data for HEC events in the grids to model the spatial spread and extent of human-elephant conflict (HEC) incidents obtained from the questionnaire survey as a response variable (Dan Clark, 2020). For the binomial distributions, the HEC presence/absence (presence coded as '1' and absence as '0') within the grid cell (25 km<sup>2</sup>) was used as a response variable and the other 12 landscape predictors as an explanatory variable (Table 1). Similarly, the frequency of HEC events within the grid cells was used as the response variable for the Poisson distribution with the same explanatory variables.

Multicollinearity test among these 12 explanatory variables (Table 5.1) was performed using VIF functions (vifcor function in package 'usdm') in R (Naimi, 2017). None of the variables were highly correlated (VIF value >5) (S2, Table 2). Thus, we used all the variables for model building (Chatterjee and Hadi, 2012). Next, we performed multivariate logistic regression by constructing the Generalized Linear Model (GLM) (Zuur et al., 2010) with the binomial and Poisson distributions of the response variable to analyze the effect of landscape features and human presence for HEC within the CMTL. We performed Moran's Index test using the ArcGIS Spatial Analyst tool for the initial model. The Morans test result showed the z-value (11.992), Moran's Index (0.), and (p-value < 0.01), which indicates, there is a less than 1% likelihood that spatial clustering of the HEC events was due to random chance (Bivand et al., 2013) and the distance threshold between each neighboring HEC site was 5,000.5 m. Finally, we performed

z-transformation of the variables to standardize the data and obtain the final model with standardized variables (Graf, 2004).

We constructed all possible models using the 'MuMIn' package in R version 1.43.17., with a combination of predictor variables and ranked them based on the small-sampled AIC (lower AICc value indicates higher model ranking) (Barton and Barton, 2020). We obtained the final model by averaging the top candidate models ( $AICc \leq 2$ ) (Burnham and Anderson, 2001). From the total data of 1,407 grid cells, 80% of samples were randomly selected for model building (training sample) and 20% for model validation (test sample). We checked the model's accuracy by comparing the predicted values and the actual value of the test samples. Predicted values of the model with the highest accuracy were reported.

Further, we generated the ROC curve and AUC values to predict the reliability of the dominant models using package ROCR in R 4.0.3. Finally, we expected the potential conflict hotspots based on the model results of the best performing and highest accuracy models. We used Arc Gis Pro (version 2.8.2) for preparing the HEC risk map from the best model of both binary and count data using the predictor variables (Naha et al., 2020a, 2019).

## **5.4. Results**

### **5.4.1. HEC records and interviews with the victims**

A total of 10,798 records of human-elephant conflicts (HECs) events were recorded within 203 grids (5\*5 km<sup>2</sup>) between January 2000 and June 2020. Out of which, 274 cases were human fatalities, 138 cases of human injuries, 6,606 cases of crop damages, and 3,757 cases of property damages (Table 5.2). The number of HEC incidents reported to the respective authorities since

2009 shows a gradual increase till 2017 and slightly decreased afterward. The highest number of HEC incidents were recorded in 2017 and 2018.

*Table 5.2: Spatial extent of HEC in the CTML.*

<b>District</b>	<b>Crop damage</b>	<b>Human death</b>	<b>Human injury</b>	<b>Livestock loss</b>	<b>Property damage</b>	<b>Total</b>
Banke	5	2	1			8
Bara		20	4			24
Bardiya	2,006	40	26	10	958	3,040
Chitwan	918	26	17	3	529	1,493
Dhanusha		9	3			12
Ilam		4				4
Jhapa	1,789	41	25	3	1,314	3,172
Kanchanpur	41	5	10		11	67
Mahottari		1				1
Makwanpur		5	4			9
Morang	1	8	4	6	15	34
Nawalparasi		1		1	3	5
Parsa	194	21	7	2	113	337
Rautahat		7	1			8
Saptari	403	23	11		276	713
Sarlahi		5	4			9
Sindhuli		9	3			12
Siraha		16	3			19
Sunsari	1,227	15	15		532	1,789
Udaypur	22	16			4	42
<b>Total</b>	<b>6,606</b>	<b>274</b>	<b>138</b>	<b>25</b>	<b>3,755</b>	<b>10,798</b>

Human elephant conflict (HEC) is distributed in the 20 districts of the CTML, which explored landscape-level spatial spreads of HEC throughout the landscape except for some districts viz. Nawalparasi, Kapilbastu and Rupandehi (Table 2). Similarly, the temporal pattern shows significantly fewer incidents before 2009 and increased spontaneously in 2017. The number of reported incidents slightly decreased afterward (figure 5.1).

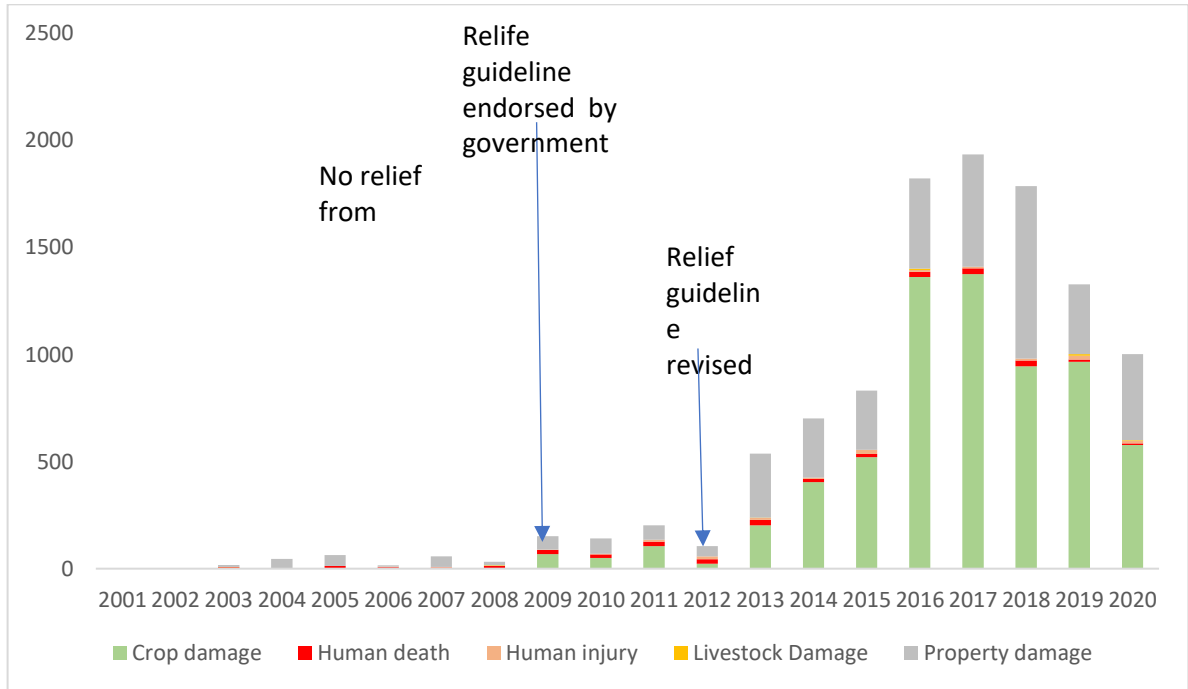


Figure 5.1: Temporal extent of human-elephant conflict (HEC).

Out of 10,798 HEC incidents, we interviewed ~10.3% of total households (n=1,116) and presented their characteristics in Table 5.2. There was no significant difference between HEC frequency and education of the respondents, cropping seasons. In contrast, HEC frequency differed significantly with ethnic groups, house types of respondents, and family size, which supported the first hypothesis, i.e., HEC is associated with the demographic feature of the respondents (Table 5.3).

Table 5.3. Characteristics of respondents.

Variables	Variable Components	Frequency	Percentage %	
Household Head	Female	242	21.7	
	Male	874	78.3	
Education of respondent	higher education	5	0.4	$\chi^2= 20.56, df = 12, p<0.06$
	Illiterate	537	48.1	
	Literate	201	18	
	Primary level	222	19.9	
Cast/Ethnicity	Secondary level	151	13.5	$\chi^2= 43.78, df = 12, p<0.000$
	BCT	416	37.3	
	Dalit	147	13.2	
	Janjati	466	41.8	
	Madhesi	76	6.8	
Season of conflict	Muslim	12	1.1	$\chi^2=3.52, df = 9, p<0.94$
	Monsoon	416	37.3	
	Spring	147	13.2	
	Summer	466	41.8	
Types of houses	Winter	76	6.8	$\chi^2= 146.88, df = 15, p<0.001$
	Cemented house	117	10.48%	
	GI roof house	441	39.52%	
	Thatch house	499	44.71%	
	Thatch roof house	26	2.33%	
	Tiled roof house	32	2.87%	
Family size	Wooden house	1	0.09%	$\chi^2= 21.10, df = 9, p<0.01$
	<5 person	499	44.71%	
	5-10 person	541	48.48%	
	10-15 persons	50	4.48%	
	>16	26	2.33%	
	Total	1,116		

## 5.4.2. Landscape predictors of HEC

We ran GLMs with the binomial distribution (presence of conflict -1, absence of conflict 0) and also with Poisson distribution (grid wise count of conflict incidences). The direction of influence of predictor variables on response was consistent across both response variables presence/absence of conflict (binary) and number of conflict incidences (count) (Table 5.4a,5.4b). The results of binomial GLMs are presented in table 5.4 a) and 5.5, and of Poisson GLMs result presented in Table 5.4b) and Table 5.6. The model with additive influence of Area of open forest (AOF), Area of permanent water (APW), Area of seasonal water (ASW), Altitude (DEM), Distance to forest area (DF), Length of the stream (LS), Effective mesh size (MESH), Mean perimeter area ration (MPAR), Population density (PD), and Landscape heterogeneity (SHDI) appeared as best model among the candidate set (Table 5.4a). However, there is high amount of model uncertainty among candidate set indicted by similar model weight (Table. 5.4a). And, since no single model appeared to explain the data substantially, we did full model averaging to compute effect size of the predictor variables (Table 5.5).

Table 5.4: Second-order Akaike Information criterion scores (AICc ,  $\Delta AIC$  & AIC weight) of a generalized linear model with a) Binomial and b) Poisson structure predicting HEC using landscape predictors.

Component models*	df	AICc	$\Delta AIC$	AIC weight	LogLik
a) Binomial distribution					
AOF + APW+ ASW+ DEM + DF + LS +MESH+ MPAR+ PD + SHDI	9	699.09	0	0.27	-340.46
AOF + APW+ ASW+ DEM + DF + MPAR+ SHDI	8	699.69	0.6	0.2	-341.78
AOF + APW + ASW + DEM + DF + LS+ MESH+ MPAR + SHDI	10	699.77	0.68	0.19	-339.79
AOF + APW + ASW + DEM+ DF MESH+ MPAR + SHDI	9	700.56	1.47	0.13	-341.2
AOF + APW + ASW + DEM + DF + DPA + LS + MPAR+ SHDI	10	700.66	1.57	0.12	-340.23
AOF + APW +ASW+ DEM+ DF+ LS + MPAR + PD + SHDI	10	701.05	1.96	0.1	-340.43
b) Poisson distribution					
AOF+ APW+ ASW +DEM+ DF+DPA+ LR+ MPAR + PD+ SHDI	11	4963.7	0	0.27	-2470.76
AOF+ APW+ ASW +DEM+ DF+DPA+ LR+LS+ MPAR + PD+ SHDI	12	4963.99	0.29	0.24	-2469.88
APW+ ASW +DEM+ DF+DPA+ LR+ MPAR + PD+ SHDI	10	4964.16	0.45	0.22	-2472

\* The variables used in the model are Area of Open Forest (AOF), Area of Permanent Water (APW), Area of Seasonal Water (ASW), Digital Elevation Model (DEM), Distance to Forest (DF), Distance to Protected Areas (DPA), Length of the Road (LR), Length of the Stream (LS), Effective Mesh Size (MESH), Mean Perimeter Area Ratio (MPAR), Landscape Shape Index (SHDI)

Results of the dominant model demonstrate that the probability of HEC increased with decreasing distance from the forest (DFA), protected area, elevation and area of permanent water. However, probability of HEC increased with increase in open forest area (AOF), area of seasonal water (ASW), mean perimeter areas ratio (MPAR) and landscape heterogeneity (SHDI) (Table 5.5). The fragmentation metrics viz. mean perimeter area ratio (MPAR) and landscape heterogeneity (SHDI) have increased the intensity of human elephant conflict, so it justified the second hypothesis. Similarly, the increased in the area of seasonal water and decreased in the area of permanent water (APW) have also positive effect on the increasing HEC in the study area, which justified third hypothesis (Table 5)

Table 5.5: Coefficients of the best GLM model with binomial structure.

	Estimate	Std. Error	Adjusted SE	z value	Pr(> z )	Significance	CI (2.5% - 97.5%)	
(Intercept	-3.13	0.25	0.25	12.66	< 2e-16	***	-3.70	-2.71
AOF	0.29	0.10	0.10	2.74	0.01	**	0.07	0.48
APW	-0.62	0.23	0.23	2.77	0.01	**	-1.10	-0.23
ASW	0.77	0.21	0.21	3.68	0.00	***	0.39	1.20
DEM	-2.71	0.40	0.40	6.72	< 2e-16	***	-3.70	-2.08
DF	-1.44	0.42	0.42	3.45	0.00	***	-2.27	-0.58
LS	0.12	0.12	0.12	0.99	0.32		-0.02	0.40
MPAR	0.39	0.15	0.15	2.60	0.01	**	0.01	0.63
SHDI	0.32	0.14	0.14	2.28	0.02	*	0.07	0.65
MESH	0.05	0.11	0.11	0.46	0.64		-0.13	0.45
DPA	-0.01	0.04	0.04	0.20	0.84		-0.28	0.15
PD	0.00	0.06	0.06	0.08	0.93		-0.44	0.25

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

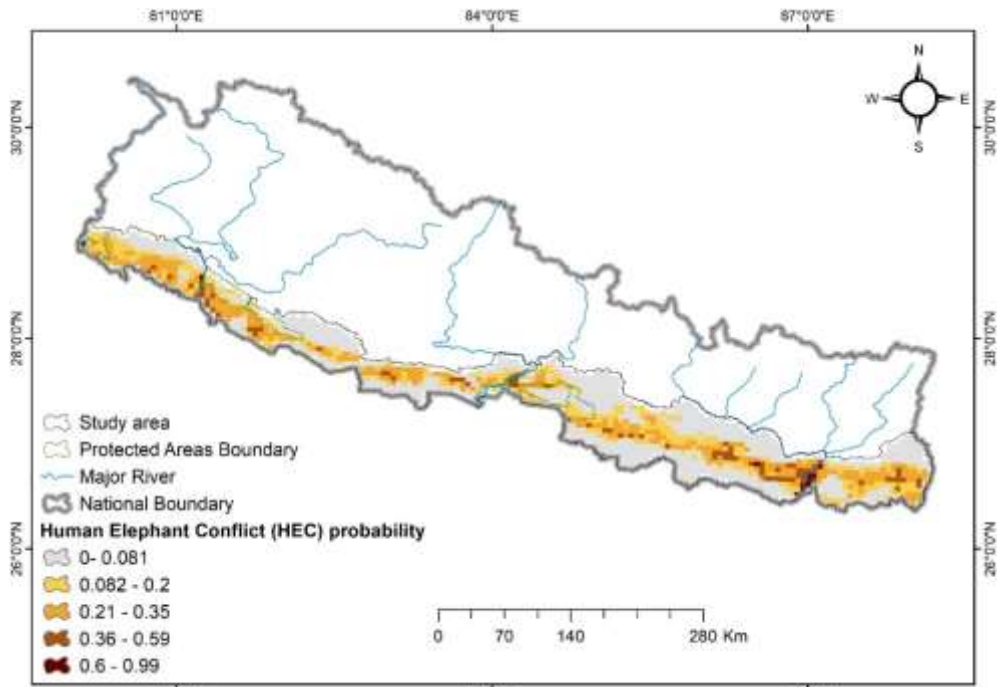
Table 5.6: Coefficients of the best GLM model with Poisson structure.

	Estimate	Std. Error	Adjusted SE	z value	Pr(> z )	Significance	CI (2.5% - 97.5%)	
(Intercept)	-2.29471	0.11962	0.11972	19.167	< 2e-16	***	-2.5337	-2.06534
AOF	0.02481	0.0334	0.03341	0.743	0.458		-0.01967	0.107541
APW	-0.27476	0.03735	0.03738	7.35	< 2e-16	***	-3.53E-01	-2.07E-01
ASW	0.18952	0.02883	0.02885	6.569	< 2e-16	***	0.125463	0.240228
DEM	-3.07785	0.17765	0.1778	17.311	< 2e-16	***	-3.44E+00	-2.75E+00
DF	-0.88687	0.19693	0.1971	4.5	6.80E-06	***	-1.33384	-0.49423
DPA	-0.81414	0.05065	0.05069	16.06	< 2e-16	***	-9.30E-01	-7.29E-01
LR	-0.17987	0.04393	0.04397	4.091	4.30E-05	***	-0.26243	-0.09016
MPAR	0.1785	0.01822	0.01824	9.787	< 2e-16	***	0.137806	0.214669
PD	-0.34738	0.08095	0.08102	4.288	1.81E-05	***	-0.52036	-0.2005
SHDI	0.84876	0.05138	0.05142	16.505	< 2e-16	***	0.717825	0.9705
LS	0.02755	0.03877	0.03879	0.71	0.477		-0.02789	0.123817
NDVI	-0.01263	0.03118	0.0312	0.405	0.686		-0.12201	0.051404

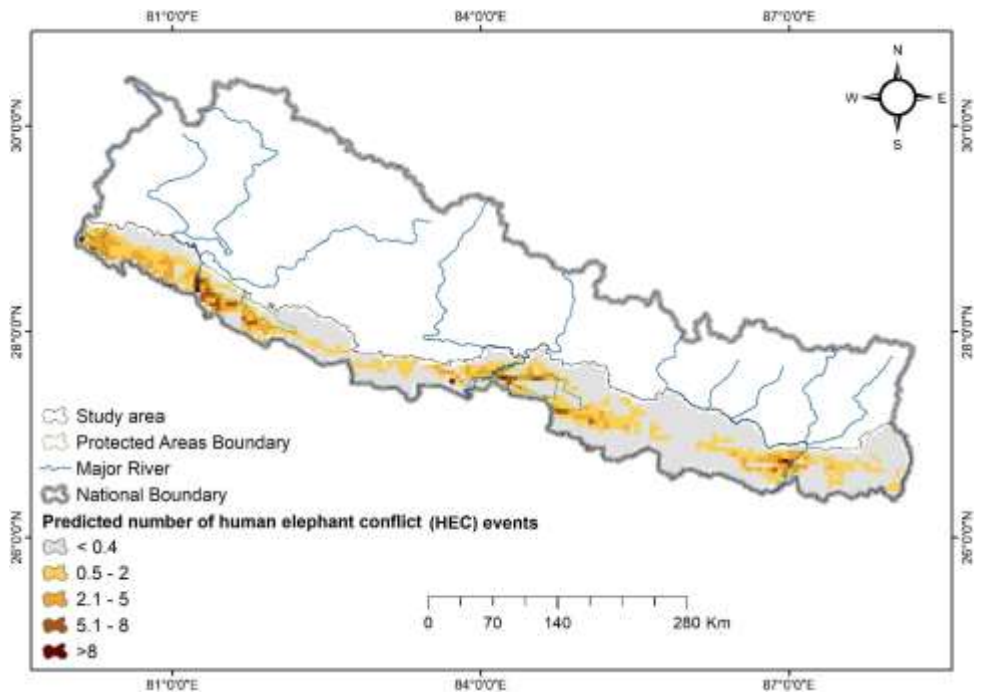
Significance codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

### 5.4.3. HEC prediction in Chure Terai Madhesh Landscape

The receiver operating curves (ROC) values for the dominant model (GLM with binomial structure) were estimated at 0.86 (86.83% accuracy). The HEC probability maps were prepared based on best model coefficients, indicated that Jhapa and Koshi (eastern region), Parsa and Chitwan (central region), and Bardia and Shuklaphanta (far western region) areas were the highest HEC hotspots. We also found that HEC probabilities were higher near the forest boundary and in the proximity of protected areas. The binomial probability and Poisson prediction of Human elephant conflict (HEC) risk map showed that HEC is distributed throughout the Chure Terai Madhesh Landscape (CTML) (Figure 5.2a, b). The HEC prediction map also showed that the probability of HEC will also be higher in Jhapa, Koshi, Chitwan- Parsa complex and Bardiya with highest expected numbers >8 events per grids. (Figure 3b)



a)



b)

Figure 5.2: a) HEC probability map using the binomial model results, darker areas indicate high risk areas, b) expected number of HEC risk map using the best model of Poisson structure. The darker color means the higher probability of conflict.

## 5.5. Discussion

This is a comprehensive study on landscape predictors of HEC in Nepal. We documented a high level of HEC, primarily crop and property damage, clustered in four sites of CTML (Jhapa, Koshi, Chitwan, and Bardiya). The extent of conflict differed significantly among various communities based on their socio-economic status and cropping patterns which support the first hypothesis (Table 3). Our results suggest that landscape features are significant predictors of HEC in CTML. Landscape structure, water availability, elevation, and human footprint were the significant factors associated with HEC. which supports the second and third hypothesis (Table 5).

### 5.5.1. The Spatio-temporal extent of HEC in the CTML.

Although human-elephant conflict (HEC) was recorded from the 20 districts of the CTML (Table 2), Bardiya, Chitwan, Parsa, Jhapa, and Sunsari districts experienced the highest HEC (Ram et al. 2021; Acharya et al. 2016). The highest number of HEC events occurred around protected areas (PAs) except in the Jhapa district (Table 2). The elephant population is concentrated in and around protected areas (e.g., >100 in Bardia, 40-60 in Chitwan/Parsa) (Ram and Acharya, 2020a). Thus, a higher conflict probability close to these forests is expected (Gross et al., 2019). HEC incidents are relatively high in eastern Nepal (Koshi and Jhapa) despite the small population of elephants. The reason could be a) widespread forest fragmentation, loss of forest corridors in this region (Ram et al., 2021b), and b) seasonal migration of elephants from a nearby park in India (Naha et al., 2019; Padalia et al., 2019). Studies from the other elephant range in India, Srilanka, and Africa also show similar findings with a clustered pattern of HEC (Fernando et al., 2021; Gubbi, 2012).

Elephant population was small and confined in a few pockets in Jhapa, Parsa, and Shuklaphanta in Nepal before 2000; and low level of HEC was reported (Shrestha et al., 1985; Smith and Mishra, 1992), HEC is gradually increasing after 2000 (Acharya et al. 2016; Ram et al. 2021),

along with growing elephant population. There was no systematic recording of HEC incidents in Nepal before 2009, although buffer zone programs kept a record of the relief payment for the loss from wildlife, including elephants (Lamichhane et al., 2018). HEC events were recorded systematically after the Government endorsed relief for wildlife damage nationally in 2009 ((Acharya et al. 2016; Pant et al. 2015; Ram et al. 2021). Initially, only human death and injuries on elephant attacks were considered for relief. Thus, crop and property damage events were not reported. The relief guideline was further amended in 2012 to include crop and property damage by elephants, and the payment procedure was clearly defined (Figure 5.3). Afterward, a continuous increase was seen in registering human Elephant conflict (HEC) events with a peak in 2017(Lamichhane et al., 2018). In 2020, we only included HEC incidents up to June. Thus, the incidents seem comparatively more minor (Figure 3). Increasing HEC incidents have been reported in other elephant range countries (e.g., India, Srilanka) (Karanth et al., 2013; Ranjeewa et al., 2017; Shaffer et al., 2019, 2014) .

