Aspects and Determinants of Human-Carnivore Conflict in Tiger Corridors of Terai, Western Circle, Uttarakhand

THESIS

SUBMITTED TO THE

FOREST RESEARCH INSTITUTE DEEMED to be UNIVERSITY

DEHRA DUN, UTTARAKHAND

For

THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY IN FORESTRY

(Wildlife Science)

By

Vivek Ranjan

Wildlife Institute of India

2024

भारतीय वन्यजीव संस्थान
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4. The Topic of research approved by the FRI University **"Aspects and determinants of human-carnivore conflict in Tiger corridors of Terai, Western circle, Uttarakhand."**
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CONTENTS

List of Abbreviations

HWC	Human-Wildlife Conflict
HLCC	Human-Large Carnivore Conflict
TAL	Terai Arc Landscape
TCL	Tiger Conservation Landscape
KKS	Kilpura-Khatima-Surai
BB	Boom-Brahmadev
HH	Household
LPG	Liquefied Petroleum Gas
HWI	Human-Wildlife Interaction
LULC	Land Use Land Cover
EVI	Enhanced Vegetation Index
NTL	Night Time Lights
PA	Protected Area
IHR	Indian Himalayan Region
WWF	World Wide Fund for Nature
CTR	Corbett Tiger Reserve
AFD	Almora Forest Division
RFD	Ramnagar Forest Division
PCR	Pawalgarh Conservation Reserve
THB	Tiger Habitat Block
NWLS	Nandhaur Wildlife Sanctuary
HFD	Haldwani Forest Division
PTR	Pilibhit Tiger Reserve
UP	Uttar Pradesh
TEFD	Terai East Forest Division
CFD	Champawat Forest Division
SNP	Sukhlaphanta National Park
KFD	Kanchanpur Forest Division
NH	National Highway
NDVI	Normalized Difference Vegetation Index
KWLS	Katerniaghat Wildlife Sanctuary
FD	Forest Division
TR	Tiger Reserve
UKFD	Uttarakhand Forest Department
INR	Indian Rupees
CC	Concrete and Cemented
NC	Non-Cemented
IF	Inside Forest
FF	Forest Fringe
OF	Outside Forest
IVI	Importance Value Index
CT	Camera Trap
FAP	Fast-As-Possible
BA	Basal Area
RF	Relative Frequency
RD	Relative Density
RBA	Relative Basal Area
RAI	Relative Abundance Index
AITE	All India Tiger Estimation
UNEP	United Nation Environment Programme
WCMC	World Conservation Monitoring Centre
GIS	Geographic Information System
KDE	Kernel Density Estimation
USGS	United States Geological Survey
ETM	Enhanced Thematic Mapper
WRS	Worldwide Reference System
MODIS	Moderate Resolution Imaging Spectroradiometer
VIIRS	Visible Infrared Imaging Radiometer Suite
VNL	VIIRS Night time Light
GLW	Gridded Livestock of World
GLM	Generalized Linear Model
IBM	International Business Machines
SPSS	Statistical Package for Social Science
AIC	Akaike Information Criterion
DA	Dasymetric Assesment
FAO	Food and Agriculture Organisation
IWPA	Indian Wildlife Protection Act

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Summary

Human-wildlife interaction with negative consequences, commonly termed Human-Wildlife Conflict (HWC), is a global conservation challenge. Understanding the cause-effect relationship resulting in HWC is essential to resolve and mitigate the conflict and promote human-wildlife coexistence. However, the increasing human population and rapidly changing demography severely affect the contiguity of forested landscapes and habitats, becoming a major challenge for conserving wide-ranging large mammals. The conservation and protection of wildlife corridors are vital for the survival of wide-ranging large mammals in the landscape. The Terai landscape, located in the foothills of the Himalayas and proximate plains of the Indian Himalayan Region, is one of the most significant and distinct transboundary landscapes worldwide. In recent decades, the Terai region has recorded a rapid increase in human population and industry growth due to its conducive topography for industrial development in the hilly state of Uttarakhand. The region is also home to diverse wildlife, and increased conservation efforts and protection have yielded positive results, with an increased population of endangered wildlife species like tigers in the last few years. With increasing population and shrinking wildlife habitat, human and wildlife's peaceful and sustainable coexistence is distressed, leading to an increased probability of negative human-wildlife interaction.

The study aims to assess the aspects and determinants of Human-Large Carnivore Conflict (HLCC) in the wildlife corridors and their adjoining habitats in the eastern terai landscape of Uttarakhand state of India. The large carnivores considered for the purpose of this study are tiger and leopard only, which are common in the landscape of the study area. The study has three objectives: to assess the nature and extent of human-wildlife conflict due to large carnivores, the habitat structure and composition of the wildlife corridors and the diet

preferences and consumption patterns of large carnivores in the corridor habitat. The thesis has been divided into six chapters, where the first two chapters are a general introduction and literature review, and the following four chapters talk about socio-ecological factors, habitat quality of corridor habitats, implications of habitat changes on HLCC, and diet profile of two sympatric large carnivores of the study area, i.e. tiger and leopard.

The study area is part of Terai Arc Landscape (TAL), a Tiger Conservation Landscape (TCL_Id-44) of global importance with the potential for increasing the wild tiger population. The study was conducted in the delineated wildlife corridors for large mammals in the terai landscape of Uttarakhand state of India. The study focuses on the critical wildlife corridor in high tiger density and transboundary areas, providing crucial connectivity of habitats and wildlife populations. The study area is divided into two study blocks for the spatial convenience of the study: Block 1 comprises the Kosi Corridor, and Block 2 comprises the Kilpura-Khaṭima-Surai (KKS) and Boom-Brahmadev (BB) corridor and their adjoining forests. Kosi corridor connects Corbett Tiger Reserve to Pawalgarh Conservation Reserve in Ramnagar forest division. The KKS and BB corridors in Block 2 have contiguous and interconnected habitats adjoining Nandhaur Wildlife Sanctuary in the Haldwani Forest Division of Uttarakhand, connecting to Pilibhit Tiger Reserve and Sukhlaphanta National Park through forest of Nepal. The study area is rich in faunal diversity and home to a few important large mammals, such as the Tiger, Leopard and the Asian elephant.

In order to understand the nature and extent of HLCC in the landscape, it was essential to understand the socio-economic conditions and perceptions of the communities. We conducted random household (HH) semi-structured questionnaire surveys and discussions in the villages located in the corridors. The information on HWC compensation records was also collected from the Uttarakhand Forest department to analyze the patterns of conflict incidences. The results show that livestock grazing, fuelwood, and fodder collection from the forest are common and prevalent practices. About 90% of the households have LPG connections at home, yet most HH members still visit forests for collection. The education level among the respondents is low, with maximum HHs having an annual income of less than one lakh. The major occupation as the primary source of income in the study area is casual labour work, and most of the HHs have land holdings of less than an acre.

The incidences of HLCC mainly occurred inside the forest areas and later half of the daytime, i.e., from noon to evening. The season of incidence and condition of the body of the depredated livestock show significant association with the place of incidence. The seasonality pattern of HLCC incidences shows maximum incidents during monsoon in study block 1, whereas in block 2, it is in winter. The trend of incidences over the last 13 years in study block 1 shows a peak in tiger and leopard cases during July and August and forecasts an increase in cases over upcoming years. The annual trend of HLCC in the two study blocks is significantly different.

The nature of HLCC in the study area is both tangible, which can be visually observed and intangible, which has imbibed effects with direct and indirect impacts. The tangible nature of large carnivore conflict is the direct impacts in the form of human casualty and livestock depredation. The intangible nature of the conflict with indirect impacts are psychological– fear of large carnivores and sense of insecurity, social – loss of livelihood and family security. The aspects of HLCC are socio-ecological, with both the social factors of communities residing around the forest and the ecological processes influencing the HWI. In rapidly transforming human-dominated landscapes, anthropogenic activities and disturbances significantly impact the ecological processes and landscape characteristics.

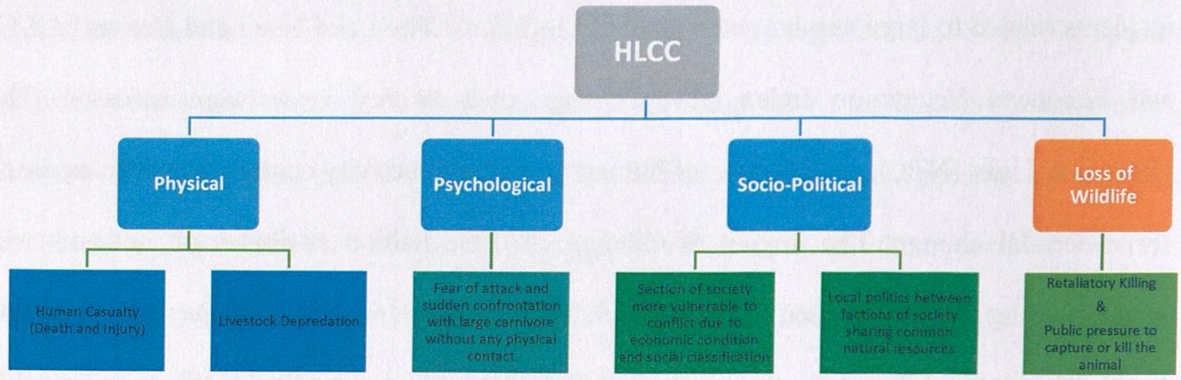
The habitat quality was assessed using the nested quadrat method for vegetation and camera trapping for large carnivore population estimation and prey availability. The camera trapping was done using the capture-recapture method in 2 sq. Km sampling grids. The results show maximum tree diversity in the BB corridor, with good to fair Sal regeneration in all three corridors. However, most of the tree species show poor to no regeneration. Sixty-one species of trees were recorded from the three corridor areas sampled. As an invasive plant species, *Lantana camara* is more prevalent and extensive in study block 1 and *Ageratina adenophara* in block 2. The grassland habitat is shrinking, and less in all three corridor habitats. Anthropogenic disturbance is high in block 2 in comparison to block 1, while tree cutting and lopping are the most prevalent anthropogenic disturbance signs observed in all three corridors at equivalent levels. The medium-sized prey is the most abundant prey base in both the study blocks, with maximum relative abundance of Spotted deer. However, the relative abundance of Sambar deer is higher in the bhabar topography area of corridors and maximum in large-sized prey. The study block 1 has 16 adult tigers and 22 leopards, while block 2 has 31 adult tigers and 40 leopards.

The wildlife habitats of the three corridor areas studied have good tree diversity and complexity. However, the regeneration of tree species is poor for most species. The shrub and herb cover are also low for most areas in all three corridors, affecting the lower structure of forest habitats. The extensive growth of weed species like *Lantana camara* and *Ageratina adenophora* also affects understory species' composition, structure, and tree regeneration. The poor regeneration and deteriorated lower strata vegetation with sparse undergrowth are unfavourable conditions for breeding large carnivores, which requires dense patches for hiding their offspring. The lack of such patches and high human disturbance forces them out of the forest to use sugarcane farm fields to raise and hide their young ones, as has been observed in many instances in the Terai-Bhabar landscape. Using human-modified landscapes by large carnivores for their life cycle stages is unsuitable for human-wildlife coexistence and increases the vulnerability of negative HWI.

The implications of habitat transformations on HLCC were assessed by identifying spatial conflict hotspots based on compensation records of the last 14 years and the magnitude of incidents related to large carnivores in different locations. The Land Use Land Cover (LULC) and Enhanced Vegetation Index (EVI) change over twenty years were assessed. The Nighttime Light (NTL), an indicator of human growth and activity centres, was also assessed for a decadal change. The impact of changes in these habitat attributes on hotspots was assessed using the Generalized Linear Model. The model shows that the impact of vegetation health change and human activity or disturbances have a significant effect on conflict hotspots. The very high-risk zones are also located in the delineated corridors near bottleneck areas. The study has highlighted that the implications of habitat changes are significant for HLCC. The implications of habitat changes vary with the landscape and regional attributes, as observed in our study at two sites with varied underlying factors other than habitats.

In the present conservation paradigm of large carnivores, it is essential to understand the feeding habits and prey-predator dynamics outside protected areas. Our study fills this gap in our understanding of the dietary habits of sympatric large carnivore species outside protected areas (PAs) in the terai landscape of India. It focuses on the feeding ecology of tigers and leopards in wildlife corridor habitats outside PAs. Our results show a significant dependence of tigers and leopards on medium-sized prey, i.e., Wild boars and spotted deer. It also shows a 93% overlap between tiger and leopard diets in the study area. However, it is crucial to augment wild prey availability in the wildlife corridor habitats, where grazing pressure is high. The problem of stray cattle has further escalated the issue of livestock depredation by large carnivores. Conservation strategists must consider the feeding habits of the predators and how these are changing due to the induced effects of anthropogenic activities.

