Heliyon 10 (2024) e26386

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Correlates and impacts of human-mammal conflict in the central part of Chitwan Annapurna Landscape, Nepal

Jagan Nath Adhikari [a,b,c], Bishnu Prasad Bhattarai [a,c,*], Tej Bahadur Thapa [a]

[a] Central Department of Zoology, Institute of Science and Technology, Tribhuvan University, Kirtipur, Kathmandu, 44600, Nepal
[b] Department of Zoology, Birendra Multiple Campus, Tribhuvan University, Bharatpur, Chitwan, 44200, Nepal
[c] Nepal Zoological Society, Kirtipur, Kathmandu, Nepal

ARTICLE INFO

Keywords:
Chitwan Annapurna Landscape
Crop damage
Livestock depredation
Conservation
Conflict
Human mammals' interaction

ABSTRACT

Crop damage, predation on domestic animals and human attacks are often associated with human-wildlife conflict. The abundance and encounter rate of wild mammals are often associated with human wildlife conflict. Crop damage, livestock depredation and human injury and their relation with environmental factors and encounter rate of the mammals was evaluated in the central region of Chitwan Annapurna Landscape. The abundance and the encounter rate of large mammals were determined by dividing the study area into four different study blocks (A, B, C and D) based on river course and topography. A total of 150 transects (average length = 3.18 ± 0.11 km), were administrated for data collection. Similarly, information on human-wildlife conflict was collected using 600 semi-structured questionnaires (150 from each block). The chital was the most abundant mammal (encounter rate (ER) = 1.49 and relative abundance (RA) = 55.45%) in block A whereas muntjac had the highest encounter rate in blocks B, C and D (ER = 0.34, 0.31, 0.79 respectively) but the relative abundance of rhesus was comparatively higher in blocks B, C and D. The signs of tiger were reported from block A only whereas signs of leopard were reported from all blocks. But signs of Himalayan black bear were reported from B, C and D. The encounter rate of the mammals correlated with the monetary loss caused by them. Greater one-horned rhino, wild pig and chital in lowland and monkeys, northern red muntjac, and Himalayan black bear in mid-hills (blocks B, C and D) were the principal crop raiders with a total average annual loss of US$ 11.45 per household. Similarly, the total annual monetary loss by livestock depredation was US$ 76.60 per household. This study evaluated the encounter rate of mammals and their effects on the conflict with people. However, the negative effects arrived from human-wildlife conflicts always threaten large mammals. Hence, this study suggests future intensive studies related to mitigation and prevention methods to mitigate the issues of human-wildlife conflicts.

1. Introduction

The conservation of wildlife especially mammals occupying larger area is commonly dependent on land use and land sharing with local people outside protected areas [1,2]. The interrelations between wild animals, their environments and people in

* Corresponding author. Central Department of Zoology, Institute of Science and Technology, Tribhuvan University Kirtipur, Kathmandu, 44600, Nepal.
E-mail address: bishnu.bhattarai@cdz.tu.edu.np (B.P. Bhattarai).

https://doi.org/10.1016/j.heliyon.2024.e26386
Received 12 July 2023; Received in revised form 18 January 2024; Accepted 12 February 2024
Available online 16 February 2024

human-dominated landscapes are the key factors in wildlife conservation. In these landscapes, both animals and human ecology are closely correlated [3] and both are affected as well.

Human-wildlife conflict has been a common phenomenon since ancient times when people and wildlife use the same habitat, landscapes and natural resources [4], but it has increased with the increase in the population of wildlife and human [5]. Crop-raiding, livestock depredation, property damage and human casualties are the forms of conflicts resulting in huge economic losses [6]. Conflicts sometimes force the people to migrate from high conflict to low conflict areas [6,7]. Animal husbandry and agriculture are the major occupations of most of the rural populations of developing countries [8]. The main leading factors of human wildlife conflict (HWC) are habitat loss, degradation and fragmentation through human activities [6,9,10].

In recent years, more than 30% of the agricultural land of rural area of mid-hill landscape of Nepal has already been abandoned and the people have migrated to the urban and semi-urban areas [11,12]. Furthermore, these abundant crop lands have been converted into bush or forest area due to regenerate the tree species that make the wild animals easy to reach closer to the settlement areas and causes HWC [7,13]. Besides this, community forest programs in the rural area improved the forest quality and help to significantly increase of wildlife population in the mid-hills [14–16]. Unfortunately, this increases the probability of encounters with wild animals and causes HWC events [6,17–19].

Human-wildlife Conflict (HWC) is a common problem in the majority of the protected areas (PAs), protected forests, national forests and community forests in Nepal [17,20]. On increasing the wildlife population in the forest, the trends of HWC also increase in the surrounding settlements [18]. The key wildlife species that govern HWC in the lowland of central Nepal (e.g., Chitwan National Park (CNP) and surrounding areas) are the greater one-horned rhino (*Rhinoceros unicornis*), wild pig (*Sus scrofa*), Asian elephant (*Elephas maximus*), tiger (*Panthera tigris*) and leopard (*Panthera pardus*) [2,21,22]. Crop raiding by monkeys (*Macaca mulatta* and *Semnopithecus* spp.), northern red muntjac (*Muntiacus vaginalis*), wild pig, Himalayan black bear (*Ursus thibetanus*), livestock depredation by leopard and human injuries and casualties by leopard and Himalayan black bear are common effects of HWC in mid-hills of Nepal [2,17].

The idea of knowledge of mammal's distributions and their interaction with humans, could help to conserve the mammals and minimize economic loss from HWC in such areas [23,24]. Most of the research on the abundance of large mammals and their interaction with people in the Chitwan Annapurna Landscape (CHAL) focused either in CNP [2,25–27] or in Annapurna Conservation Area (ACA) [19,28]. Few studies have been made in such human dominated landscape but they were focused only on a particular area or region i.e., in Panchase [17], in Tanahun district [18,29], in Kaski [17,30] but these studies are mainly focused on economic loss. Hence, there was scarce information on abundance of the mammals, their relation with the HWC landscape level, and the factors

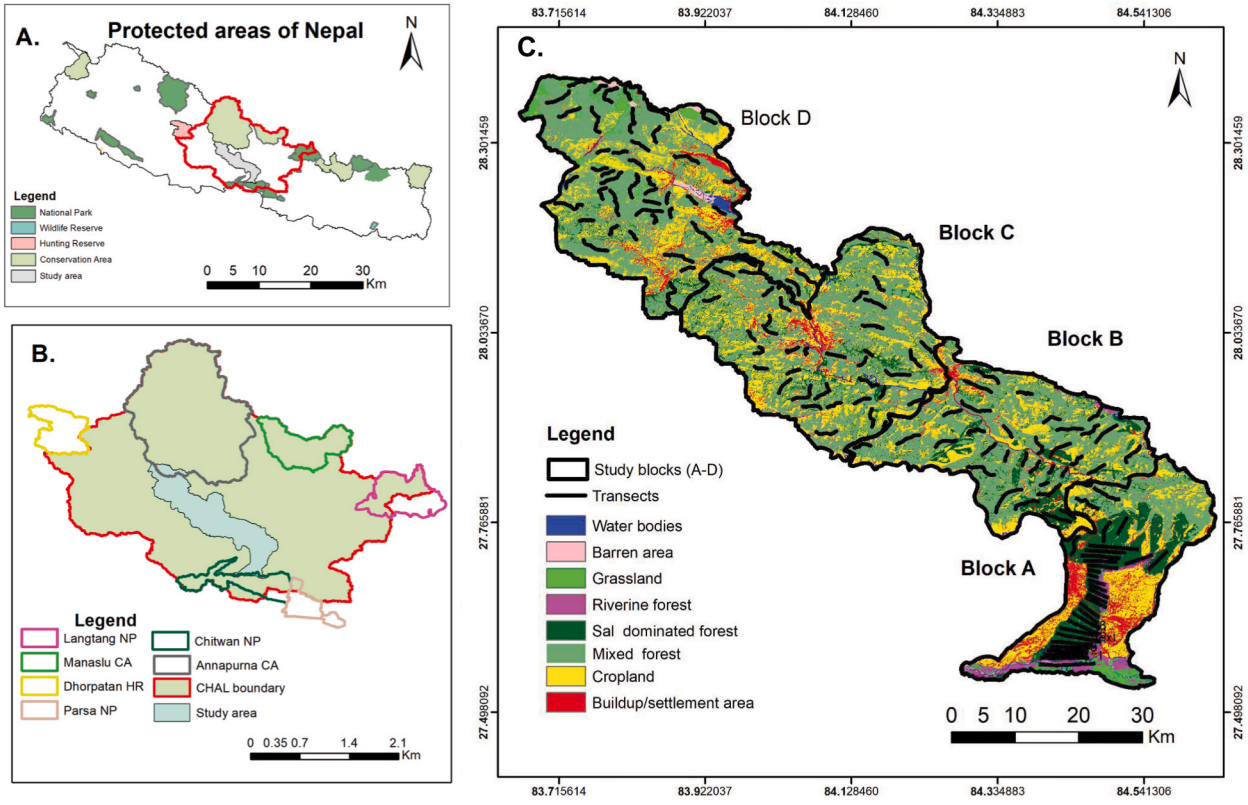

Fig. 1. A. Protected Areas of Nepal and location of CHAL along with study area, B. Map showing the location of CHAL and intensive study area, C. Design of study blocks and transects for the survey of mammals in CHAL.

associated that causes HWC in the human-dominated mid-hill landscape between CNP and ACA. Therefore, this study aimed to (i) evaluate the relative abundance and encounter rate of large mammals, (ii) explore human-wild mammal conflict and correlates that affect HWC in the human-dominated mid-hill landscape between CNP and ACA i.e., central part of CHAL.