### **5.5.2. Human elephant conflict (HEC) & socio-economic status of respondents**

The HEC incidents were not evenly distributed among the various socio-economic classes of the respondents. Socio-economic features such as ethnicity, house types of respondents, and family size were associated with the conflict. The frequency of HEC was recorded higher in the Janajati (ethnic people). Many ethnic people are socio-economically marginalized and highly depend on forest resources, increasing the chances of a conflict. Moreover, the ethnic people also use/produce alcohol in their locality, attracting elephants, expanding the competition. Ram et al. (2021) also reported the increased threat of elephant attacks on humans when people are drunk (Ram et al., 2021a). There was a significant difference in the frequency of HEC incidents with the type of housing of the surveyed respondents, with people living in Thatch house or GI

roof house suffering more frequently than concrete or wooden. People living in thatch houses are generally poor and marginalized, with a high dependency on forests for their livelihood (Ram et al., 2021a). Despite some seasonal variation in the frequency of HEC incidents, the difference was not significant statistically, though the seasonality of HEC differed among the elephant range counties (Gross et al., 2018; Lakshminarayanan et al., 2016).

### **5.5.3. Landscape predictors and HEC**

Our result shows that fragmentation indices viz. Landscape heterogeneity (SHDI), Mean Perimeter Area Ratio (MPAR), and Effective mesh size (MESH) are the major predictors of HEC in the landscape (Naha et al., 2019; Ram et al., 2021b). This is due to the higher rate of forest loss and fragmentation, especially in the forests outside of the protected areas. Forest fragmentation intensifies the challenges to the conservation of large-ranging species viz. elephants and tigers which require large areas beyond the protected areas for their survival. These animals came in to contact with humans while navigating through their migratory routes in fragmented landscapes, resulting in a large number of HEC incidents (Ram et al., 2021b). The forest fragmentation is likely to increase in coming days with expansion of linear infrastructure, degradation of forest and rapid expansion of settlements along the forest edge which could worsen the HEC (Acharya et al., 2017; König et al., 2020; Naha et al., 2019; Ram et al., 2021b).

Similarly, the HEC incidents increased with the decrease in coverage of permanent water but increase in area of seasonal water. Water is the crucial component of the habitat. Elephant frequently use the areas of seasonal water while passing through the migratory routes and often come in conflict with local communities (Naha et al., 2019). In the locations with larger areas of permanent water, elephant don't need to travel long distance to find water sources. This reduces the chances of elephant encounter with the local communities resulting the reduced HEC.

Our finding shows a high HEC risk in the proximity to forest, and decreased with increasing distance from the forest boundary which is similar to previous studies (Naha et al., 2019; Pant et al., 2015; Ram et al., 2021a). HEC decreased with increasing altitude, as elephant preferred flat lands, grasslands and low land forests. Our records of HEC include the locations with the altitude between 67m (Prithiwinagar, Jhapa) and 587m (Makwanpur & Sindhuli) and elephant presence signs were detected up to 885m of Chure Hills. Prediction of HEC risks in the CTML landscape.

#### **5.5.4. Prediction of HEC risks in the CTML landscape.**

Spatial risk zones analysis is used as a practical approach to devise mitigation measures for human-wildlife conflicts globally (Treves et al., 2011). The probability map shows the high HEC probability from Jhapa to Chitwan in the eastern landscape and Banke to Kanchanpur in the western landscape (Figure 5.3) (Naha et al., 2020b, 2019). HEC incidents are high in the eastern landscape despite a relatively small resident population. Most of the elephants in the east of Nepal are males dispersed in different parts in smaller groups (Ram et al., 2021a). Males are more aggressive and, thus, confront people frequently, increasing the chances of HEC. Before 2015, a herd of migratory elephants entered Nepal annually from the Bahundangi area of Jhapa (eastern border). After installing the electric offset fence, the large herd moved southward, and only a few risk-taker bulls entered Nepal, breaking the fence. In the western landscape, the elephant population is relatively large. It causes damage while migrating Nepal-India or different forest patches in Nepal through the forest corridors and sometimes settlement areas. Therefore, the government and conservation organizations should focus their HEC management effort, including awareness campaigns, fencing, and other HEC mitigation measures in the areas with a high probability of conflicts. At present, wildlife conservation is concentrated primarily inside the protected areas (PAs), and adequate measures were not adopted in forests outside the protected areas. However, most HEC incidents were recorded

outside protected areas (Naha et al., 2020b; Ram et al., 2021b), and little effort has been made to safeguard elephants there.

Habitat fragmentation is likely to increase with ongoing and planned infrastructure development, many of them going along or passing through the CTML. For instance, Nijgadh-Kathmandu fast track (under construction), Bardiwa-Simara electric railway line, additional electric transmission lines (under construction) have also resulted in tremendous loss of forest and induced habitat fragmentation (Khatiwada, 2018; Mahat, 2020; Puri, 2021). In addition to these, forest encroachment for community purposes such as schools, colleges, temples, picnic spots, football grounds, Hat bazaars has also destroyed the forest in recent decades. Thus, fragmentation is continued in the CTML due to the highest demand for land (by the hill migrants) and valuable timber (Aryal et al., 2020; Laudari et al., 2020).

## **5.6. Conclusion**

Our results conclude that forest fragmentation and degradation, proximity to forest, altitude, and surface water availability were the significant landscape predictors contributing to the HEC. Socio-economically marginalized communities living close to forests are more vulnerable to HEC. HEC is a multifaceted issue, not limited to protected areas. Thus, it is necessary to extend our conservation priority beyond the boundary of the protected areas. Our study recommends the requirements of a long-term landscape-level HEC strategy and action plan to mitigate HEC in the predicted HEC risk zones in forest proximity.

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(Photo credit: Buddi Binod Acharya)

## **Chapter 6: Synthesis**

## **Chapter 6: Synthesis**

### **6.1. Introduction:**

Elephant, as a mega herbivore, plays a vital role in ecosystem functioning by acting as an ecosystem engineer and a flagship species but is restricted to <5% of the global landmass (Leimgruber et al., 2003). It is distributed in the 13 Asian range countries while being listed as a protected species in schedule I of the wildlife conservation act of Nepal (DNPWC, 2009). However, it is served as critically endangered in some parts of Asia (Alamgir et al., 2015). Habitat loss, degradation, fragmentation has played a critical role in surviving this mega creature by staying in coexistence with humans (Karanth et al., 2012; Lambin et al., 2001).

However, elephants are not restricted inside any protected areas; they have distributed throughout the landscape (Lamichhane et al., 2017). However, some secure areas (PAs) had a residential population of elephants, and some protected areas acted as stepping stones during the dispersal (Schüßler et al., 2018). During diffusion, elephants interact with humans in the Chure Terai Madhesh Landscape (CTML), causing a massive crop and property loss. It is also fatal to humans and elephants (Ram, 2014; ten Velde, 1997).

To cope with this, GON has also initiated some alternative strategies where both humans and wildlife coexist by sharing the same resources (Chaudhary and Subedi, 2019; MoFSC, 2015), declaring protected corridors viz. Khata, Basanta, Kamdi, Barandbhar, Karnali, Balmiki Chitwan parsa, Laljhadi Mohana, and the landscape level conservation program initiated as a metapopulation approach. The Terai Arc Landscape (TAL) program is an example of such a landscape-level conservation program contributing to the conservation

of mega herbivore and many other rare and wide-ranging endangered mammals in Nepal and India (Thapa, 2014; Thapa et al., 2019).

Elephants are regarded as lord Ganesha in Hindu culture and worshiped in many Asian countries; however, some elephants are killed in retaliation (Madden, 2004; Menon Vivek, 1991; Sukumar, 2006, 1989). HEC resulted in damages to both human lives or livelihoods and threatened the survival of these mega creatures (Barua et al., 2013; Dickman, 2010; Woodroffe et al., 2005). Managing such impacts is challenging and requires a comprehensive strategy, action plan, and a clear understanding of human-elephant conflicts (HEC) for long-term conservation (Acharya et al., 2016). There are many studies carried out focusing on habitat, conflict, and population but non or very few studies were carried out in the landscape level (Acharya et al., 2017; Koirala et al., 2016; Neupane et al., 2017; Pradhan et al., 2011; Sharma et al., 2020, 2019; Wegge et al., 2012), (Acharya et al., 2016; Kanagaraj et al., 2019; Lamichhane et al., 2018). Therefore, I conducted this study on "Landscape-level modeling of Asian elephant habitat, population and its interaction with humans in Nepal" and chose the Chure Terai Madhesh Landscape (CTML) with the following chapters and answered the objectives-wise research questions in different the four chapters (2-5). I have mentioned chapter-wise research questions.

## **6.2. Research questions were**

### **Chapter 2: Status and distribution of elephants in Nepal**

- a. How much area is occupied by elephants across Nepal?
- b. How much habitat is suitable for elephants?
- c. How many individual elephants are surviving in Nepal?

**Chapter 3:** Tracking Forest loss and fragmentation in the Chure Terai Madhesh Landscape (CTML) of Nepal (*Published: Ram et al 2021*)

d. How is the forest cover changing over time?

e. How is the forest fragmentation taking place in the four elephant ranges of Nepal?

**Chapter 4:** Patterns and determinants of elephant attacks on humans in Nepal (*Published: Ram et al 2021*)

f. What are the Spatio-temporal patterns of elephant attacks on humans in Nepal?

g. What are the factors responsible for elephants' attacks on humans?

**Chapter 5:** Landscape predictors of human-elephant conflict (HEC) in the Chure Terai Madhesh Landscape (CTML) of Nepal (*Article in review*)

h. What are the significant landscape predictors responsible for inducing human-elephant conflicts in TAL and Nepal?

i. How do elephants interact with humans in the highest human-elephant conflict (HEC) hotspots?

We have answered the research questions in the four chapters (Chapter 2 - 5, presented as research papers). Two out of four chapters were published, and another one (chapter 5) is under review in the Journal of environmental challenges of Elsevier. Chapter 2 examines the historical forest loss and fragmentation between 1930 and 2020 in the elephant ranges, while Chapter 3 provides an overview of elephants' status, distribution, and population size. Chapter 4 explored the patterns and determinants of elephant attacks on humans and the factors associated with elephant attacks on humans. Chapter 5 examined the landscape

predictors that helped induce human-elephant conflict (HEC) and predicted the possible HEC hotspots in the CTML. Chapter 1 explored the study's gaps and introduced the species and the study area where last chapter 6 summarizes the findings of chapters 2 - 5.

### **6.3. Tracking Forest loss and fragmentation in the Chure Terai Madhesh**

#### **Landscape (CTML) of Nepal**

Elephant suitable habitat area is distributed to 12059 km<sup>2</sup> (Ram and Acharya, 2020). Their population and occupancy have increased in the 23 districts of the study area. This result suggests that the human-elephant conflict (HEC) will likely increase throughout the landscape except for some communities. We need to explore the historical forest cover loss, fragmentation, and human-elephant interaction status in the study area. Therefore, we accomplished this study using long-term historical data of 90 years, explored the forest cover change status and annual forest cover loss, and quantified landscape forest fragmentation status in elephant habitats. We used remote sensing, Google Earth Engine, and ArcGIS platform to analyze the forest cover change, loss, and fragmentation.

As estimated, only 24,315 km<sup>2</sup> forest cover was found in 1930 and reduced by an annual rate of 0.27% in 2020. However, the overall deforestation rate was (0.29%) between 1930 and 1975, which was higher (Ram et al., 2021b).

This study shows that 21.58% of the forest area was converted into agriculture and settlements between 1930 and 2020. The fragmentation result showed that the Core 3 size was decreased by 43.08%, whereas the length of core 2 and core 1 size was increased by 320.86%.

The historical forest fragmentation (1930-2020) analysis found that the number of patches was increased from 201 to 28,559 between 1930 and 2020. The edge metrics showed that edge density increased from 548 (m/km<sup>2</sup>) to 3630 (m/km<sup>2</sup>), mean patch edge was reduced to 2,426.63 (Ram et al., 2021b).

#### **6.4. Status and distribution of elephants in Nepal.**

This chapter presented the overall occupancy of elephants throughout the landscape using single species single-season occupancy with correlated replicates. We found that the elephants occupied 23 districts out of 25 districts partially or wholly. Furthermore, we found the naïve occupancy 0.51, detection probability 0.12, and the estimated occupancy 0.43, which shows that elephants are distributed in two subpopulations, i.e., eastern (Jhapa to Chitwan-parsa complex) and western (Kanchanpur to Kapilbastu), and only Rupandehi and western Nawalparasi districts were lacking the elephant's presence.

The previous study on elephant occupancy suggested that  $0.57 \pm 0.06$  in the same landscape with naïve occupancy 0.43 (Lamichhane et al., 2017) and Lakshminarayan et al 2016 found that the elephant habitat use was 0.04 (0.15) to 0.99(0.01) in the elephant habitat of India where the forest is intact. Still, this study shows a 0.12 detection probability, and the estimated occupancy was 0.43. It might be due to massive forest fragmentation and less elephant migration through the landscape. However, the detection probability of elephants inside the protected area was quite high in Nepal (Lamichhane et al., 2017).

We used block count methods and counted all the individual animals, photographed and visualized by following each herd in three consecutive years (Sukumar, 1989; Varma et

al., 2012). All the photographs were identified as per the phenotypic characters, counted and recorded in the excel sheet, were further analyzed, and come up with the current population by averaging the count data of three years, 2017, 2018, and 2019. As a result, we counted 203-227 residential elephants along with 120-150 additional migratory elephants and 210 captive elephants tamed in captivity (Ram and Acharya, 2020).

#### **6.5. Patterns and determinants of elephant attacks on humans in Nepal (Published: Ram et al 2021)**

We accomplished this chapter by examining the Spatio-temporal patterns of elephant attacks on humans and also explored the factors associated with elephants' attacks on humans. We further explored the determinants of elephant attacks on humans. We found that altogether 278 people were killed during the last 20 years (2000 and 2020), and also 138 people were injured severely. Elephant attacks on humans differed significantly across months, with a peak in the post-monsoon season (September to December). The number of attacks was higher outside protected areas, but the difference was insignificant. Linear regression showed a gradual increase in elephant attacks on humans. Average annual attacks were 11 ( $\pm 8.5$  SD) during 2000–2010 and increased to 29 attacks ( $\pm 11.2$  SD) during 2011–June 2020. Twenty humans were attacked each year in elephant attacks. A higher number of attacks by elephants on humans occurred in the proximity of the forest (66.99 % attacks in  $< 500\text{m}$  from forest edge), supporting our second hypothesis, and more people were attacked outside the protected areas also found the 37 solitary bulls caused 76% of the attacks on humans in the landscape (Ram et al., 2021a).

## **6.6. Landscape predictors of human elephant conflict (HEC) in the Chure Terai**

### **Madhesh Landscape (CTML) of Nepal (Article in review)**

I have examined the significant landscape predictors responsible for inducing human-elephant conflicts and predicted the hotspots in the TAL and across landscapes.

We found a total of 10,798 records of human-elephant conflicts (HECs) events within 203 grids (5\*5 km<sup>2</sup>) between January 2000 and June 2020. Out of which, 274 cases were human fatalities, 138 cases of human injuries, 6,606 cases of crop damages, and 3,757 cases of property damages (Table 2). The number of HEC incidents reported to the respective authorities since 2009 shows a gradual increase till 2017 and slightly decreased afterward. The highest number of HEC incidents were recorded in 2017 and 2018.

Human elephant conflict (HEC) is distributed in the 20 districts of the CTML, which explored landscape-level spatial spreads of HEC throughout the landscape except for some districts viz. Nawalparasi, Kapilbastu and Rupandehi. Similarly, the temporal pattern shows very few incidents before 2009 and increased spontaneously in 2017. The number of reported incidents slightly decreased afterward.

Our results conclude that forest fragmentation and degradation, proximity to forest, altitude, and surface water availability were the significant landscape predictors contributing to the HEC. Socio-economically marginalized communities living close to forests are more vulnerable to HEC. HEC is a multifaceted issue, not limited to protected areas. Thus, it is necessary to extend our conservation priority beyond the boundary of the protected areas.

The HEC prediction map indicated that Jhapa and Koshi (eastern region), Parsa and Chitwan (central region), and Bardia and Shuklaphanta (far western region) areas were the highest HEC hotspots. We also found that HEC probabilities were higher near the forest boundary and in the proximity of protected areas. Binomial and Poisson prediction of Human elephant conflict (HEC) risk map shows that HEC is distributed throughout the Chure Terai Madhesh Landscape (CTML).

Spatial risk zones analysis is used as a practical approach to devise mitigation measures for human-wildlife conflicts globally (Treves et al., 2011). The probability map shows the high HEC probability from Jhapa to Chitwan in the eastern landscape and Banke to Kanchanpur in the western landscape (Naha et al., 2020, 2019). HEC incidents are high in the eastern landscape despite a relatively small resident population. Most of the elephants in eastern Nepal are males dispersed in different parts in smaller groups (Ram and Acharya, 2020).



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## Annexures

Annex I: List of Seminars' certificates.

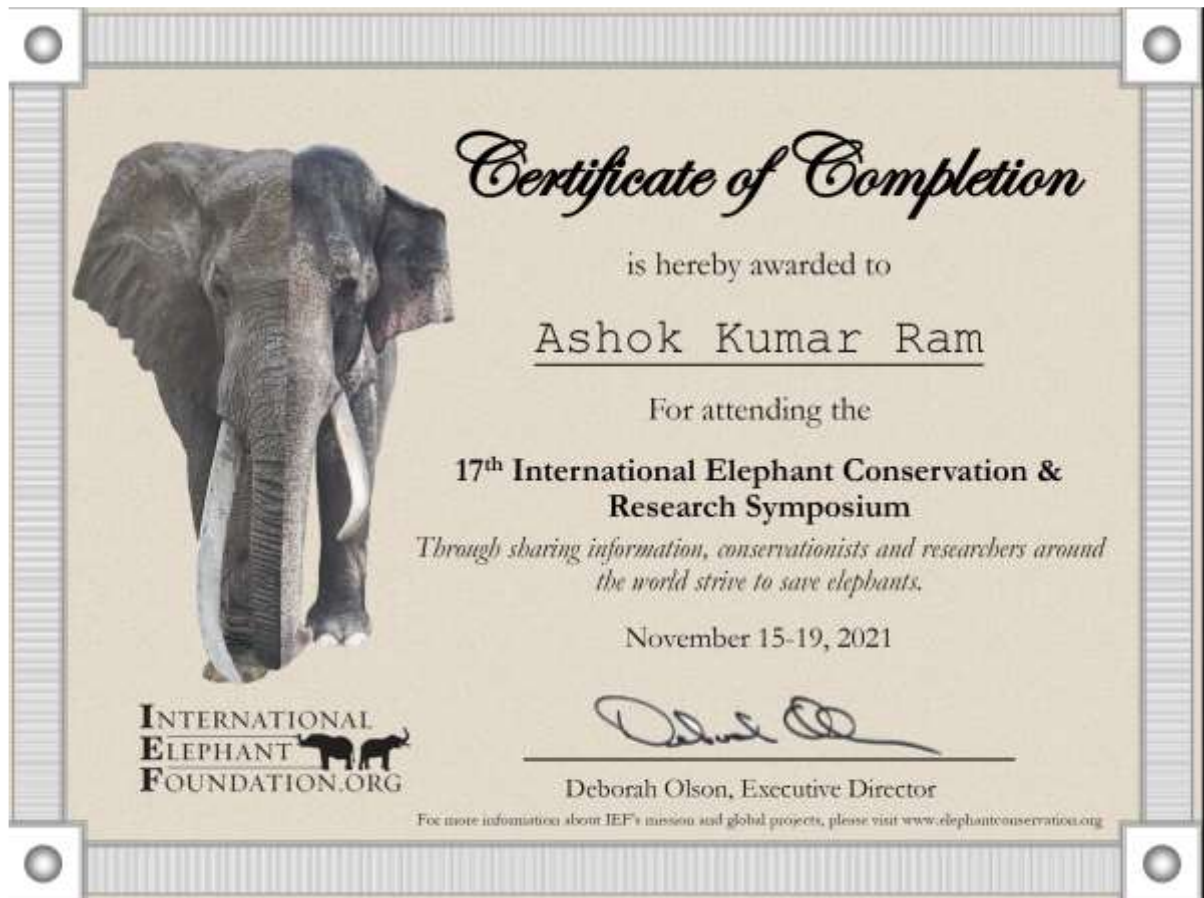
- a. I have resented on the topic “Human elephant coexistence in Nepal” at the virtual webinar episode 15, organized by Himalayan Nature on 12 Sep 2020.



b. I have resented on the topic “Human elephant conflict and coexistence in Chure Terai Madhesh Landscape of Nepal”, organized by Society for Conservation Biology under the regular “Conservation science talk series” virtually on August 31, 2021, in the



c. I have resented on the topic “Tracking Forest loss and fragmentation between 1930 and 2020 in the Asian elephant (*Elephas maximus*) range of Nepal, at the 17<sup>th</sup> International Elephant Conservation and Research Symposium virtually on November 15-19, 2021; which was organized by International Elephant foundation.



d. I have resented on the topic “Patterns and determinants of elephant attacks on humans in Nepal” virtually at the VII international conference on Mammoths and their relatives on 25-28 October 2021, organized by the Indian Institute of Science, India. (Certificates is under a process of preparation)



## Annex II: Research Ethics statement

I obtained research permissions from the Department of National Parks and Wildlife Conservation Nepal (DNPWC) (Ref no: 3066/073/74; June 02, 2017) and Ministry of Forest and Environment (MOFE) Nepal and carried out research including stakeholder consultation, focus group discussion, field occupancy survey, ground trothing and questionnaire surveys by verbal consent from the participants for the ground verifications.





OPEN

## Tracking forest loss and fragmentation between 1930 and 2020 in Asian elephant (*Elephas maximus*) range in Nepal

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Forest cover is the primary determinant of elephant distribution, thus, understanding forest loss and fragmentation is crucial for elephant conservation. We assessed deforestation and patterns of forest fragmentation between 1930 and 2020 in Chure Terai Madhesh Landscape (CTML) which covers the entire elephant range in Nepal. Forest cover maps and fragmentation matrices were generated using multi-source data (Topographic maps and Landsat satellite images of 1930, 1975, 2000, and 2020) and spatiotemporal change was quantified. At present, 19,069 km<sup>2</sup> forest cover in CTML is available as the elephant habitat in Nepal. Overall, 21.5% of elephant habitat was lost between 1930 and 2020, with a larger (12.3%) forest cover loss between 1930 and 1975. Area of the large forests (Core 3) has decreased by 43.08% whereas smaller patches (Core 2, Core 1, edge and patch forests) has increased multifold between 1930 and 2020. The continued habitat loss and fragmentation probably fragmented elephant populations during the last century and made them insular with long-term ramifications for elephant conservation and human-elephant conflict. Given the substantial loss in forest cover and high levels of fragmentation, improving the resilience of elephant populations in Nepal would urgently require habitat and corridor restoration to enable the movement of elephants.