Aspects



Determinants

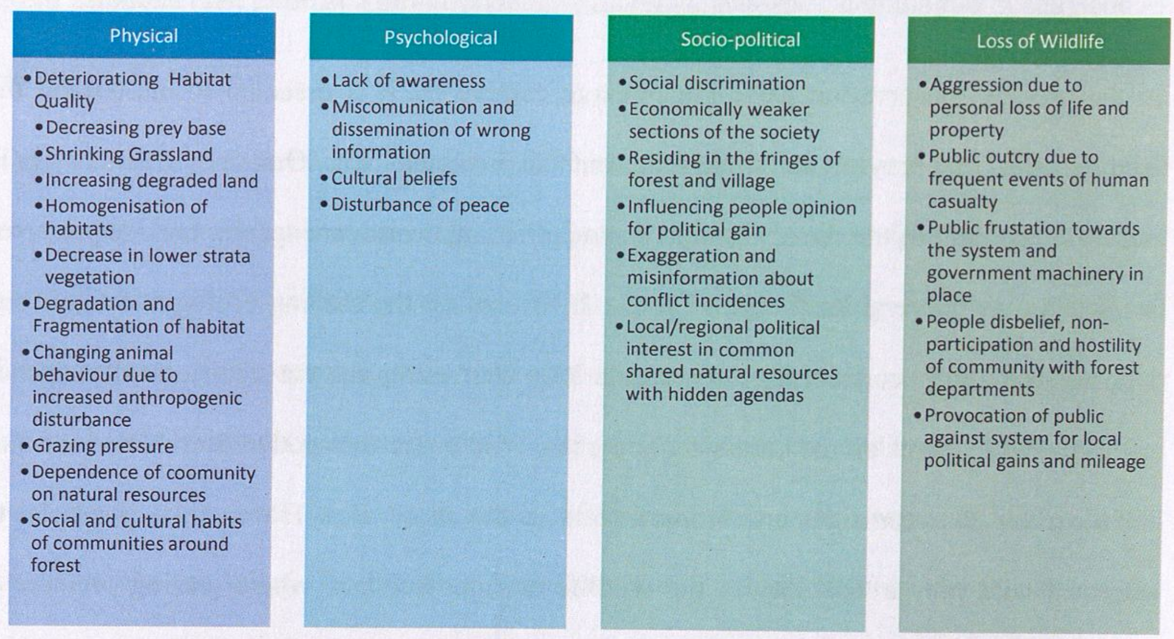


Plate 1: Aspects and Determinants of Human-Large Carnivore conflict in the study area.

Chapter 1

Introduction

The Sustainable Development Goal 15 of the 2030 Agenda for Sustainable Development is devoted to "*protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*". The outcome document of the United Nations Conference on Sustainable Development in 2012 entitled "Future We Want" reiterates the importance of implementing the strategic plan for biodiversity conservation and its critical role in maintaining ecosystems that provide essential services, which are critical foundations for sustainable development and human well-being.

Biodiversity conservation and its global challenges include habitat loss, fragmentation, deforestation, and negative Human-Wildlife Interaction (HWI) (Bodo et al., 2021; Kideghesho et al., 2013; Moranta et al., 2022). Human-wildlife interaction, which results in the loss of human livelihood, property and life, is called Human-Wildlife Conflict (HWC) (Gross et al., 2021; Nyhus, 2016). HWC is a dynamic global issue with regional traits and specificity to landscapes or regions (Göttert & Starik, 2022). Every region has specific reasons and influencing factors for negative HWI and consequential impacts. However, many of the primary factors and impacts are common worldwide. Thus, it is important to understand the cause-effect relationship resulting in HWC to resolve and mitigate the conflict and promote human-wildlife co-existence.

Wildlife conservation focuses on areas of high biodiversity and demarcates these areas as Protected Areas (PAs) with the legal status of protection, limiting and regulating anthropogenic disturbance to such areas. Wildlife conservation aims to protect, preserve, and conserve species in their natural environment while maintaining essential ecosystem functions through in-situ and ex-situ measures (Fetene et al., 2012; Zegeye, 2017). However, the increasing human population and rapidly changing demography severely affect the contiguity of forested landscapes and habitats (Arroyo-Rodríguez et al., 2017), becoming a major challenge for the conservation of wide-ranging large mammals (Macdonald et al., 2013; Wikramanayake et al., 2004). The landscape has become fragmented due to the development of industrial zones/hubs, linear infrastructures like roads, railways, man-made canals, and reservoirs, and the expansion of urban sprawl. Major land-use changes have led to the isolation of PAs and obstructing their connectivity.

Landscape planning and conservation aims to protect the region's entire ecosystem rather than focus on isolated protected forest areas. The isolation of PAs threatens large mammal diversity and existence (A. Thapa et al., 2017). Connectivity among habitats and populations is critical in determining various ecological phenomena (McRae et al., 2008). The wildlife corridors for large mammals play a significant role in metapopulation management and conservation. The conservation and protection of large mammal corridors is vital for survival or the risk of species extinction from the landscape (Sawyer et al., 2011). The degradation and loss of habitat outside PAs aggravate the problem due to habitat fragmentation. Maintaining habitat linkage and connectivity by promoting species movement and dispersal will alleviate the problems due to fragmentation (Crooks & Sanjayan, 2006). The biological characteristics of large mammals, such as large body size, complex social behaviour, low population and specialized niche preference, make them more vulnerable to extinction due to rapid habitat transition and environmental conditions (R. A. Ahmed et al., 2012).

India is a megadiverse country (Kumar & Verma, 2017) with the second most human populated country in the world. In such scenarios, balancing human needs and wildlife conservation is challenging. It is crucial to engage communities in conservation efforts and protect the rights of the indigenous people for long-term viable conservation. The areas with abundant natural resources are also preferred for developmental activities like industrialization and urbanization. Subsequently, it increases the human footprint while reducing the natural forest coverage. Similar trends have been observed in the Himalayan foothill areas of the Terai landscape in the last few decades. The Terai Arc Landscape (hereafter referred to as TAL), located in the foothills of the Himalayas and proximate plains of the Indian Himalayan Region (IHR), is one of the most significant and distinct transboundary landscapes around the world (Semwal, 2005; Wikramanayake et al., 2010). The landscape covers an area of approximately 49,500 sq. km, comprising 13 Protected Areas (PAs) starting from Parsa Wildlife Reserve in Nepal to Rajaji National Park in India (Semwal, 2005). It is an important ecoregion and is considered a high-priority conservation landscape due to the significantly rich biological diversity that it supports (Wikramanayake et al., 2010). The region is also subjected to numerous anthropogenic pressures due to the high human density and developmental growth. The high dependence rate of the local communities on forests residing in and around the forests has led to unsustainable extraction of forest resources (Johnsingh, 2006).

The wildlife in human-dominated mosaic landscapes is restricted mainly to PAs. Despite the current protection in these refuges, they face an uncertain future because many of these patches are too small to support populations large enough to withstand the consequences of inbreeding (Dinerstein et al., 2006; Seidensticker et al., 2010). It is particularly true for wide-ranging species such as tigers and elephants, whose movement patterns get disrupted due to habitat fragmentation, leading to increased incidences of HWC (Badola & Hussain, 2003; Bisht et al., 2019; Chanchani et al., 2014; Johnsingh et al., 2004; Wikramanayake et al., 2004). The increasing rate of HWC in such a priority tiger conservation landscape (TCL) is alarming for conservation.

The nature and extent of the conflict are relevant in understanding the conflict and suggesting mitigative measures (Manral et al., 2016; Ogra & Badola, 2008). Reducing conflict between wildlife and people is considered a top conservation priority, particularly in landscapes where high densities of people and wildlife co-occur. Large-bodied felids, such as tigers and leopards, are prone to conflicts with humans, mainly when they use wildlife corridors in human-dominated landscapes (Malviya & Ramesh, 2015). Humans, livestock and wild predators share common resources in the region, which leads to negative HWI that can threaten the ecosystem's continued viability and impact the local economy (Aryal et al., 2014). The impact of conservation policies on human well-being is critical to integrating poverty alleviation and biodiversity conservation. Approaches to management and mitigation of conflict emphasize its visible costs. Hidden impacts, i.e., uncompensated costs, temporally delayed and psychosocial in nature, remain poorly addressed (Barua et al., 2013). In mosaic landscapes like TAL, wildlife corridors connecting the protected areas are pivotal for the dispersal, demography and genetic variability of large mammals like tigers, elephants and leopards (K. Thapa et al., 2017).

Scientific and empirical HWC management and mitigation plans should address the underlying factors responsible for negative HWI inside and outside PAs in wildlife corridors. Wildlife corridors are critical tools for long-term landscape conservation (Dutta et al., 2018; Qureshi et al., 2014; Yumnam et al., 2014), and protecting the ecological sanctity of these habitats is of utmost importance. Anthropogenic disturbances and rapidly changing land-use patterns due to many factors affect the ecology of the habitats and overall ecosystem, especially outside the PAs (Akbar et al., 2019; Banerjee et al., 2020; Falcucci et al., 2007; Ladue et al., 2021; Zhao et al., 2006). To understand and address the root causes of HWC, it is essential to understand the socio-ecological aspects and factors driving the conflict. The study aims to assess the aspects and determinants of Human-Large Carnivore Conflict

(HLCC) in the wildlife corridors and its adjoining habitats in the eastern terai landscape of Uttarakhand state of India. The study is based on the hypothesis that both social and ecological factors of the landscape are responsible for the increase in HWC. Due to the vastness of the topic, this study focuses on the Large Carnivores, i.e., Tiger and Leopard and their negative HWI. The study is based on three objectives:

1. To assess the nature and extent of human-wildlife conflict due to large carnivores.
2. To assess the habitat structure and composition (habitat quality) of the wildlife corridors.
3. To assess the diet profile and dependency of large carnivores on livestock depredation

These three objectives explore the answers to the three research questions that we ask:

- What are the aspects and patterns of human-wildlife conflict in reference to carnivores in tiger corridor areas?
- What is the status of habitat outside Protected Areas in delineated tiger corridors of Terai, Uttarakhand?
- What are the diet preferences and consumption patterns of large carnivores in the tiger corridor landscape?

Study Area

The study was conducted in the delineated wildlife corridors for large mammals in the terai landscape of Uttarakhand state of India. Earlier studies have identified and delineated potential wildlife corridors for large mammal conservation in the Terai and Shivalik landscape in the Himalayan foothills (Chanchani et al., 2014; Johnsingh, 2006; Qureshi et al., 2014). The study focuses on the critical wildlife corridor in high tiger density and transboundary areas, providing crucial connectivity of habitats and wildlife populations. The study area is part of TAL and Tx2 Class I Tiger Conservation Landscape (TCL_Id: 44)

(Dinerstein et al., 2010; WWF & RESOLVE, 2015). The study area is divided into two study blocks for the spatial convenience of the study: Block 1 comprises the Kosi Corridor, and Block 2 comprises the Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridor and their adjoining forests (Figure 1. 1).

Block 1 is located along the Kosi River, connecting Corbett Tiger Reserve (CTR) and Almora Forest Division (AFD) to Ramnagar Forest Division (RFD) and Pawalgarh Conservation Reserve (PCR) in Nainital district of Uttarakhand. Kosi corridor comprises parts of the Kosi and Kota forest ranges in RFD, Bijrani, Sarpduli, and Mandal ranges of CTR and the Mohan range of AFD. Block 1 lies in Tiger Habitat Block-II (THB-II), and Block 2 lies in THB-III (Johnsingh et al., 2004). The KKS and BB corridors in Block 2 have contiguous and interconnected habitats adjoining Nandhaur Wildlife Sanctuary (NWLS) in the Haldwani Forest Division (HFD) of Uttarakhand. The KKS corridor connects NWLS to Pilibhit Tiger Reserve (PTR) in Uttar Pradesh (UP) through three forest ranges (Kilpura, Khatima, and Surai) of Terai East Forest Division (TEFD) in Uttarakhand. The BB corridor connects NWLS and Champawat Forest Division (CFD) in Uttarakhand, India, to Sukhlaphanta National Park (SNP) and Kanchanpur Forest Division (KFD) in Nepal through Indo-Nepal transboundary crossing Sharda River. BB corridor consists of the Sharda forest range of HFD, parts of the Kilpura forest range of TEFD, and the Dogadi and Boom forest ranges of CFD in Uttarakhand, India. Block 2 lies in the Udham Singh Nagar and Champawat districts of Uttarakhand, India. The National Highway (NH) 309 passes through the Kosi corridor, and NH-9 passes through the KKS and BB corridor. Tanakpur-Khatima railway line passes through the KKS corridor parallel to NH-9 and Sharda canal, acting as a major linear infrastructural impediment to free wildlife movement through the KKS corridor.