2. Methods

2.1. Study area

The CHAL covers full or part of the six protected areas including CNP and ACA and 19 districts of central Nepal. Hydrologically, CHAL is drained by eight major rivers including Kali Gandaki, Seti, Madi, Marshyandi, Trishuli and Rapti. This study focused on only the central part of the CHAL that connects two protected areas CNP and ACA (Fig. 1A–C). The intensive study area covers 2749.48 km^2 and includes Chitwan (around Barandabhar Corridor Forest (BCF) and surrounding areas), Tanahun (Seti River basin), Kaski and some parts of Syangja and Parbat districts (Panchase and part of ACA) within elevation ranges from 150 m to 3300 m. This central part of CHAL has given the highest priority corridor for landscape level connectivity that extends 27.282°N to 28.405°N and 84.282°E to 83.677°E [31]. The lowland of this area has tropical and subtropical climates followed by temperate and subalpine climate in mid-hills and high mountain areas respectively.

This landscape covers three among global 846 Ecoregions (Terai–duar Savanna and Grasslands, Himalayan Subtropical Broadleaf Forests, Himalayan Sub-tropical Pine Forest) [32,33] and two Ramsar sites (Beeshazari and associated lakes, Chitwan and Lake Clusters of Pokhara Valley, Kaski) [34]. CHAL is a prime habitat for mammals such as the tiger, greater one-horned rhino, leopard, clouded leopard, snow leopard, sloth bear, Himalayan black bear, sambar, chital, musk deer, hog deer, Himalayan goral, etc., various species of birds, herpetofauna, fish and many micros and macroinvertebrates [35,36].

Nepal is rich in ethnic diversity and harbors 142 ethnic groups and 124 spoken languages throughout its landscape [37]. Among these, 59 indigenous nationalities are listed as Adibasi/Janajati which cover 35.8 percent of the total population [37]. The central part of CHAL is human dominated and inhabited by diverse communities (72 ethnic groups in Chitwan, 70 ethnic groups in Tanahun, 91 ethnic groups in Kaski, 41 ethnic groups in Parbat and 39 ethnic groups in Syangja district) [37]. Bramhman (27.53%), Kshetri (11.57%), Tharu (10.09%), Tamang (7.52%), Gurung (6.92%), Bishwokarma (5.07%), Chepang (4.95%), Newar (4.92%) in Chitwan; Magar (26.04%), Kshetri (11.46%), Brahman (11.41%), Gurung (10.95%), Bishwokarma (8.19%), Newar (7.63%) in Tanahun and Brahman (26.37%), Gurung (15.35%), Kshetri (14.42%), Magar (9.73%), Bishwokarma (9.07%), Newar (4.2%), Tamang (2.68%)in Kaski, Brahman (31.31%), Kshetri (17.43%), Magar (11.65%), Bishwokarma (9.83%), Pariyar (8.97%), Mijar (7.51%), Gurung (3.19%), Thakuri (2.48%) in Parbat, and Brahman (28.14%), Magar (21.97%), Kshetri (11.92%), Gurung (8.87%), Bishwokarma (8.27%), Mijar (4.68%), Pariyar (4.08%), in Syangja districts are the most dominate ethnic groups [37]. The literacy rate of Chitwan is 83.7 percent (Male = 88.9%, Female = 78.7%) whereas literacy rate of Tanahun is 81.6 percent (Male = 89%, Female = 75.2%). Similarly, Kaski has 87.7 percent (Male = 93.4%, Female = 82.4%), Parbat has 80.1 percent (Male = 88.1%, Female = 73.1%) and Syangja has 81.7 percent (Male = 89.8%, Female = 74.8%) [37]. Agriculture and animal husbandry is the main occupation of the people of this area. About 47.4 percent of people in Chitwan, 61.4 percent of people in Tanahun, 31.8 percent of people in Kaski, 65.7 percent of people in Parbat and 69.4 percent people in Syangja districts fully depend on agriculture [37]. Besides agriculture, other significant contributors to household income in the area include salaried jobs, business, construction activities, tourism-related activities (Hotel industry, nature guide, tracking guides, porters etc.), migration for non-farm employment, and wage labor [35,38]. However, the specific bio-physical, socio-economic, and infrastructure conditions across an elevation gradient provide diverse opportunities and challenges for various livelihood options.

Nepali language is the official language and 67.79 percent of the people of the Chitwan district, 62.70 percent of the people of the Tanahun , 78.5 percent of people of Kaski, 93.87 percent of the people of Parbat and 74.71 percent of the people of Syangja speak

Table 1
Detail locations of the study blocks.

SN	Block	Detail locations
1	A	Coverage: Barandabhar Corridor Forest (BCF) and part of Chitwan district, Bharatpur Metropolitan City (Patihani, Gitanagar, Bhojad, Ramnagar, Kabilas and Chaukidanda), Ratnanagar Municipality (Sauraha, Mohana, Tikauli, Panchakanya), Kalika Municipality (Jutpani and Padampur) and part of Kalika Rural Municipality. Location: 27.282°N to 27.865°N and 84.282°E to 84.574°E and covers 535.47 km^2, elevation range: 150–1200 m Climate: tropical and sub-tropical type, temperature: average maximum 30.86 °C and average minimum 17.85 °C, rainfall: 1980.34 mm
2	B	Coverage: Devghat Rural Municipality, Anbukhaireni Rural Municipality (Gaighat area), Bandipur Rural Municipality, part of Rishing Rural Municipality and part of Vyas Municipality of Tanahun district Location: 27.752°N to 28.028°N and 84.468°E to 84.261°E and covers 626.19 km^2, elevation range: 218–2521 m Climate: The average maximum and minimum temperature 29.31 °C and 17.10 °C, respectively, rainfall: 2238.98 mm
3	C	Coverage: Part of Vyas Municipality, part of Rishing Rural Municipality, part of Ghiring Rural Municipality, Magde Rural Municipality, Bhimad Municipality, part of Shuklagandaki Municipality and part of Rupa Rural Municipality Location: 27.921°N to 28.139°N and 84.221°E to 83.942°E, and covers 786.38 km^2, elevation range: 280–2219 m Climate: The average maximum and minimum temperature 27.03 °C and 15.69 °C, respectively, rainfall: 2999.7 mm
4	D	Coverage: Panchase Protected Forest, Bharatpokhari, Nirmalpokhari, Bagmara and lower part of Annapurna Conservation Area (ACA) Location: 28.064°N to 28.405°N and 84.066°E to 83.677°E and covers 801.44 km^2, elevation range: 645–3300 m Climate: The average maximum and minimum temperature: 20.74 °C and 12.03 °C, rainfall: 5480.19 mm.

Nepali as their primary language [37].

2.2. Research design

The study area was divided into four different blocks A, B, C and D (Table 1) based on the landscape characteristics, the major river courses and topography (Fig. 1C).

Block A covers the BCF, part of CNP and surrounding areas of BCF (Kabilas, Jugedi, Kerabari, Chaukidanda, Simaldhap) up to the Mahabharat range of Chitwan district. BCF is one of the vertical corridors of central Nepal that connects CNP with the Mahabharat range. The Ratnanagar Municipality lies on the east whereas Kalika Municipality, Ichhakamana Rural Municipality lies on the northeast, and Bharatpur Metropolitan City on the west of BCF [39]. In the hilly area of this block, the human settlements are scattered and surrounded by the forest. This area is drained by the Narayani and Rapti River system [40]. The Mahabharat range of the Chitwan valley is composed of a rocky terrain of sandstone, conglomerates, slates, limestone and quartzite. The hills' soils are mainly loam, loamy rubble with a stony surface [40,41]. This block is separated by Trisuli River with Block B. BCF is one of the important bird and biodiversity areas (IBAs) among the 32 IBAs of Nepal [42] that supports 32 species of mammals, 372 species of birds, 31 species of herpetofauna and 108 species of birds [43,44].

Block B is a human-dominated mid-hill landscape along the Seti River basin. It covers Devghat, Bandipur, Abu Khairani Rural Municipalities and Vyas Municipality of Tanahun district. It is the floodplain of Seti and Trishuli River along with mid-hills. The Seti River follows through the V-shaped deep gorge forming the alluvial floodplain in many places and joining with Trishuli River. Chimkeshwori is the highest peak of this area (2521 m asl). About 100 community forests have been established in this area. Human settlements, roads and croplands are scattered and the forests are divided into large or small patches. Part of Vyas Municipality, Bandipur, Devghat, Khairenitar and Sarangghat are the dense settlements present in this block. This river is separated by the Madi and Seti River with block C. The Seti River basin harbors 267 species of birds 26 species of mammals, 267 species of birds, 13 species of herpetofauna and 44 species of fish [45].

Block C covers the Bhimad Municipality, parts of Rishing Rural Municipality, Ghiring Rural Municipality, Magde Rural Municipality and Shuklagandaki Municipality of Tanahun District and Rupa Rural Municipality of Kaski District along the Seti River basin. The Bhimad and Shuklagandaki are located on the bank of Seti River. This block is highly human-dominated and fragmented by the large cities such as Vyas, Shuklagandaki or Khairenitar and Bhimad. The mountain of this block is made of slates, quartzite, limestone and dolomites. The floodplain of Rishi Patan, Vyas, Bhimad and Kharirenitar is famous for agriculture. This block has more than 100 community forests. This block is separated from block D by the district boundary of Kaski district (i.e., Kotre River).

Block D covers Bharatpokhari, Nirmalpokhari, Pumdibhumdi, Panchase, Lumle, Ghandruk, Landruk, Deurali and the Australian Camp area. This block has four types of forests: national forest, community forest, protected forest (Panchase) and conservation area (Annapurna). Panchase Protected Forest (PPF) is rich in biodiversity indicates the healthy ecosystem of the high hills of Central Nepal. This protected forest covers 27.91 km^2 and lies in the junction of three districts- Kaski, Parbat and Syangja [17,46]. This area was declared as a 'Protected Forest' on February 27, 2011 under article 23 of the Forest Act 2002. This area signifies its rich biodiversity, forest resources as well as cultural and spiritual [46]. The lower slope of this block is covered by the floodplains of Seti River, Modi River basin and Harpan River which is very useful for agriculture. Panchase Protected Forest harbors 589 flowering plant species, 24 mammal species and 260 bird species [17,46]. ACA is also another IBAs and harbors ACAP is rich in biodiversity and is a treasure house for 1226 species of flowering plants, 105 mammals, 518 birds, 40 reptiles and 23 amphibians [47,48].