Deforestation and conversion of natural areas into human use impacts the earth's ecosystems and functions, and threatens biodiversity<sup>1,2</sup>. The population of many wildlife species are declining globally, and about a million species are under threat of extinction primarily due to habitat loss/degradation, overexploitation, climate change, illegal wildlife trade, direct persecution, and conflict with humans<sup>3-5</sup>. Fragmentation is a significant factor leading to the loss of biodiversity in forested landscapes<sup>6</sup>. Habitat fragmentation affects ecological patterns and processes by increasing the number of forest patches, reducing the patch size, interrupting connectivity within the ecological network<sup>7-9</sup>, and impacting several species<sup>10</sup>. Habitat fragmentation could alter animal communities and trigger cascading effects on plants and ecosystem functions, including their carbon storage potential<sup>11-13</sup>. Continued fragmentation can lead to microclimatic changes in the edges, reduced core habitat, and eases the establishment of invasive species towards the forest interiors<sup>14,15</sup>.

Effects of fragmentation on wide ranging large mammals like elephants is more severe and increases the extinction risks due to their needs for large and intact habitats<sup>16-18</sup>. With the current rise in anthropogenic impacts and loss of wildlife habitats, shared heterogeneous landscapes around protected areas have immense potential for long term conservation of large mammals<sup>19,20</sup>.

Elephants are the largest living terrestrial mammals facing typical threats of large mammals such as habitat loss, poaching and conflict with communities<sup>21</sup>. The increase in human population and expansion of agriculture had led to habitat loss and fragmentation, resulting in a significant decline in elephant populations across Asia and Africa<sup>22-24</sup>. Asian elephants are confined to 5% of the historic elephant range<sup>24</sup>. Elephants use large areas to meet their dietary and reproductive requirements<sup>25,26</sup>. Their home range size varies according to the forage

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Region	Forest Area in different years (km <sup>2</sup> )				Percentage forest change (annual rate of forest change)			
	1930	1975	2000	2020	1930–1975	1975–2000	2000–2020	1930–2020
Eastern	4607.92	4084.94	3781.68	3548.48	– 11.35 (– 0.27)	– 7.42 (– 0.31)	6.57 (– 0.32)	22.99 (– 0.29)
Central	4336.84	4162.02	3917.77	3771.95	4.03 (– 0.09)	5.87 (– 0.24)	3.87 (– 0.19)	13.03 (– 0.16)
Western	6703.66	5590.97	5186.52	4993.85	16.60 (– 0.40)	7.23 (– 0.30)	3.86 (– 0.19)	25.51 (– 0.33)
Far western	8667.14	7482.98	7167.34	6754.86	13.66 (– 0.33)	4.22 (– 0.17)	6.11 (– 0.30)	22.06 (– 0.28)
Total	24,315.56	21,320.92	20,053.32	19,069.14	12.32 (– 0.29)	5.95 (– 0.25)	5.16 (– 0.25)	21.58 (– 0.27)

**Table 1.** Status of forest cover by area in 1930, 1975, 2000 and 2020 in Chure Terai Madhesh Landscape (CTML), Nepal. The total forest change percentage and annual rate of forest change (in parenthesis) is presented for four different time periods.

availability and nature of the habitat<sup>27–29</sup>. Expanding human settlements and agriculture areas has reduced connectivity, caused the loss of habitats, and a rise in human impacts on elephants, resulting in frequent conflict ranging from crop damage to human casualty and persecution of elephants<sup>21,30</sup>.

Nepal is one of the elephant range countries, with an estimated 200 elephants in Nepal and additional 150 elephants seasonally migrating from India<sup>31,32</sup>. The Chure Terai Madhesh Landscape (CTML) encompasses the entire elephant habitat in Nepal<sup>33,34</sup>. Before the 1950s, the forest of CTML was reasonably intact<sup>35</sup> and had a wide distribution of elephants that reportedly occurred in high densities<sup>36–38</sup>. A large tract of forests was converted into agriculture between 1950 and 1970, and wildlife was hunted down as agricultural pests with no legal protection<sup>39</sup>. Nearly three hundred wild elephants were also captured (287 between 1800 and 1975) and put in captivity for Royal hunting expeditions, forest patrolling, transportation and national security<sup>37</sup>. Deforestation led to the further decline of the elephant population.

In the CTML, the elephant ranges run east–west along the foothills of the Himalayas and Terai plains<sup>33</sup>. Protected areas (national parks and wildlife reserves) and forests outside the protected network constitute significant elephant habitats in CTML. The landscape includes both government and community-managed forests. Different landscape-level conservation approaches, including the Terai Arc Landscape (TAL) program, were implemented for biodiversity conservation in the CTML region<sup>40</sup>. However, CTML experienced significant habitat loss and fragmentation, contributing to the escalation of human–elephant conflict (HEC)<sup>41</sup>.

Despite increasing threats to the elephant conservation, landscape-specific information on the change in forest cover and habitat fragmentation is lacking for CTML and is urgently required for effective conservation planning for elephants. This study quantifies the change in forest cover for the last 90 years (1930–2020) using high-resolution imagery, estimating forest loss and habitat fragmentation in the CTML. We use the findings to relate habitat loss, fragmentation, and trends in HEC and discuss implications for elephant conservation in the human-dominated landscapes of Nepal and elsewhere. The findings will have implications for devising actionable strategies for elephant conservation and protecting existing forested habitats within human-dominated landscapes in Nepal.

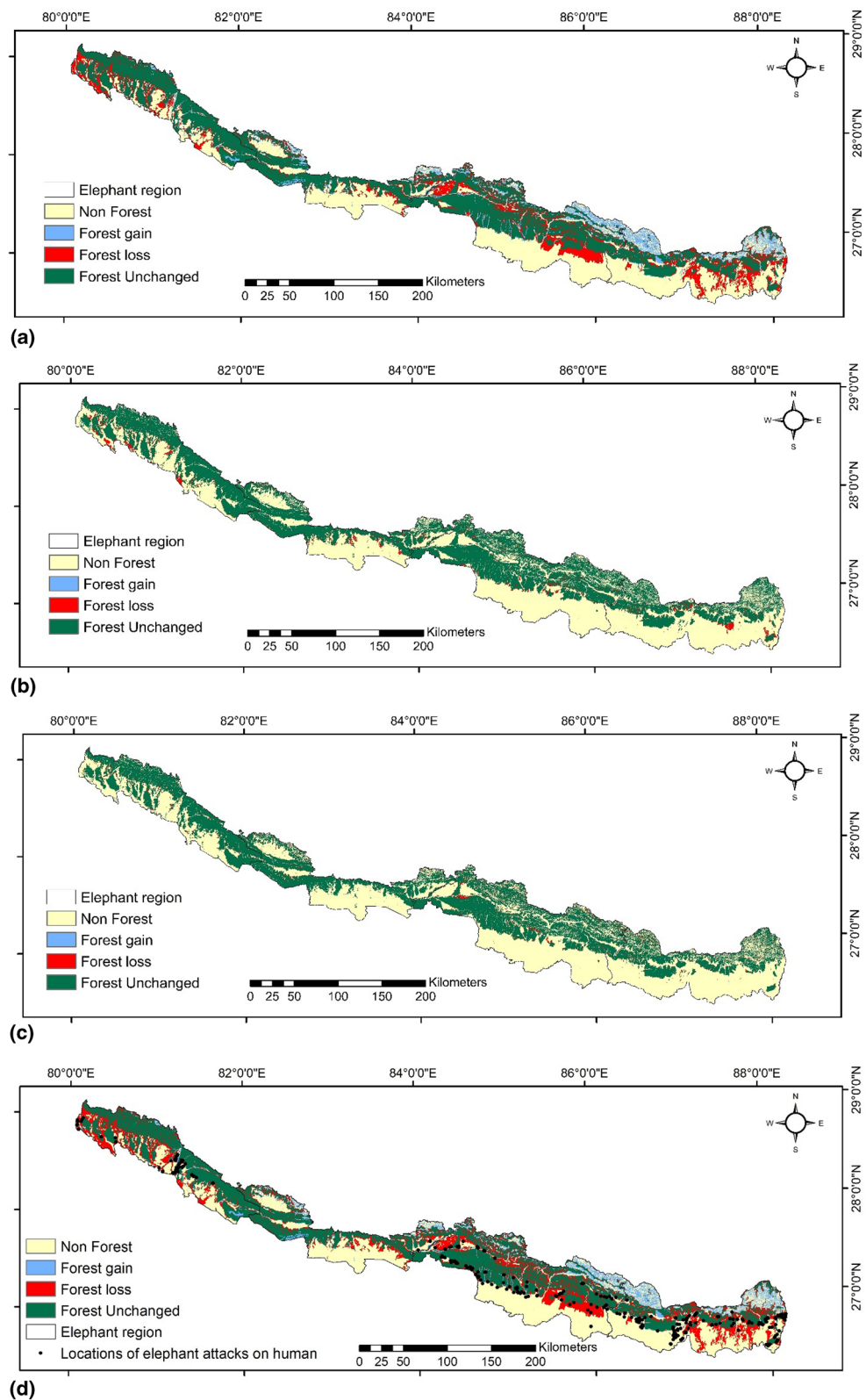
## Results

**Temporal change of forest cover in CTML.** We estimated 24,315 km<sup>2</sup> of forest cover in 1930. The forest cover was reduced to 19,069 km<sup>2</sup> in 2020, with an annual rate of 0.27%. The deforestation rate (0.29%) was higher between 1930 and 1975. The highest rate of deforestation was documented in western region (0.33%) followed by eastern (0.29%), far western (0.28%) and central (0.16%) region between 1930 and 2020 (Table 1). In 2020, the far western region had the highest forest area (35.42%), followed by the western region (26.18%), central (19.78%), and eastern region (18.61%) of CTML (Table 1).

**Spatial change in forest cover.** Altogether 1592 grids of 5 × 5 km<sup>2</sup> were used to analyze the spatial patterns of forest cover change. Deforestation was documented in most of the grids (n = 1505), and 75 grids lost entire forest area between 1930–2020 (Supplementary figure S1). Increase in forest cover was observed in only 51 grids during the same period. The massive reduction in large forest patches (< 20 km<sup>2</sup>) was documented for 26 grids (Fig. 1a–c), (Supplementary table S4, Supplementary figure S2). We found ~ 60% of the elephant attacks on human (HEC) occurred in the area where forest was converted into the agriculture/settlements between 1930 and 2020 (Fig. 1d).

We calculated historical forest fragmentation for the last nine decades (1930–2020) and found that the total number of patches increased from 201 in 1930 to 28,559 in 2020. However, the highest decrease in mean patch size (121 km<sup>2</sup> in 1930 decreased to 0.7 km<sup>2</sup> in 2020) indicates that the forest has been fragmented into small patches. The mean perimeter ratio of the forest has been increased from 187 in 1930 to 1210 in 2020. The edge metrics showed that edge density increased from 548 (m/km<sup>2</sup>) to 3630 (m/km<sup>2</sup>), reduced mean patch edge to 2426.63 ha from 66,271.31 ha. Similarly, the shape index suggested that the mean shape index (MSI) decreased sharply where the mean perimeter area ratio (MPAR) increased progressively (Table 2).

Between 1930 and 2020, 21.58% of the forest area was converted primarily into agriculture and settlements. The fragmentation analysis showed that the core forest (Core 3) size decreased by 43.08%, whereas, core 2 and core 1 size increased by 320.86% and 1107.33%. The patch area increased from 0.16 to 210.70 km<sup>2</sup> between 1930 and 2020. The edge area increased from 1086.54 to 3269.72 km<sup>2</sup>, and the entire large core forests area (Core3) reduced significantly by 9968.68 km<sup>2</sup> in 2020 (Table 3, Supplementary table S5).



**Figure 1.** Forest cover change in the Asian elephant habitat (the Chure Terai Madhesh Landscape), Nepal during the time periods (a) 1930–1975, (b) 1975–2000, (c) 2000–2020 and (d) 1930–2020. In the map of (d) 1930–2020, locations of elephant attacks on humans based on Ram et al.<sup>38</sup> is also overlaid. Map generated by Ashok Kumar Ram using ArcGIS 10.5<sup>101</sup>.

SN	Landscape metrics	1930	1975	2000	2020
1	<b>Patch density and size</b>				
a	Nump—no of patches	201	22,602	26,727	28,559
b	MPS—mean patch size (km <sup>2</sup> )	121	0.9	0.8	0.7
c	PSSD—patch size standard deviation	64,458.3	4643.1	3762.5	3187.2
2	<b>Edge metrics</b>				
d	ED—edge density (m/ km <sup>2</sup> )	548	2849	3263	3630
e	MPE—mean patch edge	66,271.3	2691.4	2451.4	2426.6
3	<b>Shape Index</b>				
f	MSI—mean shape index	1.8	1.4	1.4	1.4
g	MPAR—mean perimeter area ratio	187.4	1274.4	1245.5	1210.8
h	MPFD—mean patch fractal dimension	1.3	1.4	1.4	1.4

**Table 2.** Forest fragmentation status in the CTML, Nepal in different time periods.

Fragmentation class	1930	1975	2000	2020	Change 1930–1975	% Change (1930–1975)	Change 1975–2000	% Change (1975–2000)	Change 2000–2020	% Change (2000–2020)	Change 1930–2020	% Change (1930–2020)	% Change (1975–2020)
Patch	0.16	157.11	165.69	210.85	156.95	<sup>a</sup>	8.58	5.46	45.16	27.26	210.7	<sup>a</sup>	34.21
Edge	1086.55	2825.61	2910.84	3279.62	1739.06	160.05	85.23	3.02	368.78	12.67	2193.07	201.84	16.07
Perforated	0.67	1876.53	1430.23	1693.21	1875.86	<sup>a</sup>	– 446.3	– 23.78	262.97	18.39	1692.54	<sup>a</sup>	– 9.77
Core1	42.18	422.32	474.32	509.25	380.14	901.23	52	12.31	34.93	7.36	467.07	1107.33	20.58
Core2	49.34	157.51	182.84	207.65	108.17	219.23	25.34	16.08	24.81	13.57	158.31	320.86	31.83
Core3	23,136.67	15,881.84	14,889.4	13,168.56	– 7254.83	– 31.36	– 992.44	– 6.25	– 1720.84	– 11.56	– 9968.11	– 43.08	– 17.08
Total	24,315.56	21,320.92	20,053.32	19,069.14	– 2994.64	– 12.32	– 1267.6	– 5.95	– 984.19	– 4.91	– 5246.42	– 21.58	– 10.56

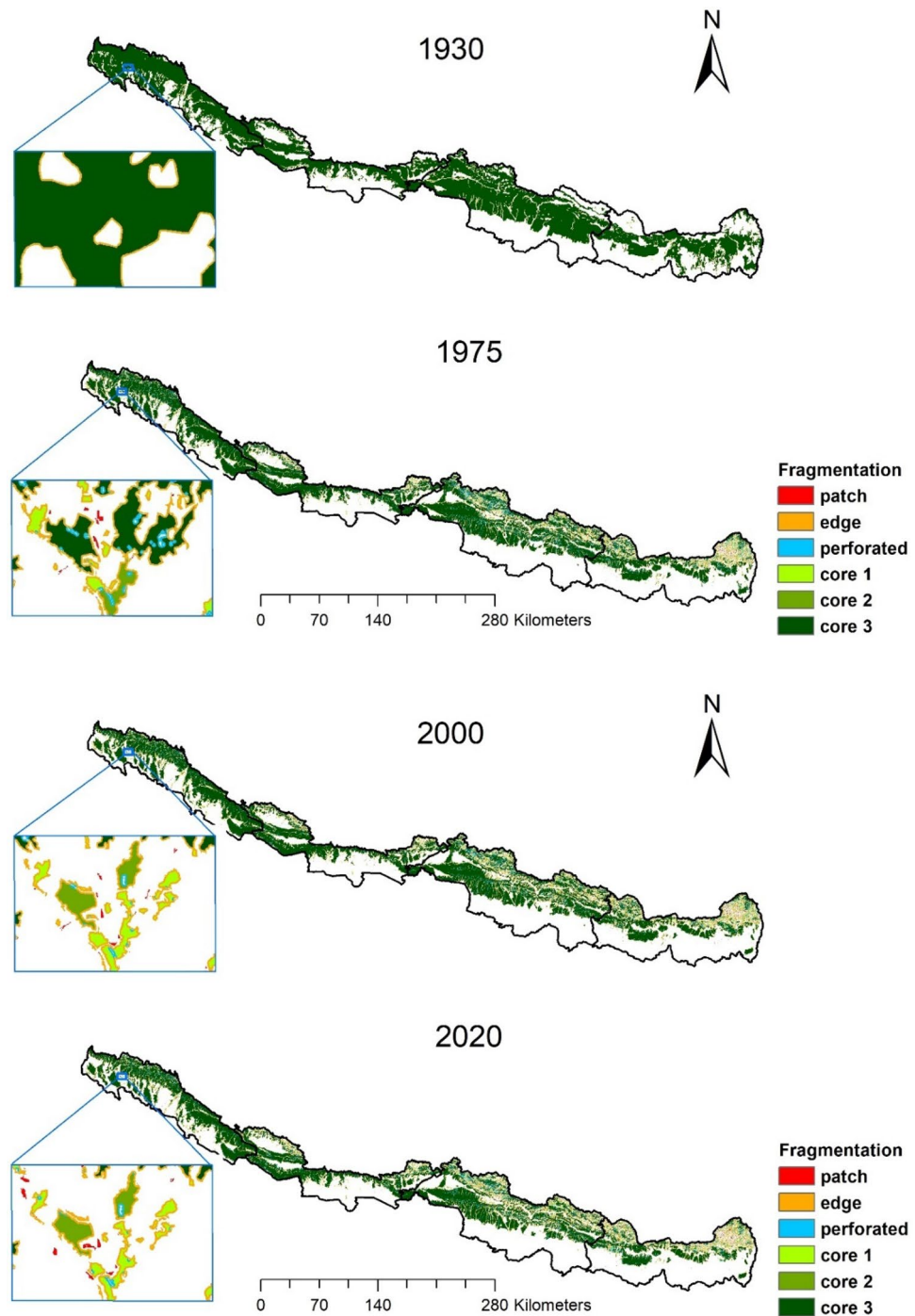
**Table 3.** Temporal forest fragmentation (area in km<sup>2</sup>). Change percentage represented by ‘a’ means the highly inflated figure due to very small denominator. <sup>a</sup>The estimate is not reliable as forest cover within these categories were very small in 1930.

Fragmentation class (area in km <sup>2</sup> )	Eastern					Central					Western					Far western				
	1930	1975	2000	2020	1930–2020% change	1930	1975	2000	2020	1930–2020% change	1930	1975	2000	2020	1930–2020% change	1930	1975	2000	2020	1930–2020% change
Patch	0.01	69.68	333.42	93.36	– 933,500.00	0.14	49.51	224.21	75.1	– 53,542.86	0.000	22.21	192.38	23.4	<sup>a</sup>	0	15.71	215.33	18.99	<sup>a</sup>
Edge	297.17	863.34	1820.37	950.68	– 219.91	322.23	1011.77	2802.83	1252.36	– 288.65	219,920	463.55	1367.61	544.19	– 147.45	247.23	486.95	1726.4	532.38	– 115.34
Perforated	0.11	457.76	1360.58	423.75	– 385,127.27	0.11	826.08	3304.97	706.05	– 641,763.64	0.240	268.44	1649.26	271.11	– 112,862.50	0.21	324.25	2088.15	292.29	– 139,085.71
Core1	15.89	162.51	8.48	177.85	– 1019.26	4.28	133.75	22.79	186.38	– 4254.67	13,200	59.21	14.89	77.71	– 488.71	8.82	66.85	21.6	67.31	– 663.15
Core2	15.2	65.74	6.7	77.38	– 409.08	8.83	40.92	18.22	66.08	– 648.36	9,990	22.44	18	26.24	– 162.66	15.31	28.42	22.24	37.96	– 147.94
Core3	4279.55	2465.92	252.14	1825.46	57.34	8331.55	5420.95	794.33	4468.89	46.36	4093.490	3326.18	675.62	2829.29	30.88	6432.07	4668.8	1112.8	4044.91	37.11
Total	4607.92	4084.94	3781.68	3548.48	22.99	8667.14	7482.98	7167.34	6754.86	22.06	4336.840	4162.02	3917.77	3771.95	13.03	6703.66	5990.97	5186.52	4993.85	25.51

**Table 4.** Region wise forest fragmentation in Nepal. Change percentage represented by ‘a’ means the highly inflated figure due to very small denominator. <sup>a</sup>The estimate is not reliable as forest cover within these categories were very small in 1930.

The Eastern region lost 22.99% of forest between 1930 and 2020. The core 3 decreased by 57.34%, whereas core 1 and core 2 increased simultaneously by 1019.26% and 409.08%. Similarly, the edge area increased by 219.91%. The central region lost 22.06% of the forest between 1930 and 2020; core 3 decreased by 46.36%, whereas core 1 and core 2 increased by 4254% and 648%, respectively. The western region lost 13.03% of the forest, and core 3 forests were reduced by 30.88%, whereas core 1 and core 2 increased by 488% and 162%, respectively. Finally, the far western region lost 5.51% of the forest, and the core 3 forest was reduced by 37.11%, whereas core 1 and core 2 increased by 663% and 145%, respectively.

The overall forest fragmentation result suggests that the highest fragmentation occurred in the eastern region (in core 3), followed by the central, far western, and western region, where the core forest (core 3) was reduced by 57.34%, 46.36%, 37.11%, and 30.88% simultaneously (Tables 3, 4, Fig. 2; Supplementary figure S2).



**Figure 2.** Habitat (forest) fragmentation of Asian elephants in the Chure Terai Madhesh Landscape, Nepal. Inset shows an enlarged view of habitat fragmentation in four different periods (1930, 1975, 2000 and 2020) at that particular location. Map generated by Ashok Kumar Ram using ArcGIS 10.5<sup>101</sup>.

## Discussion

**Patterns of forest cover change and fragmentation.** Our study provides comprehensive information on forest cover change and fragmentation within the primary elephant habitat in Nepal between 1930 and 2020. We documented the loss of more than one-fifth of the forest area and extensive fragmentation during this period. Our results suggest that the elephant habitat remained intact during the 1930s. However, the rate of deforestation was higher between 1930 and 1975 due to the conversion of forests into agricultural land. Forest cover loss was the highest in the western region, where the elephant population is the lowest. The regions with higher coverage of protected areas (central and far-western parts) had a comparatively lower rate of deforestation. Protected areas establishment (~6000 km<sup>2</sup>) and restoration through community-based conservation programs (~300 km<sup>2</sup>) may have contributed to reducing deforestation rates after 1975 in CTML<sup>42</sup>.