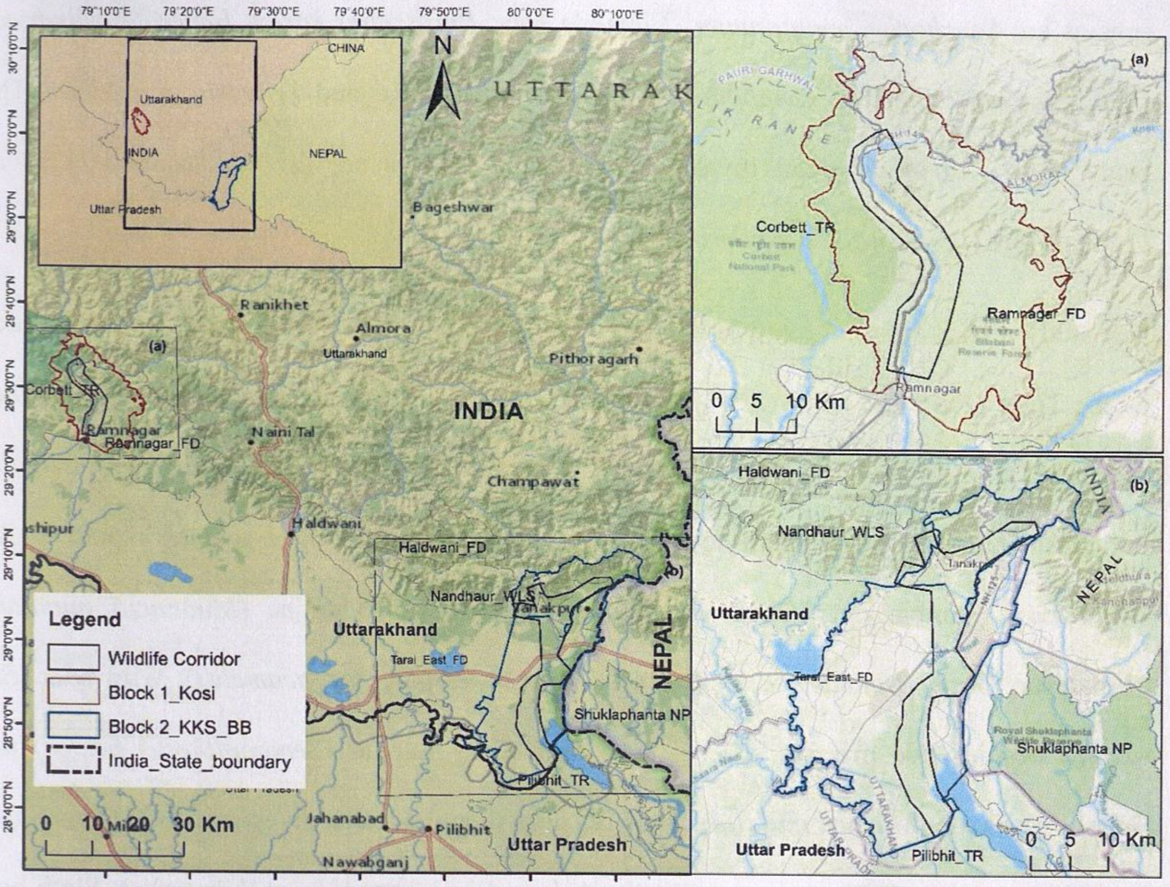


Figure 1. 1 Study area map with Block 1 (Kosi corridor) and Block 2 (Kilpura-Khatima-Surai and Boom-Brahmadev corridor).

The study area falls in 2B Himalaya-West Himalaya and 7A Gangetic Plain- Upper Gangetic Plain biogeographic provinces of India (Rodgers et al., 2000). The major forest types are moist and dry deciduous forests interspersed with alluvial and riverine grasslands (Harihar & Pandav, 2012; Ranjan et al., 2021). The landscape is primarily composed of Sal (*Shorea robusta*) forests, Teak (*Tectona grandis*) forests, and mixed forests with prominent tree species like *Terminalia elliptica, Terminalia arjuna, Terminalia chebula, Terminalia bellirica, Mallotus phillipensis, Syzygium cumini, Adina cordifolia, Anogeissus latifolia, Lagerstroemia parviflora, Holoptelia integrifolia, Ehretia laevis, Dalbergia sissoo, Bombax ceiba, Trewia nudiflora,* and *Aegle marmelos* (Anwar & Borah, 2020; Bajpai et al., 2015; Harihar et al., 2014). The woodland habitats are interspersed with tall floodplain/ riverine grasslands, open grasslands and wooded grasslands (Chanchani et al., 2014). Some of the prominent grass species are *Saccharum spontaneum, Themeda* spp., *Phragmites karka, Imperata cylindrica, Desmostachya bipinnata, Cymbopogon* spp., *Arundo donax,* and *Vetiveria zizanioides.* The study area's two widespread invasive plant weed species are *Lantana camara* (Kuri or Lantana) and *Ageratina adenophora* (Kala Basa) (Mungi et. al., 2021).

The study area is rich in faunal diversity and home to a few important large mammals, such as the Tiger (*Panthera tigris*), Leopard (*Panthera pardus*) and the Asian elephant (*Elephas maximus*). Mugger (*Crocodylus palustris*), Smooth-coated Otter (*Lutrogale perspicillata*), and freshwater turtles represent aquatic diversity. Common ungulate species include Chital (*Axis axis*), Sambar deer (*Rusa unicolor*), Northern Red Muntjac (*Muntiacus muntjak*), Himalayan Goral (*Naemorhedus goral*), Nilgai (*Boselaphus tragocamelus*), Wild boar (*Sus scrofa*) besides two primate species *viz.,* Tarai Gray Langur (*Semnopithecus hector*) and Rhesus macaque (*Macaca mulatta*). The area also supports a rich diversity of avifauna. Other important species of the study area are the Asiatic Black bear (*Ursus thibetanus*), Sloth bear (*Melursus ursinus*), Leopard cat (*Prionailurus bengalensis*), Fishing cat (*Prionailurus viverrinus*), Jungle Cat (*Felis chaus*) and Jackal (*Canis aureus*) (Anwar & Borah, 2020; Chanchani et al., 2014; Harihar & Pandav, 2012).

Geographically, the study area lies in the physiographic zones of Terai-Bhabar south of the Shivaliks at the foothills of the Himalayas in India. The topography transitions from hilly and undulating in the north Shivalik hills, transitioning through rocky and boulder-rich Bhabar to flat alluvial plains of the Terai in the south. The elevation ranges of from 200 m to 1000 m from mean sea level (msl) (Figure 1.2). The area is drained by several seasonal streams and important perennial rivers like Sharda, Nandhaur, Gola, and Kosi. The Terai area is dotted with man-made reservoirs, important wetland areas that add to the landscape's biodiversity.

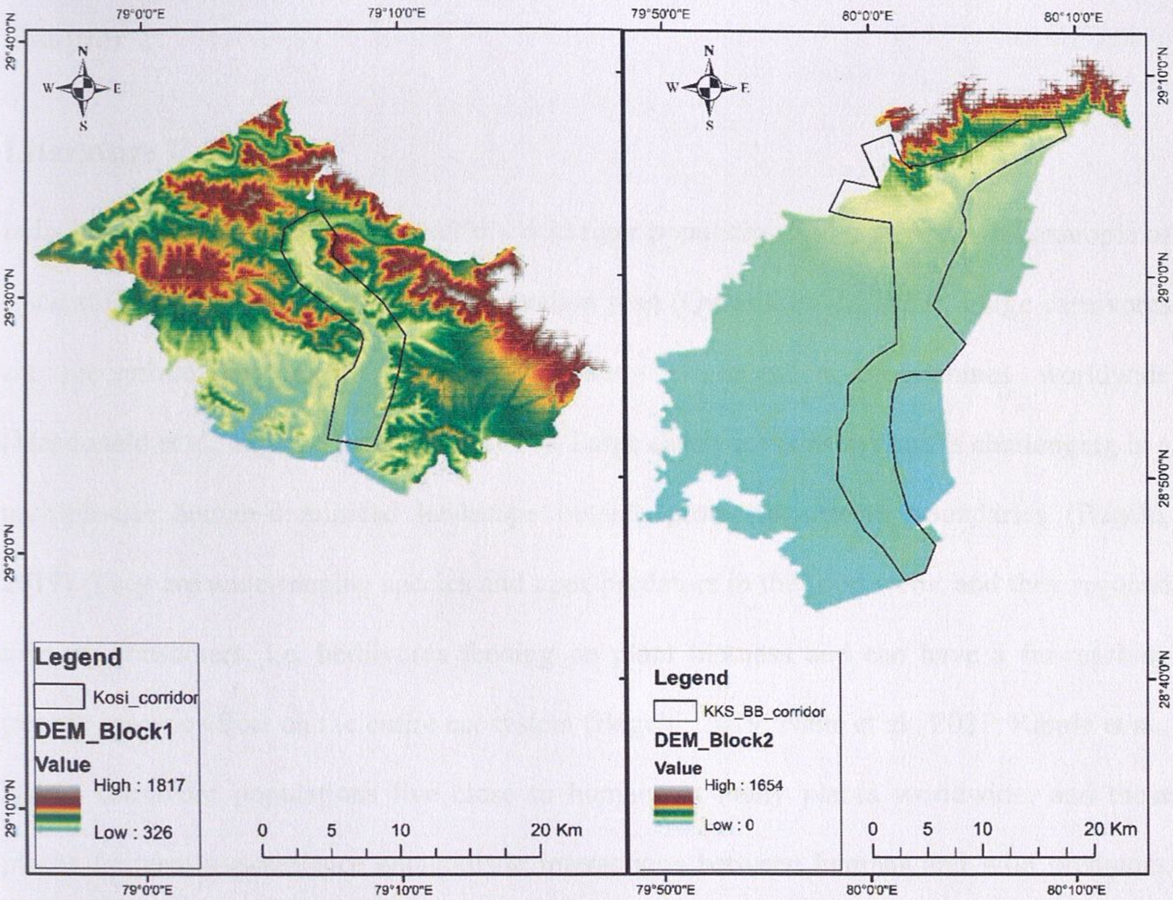


Figure 1. 2 Map of the study area with elevation profile (SRTM map of 1 arc second used as DEM basemap).

The study area observes three distinct seasons, i.e., Summer, Monsoon, and Winter. The summers are hot and humid in Terai, with temperatures rising above 40 degrees Celsius, and chilling winters have temperatures dropping below 10 degrees Celsius and above 0. The monsoon season observes the highest rainfall due to the South-West monsoon leading to seasonal flooding in terai lowlands and grasslands.

Chapter 2

Literature Review

India harbours nearly 75% of the world's wild tiger population and is a successful example of a scientific and committed species conservation plan (Qureshi et al., 2023). Large carnivores are recognized as flagship species for many conservation programmes worldwide (Macdonald et al., 2015; Ripple et al., 2014). Large carnivore conservation is challenging in a multiple-use human-dominated landscape outside protected reserve boundaries (Bagchi, 2019). They are wide-ranging species and apex predators in the food webs, and they regulate primary consumers, i.e. herbivores feeding on plant biomass and can have a far-reaching trophic cascade effect on the entire ecosystem (Bagchi, 2019; Naha et al., 2021; Ripple et al., 2014). Carnivore populations live close to humans at many places worldwide, and these places frequently experience antagonistic interactions between humans and wild predators, which can result in human-carnivore conflict and other adverse outcomes, like retaliatory killing of the species (Karanth & Madhusudan, 2002). Although the conflict between humans and wildlife species is age-old and dates from human prehistory, its increasing severity and complexity in the current scenario have made it a central wildlife management issue (Anand & Radhakrishna, 2017).

The realization that efforts beyond protected areas are necessary to maintain healthy wildlife populations is shared by conservationists. Ambitious plans, however, to expand wildlife corridors outside of protected areas need to consider the political and economic ramifications when wildlife attacks cattle, feeds on crops or poses other threats to human security (Treves et al., 2006). In a developing country like India, where PA cover merely 5% of the land (Athreya et al., 2013a) and most people are based on an agrarian economy, they are more vulnerable to HWC, especially in areas adjoining forests with high biodiversity (Badola &

Hussain, 2003; Baral et al., 2021; Manral et al., 2016). It influences the food security, livelihood and psychosocial well-being of people residing in HWC-prone areas (Manral et al., 2016). The loss of livestock and crops to wildlife near numerous protected areas (PAs) might lead to hostility towards conservation efforts (K. K. Karanth, et al., 2013b). People impacted by crop and livestock losses and the possibility of harm or death to themselves may become more antagonistic toward animals (Sillero-Zubiri, C., Sukumar, R., & Treves, 2007; Treves & Karanth, 2003). Conservation laws that make it harder for locals to deal with animal losses frequently exacerbate local animosity (A. J. Dickman, 2010). In order to develop policies that lessen the effects of conflict on people and wildlife, it is crucial to look at conflict patterns and the tolerance that goes along with them (Treves et al., 2006).