The size and the length of the transects were based on the size of the forest patches. First of all, the forest patches were identified using a base map/topographic map and then transects were overlaid on the base map. The forest patches were selected based on diameter or size. The forest patches less than 2 km in diameter were avoided for sampling. The transects were laid systematically regarding their patch size and accessibility. Among the designated 164 transects, only 150 transects (31 in block A, 35 in block B, 38 in block C and 46 in block D) were chosen and surveyed for mammals (Fig. 1C, Supplementary S1). The rest of the transect ($n = 14$) were avoided for data collection because these transects were located in inaccessible areas including deep river gorge, steep mountains, and swampy lands. The length of the transects ranged from 1.18 to 7.84 km (Supplementary S1). The distance between the two transects was maintained at least 500 m apart in the regular forest patches but may vary on the scattered habitat parches (e.g., in mid hills).

2.3. Data collection

Permission was obtained from the concerned government authority to conduct research and collect data related to human wildlife conflict. The permission was granted from the Department of National Parks and Wildlife Conservation, Nepal (Permission letter number 3372, 849 and 1216), Chitwan National Park (Permission letter numbers 2723 and 885), Division Forest Offices of Chitwan (Permission letter number 2723), Tanahun (Permission letter number 749), Kaski (Permission letter number 200) districts and Annapurna Conservation Area Project (Permission letter number 86 and 148) (Supplementary S2). Personal consent was taken from each respondent before starting the formal interview.

For this study, we selected mammal species (>5 kg body weight) that were regarded as large mammals [49–51] and much known for causing conflict with humans [18,20,52]. The abundance of the prey species (wild ungulates and monkeys) was determined by the direct sighting (visual encounter) method [53] and the abundance of carnivores (tiger, leopard and Himalayan black bear) was estimated by surveying their signs (scats, scrapes, pugmarks, kill sites, territorial marks) along transects, since the signs left by the animals are reliable sources indicating occurrence in an area [54,55]. The signs of carnivores (mainly tiger, leopard and Himalayan black bear) such as pugmarks, tracks, scat, scratch, and scrap marks were noted on 5 m the either side of the transects at the intervals of

100 m distance along the transects (Fig. 2).

The conflict data were collected from the nearby settlement of the animal sampling so that easy to judge the relation of the encounter rate of the animals with HWC. The sample size was determined by using the methods adopted by Taherdoost [56] and Hulley [57] while the total number of households in the study area was unknown.

Respondents (n = 600, 150 from each block) were asked the semi-structured questionnaires related to crop damage, livestock depredation and human casualty and injury prepared in Nepali language (Supplementary S3). The respondents were selected based on stratified random sampling. The households that are located near the transects were selected for questionnaires. Generally, more than four questionnaires were asked near the village of a transects. If the households were 1.5 km far from the transects, these were avoided for asking the questionnaires. The age, sex, ethnicity and education of the respondents were considered during the selection of the respondents for questionnaires. The focal group discussion was made for four places (one for each block, with total participants in each group = more than 10) to know the tentative scenario of HWC before starting the questionnaires. This discussion also helped us to improve the questionnaires. Informal interviews and key informant interviews (social workers, teachers, members of the community forest) were organized after finishing the questionnaires to verify the reality of the respondents' data and gather quantitative information on HWC. At least 10 informal interview and key informant interviews were made from different parts of each block.

The selected households were categorized into three groups based on their proximity to the edges of the forest such as close (<0.5 km), medium (0.5–1 km) and far (1–1.5 km). Oral consent of respondents was taken before starting the questionnaire surveys. Generally, the head of the house was chosen as the respondent but in the absence of the head, the next member was chosen. Information on HWC collected from the park office and division forest offices was used to calculate the total compensation provided for human death due to wildlife attacks. These data were used to verify the information provided by the respondents on livestock depredation, human injury and death.

2.4. Data analysis

The relative abundance of a species is defined as how common a species is relative to the other species in a defined area or location [58]. Relative abundance (RA) is calculated by the total number of individual species (Isi) divided by the total number of species population (∑Nsi) multiplied by one hundred (Equation (1)).

$$\text{Relative abundance (RA)} = \frac{\text{Isi}}{\sum \text{Nsi}} \times 100 \quad (1)$$

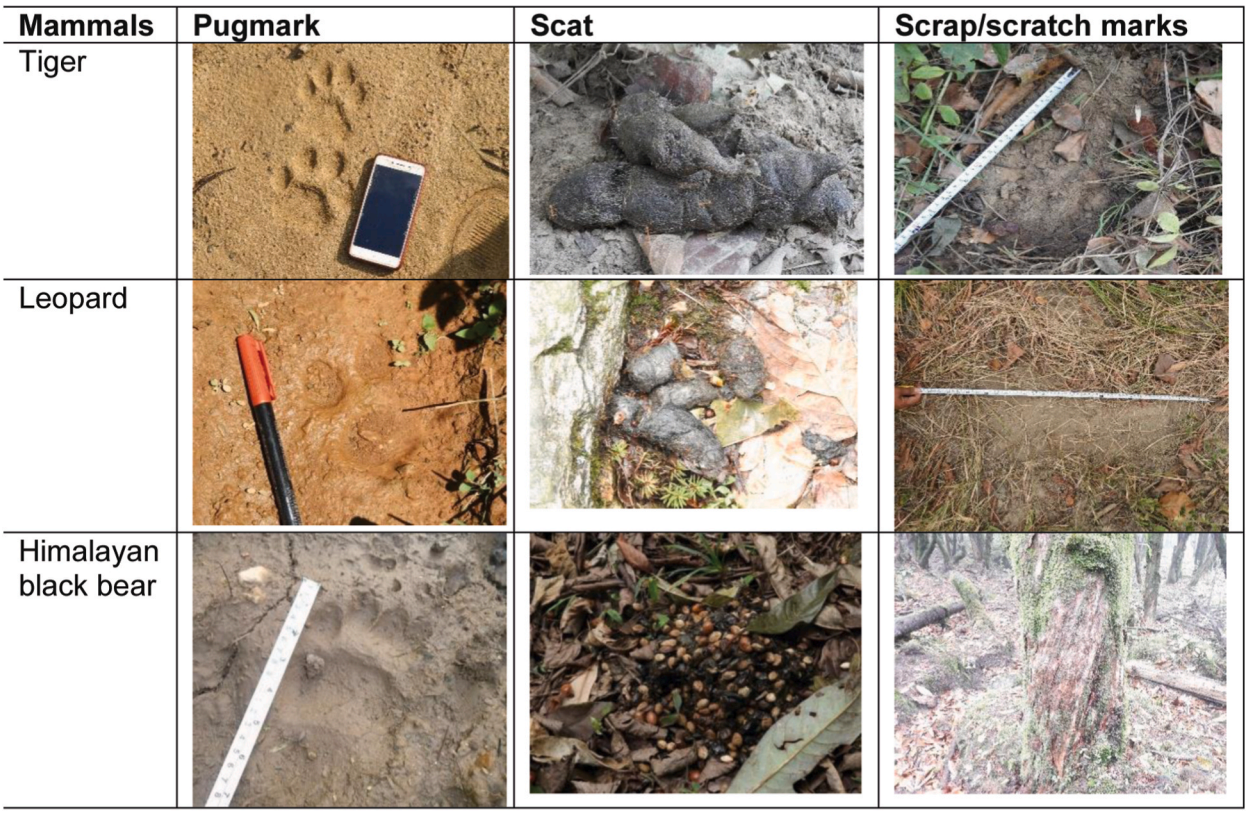

Fig. 2. Signs of tiger, leopard and Himalayan black bear reported during field.

The encounter rate is the stationary expected number of encounters in track or transects. The encounter rate of the mammals was calculated by dividing the total number of species encountered (n) by the total length of the transects (L) [59]. The signs of the carnivores such as tiger, leopard and Himalayan black bear were analyzed as sign encounter rate that indicates the occurrence and distribution of these animals (Equation (2)).

$$\text{Encounter rate (ER)} = \frac{n}{L} \tag{2}$$

The farm get price of the crops was determined by calculating the average price of the local market (average of at least 10 places of a block) and the price declared by the district agricultural office (Supplementary S4). The farm get price may vary from place to place; hence, a separate rate was used for each block. The monetary value of the total loss from crop damage was determined as equation (3).

$$\text{Total loss economic loss for a crop (NPR)} = \text{total damage} \times \text{farm get price of that crop} \tag{3}$$

Total economic loss from the crop damage was determined by adding the loss of all the crops.

Similarly, the price rate of the cattle, buffaloes, sheep, and goats was estimated by averaging the local market price and the price declared by the district veterinary office. The rate of the livestock is fixed according to their age and sex (Supplementary 5). The age, sex and number of livestock were determined based on questionnaires which were further verified by the record of the park office and division forest office. The informal and key informant interview further helped in the verification of the loss. The total monetary losses were calculated by adding all the loss of different livestock killed by predators. The package « pscl» was used in R software version 4.0.0 [60] for the generalized linear model (GLM) [61] to calculate coefficient, standard error, and p-value at 95 percent confidence level for all relationships between crop damage and livestock depredation with different correlates such as distance to forest, distance to the farm from the house, livestock holding and land holding capacity.