A previous study from the entire south Asia documented a 29.62% forest cover loss between 1930 and 2014 with a 0.68% annual rate of deforestation<sup>43</sup>. The forest loss and rate of deforestation in CTML are lower than the average for South Asia<sup>44, 45</sup>, also documented the annual rate of deforestation 0.49% for Nepal, which is higher than our results. Forests occupied 42.73% of CTML in 2020, but forest cover was not evenly distributed throughout the landscape. A large part of the remaining forest occurs in the Chure region (>70% forested), where the rate of deforestation was comparatively lower (0.18%/year between 1995 and 2010)<sup>42, 45</sup>. However, most of the flat and productive land of the CTML was converted into agricultural land with a higher rate of deforestation (i.e., 0.40%/year) between 1991 and 2010<sup>42</sup>. Among the four regions, the western part experienced the highest loss of forest cover (25.51%). The remaining forest cover (56%) and rate of deforestation (0.33) were found higher in the western region, where almost the entire forests lie outside of the protected areas. Despite massive forest clearance in Chitwan valley<sup>46</sup> and other areas of central CTML, the rate of forest loss was only 0.16% per year. The establishment of Chitwan and Parsa National Parks and the intact forest remaining in the northern part of Bara and Rautahat may have contributed to lower deforestation rates in Central CTML<sup>47</sup>. The results indicate that Government should prioritize conservation efforts to restore elephants' movement through corridor restorations within the human-dominated landscapes outside protected areas.

Elephant habitat is more fragmented outside protected areas due to the high pressure of encroachment and developmental activities<sup>48</sup>. These forests are also used more frequently by the local communities to meet their subsistence needs of livestock grazing and dependence on forest products<sup>49, 50</sup>. With increasing forest fragmentation, the elephants and other wildlife are also forced to live in smaller forest patches with spatial overlap with human activities<sup>51</sup>. This situation increases the chances of confrontation between humans and elephants, often leading to fatal attacks<sup>34, 52</sup>. The eastern region had the highest forest fragmentation (57.3% of large core forest lost) within our study, where HEC incidents were also the highest<sup>34</sup> (DNPWC 2020). The eastern region also bears a long migratory route of a large herd of elephants (> 100) and provides habitat for some residential elephants. Although the forest cover is not significant within Koshitappu Wildlife Reserve (KTWR), it still provides refugia and a corridor for elephants in the eastern region. While navigating through the highly fragmented forests, there is always a threat of elephants getting deflected due to haphazard drives and another form of human resistance resulting in elephants ending up in human-use areas off the forests, as corroborated by telemetry studies on elephants in the landscape.

Forest fragmentation results suggested that large forest patches have decreased rapidly, whereas forests in the medium and small core have increased massively. Similarly, the area of forests in the patch, perforated, and edge category has also increased during the last nine decades (1930–2020), which indicated the high rate of forest fragmentation in the CTML. Landscape metrics analysis also reveals the massive fragmentation of forests between 1930 and 2020, increasing the patch number and decreasing patch size (Table 3, 4; Fig. 2)<sup>44</sup>. Similar to Nepal, a massive decline in extensive core forests and increase in fragmented patches has been documented in other elephant range countries India, Myanmar, Bangladesh, and Sri Lanka<sup>53–56</sup>. Fragmented forest patches should be connected through a combination of the weak and high-quality habitat to enable elephant connectivity throughout the landscape. The human pressure (illegal cattle grazing, resources extraction) and risks of invasive species (*Lantana camera*, *Chromolaena odorata*, *Parthenium hysterophorus*, *Mikania micrantha*, etc.) spread are high in smaller and perforated forest patches as well as forest edges<sup>57</sup>.

Our study focused on forest cover change within elephant range. Elephants are habitat generalists and roam across large areas which comprises of a matrix of forests, grasslands, wetlands and agriculture areas<sup>58</sup>. Size of protected areas in Nepal are not large enough to sustain elephants throughout the year. The fragmented forest patches serve as refuge whereas crop fields around human settlements and periphery of protected areas act as attractants for elephants. Human-elephant conflict (HEC) intensifies along the periphery of these protected areas, forest patches. The ecotone habitats along the forest-agriculture matrix have high activity of humans leading to increased probability of human-elephant conflict<sup>34</sup>. Out of 412 cases of elephant attacks on humans (HEC), 60% occurred at forest cover loss areas during 2000–2020 in Nepal<sup>34</sup> (Fig. 1d). Human activity around riverine patches, water bodies also reduce access to such important resources for elephants. Apart from strengthening forest patches, wildlife corridors it is also important to grow unpalatable crops within ecotone habitats to reduce visitation by elephants. These changes in land use patterns have to be integrated with necessary management interventions to reduce human-elephant conflicts<sup>9, 59</sup>. Large herbivores exhibit different strategies of habitat use with seasonal variation and spatial distribution of resources<sup>60</sup>. Studies on on habitat utilization pattern by elephants<sup>61, 62</sup> shows that distribution of water resources<sup>63, 64</sup>, precipitation patterns<sup>65</sup> and social factors<sup>20</sup> influence their movement and spatial distribution. The intensity of conflict varies with distribution of resources, agricultural practices, human population, climatic conditions and connectivity between habitats<sup>66–69</sup>.

**Drivers of deforestation and fragmentation.** Several studies indicate loss of elephant habitats and fragmentation due to a combination of multiple factors such as agriculture and settlement expansion, encroachments, irrigation, infrastructure development hydropower projects, illegal logging, mining, commercial plantations<sup>53, 61, 70, 71</sup>. Additionally, expansion of oil palm plantation in Indonesia<sup>72</sup> and tea, paddy cultivation in north-east India has also contributed to habitat loss<sup>73</sup>. However, in Nepal, forest conversion into farmlands through government policy was responsible for forest loss and fragmentation in the initial years (1930–1975), whereas encroachment and infrastructure development activities have continued the fragmentation at present and recent past and expansion of agriculture is a significant factor for conversion of elephant habitat in Nepal.

A large part of the forest was lost or fragmented in CTML during the first 45 years (1930–1975). During this period, various socio-political changes and national policy of promoting forest conversion into agricultural land in Terai have contributed to such massive fragmentation of the forests in CTML<sup>39</sup>. Three significant changes were (a) fall of Rana regime and political instability, (b) private forests nationalization act 1957 and its impacts,

(c) land resettlement policy. Rana rulers used to grant forest and other lands as 'Birta' (grant their families and close relatives as private property) and provide to government employees and other servicemen to use a share of a product as a 'Jagir'. As a result, the tiny forest remained under government control<sup>74</sup>. After the fall of the Rana Regime in 1951, state of political instability in the country caused massive deforestation and wildlife hunting<sup>75</sup>. In the meantime, the government of Nepal nationalized all the private forests by promulgating the "Private Forest nationalization Act, 1957"<sup>76</sup>. As a result, owners of the private forests converted their forested land into farmlands to secure their land tenure<sup>77,78</sup>. Similarly, eradicating malaria in CTML during the 1950s and introducing a new settlement policy by the government promoted thousands of hill migrants to convert Terai forests into farmlands<sup>46</sup>. The human population in the CTML also increased many folds during this period, accelerating deforestation and forest degradation<sup>79</sup>.

The deforestation rate was lower between 1975 and 2020. The primary reasons were ((a) establishment of protected area network, ((b) initiation of community participation in forest management, (c) well-established institutional setup for forest protection and management<sup>74</sup>. With decreasing deforestation and increasing forests and wildlife conservation efforts, wildlife populations, including the elephants, have also increased (~ 50 individuals in the 1970s to > 200 in 2020; Shrestha et al.<sup>37,80</sup>). However, the forest fragmentation continues in large parts of the forests outside of the protected areas. Large-ranging species like elephants are affected by this as they come into frequent clashes with humans while navigating seasonally through these highly fragmented forests in CTML.

This study indicates that the conservation of large-ranging species like elephants and tigers in CTML has been challenging as most of the remaining forests are highly fragmented, especially outside the protected areas. With planned and ongoing infrastructure development activities in CTML, forest fragmentation continues to increase. It shows the importance of the landscape-level conservation approach and helps policymakers, protected area managers to restore corridor and connectivity by implementing metapopulation management of large mammals in Nepal and around the globe.

## Conclusion

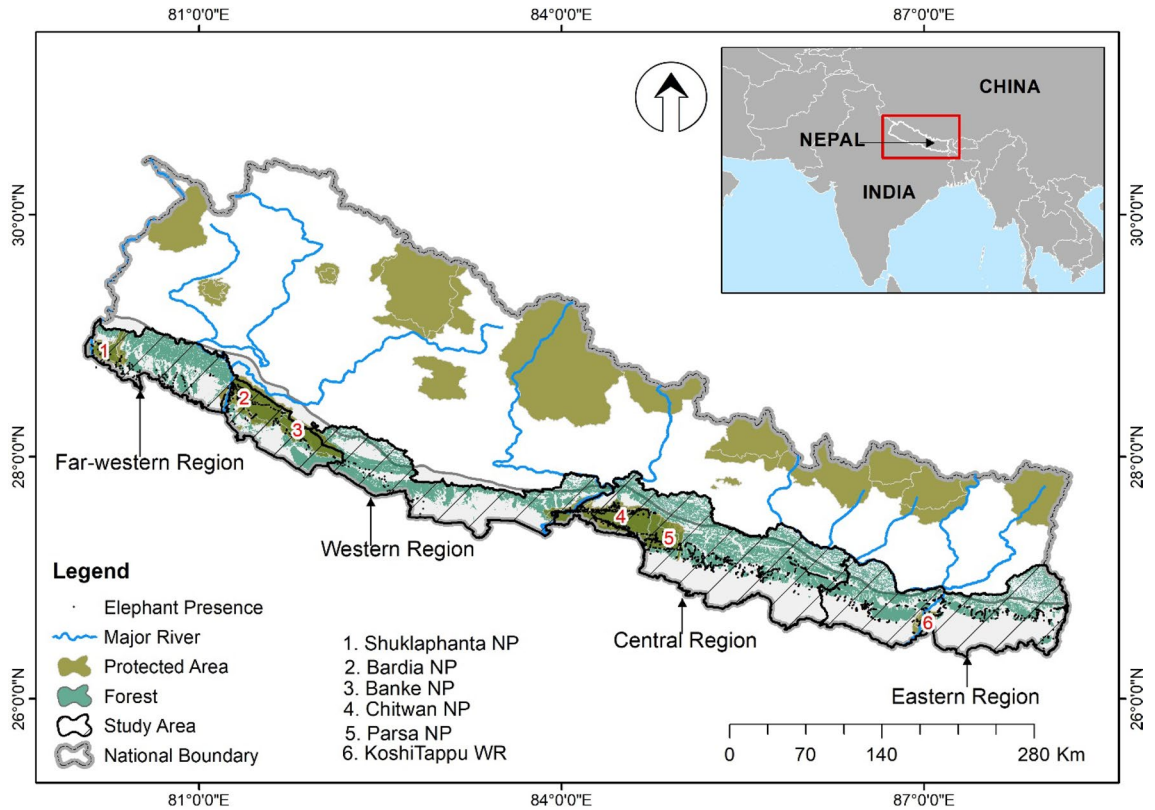
Forest loss and fragmentation induced a severe threat to elephant conservation in Nepal. Such fragmentation brought both the elephants and humans along the forest's edge, where they interact with each other, often resulting in severe human-elephant conflict (HEC). Increasing the number of forest patches also increases the visibility of elephants in the migratory routes, increasing the poaching threats. Our research findings have implications for devising appropriate policies for conserving large mammals and their habitats in human-dominated landscapes in Nepal and beyond. Further understanding of the relationship between forest loss/fragmentation and human-elephant conflict is necessary. The particular focus of elephant conservation is necessary outside the protected areas and migration corridors where habitat is highly fragmented.

## Methods and materials

**Study area.** Chure-Terai-Madhesh landscape (CTML) covers the entire elephant distribution range in Nepal. The CTML spreads across 25 districts and covers an area of 42,456 km<sup>2</sup> (Fig. 3). CTML comprises five physiographic units i.e., Chure hills (34.4%); Chure narrow gorges (2.2%); Dun/Inner Terai (8.4%); Bhavar region (14.9%); and Terai Madhesh (40%). Forty-eight percent of the landscape comprises agriculture and settlement; 47.16% forest, shrub-land, and grassland; and the rest 4.65% river and riverbed<sup>81</sup>. CTML is a part of the global biodiversity hotspot<sup>82</sup> and provides essential environmental services such as groundwater recharge for more than half of Nepal's human population (~ 15 million)<sup>83,84</sup>. The major habitat types are (a) Himalayan subtropical broadleaved forests, (b) Gangetic plains and moist deciduous forest, and (c) Terai-Duar savannas and grassland. Apart from elephants, the study area is also a refuge for several endangered large mammals, including the tiger (*Panthera tigris*), greater one-horned rhinoceros (*Rhinoceros unicornis*), Gaur (*Bos gaurus*), and wild buffalo (*Bubalus bubalis arnee*). The annual rainfall ranges between 1138 mm and 2680 mm, with over 80% of the rain occurring during monsoon months<sup>42</sup>. The altitudinal range lies between 60 and 1500 m<sup>85</sup>. CTML is densely populated with an average human density of 392 persons/km<sup>2</sup><sup>83</sup>. Sixty percent of the people depend on subsistence agriculture and are involved in farm and off-farm based livelihood activities (Chaudhary and Subedi, 2019). Paddy (*Oryza sativa*), maize (*Zea mays*), wheat (*Triticum aestivum*), lentils (*Lens culinaris*) are some major food crops, where jackfruit (*Artocarpus heterophyllus*), mangoes (*Mangifera indica*), bananas (*Musa acuminata*) are some fruit crops farmed in the area<sup>86</sup>. Large-scale linear infrastructure projects and mining activities are the major drivers of deforestation and habitat fragmentation in the landscape.

We divided CTML into four regions (Eastern, Central, Western and Far-western) of similar size to assess the extent of forest loss (Table 5). Thus, elephants are distributed in four population clusters with limited connectivity viz. (a) eastern population (Mechi River to Kamala River), (b) central population (Kamala River to Narayani River), (c) western population (Narayani River to Western boundary of Dang district), and (d) far-western population (Eastern boundary of Banke district to Mahakali River)<sup>87,88</sup> (Table 5).

**Derivation of forest cover.** We analyzed forest cover change and fragmentation using both the patch and landscape metrics and considered forest fragmentation as habitat fragmentation<sup>89</sup>. Natural Forests or plantations covering greater than 0.5 ha area were categorized as forest<sup>90</sup>. We used the hybrid classification techniques to combine high-resolution images, medium resolution images, and digitization of topographic maps. First of all, we prepared a forest cover map of the 1930s by digitizing greenwash areas shown on topographical maps prepared by Army Map Service, U.S. Army, Washington, surveyed during 1920–1940 (<http://legacy.lib.utexas.edu/maps/ams/india/>) at 1:250,000 scale. Due to the unavailability of multi-spectral satellite images of the study area before the 1970s, we relied on the existing topographic maps to obtain forest cover of 1930<sup>91,92</sup>.



**Figure 3.** The geographical location of Nepal and the study area (Chure Terai Madhesh Landscape). Map generated by Ashok Kumar Ram using ArcGIS 10.5<sup>101</sup>.

SN	Region	Coverage (districts)	Total area (km <sup>2</sup> )	% forest cover	Elephant population
1	Eastern	Jhapa to Siraha	11,116.96	31.92	Residential: 27–35; ~ 100 migratory elephants each year from West Bengal, eastern India)
2	Central	Dhanusa to Chitwan	8169.43	46.17	Residential: 45–53
3	Western	Nawalparasi to Dang	8777.95	56.89	Migratory: 8–12
4	Far-Western	Banke to Kanchanpur	14,391.54	46.94	Residential: 80–125; ~ 45 migratory (from Uttarakhand and Uttar Pradesh, India migrated to far western habitats in Nepal)
	Total		42,455.88	44.92	

**Table 5.** Four different regions within Chure Terai Madhesh Landscape Nepal, area, forest cover and elephant population status. The elephant population was obtained from Ram and Acharya<sup>80</sup>.

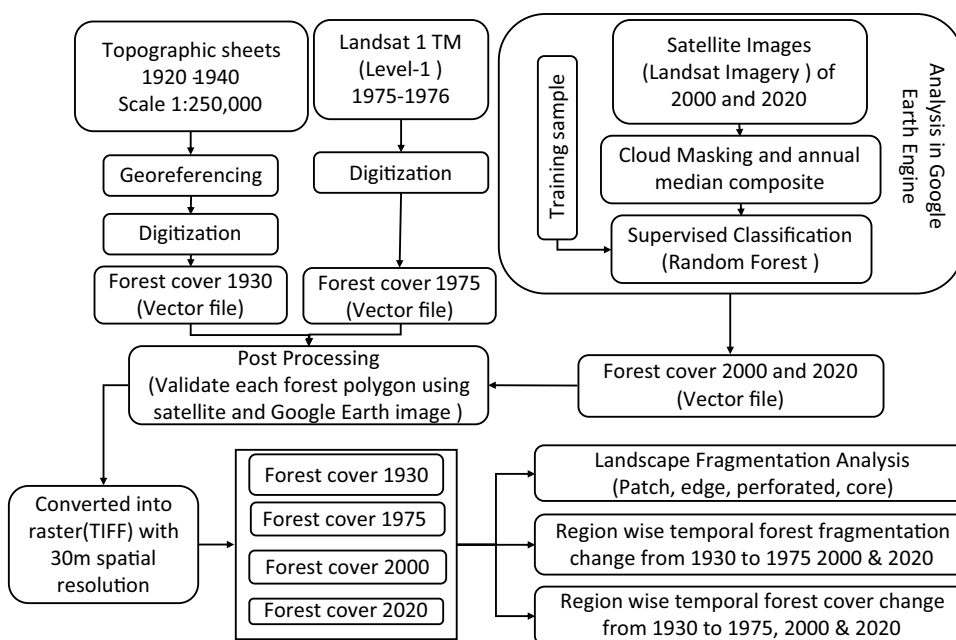
Kaim et al.<sup>93,94</sup> found 5–10% inherent errors at various stages of land cover change analysis; while using historical data and topographic maps. The inaccuracy of forest cover mapping was minimized by visual interpretation and overlay analysis in the topographic maps. In addition, we resampled all the digital images at a 30-m resolution to improve the mapping errors.<sup>93,94</sup> reported the reliability of topographical maps to reconstruct forest cover. We also obtained the forest cover map of 1975 by on-screen digitization of Landsat 1 TM level 1 satellite images.

We produced the forest cover maps of 2000 and 2020 from Landsat imagery scenes respective years with < 10% cloud cover (Table 6; Fig. 4). All the Landsat data processing was conducted using the cloud-computing technology in the Google Earth Engine (GEE) platform (<https://earthengine.google.org/>). The GEE platform carried out a fast analysis using Google’s computing infrastructure<sup>95,96</sup>. We used the pre-processed Landsat imagery available through GEE to assess forest cover change across the study area<sup>97</sup>.

We used a cloud screening algorithm to remove cloud contaminated pixels from each Landsat image by applying quality assessment (QA) bands for 2000 and 2020. Then, we produced an annual composite by taking the median value from images from the target year<sup>98</sup>. We delineated > 1000 reference points for each period 2000 and 2020, respectively. We used supervised machine learning classifiers, i.e., Random Forest (RF), to classify remotely sensed data<sup>99</sup>. Random Forest Classifier creates a set of decision trees from a randomly selected subset of the training set and aggregates the votes from different decision trees to classify the image<sup>100</sup>. The classified image was downloaded as raster tiff files. The raster was converted into vector polygons and overlaid with high-resolution google earth images of respective years. The final forest cover map was obtained with the highest accuracy by post-processing (validating) the forest polygons through onscreen digitization to match the forests visible in Google images<sup>99</sup>.

SN	Data layer	Source	Spatial resolution (m)	Year
1	Topographic map	Army Map Service, U.S. Army, Washington	Scale 1:250,000 m (based on Aerial photo)	1920–1940
2	Landsat 1 TM	Earth Explorer (USGS)	60 m	1975–1976
3	Landsat 5 Surface Reflectance Tier 1	GEE dataset (USGS)	30 m	2000
4	Landsat 8 Surface Reflectance GEE dataset	GEE dataset (USGS)	30 m	2020
5	Administrative boundary	Department of Survey, Nepal	Scale 1:25,000 (based on Aerial photo)	1996–1998

**Table 6.** Sources of data used in this study.



**Figure 4.** Overall methodological framework adopted for this study.

**Data analysis.** *Analysis of forest loss/gain.* Forest cover maps of the four different periods of 1930 (before malaria eradication), 1975 (the initial stage of PA system development), 2000 (well-established PA system) and 2020 (current scenario) were post-processed according to FAO forest definition. These layers were analyzed to understand changes in extent and location of forests using a post-classification change detection technique in Arc GIS 10.5.

We estimated the conversion of forests into the non-forest area on a grid overlay basis. We generated  $5 \times 5$  km<sup>2</sup> grids for forest cover change analysis following Padaliya et al.<sup>91</sup> and Reddy et al.<sup>43</sup> for the time series assessment and analyzed spatial distribution trends of forest cover in these grids from 1930 to 1975, 1975 to 2000, and 2000 to 2020<sup>33,91</sup>. We computed the forest cover area (distribution of transitions and persistence of forest) of four different periods in each grid using the zonal statistics tool of ArcGIS software<sup>101</sup>. Overall, forest cover change was calculated by combining all the grids and calculating the annual deforestation rate (percentage) using a compound-interest-rate formula<sup>54</sup>.

$$r = \frac{1}{t_2 - t_1} \times \ln \frac{a_2}{a_1},$$

where  $a_1$  and  $a_2$  are the area covered by forest at times  $t_1$  and  $t_2$ . The region wise rate of deforestation was computed and presented.

We also overlaid the Human elephant conflict (HEC) locations (Locations of elephant attacks on humans) of last 20 years (between 2000 and 2020) over the forest cover map of 1930 and 2020 (Fig. 1d) to examine the relation of HEC with forest cover change. We took HEC data (elephant attacks on humans) from the published article Ram et al.<sup>34</sup>.

*Modeling forest fragmentation.* We carried out habitat fragmentation analysis in the four regions of CTML (Fig. 3) and measured fragmentation in terms of core, perforated, edge, and patches. We used 30 m cell resolution for fragmentation analysis for four different periods. We used patch analyst<sup>102</sup> to obtain the patch matrix

for each region viz. patch density and size (number of patches, mean patch sizes, patch size standard deviation), edge metrics (edge density, mean patch edge), and shape index (mean shape Index, mean perimeter area ratio, mean patch fractal dimension) (Supplementary table S3).