Acharya et al. (2016) studied the patterns of human fatalities and injuries by large mammals in Nepal over five years. The findings indicate that in terms of assault frequency and fatalities, Common Leopards and Asian Elephants are the most frequently involved in attacks against humans, with spatio-temporal patterns of seasonality and location of incidents. However, the above study did not examine the loss of livestock and other human properties. Karanth, et al. (2013a) assessed the patterns of HWC in PAs of western ghats, India, which showed that crop loss is significantly higher than livestock loss where landscape estimated probability of crop loss was 0.91 and livestock loss was 0.19. A similar study was also conducted in the Central Indian landscape around PAs, where the average estimated probability of crop (0.93) and livestock (0.6) loss was higher than in the western ghat PAs landscape (Karanth et al., 2012). Tahoor et al. (2021) studied the nature and extent of HWC in the Katerniaghat Wildlife Sanctuary in the Terai landscape of Uttar Pradesh (U.P), India, and the findings showed human casualty as the most frequent conflict type followed by livestock depredation and crop damage. The findings of the above study (Tahoor et al., 2021) were considerably different from other studies in India and Nepal (Acharya et al., 2016; Aryal et al., 2014; Athreya et al., 2013a; Karanth et al., 2012; Karanth, et al., 2013a; Karanth & Madhusudan, 2002; Sharma et al., 2020) which may be due to lack of reporting for ex-gratia payment as the study draws its inference from ex-gratia payment database of forest department. Many studies have reviewed the nature and patterns of HWC across the world (Bauer et al., 2017; Braczkowski et al., 2023; Dickman, 2010; Distefano, 2005; Karanth & Madhusudan, 2002; Peterson et al., 2010; Redpath et al., 2015; van Eeden et al., 2018) and came to some common conclusion, i.e., the terminology of conflict has been largely misinterpreted and symbolizes people perception of damages to human property due to wildlife, and gives a negative connotation. The studies also highlighted that the most commonly used mitigation measures are monetary compensation or ex-gratia, fencing (solar, wall, and bio-fencing), night guards, and structural measures like predator-proof corrals (Athreya et al., 2013a; Bauer et al., 2017; Karanth et al., 2012; Karanth, et al., 2013a; Karanth & Kudalkar, 2017; Nyhus, 2016; Peterson et al., 2010; Ravenelle & Nyhus, 2017; Treves & Karanth, 2003).

Braczkowski et al. (2023) show the disparities associated with large carnivore depredation on cattle across the world and highlight that the households in transitioning and developing economies are two to eight times more vulnerable to predatory losses financially (as measured by impacts on yearly per capita income) than households in developed economies. Peterson et al.(2010) highlighted that people living subsistence lifestyles are more likely to be impacted by HWC than those living urban lifestyles. The study on livestock losses due to predators worldwide reveals that 82% of carnivore distribution ranges are outside PAs and that more than one-third of the range of five threatened species is found in the most economically vulnerable conflict zones (Braczkowski et al., 2023).

People's perceptions are crucial for large carnivore conservation and mitigation of HWC (König et al., 2020; Ogra & Badola, 2008). Dickman (2010) reviewed a broad range of case studies to demonstrate how social factors significantly affect how people perceive HWC and to emphasize the need for more inventive and multidisciplinary mitigation strategies in order to help people transition from conflict to co-existence. While preserving local and Indigenous institutions, values, and customs, community-based conservation can also benefit livelihoods and biodiversity (Esmail et al., 2023). The public participatory conservation model has been appreciated as sustainable, long-term and effective in many studies across different landscapes of the world (A. J. Dickman, 2010; Gore & Kahler, 2012; Holland et al., 2018; Manral et al., 2016; Miller et al., 2016; Redpath et al., 2015; van Eeden et al., 2018). The socioeconomic condition of the communities and households is one of the defining factors in vulnerability towards the impacts of HWC (Choi et al., 2017; Inskip et al., 2013; Sillero-Zubiri, C., Sukumar, R., & Treves, 2007; Treves et al., 2006). Morzillo et al. (2014) described a conceptual framework to evaluate HWI in multiple-use mosaic landscapes that focuses on wildlife as a driver of human behaviour and understanding the linkages between humans, wildlife, and the broader landscape.

Lischka et al. (2018) proposed a conceptual model that identifies the multiple, nested levels of influence on both human and animal behaviour by using a socio-ecological systems approach and integrating social and ecological theories to understand HWI. This model considers social and ecological processes with equivalence and facilitates a comprehensive understanding of the drivers of human and animal behaviours that lead to human-wildlife interactions. A case cross-sectional study to assess drivers of HWI in a co-existence area in a conservation reserve in Tanzania identifies that the competition for shared habitat characteristics, which comprises water, pasture, shelter, and space, are primary drivers of HWC (Linuma et al., 2022).

Habitat quality and anthropogenic disturbances are critical factors in negative HWI, especially outside PAs with high anthropogenic pressure (Johnsingh & Williams, 1999;

LaPoint et al., 2013; Z. Li et al., 2022; Malviya & Ramesh, 2015; Michalski et al., 2006). Kanagaraj et al. (2011) assessed the habitat suitability for tigers in fragmented TAL of India and Nepal and assessed the habitat quality of potential corridors linking suitable habitats. This study highlighted the deteriorating quality of habitat outside PAs, which is critical for species survival, and recommends better management focus for the corridor habitats, which have good natural suitability for large carnivores but suffer high levels of anthropogenic disturbance. Other studies from India (Dutta et al., 2013, 2015; Mallegowda et al., 2015; Qureshi et al., 2014) have also highlighted the significance of habitat quality in wildlife corridor networks connecting PAs in a human-dominated matrix landscape with rapidly changing land use land cover (LULC) and man-made barriers for large mammal movement.

Vegetation composition and structure are the primary and most essential factors for defining habitat (Harper et al., 2005). Invasive plant species affect the vegetation community composition and structure by out-competing the native flora (Duncan et al., 2004; Prasad, 2007) and changing space-use patterns by faunal species (Stewart et al., 2021). Invasive species are indicators of human disturbance and proliferate extensively in disturbed habitats (Mungi et al., 2021). Mallegowda et al. (2015) assessed the habitat quality of forest corridors in southern India based on the Normalized Difference Vegetation Index (NDVI) and its conservation implications, highlighting the rapid and unplanned LULC changes in the landscape matrix. The change analysis results over four decades show a significant loss of vegetation health due to anthropogenic activities and natural processes and an increase in green cover due to *the spread of Lantana*. The changing vegetation community affects the species dependent upon it, both prey and predator, directly and indirectly through a trophic cascade (Barnes et al., 2017; Ohgushi et al., 2012). Thapa et al. (2017) assessed the land cover changes to understand the status of a wildlife corridor in the Terai landscape of Nepal over a decade, showing that dense forest has decreased by 18% and cropland and sparse forest has increased by 10% and 9% approximately. The study identifies forest encroachment, resource exploitation, grazing pressure, invasive species, and flood as drivers of forest change.

Puri et al. (2022) studied the influence of habitat structure, ecological constraints and HWI on tiger conservation in forest corridors of Central India, which revealed that the habitat use by tigers had a negative association with forest fragmentation and anthropogenic disturbance while livestock depredation had positive association with size of human settlements and negative with anthropogenic disturbance within forests. The findings also suggest a higher likelihood of conflict with tigers in areas with constrained connectivity, acting as ecological traps. Another study of a wildlife corridor from central India highlights the shrinking water bodies and diversion of forest areas to agricultural use by encroachment and coal mining activities in the vicinity of corridors, which is a major concern (Banerjee et al., 2020). As the transformation of forested areas into human-dominated landscapes continues rapidly, the existing protected areas are becoming isolated and interspersed (Wikramanayake et al., 2004).

The habitat degradation and encroachment in corridors create a bottleneck for the isolated population of large mammals (Mateo Sánchez et al., 2014; K. Thapa et al., 2017). The ecological restoration and protection of the corridors are pivotal for metapopulation management (Dutta et al., 2018). The corridors' habitat quality, structure and composition influence the mammalian assemblage and its functionality for other coexisting species (Sawyer et al., 2011). Habitat quality is significant for the survival and sustenance of free-ranging large mammals, highlighting that merely the density of a species is a misleading indicator of habitat quality (Horne, 1983). The mammalian diversity is influenced by the structure and composition of the habitat (Ramesh et al., 2012).

Corridors in multi-use landscape matrices face severe anthropogenic disturbance, leading to changed behavioural responses (Chetkiewicz & Boyce, 2009; Yumnam et al., 2014). Prey density, habitat type, and predators' animal behaviour affect hunting patterns (K. U. Karanth & Sunquist, 2000). Prey selection of sympatric large carnivores depends on the prey availability and prey size class (K. U. Karanth & Sunquist, 1995). The diet profile of large carnivores in corridors will reveal the hunting pattern, prey selection, consumption pattern and dietary partitioning among coexisting predators (Ramesh et al., 2012). It will also give an understanding of the diet dependency of large carnivores on domesticated animals.

Diet analysis using scats or faecal matter is a well-established, non-invasive method of understanding food habits and preferences of wildlife species (Biswas & Sankar, 2002; Floyd et al., 1978; Karanth & Sunquist, 1995; Mukherjee et al., 1994). Globally, diet studies have provided insight into wild species' feeding behaviour and ecology with a reservoir of genetic information about prey and predators (Ackerman et al., 1984; Aryal et al., 2010; Biswas et al., 2023; Lyngdoh et al., 2014; Namgyal & Thinley, 2017; Royle et al., 2018; Shabbir et al., 2013; Simcharoen et al., 2018; Upadhyaya et al., 2018; Walsh, 2015; Wang & Macdonald, 2009; Yumnam et al., 2014). Extensive studies have been conducted across India to understand the dietary partitioning of sympatric carnivores (Andheria et al., 2007; Karanth & Sunquist, 1995; Majumder, 2011; Ramesh et al., 2009; Selvan, et al., 2013). The feeding ecology of large carnivores has also been studied species-wise in India (Bagchi et al., 2003; Basak et al., 2018; Dahya et al., 2023; Lyngdoh et al., 2014; Venkataraman et al., 1995). The diet studies of large sympatric carnivores show overlap in their dietary habits, especially high overlap for tigers and leopards, and partitioning based on prey type and size class (Andheria et al., 2007; Mondal et al., 2012; Ramesh et al., 2009).

Harihar et al. (2011) studied the response of leopards to tiger recovery and a decrease in anthropogenic pressure by relocating pastoralists outside the Rajaji National Park, India. The study showed a high dietary overlap between the two large carnivores and the diet shift of leopards towards livestock. A study on tigers' diet in the Terai landscape of India showed high livestock dependency in PAs, i.e., Pilibhit Tiger Reserve and Katerniaghat Wildlife Sanctuary (KWLS) with high anthropogenic disturbance, grazing and livestock in the forest areas (Basak et al., 2018). Another study of tiger diet from Bardia National Park in the Terai landscape of Nepal near Katerniaghat Wildlife Sanctuary connected with a wildlife corridor shows very low livestock depredation other than a single scat observed in the study with buffalo hair; the study infers the high density of wild prey and low anthropogenic disturbance and livestock grazing in the park as the reason for low livestock depredation.

Interference between species with similar diets is common in carnivores. Lovari et al. (2015) studied the co-existence of tigers and leopards in a prey-rich area of Sukhlaphanta Wildlife Reserve in Nepal to understand the role of diet partitioning in the sympatry of large carnivores, which showed that the staple food choice of both the species was wild prey with significantly higher intake of livestock by leopards than tigers, the diet niche breadth of the leopard was 20% larger than tiger; the study concludes that spatiotemporal partitioning had a major role than diet partitioning for apparent co-existence of tiger and leopard in that PA.

Most studies on large carnivore food habits and prey preference have been conducted in protected reserves where anthropogenic interference is low or regulated. Few studies have focused on the diet of tigers and leopards outside PAs (Biswas et al., 2023; Dahya et al., 2023; Kshettry et al., 2018). Biswas et al. (2023) assessed the food habits of tigers across TAL in India to understand the prey selection pattern and spatiotemporal pattern of livestock depredation, which revealed that large-bodied prey constituted the majority of the diet consumption with sambar, chital and livestock being the principal prey; the pattern of prey selection is determined by abundance and prey body weight, and it also shows that PAs and non-PAs of terai habitat are more prone to livestock-related tiger conflict. Dahya et al. (2023)

studied the food habits and characteristics of livestock depredation by leopards in a human-dominated landscape of Gujarat, India, where it shows that leopards feed on 17 prey items, among which four domestic prey species with maximum predation of goats, it also shows that mainly livestock are depredated during evening or night time, and most vulnerable to attack when tied in open and least vulnerable while grazing. The study on diet selection of leopards in human-use landscape in North-Eastern India showed that the leopard preyed upon both wild and domestic prey in proportion to their availability with no selectivity, 60% of biomass consumed by leopard comprised of cattle and goats, and most frequently preyed wild prey was Rhesus macaque (Kshettry et al., 2018).

The patterns of HWC vary with region, habitat feature and seasonality (Ahmed et al., 2012). A landscape-scale conservation strategy should strive to facilitate the dispersal and survival of dispersing tigers by managing habitat corridors that enable tigers to traverse the matrix with minimal conflict (Chanchani et al., 2014; Harihar et al., 2018; K. Thapa et al., 2017). Scientists have identified major tiger corridors in the Uttarakhand Terai landscape connecting three Tiger Habitat Blocks (THBs) like Chilla-Motichur, Kosi river corridor, Gola river corridor (Johnsingh, 2006), Lansdowne FD-Kalagarh TR, Chukka-Lagga Bagga corridor (Semwal, 2005), Kilpura-Khatima-Surai corridor (Jhala et al., 2008) and Boom-Brahmdev transboundary corridor (K. Thapa et al., 2017). The corridors providing ecological connectivity between core population areas isolated in interspersed protected areas will ensure metapopulation management (Dutta et al., 2013; Joshi et al., 2016).