The conflict hotspot map was prepared using the geographical coordinates of the place of the interview recorded. The Inverse

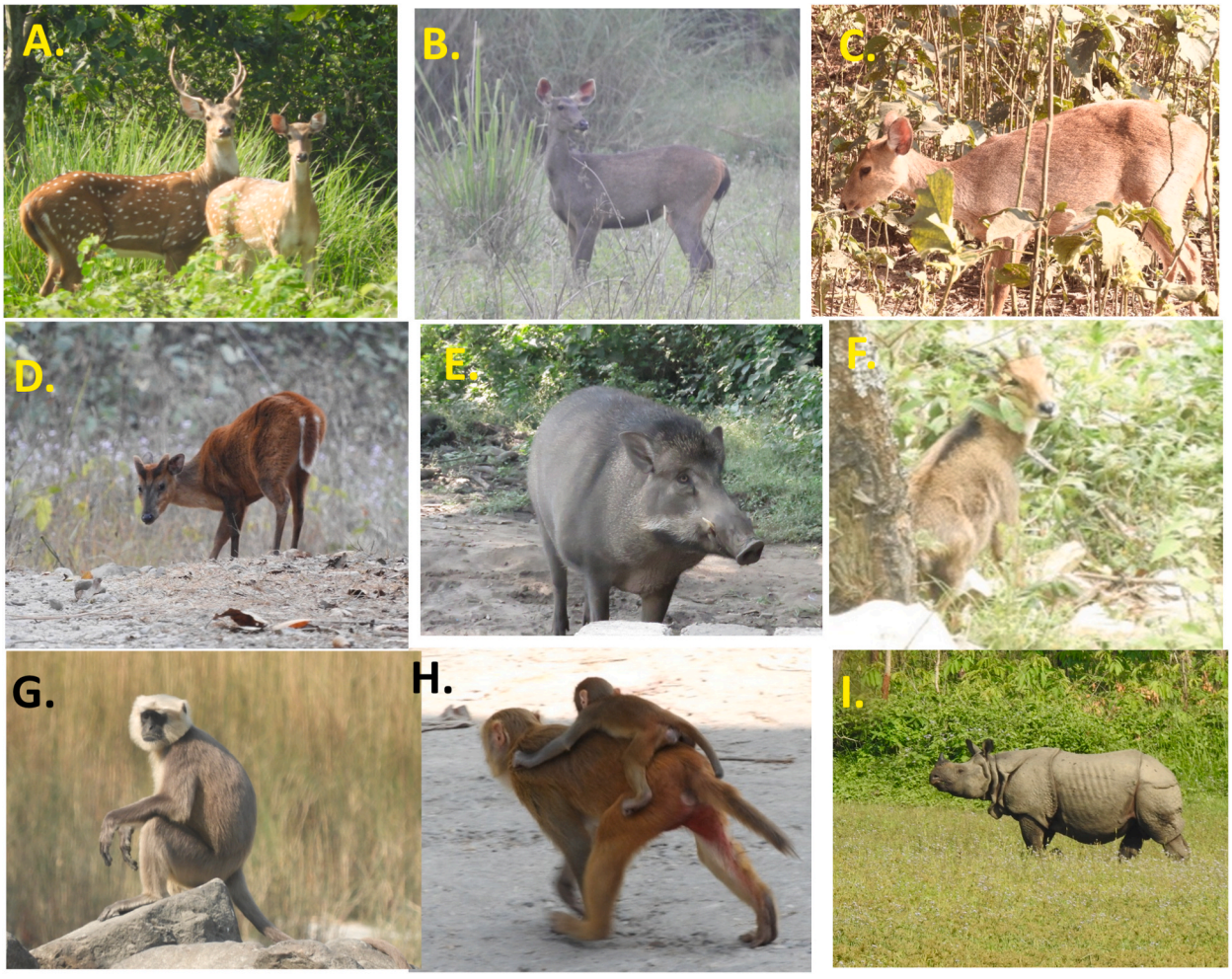

Fig. 3. Major crop depredators reported from Chitwan Annapurna Landscape, Nepal. A. Chital, B. Sambar, C. Hog deer, D. Northern red muntjac, E. Wild pig, F. Himalayan goral (male), G. Langur monkey, H. Mother of rhesus monkey with her baby, I. Greater one-horned Rhino.

Distance Weighted (IDW) algorithm [62] in ArcGIS 10.8 was used to interpolate values of expected conflict hotspots based on total monetary loss due to crop damage and livestock depredation. IDW algorithm of interpolation was used to evaluate the values of target variables at a new location. The weightage of the points closer to the predicted location is greater than the farther [63]. The conflict areas were categorized as very low, low, moderate, high and very high based on monetary loss by the respondents.

3. Results

3.1. Encounter rate of mammals

A total of 477.77 km distance was walked along 150 transects ranging from 1.18 to 7.84 km where 18 species of mammals were reported (Supplementary S6). Among them, encounters of golden jackal, Jungle cat, sloth bear, large Indian civet, Asian elephant, Assam macaque was <5, hence, excluded from the further analysis. Three carnivores (tiger, leopard and Himalayan black bear), one mega herbivore (greater one-horned rhino), two primates (rhesus and langur) and six ungulate species (hog deer, northern red muntjac, chital, sambar, wild pig and Himalayan goral) were selected for the study (Fig. 3A-I).

In block A, the chital was the highest abundant mammal (ER = 1.49) followed by a wild pig (ER = 0.62), northern red muntjac (ER = 0.62), sambar (ER = 0.38), rhesus (ER = 0.28) and langur (ER = 0.11). Similarly, the relative abundance of the chital was the highest (RA = 61.03%) followed by rhesus macaque (RA = 14.11%) and wild pig (RA = 11.26%). Hog deer was the least encountered mammal (ER = 0.05) and the greater one-horned rhino was the least abundant (RA = 0.42%) (Table 2, Fig. 3A-I). The relative abundance of rhesus macaque and langur was higher than other mammals in blocks B, C and D. The abundance of wild pig and Himalayan goral were comparatively lower than other species but the encounter rate of the northern red muntjac was the highest in blocks B, C and D. The occurrence of chital in block B was recorded only from Devghat area. The occurrence of the mammals was comparatively lower in block C (Table 2). The relative abundance and encounter rate of the wild pig in block D was lower than in other blocks B and C, but both the relative abundance and encounter rate of the goral was higher in block D than in other blocks (B and C).

The estimated sign encounter rate of tiger and leopard in block A was 0.44 and 0.51 respectively. Similarly, the sign encounter rate of the leopard and Himalayan black bear was 0.55 and 0.05 in block B, 0.39 and 0.08 in block C; and 0.89 and 0.27 in block D respectively (Fig. 4).

3.2. Human-mammal conflict

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

3.2.1. Demographic details of respondents

A total of 600 respondents (349 males and 251 females, ranging from 20 to 87 years) participated in the study. The majority of the respondents were between 40 and 60 years old (57.5%). About 12.17 percent of the respondents were illiterate but 73.33 percent of the respondents received primary and secondary level education. The primary occupation of the respondents was agriculture. About 73.44 percent of respondents depended on agriculture followed by teachers (8.34%), business (6.83%), social workers (5.83%) and service (4.67%). The ethnicity was categorized into 4 categories and 63.16 percent of the respondents were from Adibasi/Janajati category. The average family size and livestock holding capacity were 5.73 ± 0.09 and 13.98 ± 3.13 respectively. The average handholding capacity was 4705.95 ± 1104.03 m^2 and the average annual income was US$ 2300.7 ± 338.37 per household (Table 3).

Table 2
Encounter rate of the ungulates and primates reported from different study blocks A, B, C and D. Here, Ni - number of individuals, Ng - number of groups, RA (%) - relative abundance, ER - encounter rate of group.

Block	Parameter	Chital	Sambar	Hog deer	Rhino	Wild pig	Goral	Rhesus	Langur	Muntjac
A	Ni	2301	99	20	16	425	0	532	231	147
	Ng	219	50	7	12	108	0	32	15	101
	RA (%)	61.03	2.62	0.53	0.42	11.26	0	14.11	6.13	3.9
	ER/km	1.49	0.38	0.05	0.08	0.62	0	0.28	0.11	0.62
B	Ni	13	0	0	0	20	24	336	163	50
	Ng	3	0	0	0	14	10	15	12	35
	RA (%)	2.15	0	0	0	3.3	3.95	55.45	26.9	8.25
	ER/km	0.03	0	0	0	0.14	0.09	0.14	0.12	0.34
C	Ni	0	0	0	0	12	12	154	108	39
	Ng	0	0	0	0	8	8	9	7	30
	RA (%)	0	0	0	0	3.69	3.69	47.38	33.24	12
	ER/km	0	0	0	0	0.08	0.08	0.09	0.07	0.31
D	Ni	0	0	0	0	13	63	515	229	146
	Ng	0	0	0	0	9	35	31	15	109
	RA (%)	0	0	0	0	1.35	6.52	53.31	23.71	15.11
	ER/km	0	0	0	0	0.06	0.25	0.23	0.11	0.79

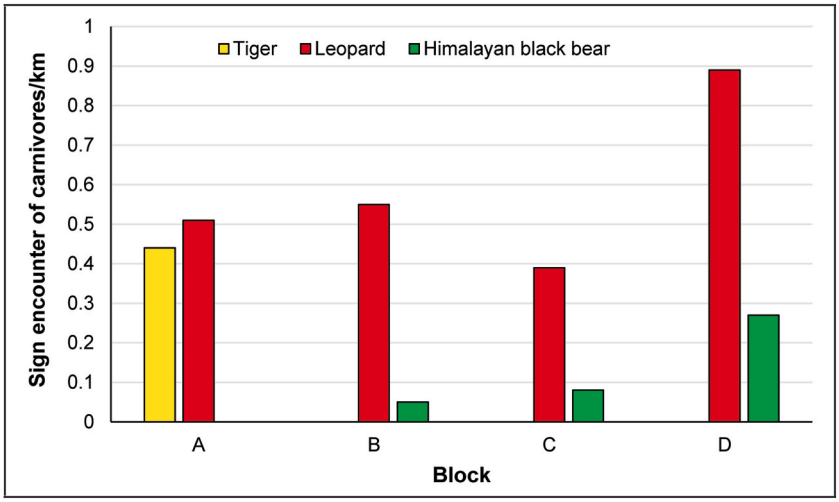

Fig. 4. Sign encounter rate of carnivores found in study blocks (A–D).

3.2.2. Crop damage

Important crops cultivated in the area were paddy, wheat, maize, potatoes and vegetables in the lowland and paddy, wheat, maize, oats, millets and potatoes in mid-hills. Similarly, pears, bananas, oranges and mangoes were the major fruit plants. Respondents (n = 600, 150 from each block) identified greater one-horned rhino, chital, northern red muntjac, monkeys and wild pigs were the major mammals that were involved in crop damage in block A, whereas muntjac, monkeys, wild pigs and Himalayan black bears in blocks B-D (Fig. 5A–C). The maize was the main target crop by wild mammals and monkeys contributed to maximum crop loss (Fig. 6A and B). But in block A, the crop damage by rhinoceros was higher than by other mammals (Fig. 6A). The crop damage per household was significantly higher in block D followed by blocks A, B and C ($\chi^2 = 1378.4$, $p = 0.0001$, Table 4). As increasing the encounter rate of the mammals, the rate of crop damage also increased except in block A. Although the encounter rate of crop raider mammals was higher in

Table 3
Demographic profile of the respondents.