Similarly, Landscape Fragmentation Tool (LFT V2.0, <http://clear.uconn.edu/tools/lft/lft2/>) was used to estimate landscape metrics<sup>103</sup>. The change of fragmentation during the 1930–2020 periods was carried out by cross-tabulating the fragmentation classes. Landscape Fragmentation Tool (LFT) classifies forests at pixel-level into fragmentation classes: core 1, core 2, core 3, perforated, edge, and patch. Core forests are located far from the forest/non-forest boundary and surrounded by other forest areas. We considered the core forest as 100 m distance from the edge<sup>104</sup>. The core forests include three different types (1) Core 1: forest patches area < 250 acres (1.012 km<sup>2</sup>), (2) Core 2: medium core (forest patches area between 250 and 500 acres (1.01–2.2 km<sup>2</sup>), and Core 3: large core (forest patches area > 500 acres (> 2.2 km<sup>2</sup>)<sup>91</sup>. The peripheral forest was further classified into perforated (1) inner edge: forest pixels on the edge of small interior non-forest, and (2) edge forest or outer edge: pixels that are between forest and large non-forest areas<sup>105</sup>.

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### Data availability

Upon publication of the article, all the supporting data for obtaining the results will be made available via the online data services such as dryad.

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## Author contributions

A.K.R., N.S., S.M., P.N.K. and B.P. designed the study; A.K.R. conducted the fieldwork; A.K.R., N.K.Y. B.R.L., and B.P. analyzed the data; A.K.R., B.R.L., N.K.Y., S.M., P.N.K. and N.S. wrote the first draft of the manuscript; D.N., P.N.K., C.S.R., L.N. and, all authors revised the manuscript.

### Competing interests

The authors declare no competing interests.

### Additional information

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# Patterns and determinants of elephant attacks on humans in Nepal

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## Abstract

Attacks on humans by Asian elephant (*Elephas maximus*) is an extreme form of human–elephant conflict. It is a serious issue in southern lowland Nepal where elephant-related human fatalities are higher than other wildlife. Detailed understanding of elephant attacks on humans in Nepal is still lacking, hindering to devising appropriate strategies for human–elephant conflict mitigation. This study documented spatiotemporal pattern of elephant attacks on humans, factors associated with the attacks, and human/elephant behavior contributing to deaths of victims when attacked. We compiled all the documented incidences of elephant attacks on humans in Nepal for last 20 years across Terai and Chure region of Nepal. We also visited and interviewed 412 victim families (274 fatalities and 138 injuries) on elephant attacks. Majority of the victims were males (87.86%) and had low level of education. One fourth of the elephant attacks occurred while chasing the elephants. Solitary bulls or group of subadult males were involved in most of the attack. We found higher number of attacks outside the protected area. People who were drunk and chasing elephants using firecrackers were more vulnerable to the fatalities. In contrast, chasing elephants using fire was negatively associated with the fatalities. Elephant attacks were concentrated in proximity of forests primarily affecting the socioeconomically marginalized communities. Integrated settlement, safe housing for marginalized community, and community grain house in the settlement should be promoted to reduce the confrontation between elephants and humans in entire landscape for their long-term survival.

## KEYWORDS

Asian elephant, attacks on humans, spatiotemporal pattern, Terai–Chure region

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## 1 | INTRODUCTION

Asian elephant (*Elephas maximus*, referred to as “elephant” hereafter; Figure 1) is a globally endangered megaherbivore (Williams et al., 2020). It is an umbrella species in tropical and subtropical forests of Asia and has a strong cultural role in various Asian societies (Jadhav & Barua, 2012; Menon et al., 1996; Sukumar, 2003; Vasudev et al., 2020). Once widely distributed in Asia, elephants are now confined to ca. 5% of their historical range in highly fragmented landscapes (Sukumar, 2006). In addition, the rapid development of linear infrastructures including railways, highways, electric transmission lines and irrigation canals cause further obstruction to elephant movement. Elephants require large areas for their survival with long-distance seasonal movements (Goswami, 2017; Leimgruber et al., 2003). However, increasing habitat fragmentation brings them in frequent confrontation with humans. As a result, human–elephant conflict (HEC) is escalating and has become a prominent cause of elephant population decline (Sukumar, 2006). Attack on humans by elephants is the extreme form of HEC. Other effects upon local people from HEC include loss of crops, damage to property, and safety threats (Dickman, 2010; Gross et al., 2021); and a large number of elephants are also killed in retaliation.

Nepal is a typical example of an elephant range country with a small but growing population of >200 elephants in highly fragmented landscape (Ram & Acharya, 2020). Increasing encroachment and forest conversion in the southern lowlands of the Terai and Chure (Himalayan foothills) region have destroyed the traditional migratory routes of the elephants (Ram, 2014). Whereas a few solitary bulls living in protected areas are habituated to visiting agricultural areas for a higher quality diet causing a huge amount of fiscal losses (Koirala et al., 2016). Elephants cause the highest number of human deaths among the wildlife species in Nepal. Due to this, HEC is a serious issue throughout the lowland Nepal (Acharya et al., 2016).



**FIGURE 1** Elephants in Bardiya National Park (Photo credit: Naresh Subedi)

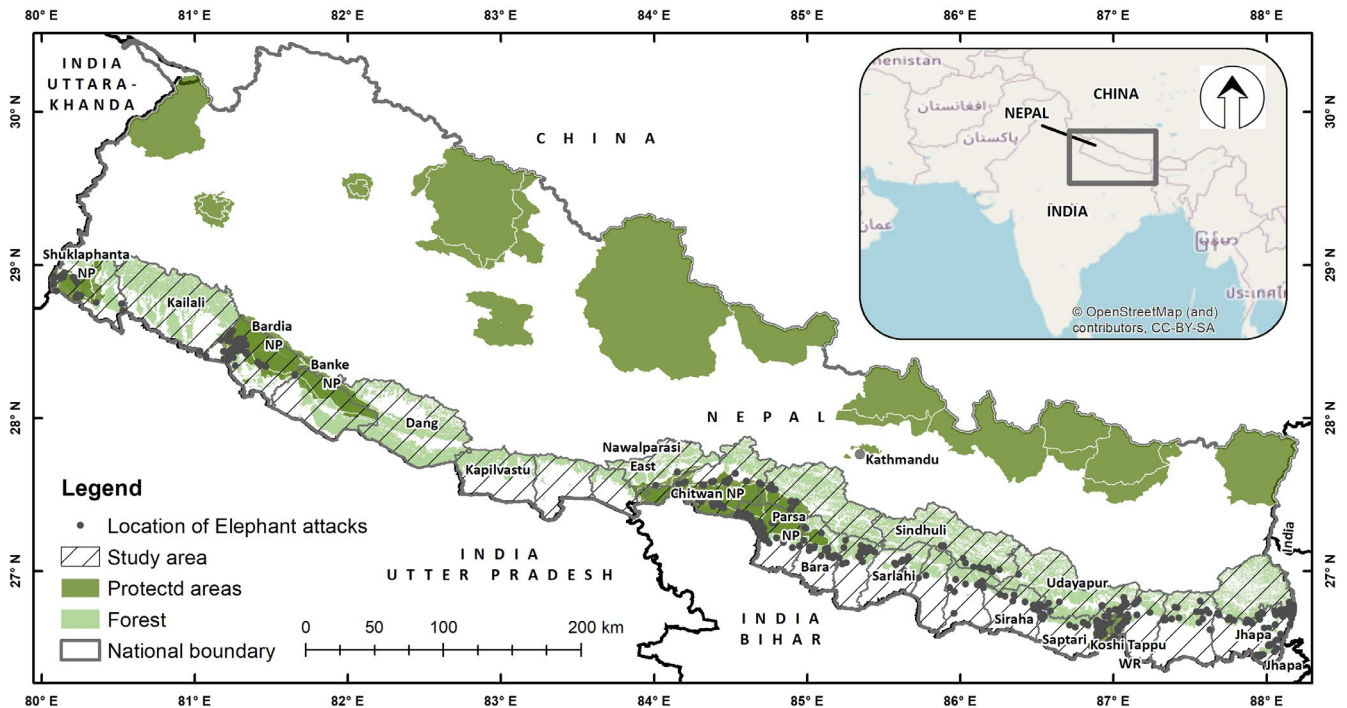
Few studies on human–elephant conflict have been carried out in Nepal primarily focusing on crop and property damage (Graham et al., 2016; Gross et al., 2021; Neupane et al., 2013; Pant et al., 2016). However, detailed studies of elephant attacks on humans are still lacking. This study attempts to document spatiotemporal pattern of elephant attacks on humans in Nepal, characteristics of the victims, and attacking elephants, determine factors associated with the attacks, and identify human and elephant behavior contributing to deaths of victims when attacked. We tested hypothesis: (a) Human activities are responsible for elephant attacks on humans; (b) encounters leading to attacks by elephants are higher in the proximity to forests, (c) elephant attacks were higher inside protected areas, and (d) solitary bull elephants are responsible for attacks on humans. The study results have long-term implications for the conservation and management of elephants in the human-dominated landscape of Nepal and beyond.

## 2 | MATERIAL AND METHODS

### 2.1 | Study area

The study was conducted across the Terai and Chure region of Nepal covering ca. 46,000 km<sup>2</sup> of elephant range in 24 districts (Figure 2). The Terai and Chure region is densely populated with 391.5 persons/km<sup>2</sup> (CBS, 2012). About 51% of total population of Nepal reside in the region with agriculture and livestock husbandry as the primary occupation. About 42% of the study area is forested providing habitats and migration corridors for the elephants (DFRS, 2015). Major cities, industrial areas, and highways fragment the forested areas. The forests in the region were intact till 1950s but afterward it is under continuous human pressure from expansion of agriculture, settlements, and built-up areas.

The study area comprises various habitats including highly productive alluvial floodplain grasslands, riverine forests, and climax sal (*Shorea robusta*) forest supporting many rare and globally threatened species including tiger (*Panthera tigris*), dhole (*Cuon alpinus*), and greater one-horned rhinoceros (*Rhinoceros unicornis*). The study area has a subtropical climate characterized by hot and humid summers (mid-March/mid-June), intense monsoons (mid-June/mid-September), and dry autumns/winters (mid-September/mid-March) (Lamichhane, Persoon, et al., 2018; Lamichhane, Subedi, et al., 2018). The maximum temperature varies from 35 to 40°C in summer and 14 to 16°C in winter (Jackson, 1994). The mean annual rainfall ranges between 1,138 and 2,680 mm, with over 80% of the rain occurring during the 3 monsoon months (Lamichhane, Persoon, et al., 2018; Lamichhane, Subedi, et al., 2018). Elephants in Nepal are found in four population clusters that is, eastern (Koshi to Jhapa), central (Chitwan to Mahottari), western (Bardiya to Dang), and far-western (Kanchanpur & Kailali). Elephants frequently migrate along the Nepal–India border through forest connectivity in the Indian region along the east (northern part of West Bengal), west (Uttarakhand), and a few localities in the south (Bihar and Uttar Pradesh).



**FIGURE 2** Study area location, forest cover, protected areas, and locations of elephant attacks on humans in Nepal

**TABLE 1** Variables used in binomial logistic regression and their type/source

Variables	Type of variable	Categories/values	Data source
<b>Elephant characteristics</b>			
Herd type/size	Categorical	Solitary adult bulls, sub-adult male, sub-adult male group, herd without calves, female with calves	Questionnaire survey
Musth	Binomial	1, 0, NA (1—Yes, 0—No, NA—Don't know)	Questionnaire survey
<b>Human characteristics</b>			
Response to elephant	Categorical	Shouting, firecracker, stones,	Questionnaire survey
Alcohol use	Binomial	1,0, NA (1—Drunk, 0—not drunk, NA—Don't know)	Questionnaire survey
Victim sex and age	Categorical	Sex (Male, Female) Age (<15, 15–24, 25–44, 45–64, 65+),	Questionnaire survey
Victim ethnicity	Categorical	1. BCT (Brahmin, Chhetri, and Thakuri); 2. Janjati (Ethnic communities of hills and Terai like Gurung, Magar, Tamang, Newar etc.); 3. Indigenous Terai (Tharu, Bote, Darai, Mushahar); 4. <i>Dalit</i> (under-privileged casts of Kami, Damai, Sarki etc.); 5. Madhesi, and 6. Muslim	Questionnaire survey
Education	Categorical	Illiterate, literate, primary, secondary, or above	Questionnaire survey
Activity of the victim at the time of incident	Categorical	Chasing elephants, resting at home, guarding crops, traveling on foot	Questionnaire survey
House type	Categorical	Concrete, CGI sheet, tile house, thatch house	Questionnaire survey
<b>Environmental and habitat characteristics</b>			
Proximity to forest	Numeric		GIS & questionnaire survey
Season	Categorical	Winter, summer, monsoon	Questionnaire survey
Land use type	Categorical	Farmland, settlements, forests/grassland	GIS

*Note:* The human casualty in elephant attack was the dependent variable, and the independent variables included elephant characteristics, human characteristics, and environmental and habitat characteristics.

## 2.2 | Elephant attacks data collection

We compiled all available data of elephant attacks on humans (death and injury) from the Divisional Forest Offices (DFO) and Protected Area (PA) offices across the study area for the period 2000 to June 2020. These records are well maintained in the respective DFO and PA offices for providing monetary relief to the elephant-affected families. Details of the victims and nature of elephant attack (e.g., name, age, sex, address, date of incidence) were obtained from the official records. Each record was verified by reaching at every incident site (locations of the encounter) with the help of victim's spouses, relatives, or neighbors who knew the attack events and locations. We also conducted 30 stakeholder consultation meetings to gather information on human deaths due to elephants, livelihoods, elephant occurrence, and use of areas in and around the village and people's perception toward the elephants.

## 2.3 | Victim household questionnaire survey

We conducted structured questionnaire surveys of all affected households ( $n = 412$ ) in the study area. On consent, either the head of the household or another adult member was interviewed. GPS location of each household was recorded. Before an interview, we requested for a verbal consent with the respondents. The questionnaire included the demographic background of the interviewee and the victim (age, sex, ethnicity, family size), socioeconomic status (education, marital status, house type, income source, occupation, land tenure etc.), victim behavior/activity during attack (place of attack, drunk, activities while attacked, methods used for chasing elephant), characteristics of attacking elephant (type of elephant, musth, tusk), and habitat characteristics (land use type) (Table 1).

## 2.4 | Data analysis

We entered all the questionnaire survey data in MS Excel and prepared descriptive summaries using pivot table function (Dan Clark, 2020). We then performed data analyses in the R statistical package v. 4.0.2 (R Development Core Team, 2020). We used chi-square test of independence with the null hypothesis—there was no any significant difference on frequency of attacks (death and injury) among different districts, seasons, months, ethnicity, age group, sex, and occupation of the victim (Lamichhane, Persoon, et al., 2018). We categorized victims into five categories based on ethnicity, upper caste Hindus including Brahmin Chhetri Thakuri (BCT), *dalit* or socially disadvantaged marginal communities, *Janajati* (ethnic groups such as Gurung, Magar, Newar, Tamang, Rai, Limbu, Tharu, Bote, Darai, Rajbansi etc.), Madhesi, and Muslim. Similarly, we grouped the victims into five age categories, that is, <15, 15–24, 25–44, 45–64, and 65+ years following (United Nations, 1982). Education level of the victims was categorized into illiterate (who cannot read and write),

literate (who can read/write but have not attended formal school), primary (completed primary school), and secondary or above. Housing of the victim was categorized into cemented house, corrugated galvanized iron (CGI) sheet roof house, tiled roof house, and thatched house.

We carried out binomial logistic regression by constructing a generalized linear mixed model (GLMM) (Zuur et al., 2010) to determine the factors associated with fatalities in elephant attacks. In the GLMM, fatalities on elephant attack were used as dependent variable by coding the human fatality—1 and injury—0. Fourteen explanatory variables representing elephant characteristics, human characteristics, and site characteristics were defined (Table 1). Elephant behavior included social characteristics (solitary bulls or herd elephant), and the elephant was in *musth*. The human characteristics included age and sex of the victim, education, activities of the victim during elephant attack, location of attack, and type of house of victims. Human behavior or response toward elephants (chasing with fire, explosives, or gun) was also included. Site characteristics included place of attack, migration route of elephants, and proximity to forest. We extracted the victim location's habitat and environmental variables (Naha et al., 2019) (Table 1) using Google earth engine platform (Buchholtz et al., 2020; Gorelick et al., 2017) and Arc-GIS v 10.5 (ESRI, 2016; Wang et al., 2018).

We ranked models by the small-sampled corrected Akaike's information criteria (AICc, lower AICc value indicates higher model ranking) using multi-model inference in "MuMIn" package in R (Barton, 2020). The top model for making ecological inference was obtained by averaging the models in the candidate set supporting the data equally well ( $AICc \leq 2$ , (Burnham & Anderson, 2001).

## 3 | RESULTS

### 3.1 | Victim characteristics

There were 412 records (274 fatalities and 138 injuries) of elephant attacks on humans for the period of 2000–2020 June. Men were attacked more frequently than women. Ethnic or *Janajati* people were the most affected group followed by BCT, *socially disadvantaged*, *Madhesi*, and Muslim. Age of the victims on elephant attacks range from 7 months to 80 years but most of them (71%) were adults between 25 and 64 years (Table 1). A quarter of elephant attacks occurred while people were chasing elephants and half took place around settlements or homes (Table 2). Most of the people attacked (88.8%) had low level of education (illiterate, literate, or primary education only), and the two third of the victims of elephant attacks were living in the thatched house (Table 3).

### 3.2 | Elephant characteristics

Most of the elephant attacks on humans (85.2%,  $n = 412$ ) were caused by solitary adult bulls or subadult male groups and rest of the

**TABLE 2** Characteristics of victims attacked by elephants in Nepal's Terai and Chure region of Nepal between 2000 and June 2020

Victim characteristics	Incident type		Total
	Death	Injury	
Sex			
Women	116	38	154
Men	158	100	258
Caste/ethnicity			
BCT	74	49	123
Dalit	46	20	66
Janajati	115	50	165
Madhesi	36	15	51
Muslim	3	4	7
Age			
<15	19	7	26
15–24	39	23	62
25–44	101	61	162
45–64	92	39	131
65+	23	8	31
Education			
Illiterate	141	63	204
Literate	44	36	80
Primary	55	27	82
Secondary or above	34	12	46
Housing			
Cemented house	28	22	50
CGI sheet roof house	31	27	58
Tiled roof house	28	9	37
Thatched house	187	80	267
Total	274	138	412

attacks were caused by the elephants in herd or females separated from the herd (Table 4). The bulls involved in the attacks were in *musth* in more than half of the incidents.

### 3.3 | Temporal and spatial distribution of elephant attacks on humans

Elephant-related human attacks varied significantly across months ( $\chi^2 = 76.272$ ,  $df = 11$ ,  $p < .001$ ) with peak during postmonsoon season (September to December) (Figure 3a). Number of elephant-related human attacks were higher outside protected areas (Figure 5), but the difference was not significant ( $t = -1.0751$ ,  $df = 19.296$ ,  $p = .29$ ). Linear regression showed a gradual increase in elephant attacks on humans (Figure 3b). Average number of incidences of attacks was 11 ( $\pm 8.5SD$ ) during 2000–2010 and increased to 29 attacks ( $\pm 11.2SD$ ) during 2011–June 2020.

**TABLE 3** Victim activity and location of elephant attacks in the Terai and Chure region of Nepal during 2000–June 2020

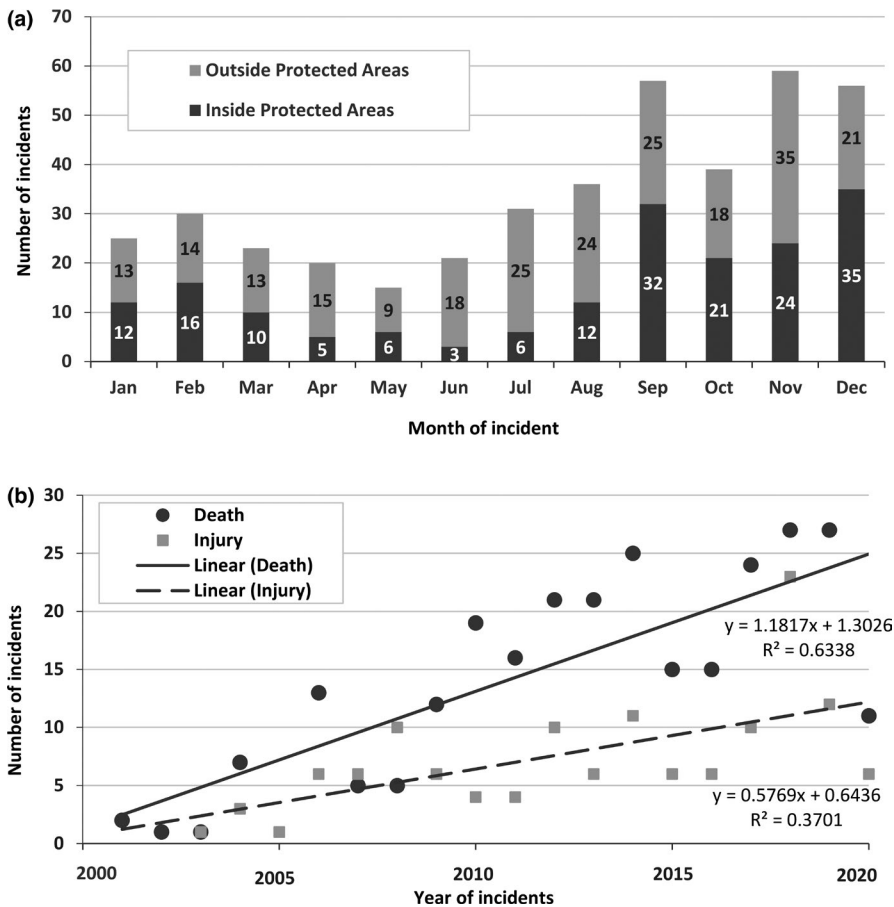
Activity of the victim	Location of attack			Total
	Crop field	Forest	Home/settlement	
Chasing elephants	11	22	70	103
Traveling	1	30	50	81
Sleeping or working at home	–	–	66	66
Fetching forest products	–	65	–	65
Guarding crops	36	1	2	39
Livestock grazing	2	23	1	26
Open defecation	–	–	21	21
Other	1	7	3	11
Total	51	148	213	412

**TABLE 4** Characteristics of the elephants involved in attacks on humans in Nepal's Terai and Chure region between 2000 and June 2020

Elephant characteristics	Attacks on humans		Total
	Death	Injury	
Group type			
Adult males	213	103	316
Adult females	6	13	19
Mixed group herd	17	11	28
Subadult male group	27	8	35
Unknown	11	3	14
Adult/subadult bull elephant			
Yes	240	111	351
No	24	24	48
Don't know	10	3	13
Elephant in <i>musth</i>			
Yes	131	76	207
No	71	36	107
Don't know	72	26	98
Total	274	138	412

In the forested areas, elephant attacks on humans were at peak in the afternoon (4–5 p.m.), whereas, in settlement areas, elephant attacks peaked in the evening (7–9 p.m.) (Figure 4).