Chapter 3

Nature and Aspects of Human-Large Carnivore Interaction

Introduction

The ecosystem is the interaction of biotic and abiotic components and its surrounding environment—ecosystem functions in complex multi-hierarchial levels, where organisms interact with other organisms positively, neutrally and negatively. Humans and wildlife have been inhabiting and coexisting together, sharing natural resources on a spatio-temporal scale (Bhatia et al., 2020; Dickman, 2010). The interaction of humans and wildlife takes many forms, from peaceful and sustainable coexistence to conflict with adverse outcomes (Nyhus, 2016; Peterson et al., 2010). The nature, behaviour and extent of Human-Wildlife Interaction (HWI) are affected by internal and external attributes of population and individuals and vice-versa (Lischka et al., 2018a). The HWI can have direct effects where physical confrontation/ encounter occurs between human and wildlife species and indirect effects where behaviour or space use is impacted due to changes in environmental features like exploitation and depletion of natural resources by humans from wildlife habitats (Balasubramaniam et al., 2021).

The landscape features influence human-wildlife interactions. The mechanisms underlying these interactions, particularly the feedback between wildlife-related impacts, human response to and behaviour resulting from those impacts, and how land use and landscape features may affect those components within coupled human and natural systems, still need to be better understood (Morzillo et al., 2014). The negative HWI is a pressing challenge in developing economies, especially when ecologically and economically significant wildlife species impact the livelihood of humans (Braczkowski et al., 2023; Manral et al., 2016; Seoraj-Pillai & Pillay, 2017). One such species group is large carnivores, which co-occurs in rural areas with low-income communities, often resulting in actual or perceived livestock losses that increase costs on impoverished households (Braczkowski et al., 2023).

Conflicts can escalate especially when human livelihood and/or recreational activities overlaps large carnivore ranges. Such overlap is the result of two distinct scenarios: Growing human populations causing encroachment of large carnivore ranges, which are already vulnerable to degradation, contraction, and fragmentation. In other scenario where large carnivore and human populations are growing, which exacerbates conflicts (Bombieri et al., 2023). This is particularly true in areas where these species were exterminated and are now making a comeback. The global distributions of carnivores and the landscapes used by humans overlap greatly (Ripple et al., 2014). Rich in potential for conservation, multi-use heterogeneous landscapes can support populations of multiple carnivore species by acting as crucial secondary habitats (Carter & Linnell, 2016).

With increasing human population and rapidly changing landscape elements, it's becoming increasingly clear that studying human-wildlife interaction requires interdisciplinary approaches that take into consideration both ecological and social processes (Lischka et al., 2018b; Teixeira et al., 2021). Understanding the human element is the most important precondition for creating effective mitigation strategies because humans are the common thread in the highly variable arena of human-wildlife conflict (HWC) and because the thoughts and actions of those involved determine the course and resolution of conflict (A. Dickman et al., 2013). However, the problem of HWC is dynamic in nature, with regional or landscape characteristics playing a vital role (van Eeden et al., 2018). India is home to 23 percent of the world's carnivore species, which occupy roughly 2.3% of the planet's land area and coexist with 1.3 billion people (Srivathsa et al., 2019). Major section of the society in rural India is agrarian and depends primarily on agriculture, livestock and livelihoods dependent on natural resources (Manral et al., 2016). The negative HWI frequently called as

HWC puts a heavy toll on the livelihood and economy of communities living around forest (Manral et al., 2016; Ogra & Badola, 2008).

The HWC in the study area involves many species of mammals and reptiles. The area is rich in large mammal diversity with rapidly increasing human population (Johnsingh, 2006; Joshi et al., 2016; Ranjan et al., 2021; Sanderson et al., 2010). This study focuses on the two key large carnivore species, i.e., tiger and leopard, and their interaction with humans. This chapter assesses the nature and aspects of human-large carnivore interaction in the wildlife corridor areas of the terai landscape. The study strives to understand the underlying factors for human-large carnivore conflict in the landscape.

Methods

Study Area

The study area includes villages in three delineated wildlife corridors, i.e. Kosi, Kilpura-Khatima-Surai (KKS), and Boom-Brahmadev (BB). Kosi corridor is part of study block 1, and KKS and BB are part of study block 2. The villages in Block 1 are located in the Nainital district of Uttarakhand, India. Three hamlets in the Kosi corridor, i.e., Mohaan, Sundarkhal, and Devichaud, are not revenue villages. Mohaan was settled by Britishers on lease land, locally known as *Patta*, while Sunderkhal and Devichaud were settled post-independence (1960–1980) on forest land along river Kosi primarily by hill people from Garhwal. The villages located in the corridors were surveyed for the study.

The villages surveyed in Block 2 fall in the KKS and BB corridor areas. Block 2 is densely populated with several legal and illegal human settlements. Due to the vast number of hamlets and villages in the area, only those villages located in the critical habitats of the corridors were selected. The villages in Block 2 lie in the Champawat and Udham Singh Nagar districts of Uttarakhand.

Methodology

Data Collection

The door-to-door household (HH) survey was conducted in the communities residing in the wildlife corridors to collect information about prevailing socio-economic conditions, nature of human-large carnivore interaction, reasons for conflict, awareness level of communities towards wildlife and mitigation measures to deal with negative human-large carnivore conflict (HLCC). The survey was conducted in six villages/ hamlets in Block 1 and 11 villages/ hamlets in Block 2. Every third HH with residing family members was randomly selected for the questionnaire survey while walking through the villages. All sides of the village area were unbiasedly and equally covered in the survey by 2 to 3 teams, and each team had at least one member who spoke the local dialect.

The questionnaire was semi-structured, with both closed and open-ended questions. It contained questions regarding respondents' profile, socio-economic status, forest resource use, HWI, livestock, and management and mitigation of HLCC. The schedule was prepared with a focus on both qualitative and quantitative aspects of HLCC. Each respondent's prior informed consent was taken for using data and information in the research work as an ethical research practice.

The secondary data on HWC was collected from compensation records of the forest range offices of the Uttarakhand Forest Department (UKFD). The ex-gratia paid by the Uttarakhand government as monetary compensation for the loss incurred to human life and property due to wildlife species is an essential source of information regarding HWC as it details about the type of loss, area of incidence, date of incidence, village-related to incidence, name of victim/owner of livestock, wildlife species involved in the incident, and amount of ex-gratia received. The register is maintained at forest range offices, where incidents are reported for ex-gratia. The records provide long-term data on HWC over the last decade; however, they lack crucial information like geographical coordinates of where the incident occurred and wildlife species involved (observed in many cases, especially for carnivore attacks). The records which do not mention the wildlife species involved in livestock depredation cases have been considered as cases of large carnivores, either tiger or leopard, labelled as Unknown in this study, as these two species are the key large carnivores present in the landscape and primarily reported to be involved in livestock killing. The secondary data of UKFD in Block 1 is available consistently from 2007 and for Block 2 from 2006. We collected the compensation data records from 2007 to 2019 for Block 1 from the Kosi and Kota forest range of RFD and 2006 to 2019 for Block 2 from the Kilpura, Khatima, and Surai range of TEFD and Sharda range of HFD.

Analysis

The information collected through the HH questionnaire survey was processed and analysed using Microsoft Excel and the PAST 4.03 tool. The cross-tabulation and descriptive analysis were performed using the Ms-Excel and Chi-square (X^2) test for a few variables using the PAST application. The information generated from UKFD secondary data from HWC compensation records was analysed using Ms-Excel. This study has only used the data related to large carnivore conflict. The student t-test was done to compare data sets generated from the HH survey and UKFD secondary data on the seasonality of large carnivore attacks. The charts were prepared in Ms-Excel for different descriptive summaries of the information collated.

Information and data were categorised into classes based on the data type, field observations, and study requirements. Most of the categorisation of datasets has been mentioned in the result section. In India, three prominent seasons are observed in the tropical and subtropical parts, i.e., monsoon, summer, and winter. The study area has a subtropical climate and marks these three prominent seasons: monsoon (July to September), summer (March to June), and winter (October to December, January, and February).

Comparative analysis between Block 1 and 2 was done using two-tailed paired sample t-test statistics. The annual and monthly trends of HLCC cases from 2007 to 2019, seasonality patterns, and types of livestock depredated by large carnivores collected from secondary data were compared between study Block 1 and Block 2. The information collected from the HH survey on primary sources of family income, annual family income, and landholding groups were compared between blocks 1 and 2.

Results

Block 1

A total of 121 HH were surveyed in Block 1. Out of 121 HH in block 1, 87 HH belong to the Scheduled Caste and 34 to the General caste, with 88 male and 33 female respondents. Fifteen respondents are from 20–30 years age class, 78 from >30 –60 years, and 28 from >60 years age class in block 1. The family size was classified into three categories: <=6 (n=69, 57%), 7–10 (n=37, 31%), and >10 (n=15, 12%) members per HH. Many people have settled in this area, shifting from the mountainous region to the Bhabar and Terai plains for livelihood opportunities. As per the sampled hh, the majority of hh settled between 1974–1999 (41%) and 1947–1973 (35%), 2% after 2000 and 21% (permanent) before the independence of India. Most of these settlements between 1974 and 1999 happened in Sunderkhal and Devichaud hamlets. Sixty-one per cent of sampled hh use handpumps for drinking water, while 25% still use natural water sources like springs and rivers, and only 14% have water supply at their house/home connection.

Socio-economic Status

The socio-economic conditions of the communities in and around forest areas are important to assess the vulnerability and underlying factors for negative HWI. The education of community members has been a limiting factor for livelihood opportunities, especially for the older generations. The education level of respondents shows that approx. 29% of respondents have education till Primary level (Class 5), 28% have Secondary level (Class 10/matriculation), 14% intermediate/higher secondary, 9% have University/graduation level, and 20% are illiterate with no formal education (Figure 3. 1). Illiteracy is prevalent in female respondents, with 40% illiterate and no female respondents having graduation-level education.

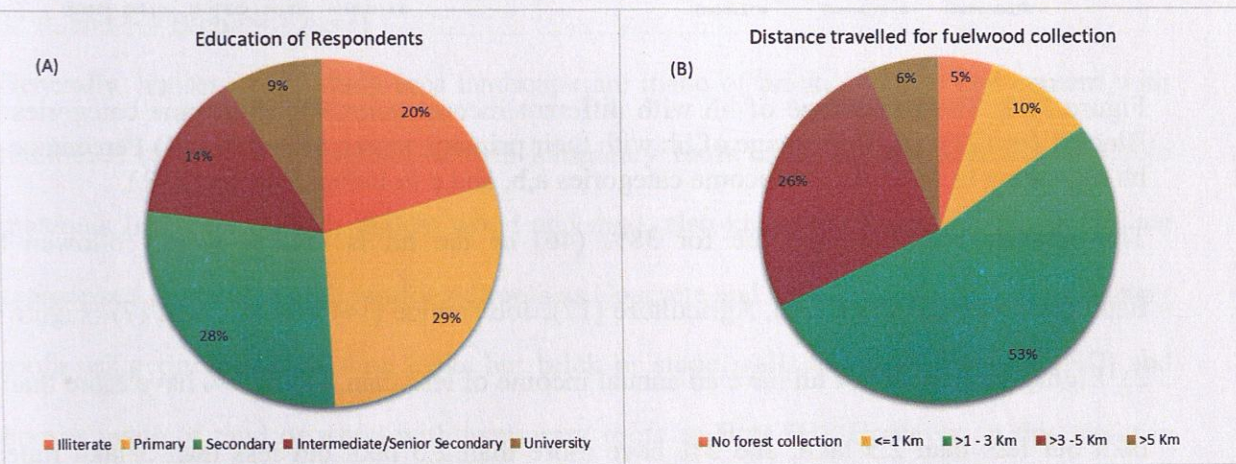


Figure 3. 1: Shows the (n=121) **(A)** Education level of respondents **(B)** Approximate distance travelled by respondents and their family members in the forest for fuelwood collection in Block 1. (Illiterate - No formal education, Primary -Class 5, Secondary - Class 10/Matriculation, Intermediate- Class 12, University - Graduation and above)

Collecting firewood/fuelwood from forests is a common phenomenon in the study area, irrespective of their socio-economic conditions. More than 90% of HHs have Liquified Petroleum Gas (LPG) connections, yet they use fuelwood as cooking fuel. Only 3% of HHs use LPG only, and 7% use only fuelwood as cooking fuel; 87% of HHs use a combination of LPG and wood for cooking, and 2% of HHs use biogas/ LPG/ fuelwood for cooking. The fuelwood/firewood used for cooking and braziers or fireplaces in winter is mainly collected from the forest. Approximately 53% of people travel 1–3 Km, 26% 3–5 Km, 10% <=1 Km and 6% more than 5 Km for fuelwood collection inside forest areas, and only 5% of people don't visit forest for fuelwood collection (Figure 3. 1).