Parameters	Category	Blocks				Total	Percentage
		A	B	C	D		
Age (Years)	20–30	4	9	6	3	22	3.67
	30–40	31	23	23	18	95	15.83
	40–50	37	46	49	44	176	29.33
	50–60	39	40	42	48	169	28.17
	60–70	24	25	18	21	88	14.67
	70 above	15	7	12	16	50	8.33
Sex	Male	105	97	50	97	349	58.17
	Female	45	53	100	53	251	41.83
Education (Years of schoolings)	Illiterate	29	21	1	22	73	12.17
	Primary	53	73	91	63	280	46.66
	Secondary	48	40	35	37	160	26.67
	Intermediate	12	11	11	14	48	8
	University	8	5	12	14	39	6.5
Occupation	Agriculture	113	115	117	101	446	74.33
	Teacher	14	11	11	14	50	8.34
	Business	7	10	5	19	41	6.83
	Service	8	5	9	6	28	4.67
	Social worker	8	9	8	10	35	5.83
Ethnicity	Braman/Chhetri	49	12	21	30	112	18.67
	Adibasi/Janajati	63	122	105	89	379	63.16
	Dalit	21	13	22	31	87	14.5
	Marginalized group	17	3	2	0	22	3.67
Family size	Number	5.6 ± 0.14	5.8 ± 0.12	5.56 ± 0.12	5.99 ± 0.14	5.73 ± 0.09	
Land	Sq m	1848 ± 100.44	4236.08 ± 255.76	5778 ± 331.12	6961.75 ± 523.06	4705.95 ± 1104.03	
Income	US$	2103.98 ± 129.45	1917.12 ± 133.18	1876.801 ± 132.78	3304.58 ± 252.77	2300.7 ± 338.37	
Livestock holding	Number	7.87 ± 0.68	18.22 ± 1.07	15.86 ± 1.17	23.93 ± 4.22	13.98 ± 3.13	

block A, the crop damage was lower than in other blocks (B and D, Table 4).

The economic loss due to crop damage was significantly higher in areas close to the forest than in area far from the forest. Similarly, the economic loss through crop damage was significantly higher in the farms far from the houses of respondents. The landholding of the respondents also showed a positive response toward crop damage (Table 5).

3.2.3. Livestock depredation

It was reported by the respondent that domestic animals (e.g., cow calves, young buffalo, goats and sheep) were killed by the predators in the study landscape (Figs, 5 D-F). Tigers and leopards are the major predators in lowland (block A) whereas leopards are in mid-hill and high-hills (blocks B-D). A total of 263 cases were reported in this study among them, block D had the highest cases (n = 110) followed by block B (n = 80), C (n = 44) and A (n = 29). Among the domestic animal goat and sheep were killed in the highest number (66.54%) followed by ox/cow (15.96%), buffalo (9.88%), dog (6.08%) and pig (1.5%). The highest number of goats were killed in block B (n = 72) compared to other blocks (Fig. 7A).

A total of US$ 44764.71 (US$ 74.60 per HH) was lost per year in this landscape. The economic loss was higher in block D (US$

Fig. 5. Crop damage and livestock depredation by mammals: A. Crop damage by rhinoceros, Ghatghain area, B. Crop damage by rhesus monkey, in Tanahun, C. Crop damage by rhinoceros, in Baderni area, D. livestock depredation-goat killed by leopard in Rumsi, Tanahun, E. Cow killed by leopard, in Panchase area, F. Goat injured by the attack of leopard in Gauriganj area.

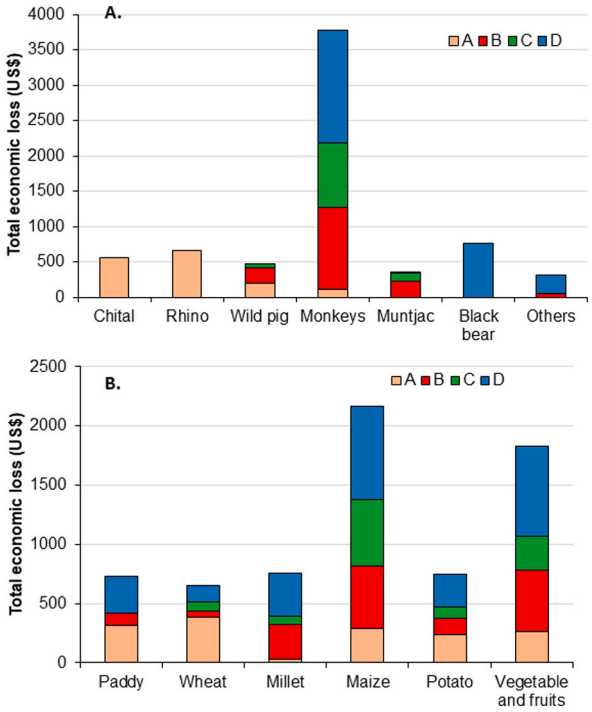

Fig. 6. Crop damage in CHAL A. crop damage by different mammals, B. damage based on crop types.

Table 4
Relation between the encounter rate of the mammals (crop depredators and livestock predators) per km and monetary loss in US$ per household. (Here, ER = encounter rate of mammals and, 1US$ = NPR 119, HH = Household).

Block	Crop depredators		Livestock depredators (Predators)	
	ER/km	Monetary loss (US$)/HH	Sign encounter/km	Monetary loss (US$)/HH
A	3.63	10.11	0.95	50.81
B	0.86	8.66	0.55	56.97
C	0.63	7.18	0.39	47.11
D	1.44	22.15	0.89	143.52

Table 5
Generalized Linear Model (GLM) showing the relation of crop damage and livestock depredation with different variables.

Crop damage					
Category	Estimate (β)	Std. Error	z value	p-value	Significance
Intercept	−1.31	0.44	−2.97	0.003	**
Distance to forest	−0.0005	0.0003	−2.04	0.04	*
Distance to farm	0.01	0.0012	11.59	<0.0001	***
Land holding (m^2)	0.00006	0.00002	2.62	0.008	**
Livestock depredation					
Intercept	10.57	0.002	5236.01	<0.0001	***
No of livestock holding	0.0002	0.00003	6.79	<0.0001	***
Distance to forest	−0.0043	0.000003	−1391.51	<0.0003	***
Distance to shed from house	0.0001	0.000003	55.49	<0.0004	***

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

143.52 per HH) than in other blocks (Fig. 7B). As increasing the sign encounter rate of predators, the rate of livestock depredation also increased except for block A. In block A, the depredation rate was comparatively lower though the sign encounter rate of the predators was higher (Table 4).

It was observed in the table that the rate of livestock depredation was significantly higher in the proximity of the forest ($z = -1361.51$, $p < 0.0003$). On increasing the distance from shed to house, livestock depredation was significantly increased ($z = 55.49$, $p < 0.0004$). The livestock depredation was also significantly higher on the livestock holding of the farmers (Table 5).

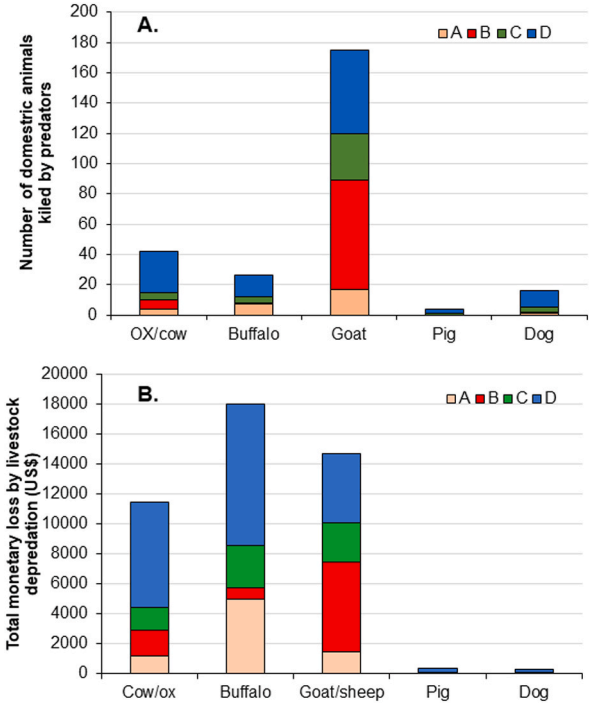

Fig. 7. Livestock depredation: A. Number of livestock killed by predator, B. Total monetary loss in US$.

3.2.4. Human casualty and injury

The results presented revealed that the tiger, rhinoceros and wild pig in block A, leopard, Himalayan black bear, wild pig and monkeys in block B, leopard, bear and monkeys in block C and D were the principal mammals that commonly attacked the people. A total of 26 cases of attack (20 injuries, 6 fatal) were recorded along this landscape. The highest cases of attacks were found in blocks C and D (n = 8). The government of Nepal provided a total of US$ 8403.36 (NPR 1000000) as compensation for cases resulting in fatalities by wildlife attacks. Among these cases, the Himalayan black bear alone contributed 30.76 percent of the total attacks followed by monkeys (26.92%), leopards (19.23%), wild pigs (11.53%), rhinoceros (7.69%) and tigers (3.84%). The attack cases by tigers and rhinoceros were only reported from block A whereas the attack cases of wild pigs were reported from block A and B (Fig. 8).

3.2.5. Conflict hotspots

The IDW map prepared based on monetary loss clearly showed that the conflict was comparatively higher in mid-hills (blocks B and C) and high-hills (block D) than lowlands (block A). Panchase and part of ACA of block D had more conflict incidents than other parts of CHAL (Fig. 9).