The number of attacks on humans varied significantly among the districts ( $\chi^2 = 338.49$ ,  $df = 19$ ,  $p < .01$ ) with the highest number of



**FIGURE 3** Temporal distribution of elephant attacks on humans (death and injuries) in Nepal during 2000 and June 2020 (a) over the months and (b) years

incidents ( $n = 66$ ) from Jhapa and Bardiya districts (Figure 5). The majority of elephant attacks (67%) occurred within 500 m from the forest edge (Figure 6).

### 3.4 | Factors associated with human fatality

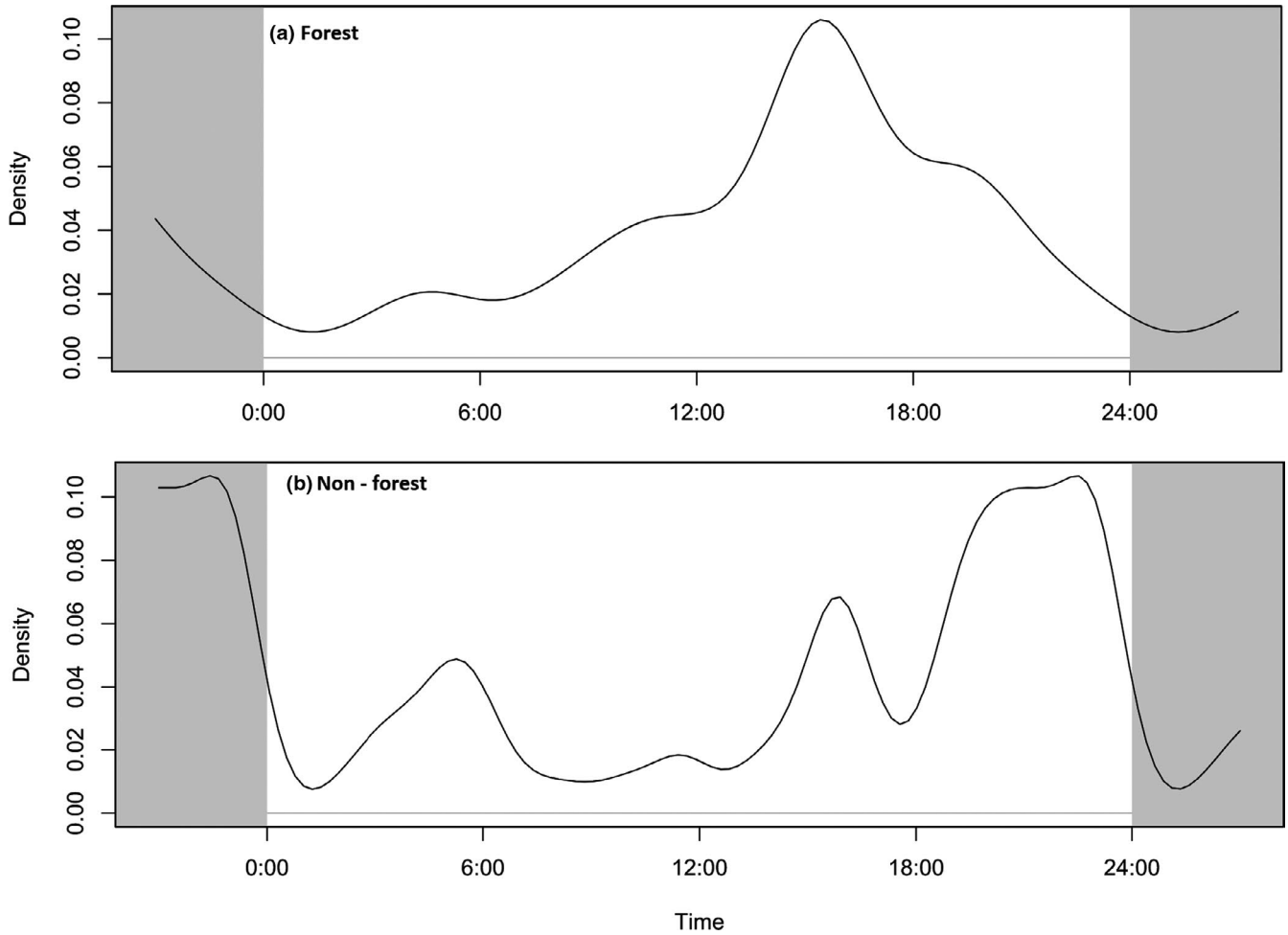
People who were drunk and chasing elephants using firecrackers were more vulnerable to fatalities while chasing elephants using fire was negatively associated with fatalities (Table 5).

## 4 | DISCUSSION

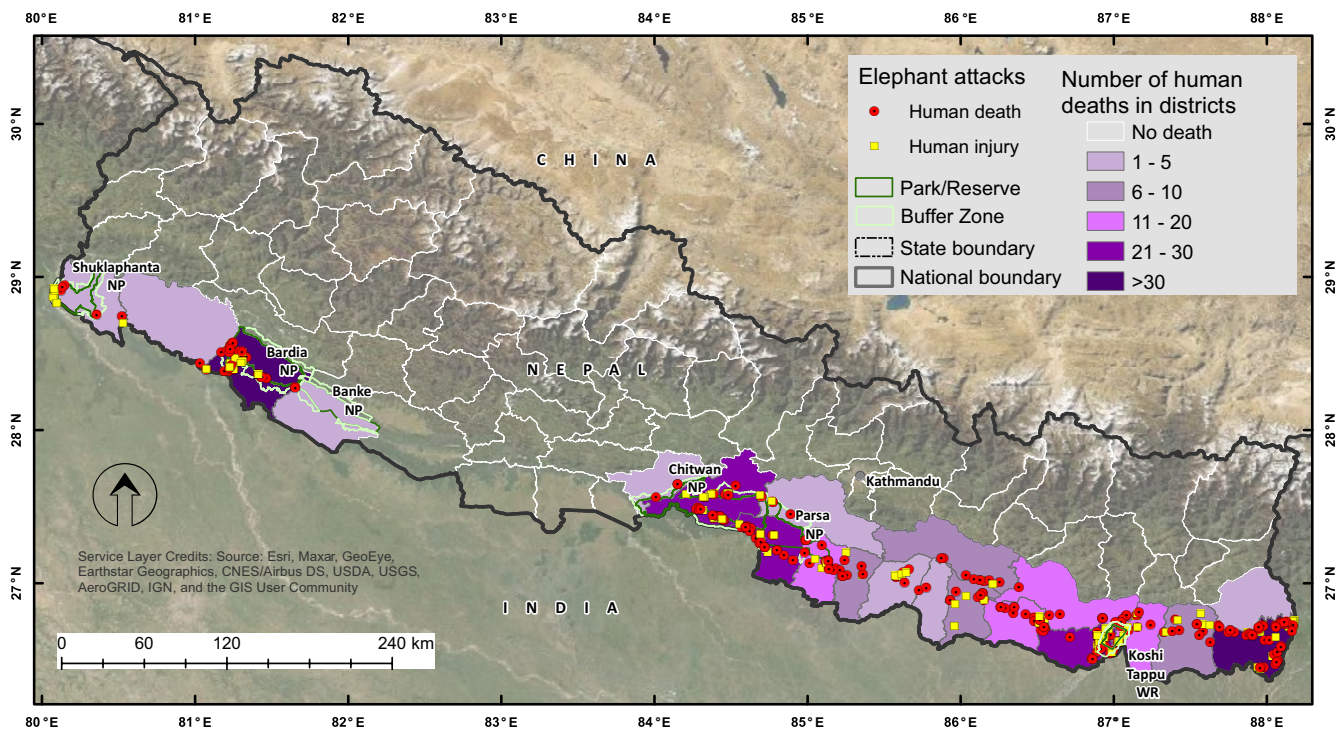
Our study presents the most comprehensive analysis of the elephant attacks on humans in Nepal. Elephants attacked an average of 20 humans per year with two thirds resulting into fatalities in the Terai and Chure region. We documented the increasing trend of Elephant attacks on humans over the years. Human response toward elephants was a major factor resulting in elephant attacks, supporting our first hypothesis. Higher number of attacks by elephants on humans occurred in proximity of the forest (66.9% attacks in <500 m from forest edge) supporting our second hypothesis. In contrast to our third hypothesis, more people were attacked outside the protected areas. Over 76% of the attacks on humans were caused by the solitary bulls supporting our third hypothesis.

### 4.1 | Characteristics of the victims of elephant attack

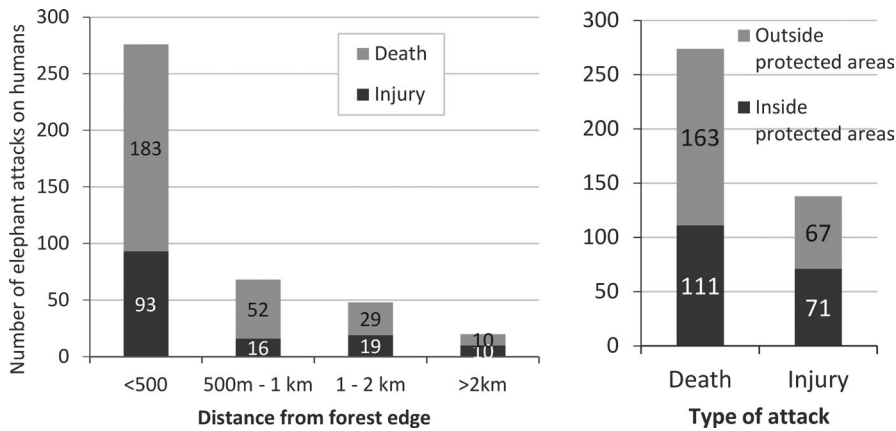
Elephants attacked men more frequently than women which can be associated with the high mobility of males and their involvement in chasing the elephants (Sarker et al., 2015). For instance, majority of the males were attacked while chasing elephants or traveling whereas females were attacked more frequently while fetching forest products or working at home (Supplementary information S1). Most of the attacks on humans occurred close to forests where socio-economically marginalized people reside (Neupane et al., 2017; Pant et al., 2016). Marginalized communities refer to the people or communities at the lower level of the society with limited access to economic opportunities and the social decision-making. Mostly, they live in vulnerable areas such forest encroachment, river sides, and roadsides. Such communities have often excluded from the mainstream activities (economic, political, cultural, and social) of the society and less access to the government resources. Most of the attacked persons were illiterate, living in thatched house, an indicator of poor social and economic condition (Neupane et al., 2013). People living in thatched house often keep their grain storage close to where they sleep due to limited space in the house. It increases the chances of elephant damage in their house and risks of elephant attack (Naha et al., 2019). Neupane et al. (2013) documented low level of education and awareness about elephants as an important determinant of the elephant attacks on humans. High



**FIGURE 4** Elephant attacks on humans at the different time of day in (a) forested areas and (b) settlement and agriculture areas outside forests



**FIGURE 5** Spatial distribution of elephant attacks on humans in Nepal



**FIGURE 6** Spatial distribution of elephant attacks on humans in Nepal with respect to distance from forest edge (left) and inside/outside of the protected areas (right)

**TABLE 5** Factors associated with human fatalities on elephant attacks in Nepal

Parameters	Estimate	SE	Adjusted SE	z value	Pr(> z )	Significance
(Intercept)	0.652	0.795	0.798	0.818	0.413	
Crackers_Drums	1.095	0.508	0.511	2.142	0.032	*
Drunk	1.124	0.380	0.382	2.938	0.003	**
Fire_chasing	-1.715	0.576	0.579	2.961	0.003	**
House_typeCGI	0.063	0.588	0.592	0.107	0.915	
House_typethatched	0.795	0.504	0.508	1.566	0.117	
House_typediled	1.585	0.828	0.833	1.903	0.057	.
Place_attackForest	-0.914	0.530	0.533	1.715	0.086	.
Place_attackHome/settlement	-0.272	0.522	0.526	0.518	0.605	
prox_forest	-0.001	0.000	0.000	1.919	0.055	.
Age	0.013	0.010	0.010	1.219	0.223	
Ele_Musth	-0.294	0.358	0.360	0.816	0.414	

Note: Significance codes: <0.001 "\*\*\*\*" 0.001 "\*\*\*" 0.01 "\*\*" 0.05 "." 0.1 " " 1.

proportion of attacks on *Janajati* (ethnic) people can be associated with their involvement in local liquor production, consumption, and selling for their livelihood (Lamichhane, Subedi, et al., 2018; Parajuli et al., 2015). Such liquor also attracts elephants (Naha et al., 2019), primarily the solitary bulls, and increases the chances of encounter with humans. Thus, people living in the settlements near to the forest edge, especially on the elephant migration routes, are vulnerable to elephant attacks (Jadhav & Barua, 2012; ten Velde, 1997). The findings of this study clearly indicate a need of devising strategies and actions to stop elephants entering into the settlements and help poor and socially marginalized communities to secure their livelihoods (Gross et al., 2021).

## 4.2 | Characteristics of elephants attacking humans

Mixed herd elephants rarely attacked humans (<5% of the incidents) although they are involved in crop raiding during migration through agriculture areas or settlements (Naha et al., 2020). Solitary adult bull elephants caused majority of attacks on humans in Nepal (Acharya

et al., 2016) but it varied among elephant individuals. A few individual bulls that repeatedly visited human settlements and agriculture areas were involved in the majority of the attacks. Similar findings of attacks on humans by solitary bulls are reported from some parts of Bangladesh (Sarker et al., 2015). In general, bulls range widely, operate solitarily or in small groups and young bulls that disperse out of natal herds lack the social buffering that herd individuals would have. Thus, young bulls can be more excitable and due to their wide movement, bulls can come into frequent contact with people, some of which can turn severely negative (Fernando et al., 2008). However, they are also harassed by people most of the time while raiding crops or grain stores. These irritating actions of humans make them more aggressive resulting in violent attacks (Sampson et al., 2019). We identified 37 such bulls causing three quarters of all attacks on humans in the last twenty years, some of them caused a disproportionately higher number of attacks (up to 36). Such individuals can be termed "problem individuals" need to be closely monitored, particularly their movement patterns and ranging behavior (Lamichhane et al., 2017). The knowledge thus gained through monitoring can be helpful in prioritizing appropriate management strategies.

### 4.3 | Temporal patterns of elephant attacks

Documented records of elephant attacks on humans in Nepal goes back to the 1970s (B.N. Uprety, 2020, Personal Communication.) with sporadic records until the late 1990s (Smith & Mishra, 1992). In our study, we only included data between 2000 and June 2020. The wild elephant population has gradually increased in Nepal from 52–53 individuals during the 1990s (Smith & Mishra, 1992) to 107–145 individuals in 2007 (DNPWC, 2009) and >200 individuals in 2020 (Ram & Acharya, 2020). Human population growth rate in the Terai and Chure region (1.72%) is also higher compared with the national average (1.35%; CBS, 2012). Consequently, the deforestation rate is also higher in this region especially in the Chure (0.18% annually) (DFRS, 2015). The remaining forests are also becoming increasingly fragmented with planned and ongoing large-scale infrastructure development such as roads, railways, canals, industries, airports, and urban areas forming barriers to elephant migration (MOFSC, N, 2015). Overlap in forest use by elephants and humans is increasing, resulting a high human–elephant interactions (Acharya et al., 2016; Lamichhane, Persoon, et al., 2018; Mariki et al., 2015; Mukeka et al., 2019).

Elephant attacks on humans occurred throughout the year but peaked during September–December coinciding with the rice harvesting season. Lamichhane, Persoon, et al. (2018) also shows that elephants use both forested and human-dominated areas but use of human-dominated areas varies seasonally with peak in the autumn. Premonsoon (March–June) had the lowest level of attacks as agriculture areas are devoid of crops and elephants are concentrated primarily in the forests feeding on natural vegetation (Koirala et al., 2016; Lamichhane, Persoon, et al., 2018).

Elephant attacks inside forests peaked during the afternoon (~16:00) when human activity, mainly cattle grazing, and fodder and forest resource collection would remain high inside the forests. The elephants generally rest during the mid-day hot period and start become active with decreasing temperature in the afternoon (after 15:00) (Thapa et al., 2019). This increases the chance of interaction between elephants and humans. Close to the time of sunset (~18:00), most of the people are returning home from the forest while elephants remain inside forest so decreasing the chances of interaction between them. Elephant attacks again increase in the evening (19:00–21:00) when elephants enter the settlements or agricultural fields and people come in direct confrontation while chasing elephants away. Changing behavior of people through conservation education, restoration of the elephant movement corridors and bottlenecks, devising elephant and people friendly land use policies will contribute to human–elephant coexistence.

### 4.4 | Spatial pattern of elephant attacks

Two-thirds of elephant attacks on humans occurred within 500 m from the forest edge. People living in proximity of forests are vulnerable to elephant attacks because (a) chances of encountering

elephants are high at close distance to forest, (b) generally economically marginalized communities live in these areas with lack of proper housing (thatched houses), which is often flimsy. Similar finding of a higher number of attacks by wildlife close to forest or park boundary (<1 km) and an inverse relationship between the distance from the forest edge and wildlife attacks is reported in other studies (Gurung et al., 2008; Lamichhane, Subedi, et al., 2018; Pant et al., 2016).

A higher number of elephant attacks outside protected areas (59.5%) in our study is consistent with Acharya et al. (2016). Similar results with higher conflict incidents outside protected areas have been reported from north-east India as well (Choudhury, 2004). Elephants require large areas to meet their nutritional and social needs. In fragmented habitats where the forests have become insular in human-use areas, elephant home ranges are not limited to protected areas, but encompass human-use areas as well. People living close to protected areas are aware of elephant behavior and respond accordingly (Lamichhane et al., 2019). However, beyond protected areas, human response toward elephants is more aggressive due to low level of awareness, resulting in a high number of human casualties as well as retaliatory killing of elephants (25 out of 33 retaliatory killing in past 20 years, unpublished data compiled by the first author).

The elephant attacks on humans were concentrated in four pockets, Jhapa, Koshi, Chitwan Parsa, and Bardiya. Despite the smaller population of elephants (~35) in eastern Nepal, the number of attacks on humans is relatively higher (43% of total attacks in Nepal). The reason for such a high casualty in eastern Nepal especially in Jhapa district of south-eastern border of Nepal is because of (a) the highly fragmented habitats outside of the protected areas, (b) severe disruption in the historical migratory corridors of elephants from West Bengal, India, straddling the national boundary, and (c) incompatible human behavioral response toward elephants in interface areas where interactions have become common. Historically, ~100 elephants used to migrate annually from West Bengal (India) entering Nepal from the eastern border during September–October and May–June (Mallick, 2012). While migrating, they often came in confrontation with people as they are forced to travel through settlements and agricultural land, with a large part of their historic migration route encroached by people (Choudhury, 2004). A fence installed in Bahundangi area (Jhapa district) at the Eastern border of Nepal has contributed to reducing human–elephant conflict in the fenced areas (Naha et al., 2019). However, the elephant continues their movement in Nepal from south of the fenced area (NTNC, 2019). Some elephants, especially males, break the fence and continue their movement up to Koshi Tappu Wildlife Reserve (KTWR) and westwards.

A quarter of all elephant attacks on humans in Nepal occurred in KTWR and its periphery. KTWR acts as a stepping stone for the elephant population in eastern Nepal. The KTWR (173 km<sup>2</sup>) is much smaller than the home range of elephants (188–400 km<sup>2</sup>, Williams et al., 2008; Alfred et al., 2012; Williams et al., 2015). With the high dependency of communities on the reserve for grazing, fodder, firewood, and fishing, elephants and people come in frequent

confrontation. The situation is further aggravated in the densely populated agrarian areas in the periphery of the reserve.

Human casualty was recorded throughout Central (up to Nawalparasi East) and Eastern Terai. In the Chitwan-Parsa Complex in central Nepal, 27.4% of the elephant attacks were recorded, mostly from Chitwan, Parsa, and Bara districts. There is a gap in elephant distribution between the central population (Nawalparasi East) and the western population (Bardiya) with only a sporadic presence in Banke, Dang, and Kapilvastu districts (Lamichhane, Persoon, et al., 2018). The largest elephant population (>100) in Nepal exists primarily in Bardiya NP in western Nepal where 16.7% of total elephant attacks on humans occurred. Elephants in the western population also migrate through the Chure foothills west of Bardiya reaching up to Shuklaphanta NP causing some incidents of attacks on humans (ten Velde, 1997).

#### 4.5 | Factors associated with the human fatality

Our results of two third of elephant attacks resulting in the fatality are consistent with Acharya et al. (2016). Human behavior and responses toward elephants were the major factors to cause elephant attacks on humans. Aggressive human behavior toward elephant with intolerance was the major determinant of human fatality in elephant attack (Nelson et al., 2003). People were killed mostly while chasing wild elephants using firecrackers and other high sound and light objects. Such elephant drives when haphazardly done would increase the fear and trigger defensive offensive behavior in elephants increasing the probability of human attacks. In the Terai, consumption of alcoholic beverages by local communities during the leisure hours of evening and night is high. Driving elephants when they come to crop fields in an inebriated state can increase the vulnerability of attacks by elephants (Neupane, et al., 2017). Negative association of fatalities while chasing elephants using fire torch indicates it as a safe and effective method for pushing elephants outside of the village.

## 5 | CONCLUSIONS

Human casualties from elephants have been increasing with its multifaceted impact on human–elephant coexistence in Nepal. Elephant attacks were concentrated in proximity of forests primarily affecting the socioeconomically marginalized communities. Most of the attacks on humans were caused by solitary bull elephants. Human response toward elephant was a major factor associated with the elephant attacks on humans. Chances of elephant attacks and human fatalities increase when drunk people are chasing elephants. Local people as well as the Government of Nepal (GON) have adopted various preventive and curative measures such as fences in hotspots, problem animal management, and relief support for victims/families to reduce both human casualties and elephant retaliation. These measures should be continued and additional activities such as integrated settlement, safe housing for socioeconomically marginalized

community, and community grain house in the settlement could be promoted to reduce the confrontation between elephants and humans. Revising the “elephant conservation action plan and strategy for Nepal” and its effective implementation will promote human–elephant coexistence HECx and sustain increasing elephant populations of Nepal.

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#### CONFLICT OF INTEREST

None declared.

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#### ETHICAL APPROVAL

We obtained research permissions from the Department of National Parks and Wildlife Conservation Nepal (Ref no: 3066/073/74; June 02, 2017). We did not carry out any experiments with live animals. We only carry out stakeholder consultation and questionnaire survey by taking verbal consent from the participants. We removed

individual information of participants prior to analyze data to protect the participants' privacy.

## DATA AVAILABILITY STATEMENT

Data related to this article are deposited in Dryad and are available via the following link. <https://doi.org/10.5061/dryad.fxpnvx0s1>.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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## Landscape predictors of human elephant conflicts in Chure Terai Madhesh Landscape of Nepal



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### ABSTRACT

Human elephant conflict (HEC) is rapidly increasing throughout the Asian elephant range countries including Nepal. HEC occurs in the form of human deaths and injuries, and crop as well as property losses. We compiled 10,798 incidents of HEC including attacks on humans, crop and property losses caused by elephants in the Chure Terai Madhesh Landscape, Nepal, between January 2001 and June 2020. We interviewed 10.3% of the total households affected by HEC using structured questionnaire. We used multivariate analysis to identify landscape predictors associated with HEC. The intensity of HEC was high in the areas with higher forest fragmentation, vicinity to forests, protected areas, and larger coverage of seasonal surface water. Landscape heterogeneity, effective mesh size and altitude also contributed in HEC. Socio-economically marginalized communities living close to forests are more vulnerable to HEC. The spatial risk map of HEC identified Jhapa and Koshi in the eastern region; Parsa and Chitwan in the central region, Bardiya and Kanchanpur in the western region as HEC hotspots. Restoration of forests and corridor functionality in these hotspots could reduce HEC. The comprehensive understanding of HEC from this study provides important insights to devise strategies and actions for mitigating the HEC at the landscape level.