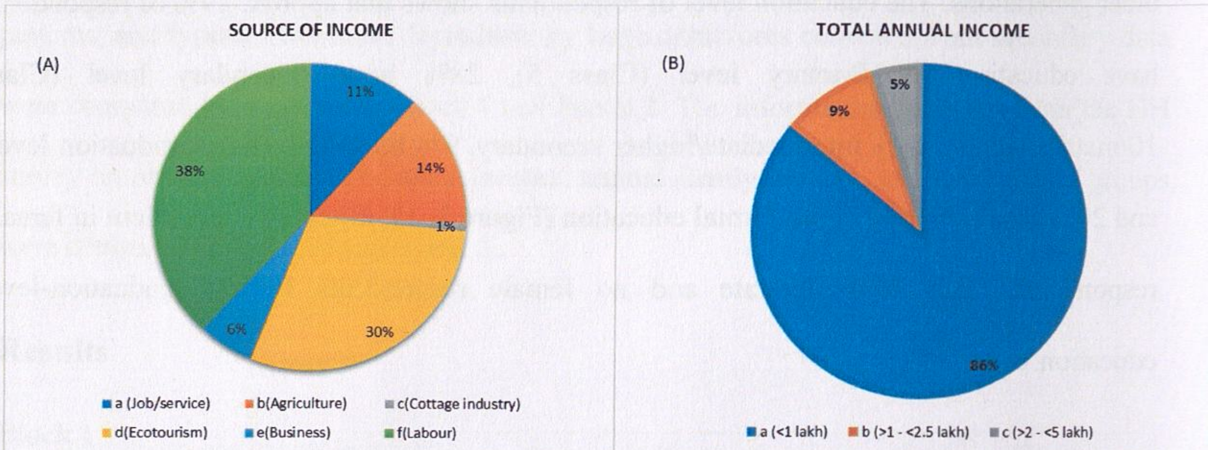


Figure 3. 2: The percentage of hh with different income sources and income categories in Block 1 (n=121). (**A**) Percentage of hh with their primary source of income (**B**) Percentage of hh belonging to three annual income categories a,b, and c in Indian Rupees (INR).

The primary source of income for 38% (46) of the hh is Labour work, followed by Ecotourism-related work (36), Agriculture (17), Job/service (14) and Business (7) (Figure 3. 2). Eighty-six per cent of hh have an annual income of less than 1 lakh, 9% have more than 1 lakh but less than 2.5 lakh, and 5% have more than 2.5 lakh but less than 5 lakh rupees (Figure 3. 2). Agricultural production is low and consumed mainly by family members, except for large landholders. In this study, land holdings have been categorised into five categories: Landless (No land for agriculture other than the house living in), <=2 Bigha, >2–6 Bigha, >6–12 Bigha, and more than 12 Bigha of land. Out of 121 HH, 12 hh are landless other than the house they are living in, 32 hh have less than or equal to 2 bigha of land, 54 hh have more than 2 to 6 bigha of land, and only 10 hh have more than 12 bigha of land (Figure 3. 3).

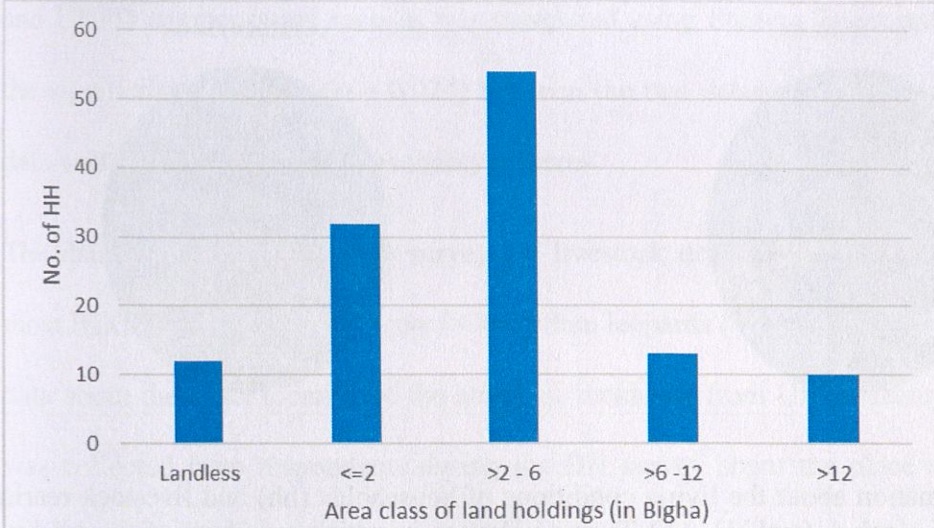


Figure 3. 3 The land holdings of respondents who participated in the survey (n=121). The land holding area has been documented in terms of Bigha, a regional area measurement unit widely used in Uttarakhand. (For reference in this study, 1 Bigha = 6806 sq. Feet, i.e. 82 ft x 82 ft, and 6.4 Bigha = 1 Acre)

Generally, houses in the study area landscape are made of brick, concrete and cement with reinforced roofs; bricks and stones with temporary roofs using tin and naturally available materials like slate rock or thatch; wood and mud, also known as Huts. For this study, we categorised the houses with reinforced roofs as Concrete and Cemented (CC), with temporary roofs using tin, thatch or slate rocks but brick or stone walls as Non-Cemented (NC) and houses made of mud or wood with temporary roofs as Huts (H). However, in this study in Block 1 villages, it was observed that few families (8% of HHs) use both CC and NC houses for their routine living; thus, combining these two types of houses is considered a fourth category, i.e. CC/NC. Fifty-three per cent of HHs live in houses without reinforced roofs, i.e. NC, 27% in CC type of houses, also referred to as *Pukka* houses and 12% of hh live in huts (Figure 3. 4).

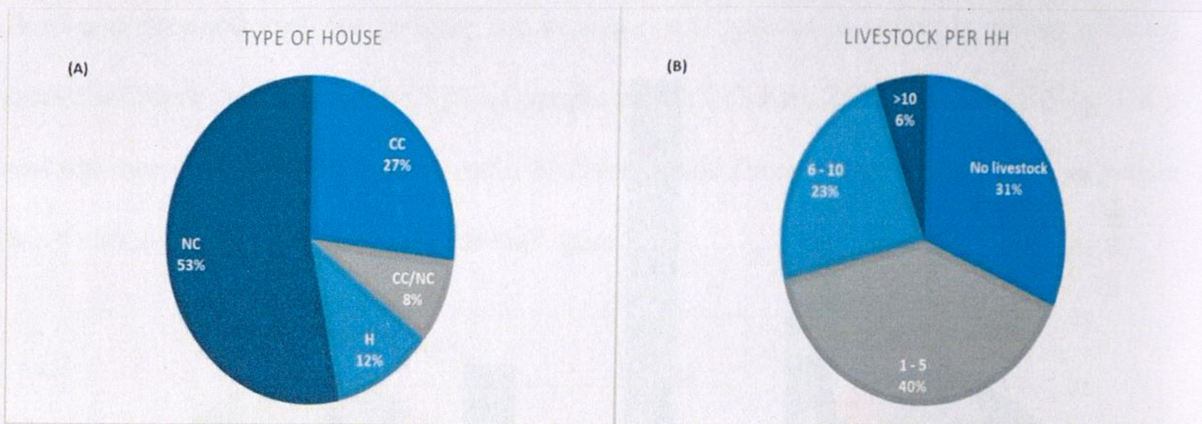


Figure 3. 4 Information about the living conditions of households (hh) and livestock rearing in the villages of block 1 (n=121). **(A)** Type of Houses in which members of the hh lives [CC– Concrete & Cemented, NC– Non-Cemented, H– Huts, CC/NC– a combination of CC and NC] **(B)** Number of livestock per hh categorised into 4, with per cent of hh in each category [No livestock, 1–5, 6–10, and >10 number of adult individuals of livestock per HH; Livestock includes Cow, Buffalo and Ox species].

Livestock are essential to agrarian and rural economies, providing dairy products for household consumption and a source of income. However, rearing animals is also challenging when living near forests with large carnivores, where the probability of getting depredated by wild carnivores is high. Information collected for livestock species in HHs during the survey highlighted three primary livestock species in Block 1 villages: Cow, Buffalo, and Ox. Based on the total number of livestock present per HH, four categories were used: 1–5 (40% HH), 6–10 (23% HH), more than ten adult (6% HH) individuals per HH and No livestock (31% HH) (Figure 3. 4).

Conflict

The information regarding the time and place of HLCC incidence collected through a questionnaire survey in villages was analysed. However, factual information available from compensation records of UKFD, like the date of incidence, which further provides information about the season of occurrence and livestock/human killed or injured, was used to analyse the patterns to remove the biasedness of the responses based on the respondent's memory. The number of HLCC cases in different seasons based on the questionnaire survey and UKFD compensation records was compared using Student T-test statistics, highlighting the significant difference ($p = 0.024$) between the two datasets. Thus, compensation records data was used for assessing seasonality patterns.

The data generated by the HH survey for livestock depredation from Block 1 reveals that most HLCC cases are due to tigers (~90%) than leopards (~10%). Due to the unavailability of data about the exact location of the attack or incidence from UKFD records, the information was collected from respondents during the HH survey about the place and approx time of incidence in whichever HH any case of HLCC has occurred in the last few years, whether reported or unreported to the forest department. The place of incidence was categorised into three, i.e., Inside Forest (IF), Fringe of the Forest (FF), and Outside Forest (OF), which includes village areas and settlements. The incidence time was categorised into Day (anytime during daylight), Morning, Noon (before noon to afternoon), Evening, and Night. As per the HH survey, most of the HLCC incidences occurred inside the forest areas (41%) and outside the forest (39%) in anthropogenic regions and settlements (Figure 3. 5). Most cases happened during the middle of the day in noon (34%) and evening (33%). The place and time of incidences are significantly associated (p=0.007, X^2=21.03) and complement each other as anthropogenic movement in the forest is maximum during the middle of the day till early evening, constituting a maximal chance of encountering wildlife.

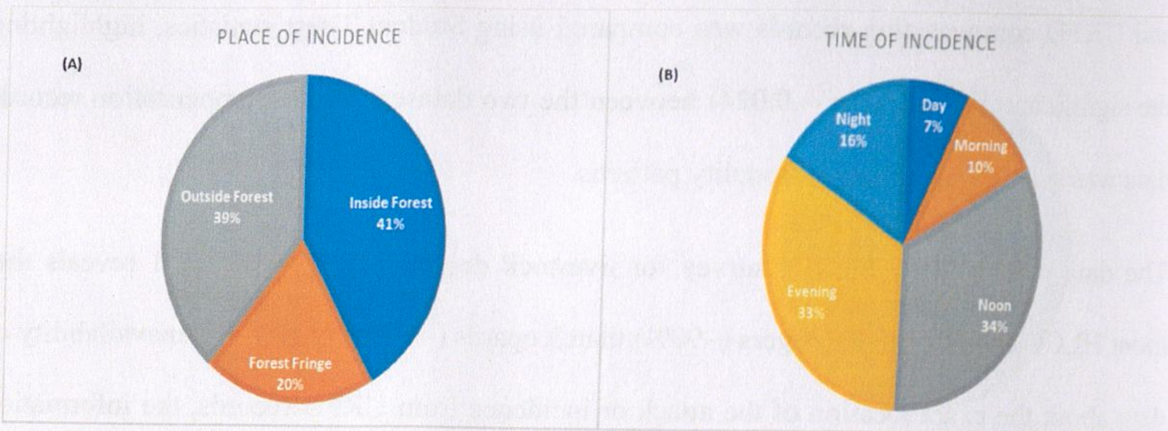


Figure 3. 5: Place and time of occurrence of human-large carnivore conflict (HLCC) incidents (n=112). **(A)** Place of incidence of HLCC **(B)** Time of incidence of HLCC. [Day–anytime during daylight, Noon–before noon to afternoon].

In the HH survey, information regarding the condition of the body of the livestock depredated by large carnivores at the time of detection or identification, i.e. whether the livestock was majorly eaten by the predator (eaten) or partially eaten or just killed without eating or injured. In most cases, the depredated livestock was eaten, and the place of attack and the condition of the depredated livestock body by large carnivores are significantly associated (p=0.016, X^2=15.55). The place of incidence of livestock depredation by large carnivores also shows a significant association with the season (p=0.024, X^2=11.18). However, no significant association was observed between incidence time and season (p=0.77).

According to the compensation records of UKFD from corridor areas of Block 1 and adjoining forest, a total of 1052 cases of HLCC have been reported from 2007 to 2019, with 505 cases involving tiger, 70 of leopard, and 477 incidents not mentioning the species of the large carnivore. Out of 1052 cases, 13 cases of human casualty, including five incidents with females (all tiger-related) and eight incidents (4-tiger, 2-leopard, and 2-unknown) with the male members. As per the reported cases, six types of livestock are depredated by large carnivores, i.e., Cow (54%), Buffalo (8%), Ox (26%), Goat (3%), Horse (1%), and Calf (8%) of Cow and buffalo (Figure 3. 6). Most of the HLCC incidences occur in monsoon (43%) followed by summer and winter (Figure 3. 6).