4. Discussion

Human-wildlife conflicts in CHAL were attributed to multiple species of mammals at varying intensities and patterns. Six herbivores and three carnivore species were reported to HWC in CHAL. Of these species, rhino, chital and wild pig in the lowland and muntjac, monkeys, Himalayan black bear, and wild pig were the top crop depredators in the mid-hill. Tiger and leopard in the lowland and leopard in the mid-hill are the main livestock depredators. Among the cases reported, the attack of Himalayan black bear on people ranked the highest. Monkeys in the mid-hills also attacked the people where more than 26 percent of cases were contributed by them. The crop damage and livestock depredation depend upon the abundance of the respective animals present in that area [52]. On increasing the encounter rate of crop depredator (e.g., chital, muntjac, monkey, wild pig and black bear) and the predators (e.g., tiger and leopard), the probability of the crop damage and livestock depredation also increased. But in block A (BCF and surroundings), although the encounter rate of crop depredator mammals was higher but were fewer cases of depredation. This is because BCF is well-managed and provides adequate resources for both predators and prey inside the forest, while the fencing controls the exit of animals from the forest to villages [22,64]. Since proper management of forests and grasslands can hold the animals inside their habitat [64]. But in the mid-hill, scattered settlements, croplands and forests increased the cases of conflict. As this study, many researchers reported that human-large carnivore conflict, human-herbivore conflict, human-elephant conflict and human-rhino conflict are very common in Terai [6,21,65–67]. Similarly, human-bear conflicts, human-leopard conflicts, human-monkey conflicts and human-herbivore conflicts are the most serious HWC in the mid-hills and Himalayan areas of Nepal [68–71]. However, the majority of conflict issues that arise in human-dominated landscapes (such as mid-hills) always necessitate proper conservation management

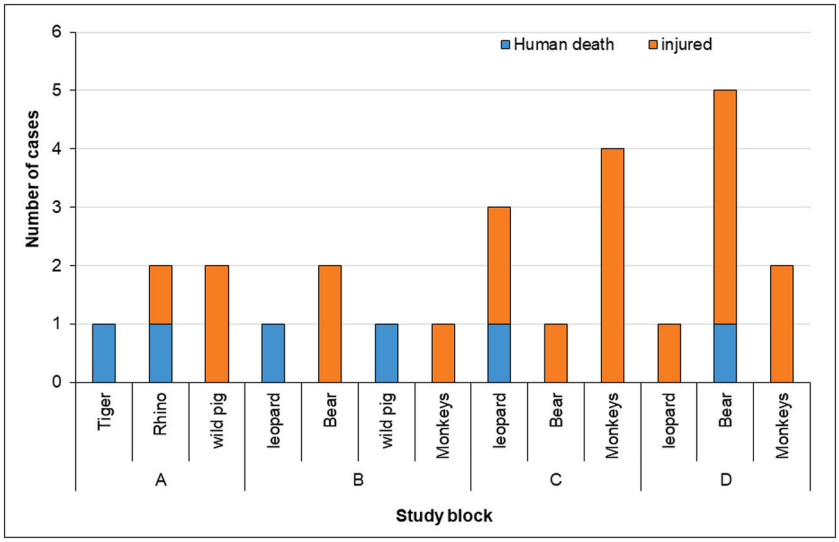

Fig. 8. Human fatalities and injury by mammals.

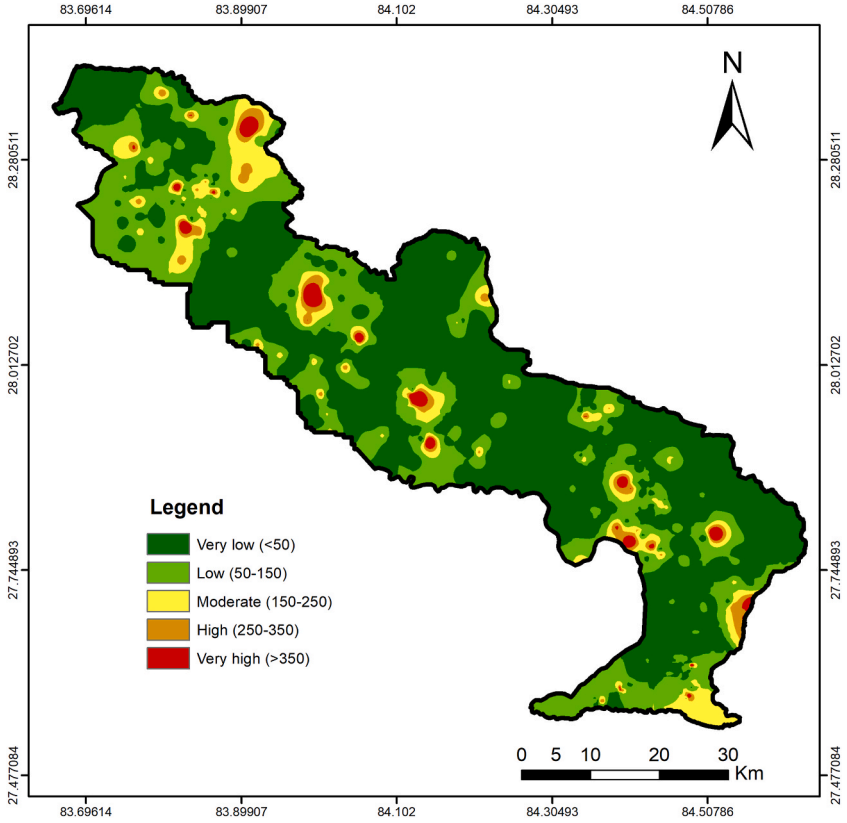

Fig. 9. Conflict hotspots on the basis of monetary loss (in US$) from crop damage and livestock depredation.

outside the PAs [13,21].

Primates, mainly rhesus and langurs coexist with humans in both rural and urban areas and utilize similar resources such as food and space, hence are considered pest [72,73]. Primates are involved in crop-damaging, robbing foods and attacking people [66]. The people of the mid-hill of this landscape were commonly suffering from such type of problems from monkeys and caused high monetary loss from crop damage. Among the ungulates, muntjac was the main crop raider in mid-hill but rhino and chital were in the lowland

(block A). The distance between the farm and forest, farm and house also play a significant role in crop damage. The farms nearer to their house, have fewer crop-raiding cases, as the people can easily guard their crops. Similar studies conducted by Baral et al. [18], in Tanahun and Kaski district reported that crop damage is the most widespread in mid-hill of Nepal.

Animal husbandry and agriculture are an important source of income for families in human-dominated mid-hills, resulting in resource competition between local communities and wildlife that governs HWC. The study of Koirala et al. [74] reported total economic loss from livestock predation per household in ACA was US$ 95 in 2009 and US$ 42 in 2010, in which leopards alone contributed 94.9 percent of total losses. Leopards caused extensive monetary loss in the rural area [6]. But in the lowland, the tiger and leopard are both responsible for the livestock depredation whereas the leopard alone contributed in the mid-hills and high hills (blocks B-D). The study also reported that as increasing the sign encounter, the depredation rate also increased except in block A (lowland). A similar type of study conducted by different researchers found that increasing the tiger population in the protected areas (e.g., Chitwan National Park) is associated with increased livestock depredation by leopards outside the protected area [75]. Free grazing system of the livestock, scattered settlements inside the forest, weak corals and low distance between the forest and the shed in the mid-hills are the major causes of higher depredating cases. This study indicates variations in conflict hotspot areas across the central part of the CHAL. The analysis revealed that most of the conflict areas were at mid-hills than lowlands. Globally, large mammals are reported to be involved in crop damage and livestock depredation [76]. The major conflict hotspots in this study were found nearer to the human settlements in the mid-hill which coincides with the study of Sharma et al. [66].

Among reported human attack cases, tigers, rhinos and wild pigs in the lowland and Himalayan black bears, leopards, monkeys, wild pigs in the mid-hill were the major contributors. The attack cases were reported maximum from the Panchase and ACA area (block D) and mid-hill (Tanahun District). A study of Baral et al. [18] reported six human deaths and 16 injury cases from Tanahun from 2011 to 2019. But this study reported 13 cases of attacks (3 killed and 10 injured) within one year including 5 attack cases by monkeys in Tanahun. The study of various mountain areas around the world concluded that the Himalayan black bear and leopard are the major mammals responsible for human attacks [77–80]. The wide distribution of leopard and Himalayan black bear causes conflicts along the entire mid-hills of Nepal which are far from the PAs [70]. This study didn't cover the whole area of the CHAL due to resources and time, hence, this study solely concentrated on the issues and status of conflicts in the central part of the CHAL. This study showed a distinct picture of HWC in the central part of CHAL, which is identified as a potential wildlife corridor. Hence, this type of study at the landscape level could serve as a blueprint for similar studies in other regions of Nepal. This study recommends further research on the mitigation and prevention methods to reduce human-wildlife conflicts. This study recommends (i) cultivation of unpalatable crops in the farmlands close to the forest, (ii) construction of predator-proof corals (iii) establishment of effective and fast distribution of relief funds provided by the government and (iv) implementation of insurance programs for crop and livestock.

5. Conclusions

The most common issues of conflict in this landscape were crop damage from ungulates and primates, livestock depredation from leopards and human injuries and deaths from leopards, Himalayan black bears, monkeys, rhinos, wild pigs and tigers. The maize was the predominant crop and the total monetary loss from the crop damage and livestock depredation was comparatively higher in block D i.e., the Panchase and Annapurna areas (economic loss (US$) = 22.15/HH from crop damage and 143.52/HH from livestock depredation). Crop damage and livestock depredation were significantly higher in the vicinity of the forests ($Z = -2.04$, $p = 0.04$ for crop damage and $Z = -1391.51$, $p < 0.0003$ for livestock depredation). Tiger and leopard in the lowland and leopard in the mid-hill contributed to livestock depredation (e.g., target livestock-goat and sheep). The encounter rate of the mammals correlates with crop damage and livestock depredation as increasing the encounter rate of mammals, the economic loss per household also increases. This research concentrated on the major issues and current status of human-mammal conflicts in the CHAL. Further study on human-wildlife conflict mitigation and control measures is recommended.

Data availability statement

Data included in the article, supplementary materials and referenced in the article. Raw data can be provided on the request with Corresponding author. Respondents' interview data are not publicly available to protect the privacy of interviewees but may be shared on request.

CRediT authorship contribution statement

Jagan Nath Adhikari: Writing – original draft, Writing – review & editing, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bishnu Prasad Bhattarai:** Writing – original draft, Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tej Bahadur Thapa:** Writing – original draft, Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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.