### 1. Introduction

Habitat loss, fragmentation, overexploitation of resources, and climate change are major anthropogenic drivers causing the purported 6th mass extinction on the earth (Mishra et al., 2020; Reid et al., 2005; Wagler, 2017). Over a million species face threat of extinction due to human impacts (Bongaarts, 2019). Because of high mobility, large resource requirements and highly prized body parts, large mammals are particularly vulnerable to local and regional extinctions (Hoare, 1999; Liu et al., 2017; Sukumar, 1989). In addition to species extinctions, paradoxi-

cally, pervasive human impacts on the planet had also have also triggered human-wildlife conflict (HWC). Human-wildlife conflict (HWC) is disproportionately higher in fragmented landscape (Daskin and Pringle, 2016; Gubbi, 2012; Naha et al., 2020a; Tilman et al., 2017).

Asian Elephant (*Elephas maximus* Linnaeus, 1958; hereafter referred to as "elephant") is an umbrella species native to mainland Asia (Sukumar, 2003). Once distributed widely across Asia, the elephants are now confined to ~5% of their historical range (Leimgruber et al., 2003) within 13 countries with an estimated population of <50,000 (Williams et al., 2020). While elephants have cultural reverence in parts

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of South Asia, they are hunted for ivory and meat in Southeast Asia (Sukumar, 2003). Despite their essential natural and cultural role, elephants face high extinction risk and are categorized as endangered in the IUCN Red List (Williams et al., 2020).

The intensity of human-elephant conflicts (HEC) varies widely across Africa and Asia due to various ecological and socioeconomic factors, including food availability, size of protected areas, agricultural practices, human density, seasonal variations of climate and socio-cultural beliefs (de Boer et al., 2015; Shaffer et al., 2019). Nevertheless, human-elephant conflict (HEC) is a pervasive threat to human-elephant coexistence within shared landscapes (Acharya et al., 2017; Lamichhane et al., 2018; Naha et al., 2020b). Crop, property damage and occasional attacks on humans might reduce societal tolerance and provoke retaliatory killings impacting the elephant populations (Karanth et al., 2013).

Human elephant conflict (HEC) leads to a large number of human deaths and injuries, threatening the survival of Asian elephant throughout its range (Fernando et al., 2005; Sukumar, 2003, 1989). The nature and extent of HEC varied among ethnic groups, cultural practices, type of crops, season of cropping, habitat characteristics (availability of water and food), elephant population size, environmental conditions along with individual elephant behavior and the peoples' willingness to protect elephants (Dickman, 2010; Ram and Acharya, 2020; Shaffer et al., 2019). Nepal has a small population of wild Asian elephants estimated to be ~230 individuals (Ram and Acharya, 2020). These individuals form a part of the meta-population network of elephants across the Terai region encompassing the neighboring countries of India, Bhutan, Bangladesh and Myanmar (MoFSC, 2015). The Chure Terai Madhesh Landscape (CTML) comprises of the entire elephant range in Nepal and provides connectivity for the meta-population across the Terai region (Ram et al., 2021a).

Forest cover is a primary determinant of elephant distribution, thus, understanding impact of forest loss and fragmentation is crucial for elephant conservation (Padalia et al., 2019). About 22% of elephant habitat was lost between 1930 and 2020, with a larger proportion i.e., (12.3%) forest cover loss between 1930 and 1975 (Ram et al., 2021b). At present, only 19,000 km<sup>2</sup> forest cover is available as an elephant habitat in Nepal which has been gradually reduced at an annual rate of 0.27%. The continued fragmentation had fragmented elephant populations during the last century and escalated human-elephant conflict (HEC) (Ram et al., 2021b).

Presently, there is considerable movement of large mammals within the Chure Terai Madhesh Landscape (CTML) including the elephant, tiger (*Panthera tigris*), one-horned rhinoceros (*Rhinoceros unicornis*), and others (Acharya and Ram, 2017; Service, 2021; Sharma et al., 2019). The CTML covers both the Gangetic flood plains and the Siwalik Mountain range of Nepal. CTML is also a remnant elephant habitat with highly diverse flora and fauna, gradually experiencing elephant poaching and ivory trade (CTML) (Singh et al., 2019). The elephant habitat in CTML is interspersed with humans and thus, the negative interactions between the two species are frequent (Acharya et al., 2016; Lamichhane et al., 2019; Ruda et al., 2018). HEC has resulted in ~20 human deaths with large amount of crop, property damages along with the deaths of ~5 elephants due to retaliation each year in Nepal (Ram et al., 2021a).

Elephants are one of the less researched megaherbivore species in the CTML, Nepal with a large knowledge gap particularly with respect to HEC. The HEC situations are dynamic, and periodic assessments should be conducted to develop appropriate management strategies. In this study, we examined a) the landscape features associated with the HEC, and b) mapped conflict hotspots by modeling the probability of HEC. We examined three hypotheses; a) HEC is associated with demography (ethnicity, education, family size) of the respondent and the season, b) Fragmentation intensify HEC in the landscape, c) Water availability is associated with increased probability of HEC in the landscape.

## 2. Methods and materials

### 2.1. Study area

The study was carried out throughout the elephant range in Nepal's Chure-Terai-Madhesh landscape (CTML), which spreads across 24 districts of six provinces in Nepal (26.4154° to 29.1134°N and 80.1259° to 88.0849° E, area – 42,456 Km<sup>2</sup>) (Fig. 1). The CTML, extending from east to west in southern Nepal, has rich biological diversity and provides important ecological services (especially groundwater recharge) for more than half of the country's population (~15 million) (CBS, 2014; Chaudhary and Subedi, 2019; Hamilton and Radford, 2007). CTML comprises of 48% agriculture and settlement; 47.16% forest, shrub-land and grassland; and the rest 4.65% river and riverbed (GoN/PCTMCDB, 2017). Vegetation types in CTML include a) Himalayan subtropical broadleaved forest, b) Gangetic plains and moist deciduous forest, and c) Terai-duar savannas (Chaudhary and Subedi, 2019). The study area has a sub-tropical monsoonal climate with four distinct seasons defined here as winter (mid-December/mid-March), pre-monsoon (mid-March/mid-June), monsoon (mid-June/mid-September), and autumn (mid-September/mid-December) (Lamichhane et al., 2017). The maximum temperature varies from 35 to 40 °C during summer and 14–16 °C in winter (Jackson, 1994). Because of fragmented landscape, elephant occurs in four isolated populations (Pradhan et al., 2011; Ram, 2014; Ram et al., 2021b). The annual rainfall ranges between 1138 and 2680 mm, with over 80% of the rain occurring during monsoon months (DFRS, 2015). The altitudinal range varies between 60 and 1500 m (Chaudhary et al., 2016). CTML is densely populated with an average human density of 390 persons/km<sup>2</sup> (CBS, 2014), with sixty percent of the people depending on subsistence agriculture (Chaudhary and Subedi, 2019) (Fig. 1).

### 2.2. Data collection

#### 2.2.1. Human elephant conflict (HEC) data

The farmers who experienced elephant-related losses, started reporting HEC incidents after implementation of Buffer Zone programs (1998 or later), which used to provide relief to victims in the form of ex-gratia. As a part of this program, human-wildlife conflict data are maintained systematically by the wildlife management authorities (Lamichhane et al., 2018). In 2009, government endorsed the directives on relief payment for wildlife damage including elephants (Acharya, Paudel, Neupane and Köhl, 2016). We compiled all such data of HEC (Human death, injury, crop, and property damage) from the Divisional Forest Offices (DFO) and Protected Area (PA) offices across the CTML for twenty years (July 2001 to June 2020). We collected a comprehensive dataset for our study but it is not the complete census of HEC incidents. Some of the HEC incidents remain undocumented as victim families do not report it. All reported HEC incidents were verified by the wildlife staff prior to compensation. We verified all HEC data from the annual reports of PAs, divisional forest offices, Department of National Parks & Wildlife conservation (DNPWC), and stakeholder consultation meetings ( $n = 30$ ) (Ram et al., 2021a). The information transcribed from the data includes the victim's name and address, date of incident, type of loss, species of wildlife causing the loss, amount claimed and received.

#### 2.2.2. Victim household questionnaire survey

We identified five major HEC hotspots in the stakeholder consultation meetings and surveyed randomly 10.3% of HEC victim's households ( $n = 1116$  HH), using structured questionnaires. We interviewed either the head of the household or another adult member (age >18 years) upon receiving their consent. The interviews were also recorded electronically, along with filling the questionnaire. The wildlife officials who were present during ex-gratia payments for HEC related losses also accompanied the research team during questionnaire surveys. The

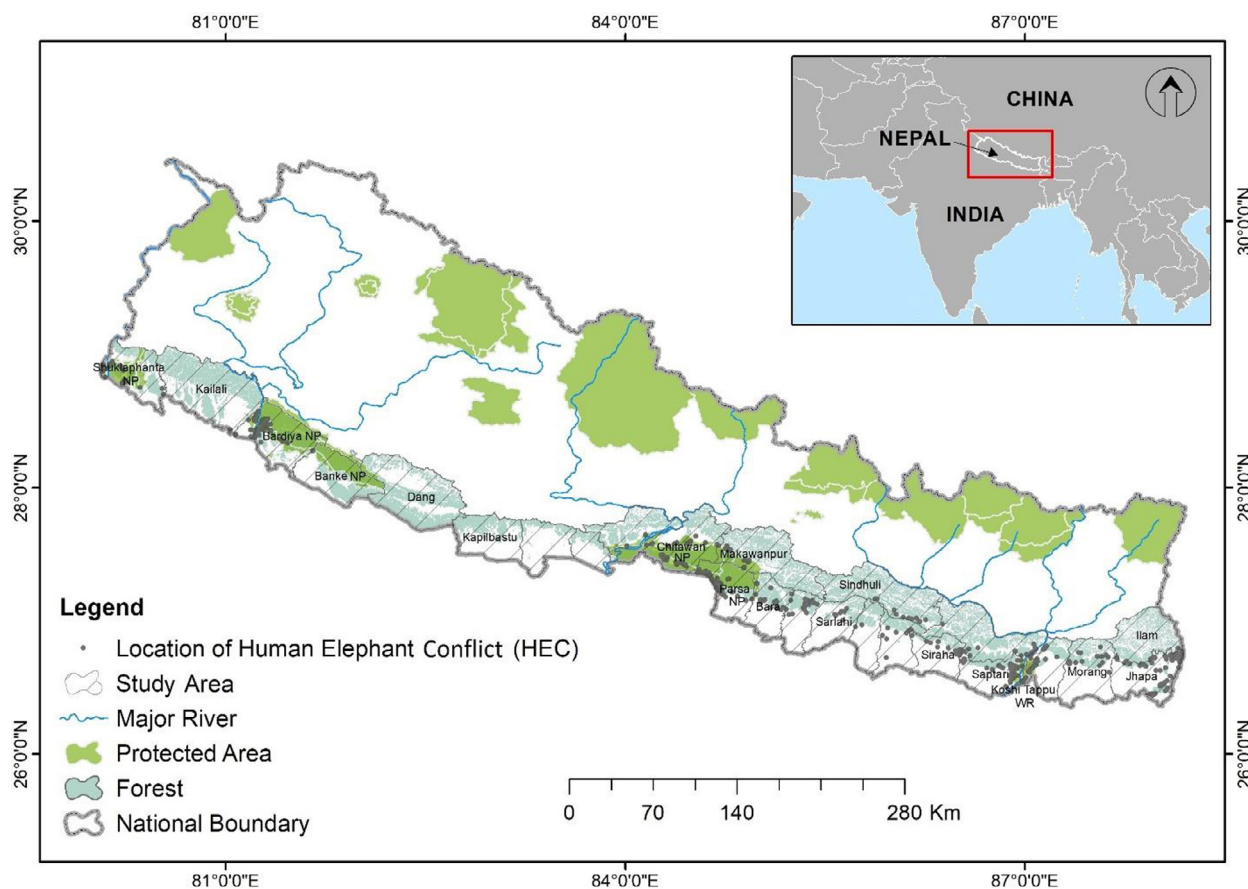


Fig. 1. Geographical location of Nepal, Study area along with human elephant conflict locations.

Table 1  
Landscape predictor variables.

Types of variables	Predictor variables	Codes	Units	Range	Source /Description of data
<b>Habitat (Fragmentation metrics)</b>	Mean Perimeter Area Ratio	MPAR	Meter/hectare	0 – 0.34	Classified satellite images of 2020 (Landsat 8, 30 m resolution)
	Effective mesh size	MESH	Hectare	0 – 2500	”
<b>Habitat (Landscape variables)</b>	Landscape Heterogeneity	SHDI	Numeric (ratio)	0 – 0.6900	”
	Area of Open Forest	AOF	m <sup>2</sup>	0 – 8231,400	”
	Distance to Protected areas	DPA	meter (m)	0 – 107,477	”
	Distance to Forest Area	DFA	meter (m)	0 – 30,953.8	”
	Digital Elevation Model	DEM	M	100 – 3602	SRTM Digital Elevation Data Version 4
	Area of seasonal water	ASW	m <sup>2</sup>	0 – 11,849,442	EC JRC/ Google Earth Engine
	Area of permanent water	APW	m <sup>2</sup>	0 – 1937,874	EC JRC/ Google Earth Engine
<b>Human footprint</b>	Length of the Stream	LS	M	0 – 197,724	Department of Survey, Nepal, digital topographic map
	Length of the road	LR	Km	0 – 99.87	Open street map
	Population density	PD	persons per km <sup>2</sup>	0 – 12,389.8	GPWv411: Population Density (resolution – 1 km2)

questionnaire included demographic details of the respondent, spatial and temporal information of the incidents, age, sex, literacy, address with GPS location, date/time of incidents, type of incident, socioeconomic status, and habitat characteristics (Karanth et al., 2013; Lamichhane et al., 2018; Mukeya et al., 2019) (Supplementary information S4).

2.2.3. Landscape and habitat metrics

We stratified the study area into 5 × 5 km<sup>2</sup> (i.e. 25 km<sup>2</sup>) grids (n = 1407) using Arc GIS 10.5 to identify spatial factors at coarser scales (Naha et al., 2020a, 2019; Ram et al., 2021b). We compiled 12 landscape predictor variables for each cell for predicting human-elephant conflicts (HEC), in three different categories viz. a) fragmentation metrics viz. mean perimeter area ratio (MPAR), effective mesh size-(MESH), land-

scape heterogeneity (SHDI) measures forest fragmentation (S1, Table 1); b) habitat characteristics (area of open forest, distance to protected areas, distance to forest area, area of permanent water, area of seasonal water, stream length, elevation); and c) human footprint (population density, length of road) (Naha et al., 2020a) (Table 1). Mean perimeter area ration (MPAR) is a shape complexity parameter describing the shape of different patches based on the relation between perimeter and area. It is used as a substitute for shape index. At class level, it decreases irregularly with the increase of area percentage for one class. The effective mesh size (MESH) is constrained by the ratio of cell size to landscape area and achieved when the corresponding patch type consists of a single one-pixel patch. Shannon Diversity Index of land use categories is used as an index of landscape heterogeneity (SHDI). It is ‘0’ when the landscape contains only 1 patch (i.e., no diversity). The index increases

as the number of different patch increases and/or the proportional distribution of area among patch types becomes more equitable (de Beer and van Aarde, 2008; Fahrig, 2003; Haines-Young and Chopping, 1996). Finally, we generated the binary and count statistic for the surveyed HEC events (treating each human fatality, injuries, crop, and property damage as a single event) within each grid cell (Naha et al., 2020b, 2020a, 2019).

#### 2.2.4. Data analysis

We carried out data analyses in the R statistical package v. 4.0.2 (R Core Team, 2020). We used the Pearson Chi-square test of independence (statistical significance  $\alpha = 0.05$ ) (Franke et al., 2012; Rao, 2002) to compare the association between frequency of elephant attacks and education of the respondent, ethnicity of the respondents, seasons of conflict, types of houses and family size. We used binary and count statistic data for HEC events to model the spatial spread and extent of human-elephant conflict (HEC) incidents obtained from the questionnaire survey as a response variable (Clark, 2020). For the binomial distribution, the HEC presence/absence (presence coded as '1' and absence as '0') within the grid cell (25 km<sup>2</sup>) was used as a response variable and the other 12 landscape predictors as explanatory variables (Table 1). Similarly, for the Poisson distribution, the frequency of HEC events within the grid cells was used as the response variable with the same explanatory variables.

Multicollinearity test among these 12 explanatory variables (Table 1) was performed using VIF functions (vifcor function in package 'usdm') in R (Naimi, 2017). None of the variables were highly correlated (VIF value >5) (S2). Thus, we used all the variables for model building (Chatterjee and Hadi, 2012). We run two sets of Generalized Linear Models (GLM) (Zuur et al., 2010) with the binomial and Poisson error distribution respectively, to analyze the effect of landscape features and human presence on HEC. We performed Moran's Index test using ArcGIS Spatial Analyst tool to test spatial auto-correlation and found the z-value (11.992), Moran's Index (0.) and (p-value < 0.01), indicating that there is a less than 1% likelihood that the spatial clustering pattern of the HEC events was due to random chance (Bivand et al., 2013). We also found that the distance threshold between each neighboring HEC site was estimated to be 5000.5 m. Finally, we performed z-transformation of the variables, which allowed us to interpret the model coefficients and to compare effect sizes between alternative models (Graf, 2004).

Using the multi-model inference 'MuMin' package in R version 1.43.17., we constructed all possible models with a combination of predictor variables and ranked them based on the small-sampled AIC (lower AICc value indicates higher model ranking) (Barton and Barton, 2020). We obtained the final model by averaging the top candidate models (delta AIC  $\leq 2$ ) (Burnham and Anderson, 2001). From the total data of 1407 grid cells, 80% of samples were randomly selected for model building (training sample) and 20% for validation of the model (test sample)

We checked the model's accuracy by comparing the predicted values and the actual value of the test samples. Predicted values of the model with the highest accuracy were reported. Further, we generated the ROC curve and AUC values to predict the reliability of the dominant models using package ROCR in R 4.0.3. We predicted the potential conflict hotspots based on the coefficients of the dominant models. We used ArcGIS Pro (version 2.8.2) for preparing the HEC risk map (Naha et al., 2020a, 2019).

### 3. Results

#### 3.1. HEC records and interview with the victims

A total of 10,798 records of human-elephant conflicts (HECs) events were recorded within 203 grids between January 2000 and June 2020. Out of which, 274 cases were human fatalities, 138 cases of human injuries, 6606 cases of crop damages, and 3757 cases of property damages

(Table 2). The highest number of HEC incidents were recorded in 2017 and most of the people got the relief in the form of ex-gratia payment.

HEC was distributed across the 20 districts of the CTML (Table 2). Similarly, temporal pattern shows very less incidents before 2009 (probably underreported or less incident happened) and increased spontaneously reaching maximum in 2017. The number of reported incidents slightly decreased afterwards.

Out of 10,798 HEC incidents, we interviewed ~10.3% of total households ( $n = 1116$ ), and their details are presented in Table 2. There was no significant difference between frequency of HEC and education of the respondents and seasons. However, HEC frequency differed significantly between ethnic groups, types of houses, and family size, which supported the first hypothesis i.e., HEC is associated with the demographic feature of the respondents (Table 3).

#### 3.2. Landscape predictors of HEC

We run GLMs with the binomial distribution (presence of conflict -1, absence of conflict 0) and also with Poisson distribution (grid wise count of conflict incidences). The direction of influence of predictor variables on response was consistent across both response variables presence/absence of conflict (binary) and number of conflict incidences (count) (Table 4a,4b). The results of binomial GLMs are presented in table 4 a) and 5, and of Poisson GLMs result presented in Table 4b) and Table 6. The model with additive influence of Area of open forest (AOF), Area of permanent water (APW), Area of seasonal water (ASW), Altitude (DEM), Distance to forest area (DF), Length of the stream (LS), Effective mesh size (MESH), Mean perimeter area ration (MPAR), Population density (PD), and Landscape heterogeneity (SHDI) appeared as best model among the candidate set (Table 4a). However, there is high amount of model uncertainty among candidate set indicted by similar model weight (Table. 4a). And, since no single model appeared to explain the data substantially, we did full model averaging to compute effect size of the predictor variables (Table 5).

Results of the dominant model demonstrate that the probability of HEC increased with decreasing distance from the forest (DFA), protected area, elevation and area of permanent water. However, probability of HEC increased with increase in open forest area (AOF), area of seasonal water (ASW), mean perimeter areas ratio (MPAR) and landscape heterogeneity (SHDI) (Table 5). The fragmentation metrics viz. mean perimeter area ratio (MPAR) and landscape heterogeneity (SHDI) have increased the intensity of human elephant conflict, so it justified the second hypothesis. Similarly, the increase of seasonal water area and decrease of permanent water area have also positive effect on the increasing HEC in the study area, which justified third hypothesis (Table 5)

#### 3.3. HEC prediction in Chure Terai Madhesh Landscape

The receiver operating curves (ROC) values for the dominant model (GLM with binomial structure) were estimated at 0.86 (86.83% accuracy). The HEC probability maps were prepared based on best model coefficients, indicated that Jhapa and Koshi (eastern region), Parsa and Chitwan (central region), and Bardia and Shuklaphanta (far western region) areas were the highest HEC hotspots. We also found that HEC probabilities were higher near the forest boundary and in the proximity of protected areas. The binomial probability and Poisson prediction of Human elephant conflict (HEC) risk map showed that HEC is distributed throughout the Chure Terai Madhesh Landscape (CTML) (Fig. 3a, b). The HEC prediction map also showed that the probability of HEC will also be higher in Jhapa, Koshi, Chitwan-Parsa complex and Bardiya with highest expected numbers >8 events per grids. (Fig. 3b).

### 4. Discussion

This is a comprehensive study on landscape predictors of HEC in Nepal. We documented a high level of HEC, primarily crop and prop-

**Table 2**  
Spatial extent (District wise) of HEC incidents reported from Nepal between January 2001-June 2020.

District	Crop damage	Human death	Human injury	Livestock loss	Property damage	Total
Banke	5	2	1			8
Bara		20	4			24
Bardiya	2006	40	26	10	958	3040
Chitwan	918	26	17	3	529	1493
Dhanusha		9	3			12
Ilam		4				4
Jhapa	1789	41	25	3	1314	3172
Kanchanpur	41	5	10		11	67
Mahottari		1				1
Makwanpur		5	4			9
Morang	1	8	4	6	15	34
Nawalparasi		1		1	3	5
Parsa	194	21	7	2	113	337
Rautahat		7	1			8
Saptari	403	23	11		276	713
Sarlahi		5	4			9
Sindhuli		9	3			12
Siraha		16	3			19
Sunsari	1227	15	15		532	1789
Udaypur	22	16			4	42
Total	6606	274	138	25	3755	10,798

**Table 3**

Socioeconomic characteristics of respondents interviewed ( $n = 1116$ ). Frequency (count), percentage (proportion) of the respondents and chi-square test of independence among different categories (where relevant) is presented in separate columns.