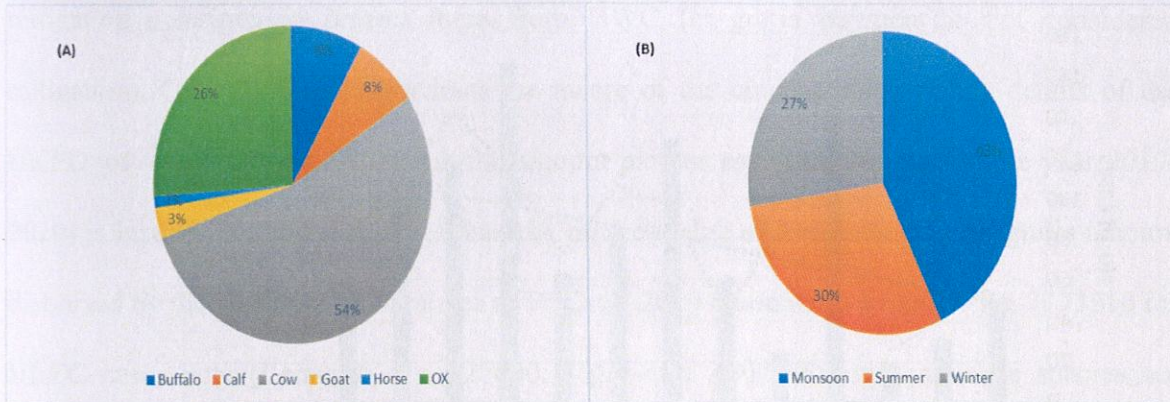


Figure 3. 6: HLCC cases reported from Kosi corridor and adjoining forest areas **(A)** Types of livestock depredated by large carnivores (n=1041) [Calf includes both cow and buffalo calves] **(B)** Seasonality of the HLCC (n=1052).

The secondary data from the forest department provides insight into the yearly trends of HLCC cases reported in the area over a decade. 2016 showed the highest peak over the years for HLCC cases (Figure 3. 7). The linear forecast of HLCC cases shows an increasing trend over the years. However, the two-period moving average (average number of incidences based on the average of the last two consecutive years) indicates a progressive increase after every plunge (Figure 3. 7) in large carnivore incidents. The monthly trend of HLCC cases shows the peak in August for overall cases of large carnivores followed by July (monsoon season) and October in post-monsoon (Figure 3. 7 B). The monthly trends highlight July as the peak month for both tiger and leopard cases (monsoon season) since August has 100 cases where conflict species are not mentioned (Unknown).

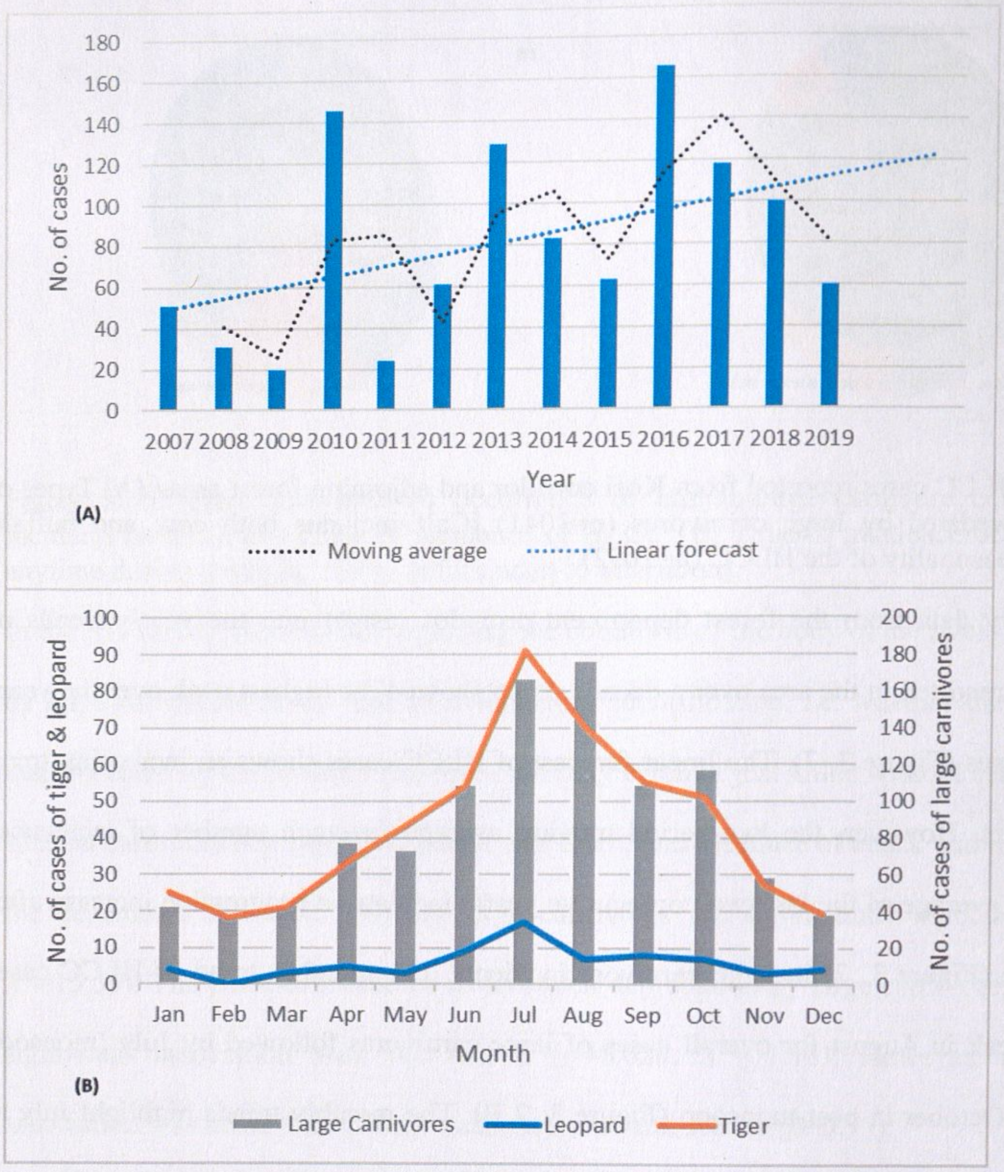


Figure 3. 7: Trend of human-large carnivore conflict cases from 2007 to 2019 in Block 1 around the Kosi corridor. **(A)** Yearly trend— number of large carnivores cases (n=1052) per year, trendline showing two-period moving average and linear forecast over the years. **(B)** The monthly trend of tiger and leopard cases (lines)— number of cases of tiger (n= 509) and leopard (n=71) in each month over the years in the primary vertical axis; the secondary vertical axis (columns) shows the number of cases of overall large carnivores in each month. [Large carnivores includes all cases related to tiger, leopard, and Unknown–cases of depredation without species name(n=481)]

People's perception of conflict and mitigation

The HH survey revealed that 45% of respondents think conflict with tigers and leopards has increased in the last five years, 37% perceive a decrease, and 18% can't say whether it increased or decreased. Approximately 97% of respondents in Block 1 say there are no mitigation measures to protect them from HWC (ex-gratia payment is not considered mitigation). Only 33% of respondents are aware of the compensation policy details of the UKFD, of which around 50% think the amount paid as ex-gratia (amount in the year 2019-2020) is insufficient and much less than the market value of livestock. The ex-gratia amount disbursed by the Kosi and Kota ranges of RFD till 2019 amounts to a total of Rs. 7773216 for HLCC cases only (Leopard– Rs. 327600, Tiger– Rs. 4915190, and carnivore species not mentioned– Rs. 2530426). The potential reasons for HLCC, as per the responses recorded in the HH survey, are:

- Direct encounters with the wildlife may be due to visiting inside the forest for fuelwood and fodder collection or when wildlife species enter the village areas.
- Lack of prey and degradation of habitats inside the forest areas.
- Disturbance due to excessive tourism, affecting the behaviour of wild animals towards humans, reduced fear/shyness of humans in the animals, and unmanaged garbage disposal by hotel industries. Movement of tourists/vehicles on village roads at night.
- Increased population of large carnivores and obstruction in their movement corridors.
- Ageing and injury of large carnivore species.
- Availability of livestock, which is an easy prey for large carnivores.

Most respondents proposed mechanical or physical fencing (stone walls, solar fencing) as a mitigation measure for HWC. Few respondents suggested street lighting and removal of shrubs/bushes around the settlements. Some respondents suggested avoiding visits to the forest and providing fuelwood and fodder at villages by the government as mitigation. Respondents have complained about frequent crop raiding by ungulates like Wild boar, sambar deer, spotted deer, and elephants. They argue that ungulates coming to the villages also attracts large predators to their villages. No carcass dumping of dead livestock or domestic animals in the open was observed in the Block 1 area.

Block 2

188 HH were surveyed in block 2, covering 11 villages and hamlets. 117 HH belong to the General caste, 33 to the Scheduled caste, 34 to the Other Backward caste, and four respondents didn't say their caste. Out of 188 respondents, 129 were male, and 59 were female, belonging to three age classes: 20–30 years (14), >30–60 years (129), and above 60 years (45). The family size was classified into three categories based on the number of members per HH, i.e., HH with <=six individuals (n=108, 58%), 7–10 individuals (n=57, 30%), and more than ten persons (n=23, 12%) in each HH. People from different regions of India, like Uttar Pradesh, Bengal, and Punjab, other than the hill people of Uttarakhand, have come and settled in the Terai region. People from Nepal have also settled in this region for better livelihood opportunities. The settlement of various communities has occurred over a period of years. We categorised the settlement year into four categories: the pre-independence era before 1947 (11% of HH), after 1947 to 1973 (52%), 1974 to 1999 (33%), and the recent settlement of 2000 and later (4%). 1973 was the year of the launch of Project Tiger, and 1972 was the year of the enactment of the Indian Wildlife Protection Act; these were significant events for wildlife conservation in India. Major settlement occurred after independence till 1973 by hill people of Uttarakhand who were seasonal migrants to these areas during winters. However, people from other regions mainly settled from 1974 to 1999 for livelihood, agriculture and other political reasons. Amongst the surveyed HH in block 2, 34% of HH have a home connection to drinking water supply, 65% use handpumps, and 1% of HH use natural springs/river water for drinking.

Socio-economic Status

The education level of respondents in block 2 shows that most of the respondents have education in the primary (29%) and secondary (27%) levels (Figure 3. 8). Twenty-three per cent of respondents are illiterate, i.e., without formal education. Visiting the forest to collect fuelwood/firewood and fodder is very prevalent in the study area. Most of the HHs have an LPG connection, yet 11% of HHs use wood as cooking fuel, 80% use both wood and LPG as cooking fuel and only 9% of HHs use only LPG for cooking. Most people collect fuelwood from the forest; about 35% of HHs go 1–3 km, 21% <= 1 km, and 10% go more than 5 km inside the forest for fuelwood collection (Figure 3. 8). However, 20% of the respondents say they don't visit forests for fuelwood collection.

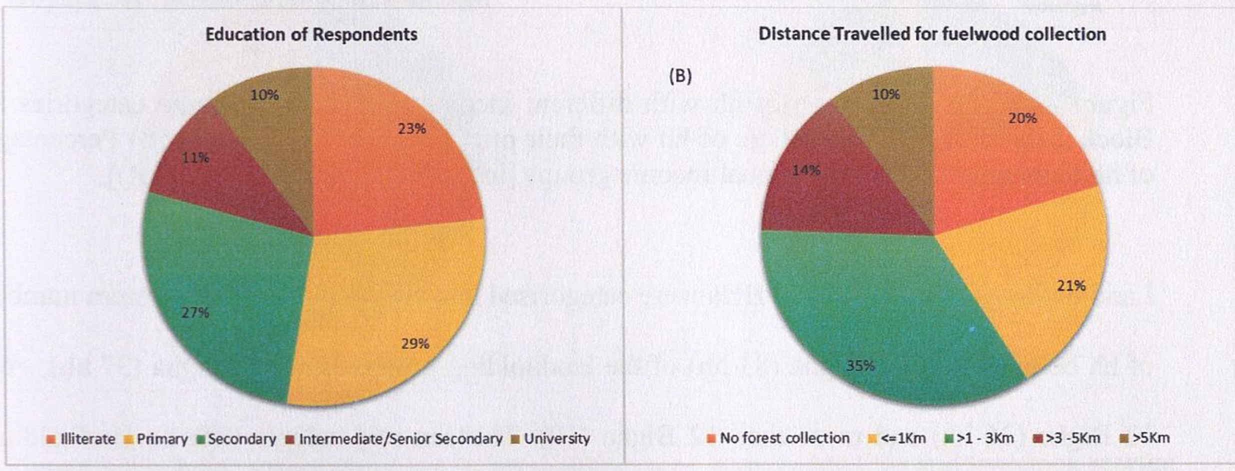


Figure 3. 8: Shows the (n=188) (A) Education level of respondents (B) Approximate distance travelled by respondents and their family members in the forest for fuelwood collection in Block 2. (Illiterate - No formal education, Primary -Class 5, Secondary - Class 10/ Matriculation, Intermediate- Class 12, University – Graduation and above)

The primary sources of income and occupation in the Block 2 communities are labour work (34%) and agriculture (33%), followed by job/service (19%) (Figure 3. 9). The land in the Terai region is highly productive and fertile. Mango and litchi orchard practices are popular in the bhabar areas of Block 2 as they are low maintenance and high profit. Poultry businesses (3%) are mainly practised in villages of BB corridor, which has proved to be a profitable livelihood. Most of the HH have an annual income of less than 1 lakh rupees (51%), and 26% of HH have an annual income between 1 lakh to 2.5 lakh (Figure 3. 9). Six per cent of HH falls in >5–10 lakh yearly income group.