Acknowledgments

We are grateful to the Department of National Parks and Wildlife Conservation (DNPWC), Nepal (Permission letter number 3372, 849 and 1216), the Chitwan National Park (Permission letter number 2723 and 885) and Annapurna Conservation Area (Permission letter number 86 and 148), Division Forest Offices of Chitwan (Permission letter number 2723), Tanahun (Permission letter number 749), and Kaski (Permission letter number 200) districts for providing the research permission and information about livestock depredation and human injury and death. Our thanks also go to the field assistants and the respondents who provided the information during data collection. We are thankful to the local people of the study area who provided valuable information about the human-mammal conflict.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e26386.

References

[1] A. Treves, K.U. Karanth, Human-carnivore conflict and perspectives on carnivore management worldwide, Conserv. Biol. 17 (6) (2003) 1491–1499, https://doi.org/10.1111/j.1523-1739.2003.00059.x.
[2] R. Dhungana, T. Savini, J.B. Karki, M. Dhakal, B.R. Lamichhane, S. Bumrungsri, Living with tigers *Panthera tigris*: patterns, correlates, and contexts of human–tiger conflict in Chitwan National Park, Nepal, Oryx 52 (1) (2018) 55–65, https://doi.org/10.1017/S0030605316001587.
[3] G. Schaller, The Deer and the Tiger, University of Chicago Press, London, 1967, p. 384.
[4] P.J. Nyhus, Human–wildlife conflict and coexistence, Annu. Rev. Environ. Resour. 41 (2016) 143–171, https://doi.org/10.1146/annurev-environ-110615-085634.
[5] S.M. Redpath, S. Bhatia, J. Young, Tilting at wildlife: reconsidering human–wildlife conflict, Oryx 49 (2) (2015) 222–225, https://doi.org/10.1017/S0030605314000799.
[6] K.P. Acharya, P.K. Paudel, P.R. Neupane, M. Köhl, Human-wildlife conflicts in Nepal: patterns of human fatalities and injuries caused by large mammals, PLoS One 11 (9) (2016) e0161717, https://doi.org/10.1371/journal.pone.0161717.
[7] K. Baral, et al., Characterization and management of human-wildlife conflicts in mid-hills outside protected areas of Gandaki Province, Nepal, PLoS One 16 (11) (2021) e0260307, https://doi.org/10.1371/journal.pone.0260307.
[8] J.P. Cromsigt, et al., Hunting for fear: innovating management of human–wildlife conflicts, J. Appl. Ecol. 50 (3) (2013) 544–549, https://doi.org/10.1111/1365-2664.12076.
[9] J.M. Mukeka, J.O. Ogutu, E. Kanga, E. Røskaft, Human-wildlife conflicts and their correlates in Narok County, Kenya, Global Ecology and Conservation 18 (2019) e00620, https://doi.org/10.1016/j.gecco.2019.e00620.
[10] P. Sharma, N. Chettri, K. Wangchuk, Human–wildlife conflict in the roof of the world: understanding multidimensional perspectives through a systematic review, Ecol. Evol. 11 (17) (2021) 11569–11586, https://doi.org/10.1002/ece3.7980.
[11] J.N. Adhikari, B.P. Bhattarai, M.B. Rokaya, T.B. Thapa, Land use/land cover changes in the central part of the Chitwan Annapurna Landscape, Nepal, PeerJ 10 (2022) e13435, https://doi.org/10.7717/peerj.13435.
[12] B. Rimal, S. Sloan, H. Keshtkar, R. Sharma, S. Rijal, U.B. Shrestha, Patterns of historical and future urban expansion in Nepal, Rem. Sens. 12 (4) (2020) 628, 3390/rs12040628.
[13] K.P. Acharya, P.K. Paudel, S.R. Jnawali, P.R. Neupane, M. Köhl, Can forest fragmentation and configuration work as indicators of human–wildlife conflict? Evidences from human death and injury by wildlife attacks in Nepal, Ecol. Indicat. 80 (2017) 74–83, https://doi.org/10.1016/j.ecolind.2017.04.037.
[14] O. Springate-Baginski, O.P. Dev, N.P. Yadav, J. Soussan, Community forest management in the middle hills of Nepal: the changing context, J. For. Livelihood 3 (1) (2003) 5–20.
[15] K.P. Acharya, Twenty-four years of community forestry in Nepal, Int. For. Rev. 4 (2) (2002) 149–156.
[16] S. Tripathi, R. Subedi, H. Adhikari, Forest cover change pattern after the intervention of community forestry management system in the mid-hill of Nepal: a case study, Rem. Sens. 12 (17) (2020) 2756, https://doi.org/10.3390/rs12172756.
[17] J.N. Adhikari, B.P. Bhattarai, T.B. Thapa, Human-wild mammal conflict in a human dominated midhill landscape: a case study from Panchase area in Chitwan Annapurna Landscape, Nepal, Journal of Institute of Science and Technology 23 (1) (2018) 30–38, https://doi.org/10.3126/jist.v23i1.22158.
[18] K. Baral, et al., Human wildlife conflict and impacts on livelihood: a study in community forestry system in mid-hills of Nepal, Sustainability 13 (23) (2021) 13170, https://doi.org/10.3390/su132313170.
[19] M. Chetri, M. Odden, O. Devineau, P. Wegge, Patterns of livestock depredation by snow leopards and other large carnivores in the Central Himalayas, Nepal, Global Ecology and Conservation 17 (2019) e00536, https://doi.org/10.1016/j.gecco.2019.e00536.
[20] R. Bista, C. Song, Human-wildlife conflict in the community forestry landscape: a case study from two Middle Hill districts of Nepal, Hum. Dimens. Wildl. (2021) 1–17, https://doi.org/10.1080/10871209.2021.1980158.
[21] B.R. Lamichhane, et al., Spatio-temporal patterns of attacks on human and economic losses from wildlife in Chitwan National Park, Nepal, PLoS One 13 (4) (2018) e0195373, https://doi.org/10.1371/journal.pone.0195373.
[22] B.R. Lamichhane, et al., Contribution of buffer zone programs to reduce human-wildlife impacts: the case of the Chitwan National Park, Nepal, Hum. Ecol. 47 (2019) 95–110, https://doi.org/10.1007/s10745-019-0054-y.
[23] R. Pal, S. Thakur, S. Arya, T. Bhattacharya, S. Sathyakumar, Mammals of the Bhagirathi basin, Western Himalaya: understanding distribution along spatial gradients of habitats and disturbances, Oryx 55 (5) (2020) 657–667, https://doi.org/10.1017/s0030605319001352.
[24] A.S. Rodrigues, J.D. Pilgrim, J.F. Lamoreux, M. Hoffmann, T.M. Brooks, The value of the IUCN Red List for conservation, Trends Ecol. Evol. 21 (2) (2006) 71–76, https://doi.org/10.1016/j.tree.2005.10.010.
[25] T.B. Thapa, Habitat Suitability Evaluation for Leopard (*Panthera pardus*) Using Remote Sensing and GIS in and Around Chitwan National Park, Nepal", Ph.D. Thesis, Faculy of Wildlife Science, Saurashtra University, 2011.
[26] B.P. Bhattarai, P. Kindlmann, Habitat heterogeneity as the key determinant of the abundance and habitat preference of prey species of tiger in the Chitwan National Park, Nepal, Acta Theriol. 57 (1) (2012) 89–97, https://doi.org/10.1007/s13364-011-0047-8.
[27] H. Kafley, M.E. Gompper, M. Sharma, B.R. Lamichane, R. Maharjan, Tigers (*Panthera tigris*) respond to fine spatial-scale habitat factors: occupancy-based habitat association of tigers in Chitwan National Park, Nepal, Wildl. Res. 43 (5) (2016) 398–410, https://doi.org/10.1071/WR16012.
[28] P.B. Singh, B.B. Shrestha, A. Thapa, P. Saud, Z. Jiang, Selection of latrine sites by Himalayan musk deer (*Moschus leucogaster*) in Neshyang Valley, Annapurna conservation area, Nepal, J. Appl. Anim. Res. 46 (1) (2018) 920–926, https://doi.org/10.1080/09712119.2018.1430578.
[29] S.R. Kandel, B. Neupane, M.S. Miya, B.M. Sadadev, N.D. Khatri, B. Dhami, An emerging issue of human-leopard conflict in the human-dominated landscape of mid-hills: a case study from Tanahun district of Nepal, International Journal of Zoology (2023) 2023, https://doi.org/10.1155/2023/5690289.