Variables	Variable Components	Frequency	Percentage% of	
Household Head	Female	242	21.7	
	Male	874	78.3	
Education of respondent	higher education	5	0.4	$\chi^2 = 20.56$ , $df = 12$ , $p < 0.06$
	Illiterate	537	48.1	
	Literate	201	18	
	Primary level	222	19.9	
	Secondary level	151	13.5	
Cast/Ethnicity	BCT	416	37.3	$\chi^2 = 43.78$ , $df = 12$ , $p < 0.000$
	Dalit	147	13.2	
	Janjati	466	41.8	
	Madhesi	76	6.8	
	Muslim	12	1.1	
Season of conflict	Monsoon	416	37.3	$\chi^2 = 3.52$ , $df = 9$ , $p < 0.94$
	Spring	147	13.2	
	Summer	466	41.8	
	Winter	76	6.8	
Types of houses	Cemented house	117	10.48%	$\chi^2 = 146.88$ , $df = 15$ , $p < 0.001$
	GI roof house	441	39.52%	
	Thatch house	499	44.71%	
	Thatch roof house	26	2.33%	
	Tiled roof house	32	2.87%	
Family size	Wooden house	1	0.09%	
	<5 person	499	44.71%	$\chi^2 = 21.10$ , $df = 9$ , $p < 0.01$
	5–10 person	541	48.48%	
	10–15 persons	50	4.48%	
	>16	26	2.33%	
Total	1116			

erty damage, clustered in four sites of CTML (Jhapa, Koshi, Chitwan, and Bardiya). The extent of conflict differed significantly among various communities based on their socioeconomic status and cropping patterns which support the first hypothesis (Table 3). Our results suggest that landscape features are significant predictors of HEC in CTML. Landscape structure, water availability, elevation, and human footprint were the significant factors associated with HEC which supports the second and third hypothesis (Table 5).

#### 4.1. Spatio-temporal extent of HEC in the CTML

Although human elephant conflict (HEC) was recorded from the 20 districts of the CTML (Table 2), Bardiya, Chitwan, Parsa, Jhapa and Sun-

sari districts experienced the highest HEC (Neupane et al., 2017, 2013; Ram et al., 2021a). Our dataset is based on self-reported and it may have potential bias as some of the victims do not report for low-cost damages. However, with the recent provisions of relief payments for wildlife damages, most of the victim file for payments (Lamichhane et al., 2018). The highest number of HEC events occurred around protected areas (PAs) except in Jhapa district (Table 2). Elephant population is concentrated in and around protected areas (e.g. >100 in Bardia, 40–60 in Chitwan/Parsa) (Ram and Acharya 2020), thus, higher conflict probability close to these forests is expected (Gross et al., 2019). HEC incidents are relatively high in the eastern Nepal (Koshi and Jhapa) despite small population of elephant. The reason could be a) widespread forest fragmentation, loss of forest corridors in this region (Ram et al.,

**Table 4**  
Second-order Akaike Information criterion scores (AICc, ΔAIC & AIC weight) of a generalized linear model with a) Binomial and b) Poisson structure predicting HEC using landscape predictors.

Component models*	df	AICc	ΔAIC	AIC weight	LogLik
<b>Binomial distribution</b>					
AOF + APW+ ASW+ DEM + DF + LS +MESH+ MPAR+ PD + SHDI	9	699.09	0	0.27	-340.46
AOF + APW+ ASW+ DEM + DF + MPAR+ SHDI	8	699.69	0.6	0.2	-341.78
AOF + APW + ASW + DEM + DF + LS+ MESH+ MPAR + SHDI	10	699.77	0.68	0.19	-339.79
AOF + APW + ASW + DEM+ DF MESH+ MPAR + SHDI	9	700.56	1.47	0.13	-341.2
AOF + APW + ASW + DEM + DF + DPA + LS + MPAR+ SHDI	10	700.66	1.57	0.12	-340.23
AOF + APW +ASW+ DEM+ DF+ LS + MPAR + PD + SHDI	10	701.05	1.96	0.1	-340.43
<b>Poisson distribution</b>					
AOF+ APW+ ASW +DEM+ DF+DPA+ LR+ MPAR + PD+ SHDI	11	4963.7	0	0.27	-2470.76
AOF+ APW+ ASW +DEM+ DF+DPA+ LR+LS+ MPAR + PD+ SHDI	12	4963.99	0.29	0.24	-2469.88
APW+ ASW +DEM+ DF+DPA+ LR+ MPAR + PD+ SHDI	10	4964.16	0.45	0.22	-2472

\* The variables used in the model are Area of Open Forest (AOF), Area of Permanent Water (APW), Area of Seasonal Water (ASW), Digital Elevation Model (DEM), Distance to Forest (DF), Distance to Protected Areas (DPA), Length of the Road (LR), Length of the Stream (LS), Effective Mesh Size (MESH), Mean Perimeter Area Ratio (MPAR), Landscape Shape Index (SHDI).

**Table 5**  
Coefficients of the best GLM model with binomial structure.

	Estimate	Std. Error	Adjusted SE	zvalue	Pr(> z )	Significance	CI (2.5% - 97.5%)
(Intercept)	-3.13	0.25	0.25	12.66	< 2e-16	***	-3.70 -2.71
AOF	0.29	0.10	0.10	2.74	0.01	**	0.07 0.48
APW	-0.62	0.23	0.23	2.77	0.01	**	-1.10 -0.23
ASW	0.77	0.21	0.21	3.68	0.00	***	0.39 1.20
DEM	-2.71	0.40	0.40	6.72	< 2e-16	***	-3.70 -2.08
DF	-1.44	0.42	0.42	3.45	0.00	***	-2.27 -0.58
LS	0.12	0.12	0.12	0.99	0.32		-0.02 0.40
MPAR	0.39	0.15	0.15	2.60	0.01	**	0.01 0.63
SHDI	0.32	0.14	0.14	2.28	0.02	*	0.07 0.65
MESH	0.05	0.11	0.11	0.46	0.64		-0.13 0.45
DPA	-0.01	0.04	0.04	0.20	0.84		-0.28 0.15
PD	0.00	0.06	0.06	0.08	0.93		-0.44 0.25

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

**Table 6**  
Coefficients of the best GLM model with Poisson structure.

	Estimate	Std. Error	Adjusted SE	z value	Pr(> z )	Significance	CI (2.5% - 97.5%)
(Intercept)	-2.29471	0.11962	0.11972	19.167	< 2e-16	***	-2.5337 -2.06534
AOF	0.02481	0.0334	0.03341	0.743	0.458		-0.01967 0.107541
APW	-0.27476	0.03735	0.03738	7.35	< 2e-16	***	-3.53E-01 -2.07E-01
ASW	0.18952	0.02883	0.02885	6.569	< 2e-16	***	0.125463 0.240228
DEM	-3.07785	0.17765	0.1778	17.311	< 2e-16	***	-3.44E+00 -2.75E+00
DF	-0.88687	0.19693	0.1971	4.5	6.80E-06	***	-1.33384 -0.49423
DPA	-0.81414	0.05065	0.05069	16.06	< 2e-16	***	-9.30E-01 -7.29E-01
LR	-0.17987	0.04393	0.04397	4.091	4.30E-05	***	-0.26243 -0.09016
MPAR	0.1785	0.01822	0.01824	9.787	< 2e-16	***	0.137806 0.214669
PD	-0.34738	0.08095	0.08102	4.288	1.81E-05	***	-0.52036 -0.2005
SHDI	0.84876	0.05138	0.05142	16.505	< 2e-16	***	0.717825 0.9705
LS	0.02755	0.03877	0.03879	0.71	0.477		-0.02789 0.123817
NDVI	-0.01263	0.03118	0.0312	0.405	0.686		-0.12201 0.051404

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

2021b), and b) seasonal migration of elephants from nearby parks in India (Naha et al., 2019; Padalia et al., 2019). Studies from the other elephant range in India, Srilanka and Africa also shows similar findings with clustered pattern of HEC (Fernando et al., 2021; Gubbi, 2012).

Elephant population was small and confined in a few pockets in Jhapa, Parsa and Shuklaphanta in Nepal before 2000; and low level of HEC was reported (Shrestha et al., 1985; Smith and Mishra, 1992), HEC is gradually increasing after 2000 (Acharya et al., 2016; Ram et al., 2021a), along with increasing elephant population. There was no systematic recording of HEC incidents in Nepal before 2009, although buffer zone programs kept record of the relief payment for the loss from wildlife including elephants (Lamichhane et al., 2018). HEC events were recorded systematically after the endorsement of directives on relief

for wildlife damage nationally by Government in 2009 (Acharya et al., 2016; Ram et al., 2021a). Initially, only human death and injuries on elephant attack were considered for relief, thus, crop and property damage events were not reported. The relief guideline was further amended in 2012 to include crop and property damage by elephants and payment procedure was clearly defined (Fig. 3). This resulted in continuous increase in registering HEC events with a peak in 2017 and slows down after 2017. The probable cause of reduction in the HEC incidents might be due to initiation of HEC mitigation measures and the initiation of participatory conservation approach viz. construction of active measures (solar fence ~500 km, GI piped fences, RCC walls, trenches etc.), and initiation of real time-based monitoring of problem elephants using satellite radio collars (Ram, 2021). In 2020, we have only included HEC

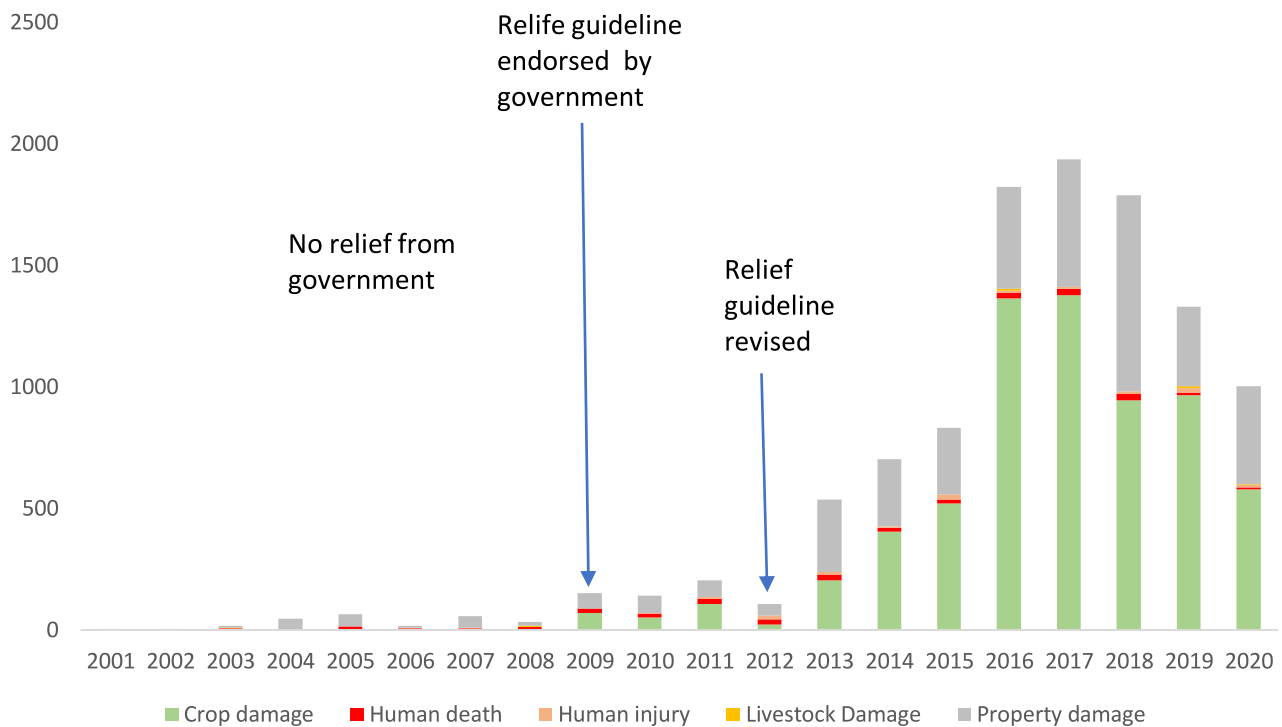


Fig. 2. Temporal extent of human elephant conflict (HEC).

incidents up to June, thus, the incidents seem comparatively less (Fig. 2). Increasing HEC incidents has been reported in other elephant range countries (e.g. India, Sri Lanka) (Karanth et al., 2013; Ranjeewa et al., 2017; Shaffer et al., 2019, 2014).

#### 4.2. Human elephant conflict (HEC) & Socioeconomic status of respondents

The HEC incidents were not evenly distributed among the socioeconomic classes of the respondents. Socioeconomic features such as ethnicity, house types of respondents, and family size were associated with the conflict. The frequency of HEC was recorded higher in the Janajati (ethnic people). This community are socio-economically marginalized and have a high dependency on forest resources, increasing the chances of conflict. Moreover, they also use/produce alcohol in their locality which may attract elephants, increasing the extent of conflict. Ram et al. (2021a) also reported the increased threat of elephant attacks on humans when people are drunk. There was significant difference in the frequency of HEC incidents with the type of housing of the surveyed respondents with people living in Thatch house or GI roof house suffering more frequently compared to concrete or wooden. People living in thatch house are generally poor and marginalized with high dependency on forests for their livelihood (Ram et al., 2021a). Despite some seasonal variation in the frequency of HEC incidents, the difference was not significant statistically. Seasonality of HEC is observed in the other elephant range countries (Gross et al., 2018; Lakshminarayanan et al., 2016).

#### 4.3. Landscape predictors and HEC

Our result shows that fragmentation indices viz. Landscape heterogeneity (SHDI), Mean Perimeter Area Ratio (MPAR), and Effective mesh size (MESH) are the major predictors of HEC in the landscape (Naha et al., 2019; Ram et al., 2021b). This is due to the higher rate of forest loss and fragmentation, especially in the forests outside of the protected areas. Forest fragmentation intensifies the challenges to the conservation of large-ranging species viz. elephants and tigers which

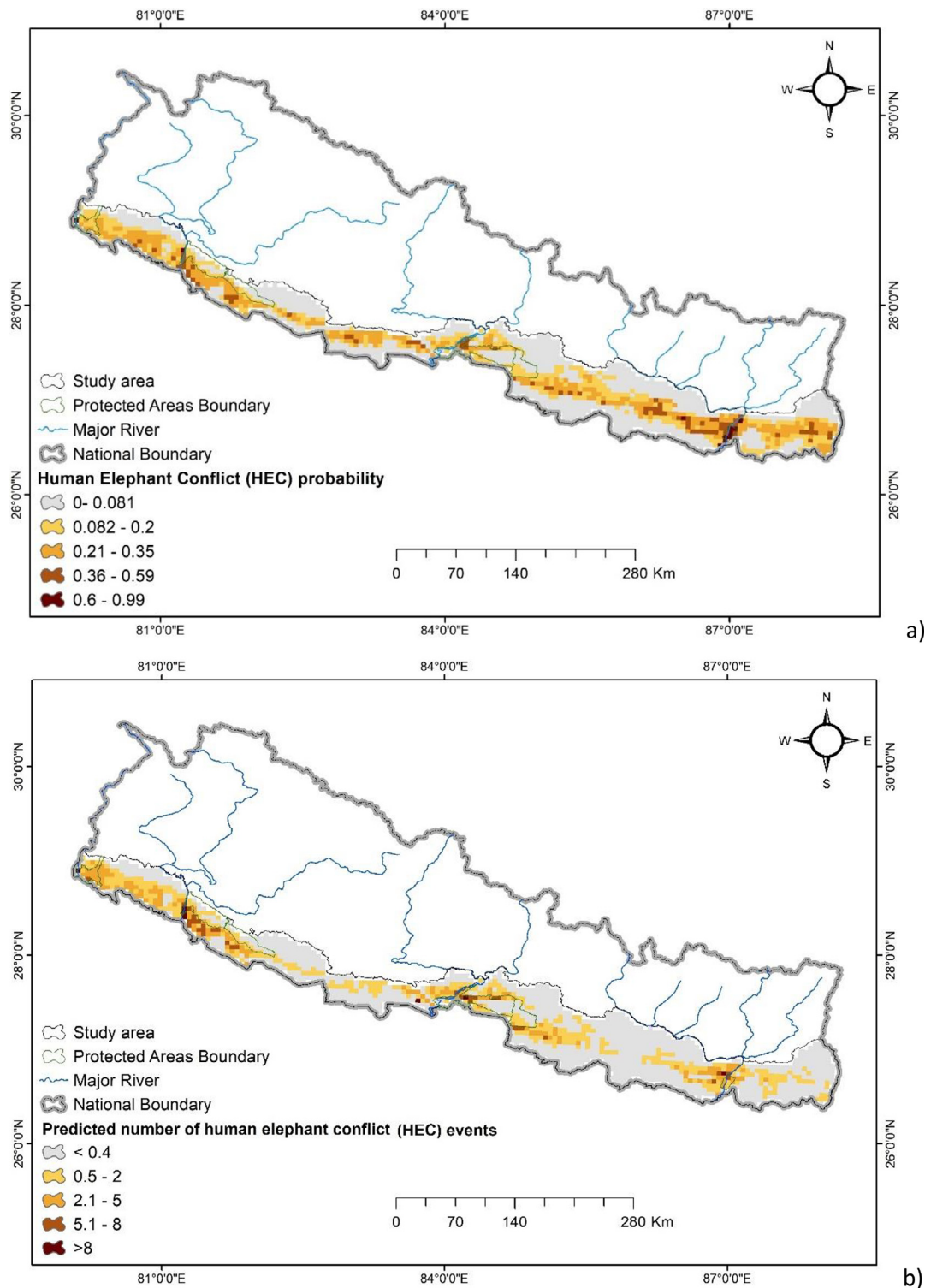
require large areas beyond the protected areas for their survival. These animals came in to contact with humans while navigating through their migratory routes in fragmented landscapes, resulting in a large number of HEC incidents (Ram et al., 2021b). The forest fragmentation is likely to increase in coming days with expansion of linear infrastructure, degradation of forest and rapid expansion of settlements along the forest edge which could worsen the HEC (Acharya et al., 2017; König et al., 2020; Naha et al., 2019; Ram et al., 2021b).

Similarly, the HEC incidents increased with the decrease in coverage of permanent water but increase in area of seasonal water. Water is the crucial component of the habitat. Elephants frequently use the areas of seasonal water while passing through the migratory routes and often come in conflict with local communities (Naha et al., 2019). In the locations with larger areas of permanent water, elephants don't need to travel long distance to find water sources. This reduces the chances of elephant encounter with the local communities resulting in reduced HEC.

Our finding shows a high HEC risk in the proximity to forest, and decreased with increasing distance from the forest boundary which is similar to previous studies (Naha et al., 2019; Pant et al., 2015; Ram et al., 2021a). HEC decreased with increasing altitude, as elephants preferred flat lands, grasslands and low land forests. Our records of HEC include the locations with the altitude between 67 m (Prithwinagar, Jhapa) and 587 m (Makwanpur & Sindhuli) and elephant presence signs were detected up to 885 m of Chure Hills.

#### 4.4. Prediction of HEC risks in the CTML

Spatial risk zones analysis is used as a practical approach to devise mitigation measures for human-wildlife conflicts globally (Treves et al., 2011). The probability map shows the high HEC probability from Jhapa to Chitwan in the eastern landscape and Banke to Kanchanpur in the western landscape (Fig. 3). In the eastern landscape, HEC incidents are high, despite relatively small resident elephant population. Majority of the elephants in eastern Nepal are males dispersed in different parts in smaller groups (Ram et al., 2021a). Males are more aggressive and, thus, come in confrontation with people frequently, increasing the chances of HEC. Be-



**Fig. 3.** a) HEC probability map using the binomial model results, darker areas indicate high risk areas, b) expected number of HEC risk map using the best model of Poisson structure. The darker color means the higher probability of conflict.

fore 2015, a heard of migratory elephants used to enter Nepal annually from Bahundangi area of Jhapa (eastern boarder). After installation of the electric offset fence, the large heard moved southward and only few risk-taker bulls entered Nepal breaking the fence. In the western landscape the elephant population is relatively large and cause damage while migrating Nepal-India or different forest patches in Nepal through the forest corridors and sometimes settlement areas. The government and

conservation organizations should focus their HEC management effort, including awareness campaigns, fencing, and other HEC mitigation measures in the areas with a high probability of conflicts. At present, wildlife conservation is concentrated primarily inside the protected areas (PAs). However, most HEC incidents were recorded outside protected areas (Naha et al., 2020b; Ram et al., 2021b), and little effort has been made to protect elephants there.

Habitat fragmentation is likely to increase with ongoing and planned infrastructure development, many of them lie partly or fully in CTML. For instance, Nijgadh-Kathmandu fast track (under construction), Bardibas-Simara electric railway line, additional electric transmission lines (under construction) have resulted in tremendous loss of forest and induced habitat fragmentation (Khatiwada, 2018; Mahat, 2020; Puri, 2021). In addition to these, forest encroachment for community purposes such as schools, colleges, temples, picnic spots, football grounds, Hat bazaars has also destroyed the forest in recent decades. Thus, fragmentation is continued in the CTML due to highest demand for land (by the hill migrants) and valuable timber (Aryal et al., 2020; Laudari et al., 2020).

## 5. Conclusion

Our results conclude that forest fragmentation and degradation, proximity to forest, altitude and availability of surface water were the major landscape predictors contributing to the HEC. Socio-economically marginalized communities living close to forests are more vulnerable to HEC. HEC is a multifaceted issue, not limited to the protected areas. Thus, it is necessary to extend our conservation priority beyond the boundary of the protected areas. A comprehensive HEC strategy and action plans to initiate HEC mitigation measures including alternative crop farming and initiating other income generating activities are recommended in the HEC risk zones.

## 6. Research Ethics statement

We obtained research permissions from the Department of National Parks and Wildlife Conservation Nepal (Ref no: 3066/073/74; June 02, 2017). We didn't carry out any experiments with live animals. We only carry out stakeholder consultation and questionnaire surveys by taking verbal consent from the participants for the ground verifications.

## 7. Data accessibility

Upon publication of the article, all the supporting data for obtaining the results will be made available via the dryad online data service.

## 8. Author contributions

AKR, NS, SM, & BP designed the study; AKR conducted the fieldwork; AKR, NKY, BRL, BK & BP analyzed the data; AKR, BRL, NKY, SM, BP & NS wrote the first draft of the manuscript; DK, HA, BKD, DN, RM, NLN, KPA, NMBP, HSB, BRD, BK and all authors revised the manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Supplementary materials

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