[30] B. Adhikari, M. Odden, B. Adhikari, S. Panthi, J.V. López-Bao, M. Low, Livestock husbandry practices and herd composition influence leopard-human conflict in Pokhara Valley, Nepal, Hum. Dimens. Wildl. 25 (1) (2020) 62–69, https://doi.org/10.1080/10871209.2019.1695157.
[31] WWF, in: Chitwan-Annapurna Landscape: Drivers of Deforestation and Forest Degradation, WWF Nepal Hariyoban Program, 2013, p. 80.
[32] E. Dinerstein, et al., An Ecoregion-based approach to protecting half the terrestrial realm, Bioscience 67 (6) (2017) 534–545, https://doi.org/10.1093/biosci/bix014.
[33] E.D. Wikramanayake, E. Dinerstein, C.J. Loucks, Terrestrial Ecoregions of the Indo-Pacific: a Conservation Assessment, Island Press, 2002.
[34] N.L.C.D.C. Lake, Database of Nepal, National Lake Conservation Development Committee, 2020. https://nepallake.gov.np/, 6/18/2020.
[35] WWF, H.B.P. WWF Nepal, in: Chitwan-Annapurna Landscape: A Rapid Assessment Baluwatar, WWF Nepal, Hariyo Ban Program, Kathmandu, 2013, p. 182.
[36] U.R. Bhuju, P.R. Shakya, T.B. Basnet, S. Shrestha, Nepal Biodiversity Resource Book: Protected Areas, Ramsar Sites, and World Heritage Sites, International Centre for Integrated Mountain Development (ICIMOD), 2007, p. 158.
[37] CBS, National Population and Housing Census, National report), in: National Statistics Office, Kathmandu, Nepal, (2021), 2021. Available: URL, https://censusnepal.cbs.gov.np.
[38] S. Paudel Khatiwada, J. Zhang, Y. Su, B. Paudel, W. Deng, Agricultural Land Use Intensity and Determinants in Different Agroecological Regions in Central Nepal Himalaya, Land Cover Change and its Eco-Environmental Responses in Nepal, 2017, pp. 281–305, https://doi.org/10.1007/978-981-10-2890-8_13.
[39] J.N. Adhikari, B.P. Bhattarai, T.B. Thapa, Determinants of abundance and habitat association of mammals in Barandabhar Corridor Forest, Chitwan, Nepal, Folia Oecologica 48 (1) (2021), https://doi.org/10.2478/foecol-2021-0011.
[40] V. Dangol, K. Poudel, Channel shifting of Narayani river and its ramification in west Chitwan, central Nepal, J. Nepal Geol. Soc. 30 (2004) 153–156.
[41] HMG, Soil survey of Chitwan division, Forest Resource Survey. Kathmandu, Nepal, Ministry of Forest, Kathmandu, Nepal, 1968, p. 126.
[42] Important B.C.N., Birding and biodiversity areas of Nepal (IBAs). Bird conservation Nepal (2022), https://birdlifenepal.org 2022/1/24.
[43] NTNC (Ed.), Barandabhar Forest Corridor Management Plan (Draft Report) Kathmandu, Development Vision-Nepal Pvt. Ltd., Kathmandu, 2003, p. 78.
[44] S. Lamichhane, R. Kandel, C. Pokheral, T. Dahal, S. Bhattarai, C.N.P. Department of national parks and wildlife conservation, norad, ramsar site international, in: Biodiversity Profile of Beeshazar and Associated Lakes, Chitwan. DNPWC, CNP, NTNC, Norad, Ramsar Site International, 2016, p. 50.
[45] GPFD, Gandaki province forest directorate, Nepal, in: Checklists of Fauna of the Seti River Corridor. Pokhara: Gandaki Province Forest Directorate, Gandaki Province, Nepal, 2021, p. 74.
[46] S. Baral, et al., Invasion of alien plant species and their impact on different ecosystems of Panchase Area, Nepal, Banko Janakari 27 (1) (2017) 31–42, https://doi.org/10.3126/banko.v27i1.18547.
[47] R. Baral, Birds of Annapurna Conservation Area Pokhara, Nepal: National Trust for Nature Conservation, Annapurna Conservation Area Project, Pokhara, Nepal, 2018, p. 74.
[48] A.C.A.P. Annapurna, Conservation area Project (ACAP). National trust for nature conservation (NTNC). https://ntnc.org.np/project/annapurna-conservation-area-project-acap.
[49] F.B. Golley, K. Petrusewicz, L. Ryszowski, Small Mammals: Their Productivity and Population Dynamics, Cambridge University Press, 1975, p. 455, 5.
[50] P. Njoroge, R. Yego, M. Muchane, M. Githiru, T. Njeri, A. Giani, A survey of the large and medium sized mammals of Arawale National Reserve, Kenya, J. East Afr. Nat. Hist. 98 (1) (2009) 119–128, https://doi.org/10.2982/028.098.0108.
[51] M.G. Erena, Assessment of medium and large-sized mammals and their behavioral response toward anthropogenic activities in Jorgo-Wato Protected Forest, Western Ethiopia, Ecol. Evol. 12 (2) (2022) e8529, https://doi.org/10.1002/ece3.8529.
[52] B.R. Lamichhane, et al., Factors associated with co-occurrence of large carnivores in a human-dominated landscape, Biodivers. Conserv. 28 (6) (2019) 1473–1491, https://doi.org/10.1007/s10531-019-01737-4.
[53] T. Storaas Wegge, Sampling tiger ungulate prey by the distance method: lessons learned in Bardia National Park, Nepal, Anim. Conserv. 12 (1) (2009) 78–84, https://doi.org/10.1111/j.1469-1795.2008.00230.x.
[54] C. McDougal, You Can Tell Some Tigers by Their Tracks with Confidence (Riding the Tiger: Tiger Conservation in Human-Dominated Landscapes), Cambridge University Press, Cambridge, United Kingdom, 1999, p. 190.
[55] R. Steinmetz, D.L. Garshelis, W. Chutipong, N. Seuaturien, Foraging ecology and coexistence of Asiatic black bears and sun bears in a seasonal tropical forest in Southeast Asia, J. Mammal. 94 (1) (2013) 1–18, https://doi.org/10.1644/11-MAMM-A-351.1.
[56] H. Taherdoost, Determining sample size; how to calculate survey sample size, International Journal of Economics and Management Systems 2 (2017).
[57] S.B. Hulley, Designing Clinical Research, Lippincott Williams and Wilkins, 2007.
[58] J. Pérez, et al., The effect of data analysis strategies in density estimation of mountain ungulates using distance sampling, Ital. J. Zool. 82 (2) (2015) 262–270, https://doi.org/10.1080/11250003.2014.974695.
[59] E. Gurarie, O. Ovaskainen, Towards a general formalization of encounter rates in ecology, Theor. Ecol. 6 (2013) 189–202, https://doi.org/10.1007/s12080-012-0170-4.
[60] R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, 2020 [Online]. Available: https://www.R-project.org/.
[61] pscl, Classes and methods for R developed in the political science computational laboratory. United States Studies Centre, University of Sydney, Sydney, New South Wales, Australia, 2020 [Online]. Available: https://github.com/atahk/pscl/.
[62] T. Hengl, A Practical Guide to Geostatistical Mapping, University of Amsterdam, 2009, p. 293.
[63] F. Huang, D. Liu, X. Tan, J. Wang, Y. Chen, B. He, Explorations of the implementation of a parallel IDW interpolation algorithm in a Linux cluster-based parallel GIS, Comput. Geosci. 37 (4) (2011) 426–434, https://doi.org/10.1016/j.cageo.2010.05.024.
[64] B.R. Lamichhane, Living with the Large Carnivores: the Interaction between Humans, Tigers and Leopards in Chitwan National Park, Nepal, Unpublished Doctoral Dissertation, Leiden University, 2019 [Online]. Available: https://hdl.handle.net/1887/71142.
[65] D. Neupane, R.L. Johnson, T.S. Risch, How do land-use practices affect human—elephant conflict in Nepal? Wildl. Biol. 1 (2017) 1–9, https://doi.org/10.2981/wlb.00313.
[66] P. Sharma, et al., Mapping human–wildlife conflict hotspots in a transboundary landscape, Eastern Himalaya, Global Ecology and Conservation 24 (2020) e01284, https://doi.org/10.1016/j.gecco.2020.e01284.
[67] D. Karki, et al., Human-wildlife conflicts in Paschim Kusaha Village of Koshi Tappu Wildlife Reserve, Sunsari district, Nepal, Journal of Resources and Ecology 13 (6) (2022) 1022–1029, https://doi.org/10.5814/j.issn.1674-764x.2022.06.007.
[68] A. Srivastava, F. Begum, City Monkeys (*Macaca mulatta*): a Study of Human Attitudes, Commensalism and Conflict: the Human-Primate Interface, 2005, pp. 258–269.
[69] K. Adhikari, L. Khanal, M.K. Chalise, Status and effects of food provisioning on ecology of Assamese monkey (*Macaca assamensis*) in Ramdi area of Palpa, Nepal, Journal of Institute of Science and Technology 22 (2) (2018) 183–190, https://doi.org/10.3126/jist.v22i2.19611.
[70] R. Bista, A. Aryal, Status of the asiatic black bear *Ursus thibetanus* in the southeastern region of the Annapurna conservation area, Nepal, Zoology and Ecology 23 (1) (2013) 83–87, https://doi.org/10.1080/21658005.2013.774813.
[71] K. Baral, et al., Impact of climate change on distribution of common leopard (Panthera pardus) and its implication on conservation and conflict in Nepal, Heliyon 9 (1) (2023) e12807, https://doi.org/10.1016/j.heliyon.2023.e12807.
[72] C.M. Hill, A.D. Webber, Perceptions of nonhuman primates in human–wildlife conflict scenarios, Am. J. Primatol. 72 (10) (2010) 919–924, https://doi.org/10.1002/ajp.20845.
[73] C.M. Hill, People, Crops and Primates: A Conflict of Interests, Commensalism and Conflict: the Human-Primate Interface, 4, 2005, pp. 40–59.
[74] R.K. Koirala, A. Aryal, A. Parajuli, A. David, Human-common leopard (Panthera pardus) conflict in lower belt of Annapurna Conservation Area, Nepal, Journal of Research in Conservation Biology 1 (2012) 5–12.
[75] A. Harihar, B. Pandav, S.P. Goyal, Responses of leopard *Panthera pardus* to the recovery of a tiger Panthera tigris population, J. Appl. Ecol. 48 (3) (2011) 806–814, https://doi.org/10.1111/j.1365-2664.2011.01981.x.

[76] K. Krafte Holland, L.R. Larson, R.B. Powell, Characterizing conflict between humans and big cats Panthera spp: a systematic review of research trends and management opportunities, PLoS One 13 (9) (2018) e0203877, https://doi.org/10.1371/journal.pone.0203877.
[77] M. Kabir, A. Ghoddousi, M.S. Awan, M.N. Awan, Assessment of human–leopard conflict in Machiara National Park, Azad Jammu and Kashmir, Pakistan, Eur. J. Wildl. Res. 60 (2) (2014) 291–296, https://doi.org/10.1007/s10344-013-0782-z.
[78] S. Sathyakumar, Status and management of Asiatic black bear and Himalayan brown bear in India, Ursus 12 (2001) 21–30 [Online]. Available: https://www.jstor.org/stable/3873225.
[79] N. Constant, S. Bell, R. Hill, The impacts, characterisation and management of human–leopard conflict in a multi-use land system in South Africa, Biodivers. Conserv. 24 (2015) 2967–2989, https://doi.org/10.1007/s10531-015-0989-2.
[80] S.A. Charoo, L.K. Sharma, S. Sathyakumar, Asiatic black bear–human interactions around Dachigam National Park, Kashmir, India, Ursus 22 (2) (2011) 106–113, https://doi.org/10.2192/URSUS-D-10-00021.1.