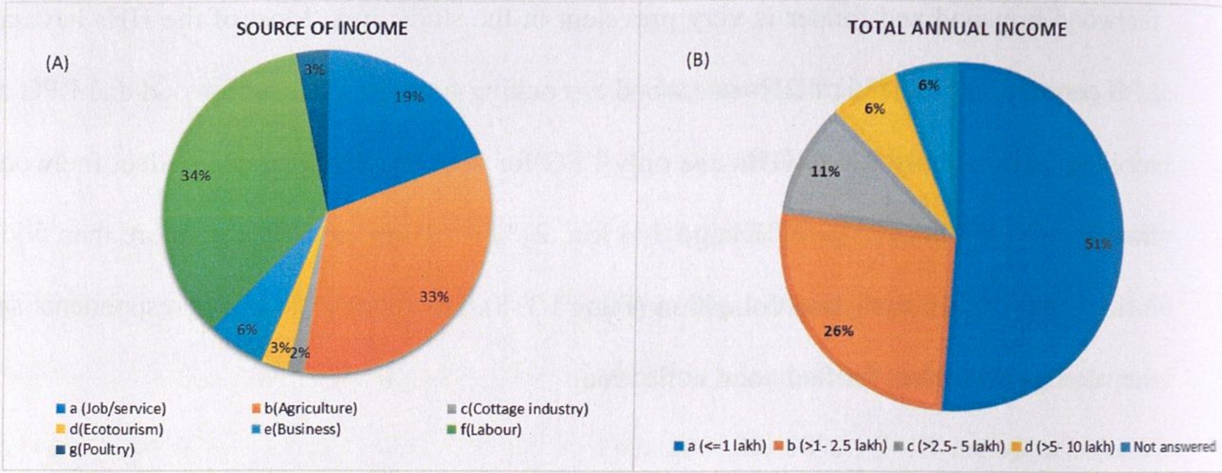


Figure 3. 9: The percentage of hh with different income sources and income categories in Block 2 (n=188). **(A)** Percentage of hh with their primary sources of income **(B)** Percentage of hh belonging to different annual income groups [income in Indian Rupees (INR)].

Land holdings of the surveyed HHs were categorised into five groups. The maximum number of hh belongs to >2–6 Bigha (83 hh) of the landholding group, then <=2 Bigha (37 hh), >6–12 Bigha (36 hh) and more than 12 Bigha (19). Thirteen respondents with no landholding other than their house are categorised as landless (Figure 3. 10).

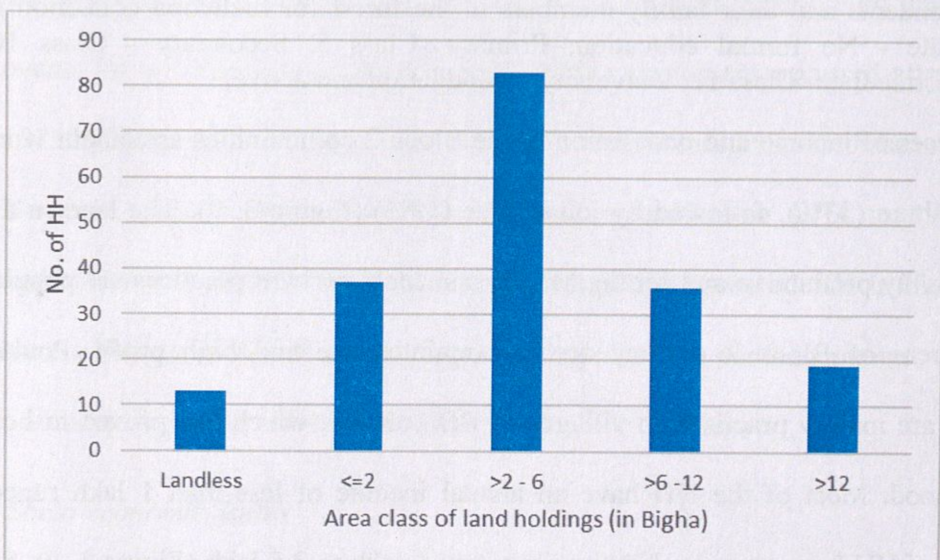


Figure 3. 10 The land holdings of respondents who participated in the survey (n=188). The land holding area has been documented in terms of Bigha, a regional area measurement unit widely used in Uttarakhand. (For reference in this study, 1 Bigha = 6806 sq. Feet, i.e. 82 ft x 82 ft, and 6.4 Bigha = 1 Acre)

Most HHs have a CC type of house (72%), and 1% of HHs use both CC and NC types of houses for living (Figure 3. 11). However, 6% of the respondents still live in Huts, also known as *Kacha* house. Around 67% of HH have 1–5 livestock per HH, and about 19% of HH don't have any livestock at their home (Figure 3. 11). Here, livestock includes Cow, Buffalo and Ox; goats and sheep were not included in the count.

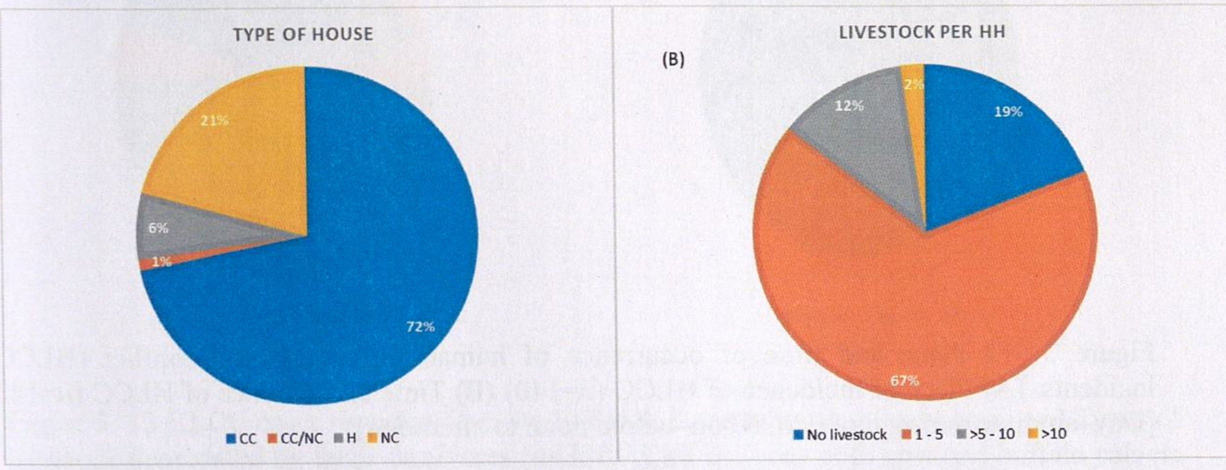


Figure 3. 11: Information about the living conditions of households (hh) and livestock rearing in the villages of block 1 (n=188). **(A)** Type of Houses in which members of the hh lives [CC– Concrete & Cemented, NC– Non-Cemented, H– Huts, CC/NC– a combination of CC and NC] **(B)** Number of livestock per HH categorised into 4, with per cent of HH in each category [No livestock, 1–5, 6–10, and >10 number of adult individuals of livestock per HH; Livestock includes Cow, Buffalo and Ox species].

Conflict

The information collected on livestock depredation by large carnivores in the HH survey reveals that ~62% of incidents are related to tigers, and ~38% are related to leopards. It also highlights that most of the incidents occurred inside the forest area (61%), then outside the forest area (32%), which includes villages, homes and cattle sheds, and 7% of incidents happened at the fringe areas of forest (Figure 3. 12). Most of the HLCC incidents occurred in the middle of the day (31%), then evening time (28%). However, the place and time of incidence in Block 2 have no association (p=1.19) as in the case of Block 1, as the proportion of leopard cases is higher in Block 2. Leopards tend to hunt opportunistically, feeding on more diverse prey than tigers and can maneuver the human-dominated landscape conveniently.

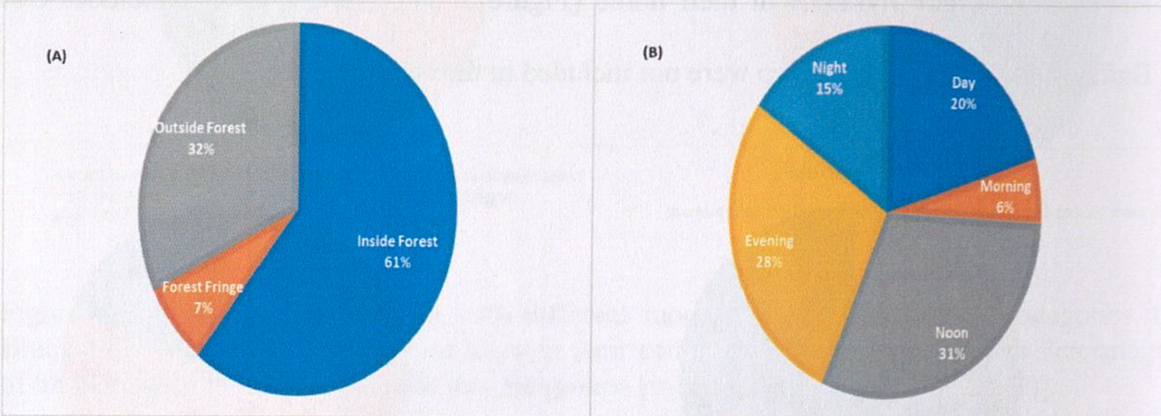


Figure 3. 12 Place and time of occurrence of human-large carnivore conflict (HLCC) incidents. **(A)** Place of incidence of HLCC (n=140) **(B)** Time of incidence of HLCC (n=143) [Day–anytime during daylight, Noon–before noon to afternoon].

The information collected from the HH survey in Block 2 shows a significant association between the place of HLCC incidence and the condition of the depredated livestock (p=0.0003, X^2=20.81) and in most incidences, livestock was eaten. The place of incidence also shows a significant association with the season of incidence (p=0.018, X^2=11.83). However, the incidence season does not show a significant association with the incidence time (p=0.058).

According to the compensation records of the UKFD collected from forest range offices comprising the KKS and BB corridor of Block 2, a total of 405 cases of HLCC has been reported from 2006 to 2019, which is less than half of the HLCC cases in Block 1 areas. Out of 405 cases, 146 cases are of leopards, 58 cases of tigers, and 201 cases of Unknown, i.e., the conflict species (large carnivore) is not mentioned. In 405 cases, 25 cases are of human casualties, comprising 19 incidents related to tigers and 6 cases of leopards. Amongst human casualties, 17 cases were related to male and eight female victims, and all six cases of leopard are related to male victims. The livestock depredation cases show that the most frequently depredated livestock is Cow (47%), followed by Goat (18%), Buffalo (16%), Ox (14%), Calf of Cow and Buffalo (5%) and only two cases of Horse depredation (Figure 3. 13). Most cases in Block 2 have been reported from winter (41%) season (Figure 3. 13).

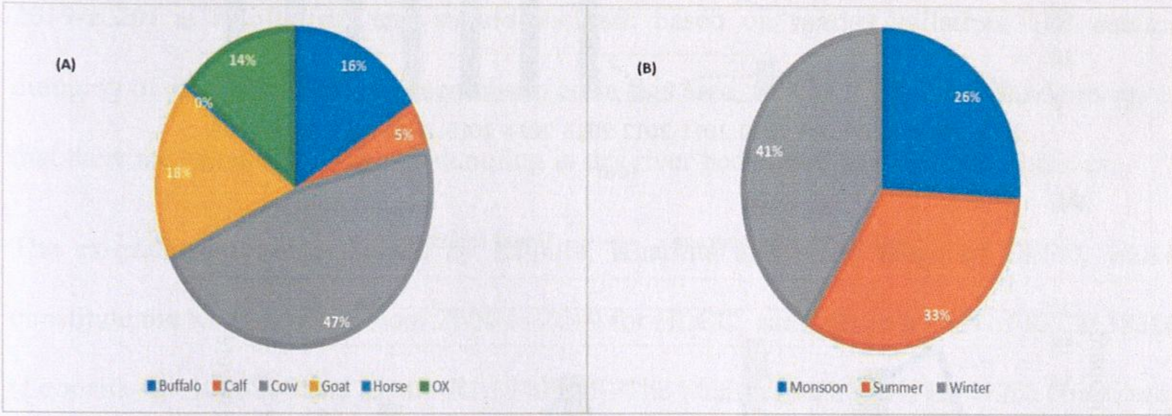


Figure 3. 13 HLCC cases reported from study Block 2 and adjoining forest areas **(A)** Types of livestock depredated by large carnivores (n=380) [Calf includes both cow and buffalo calves; 2 cases of horse thus percentage rounding shows 0%] **(B)** Seasonality of the HLCC (n=405).

The yearly trend of HLCC, based on compensation records of more than a decade, shows a peak in 2015 (73), followed by 2014 (72) and 2016 (70) (Figure 3. 14). The cases reported before 2012 are substantially less as compared to latter half of the decade. The linear forecast shows an increase in HLCC cases. The two-period moving average indicates a plunge after 2015 in the number of HLCC cases (Figure 3. 14 A). The monthly trends of HLCC over the years show a maximum during the summer month of May for overall cases of large carnivores, complimented by peaks in the monthly trends of leopard and tiger conflict cases in May. The leopard conflict cases show peaks in February (end of winter), August (monsoon), and October (early winter or post-monsoon) other than May (Figure 3. 14 B). Tiger conflict cases show prominent peaks in May and December (winter).

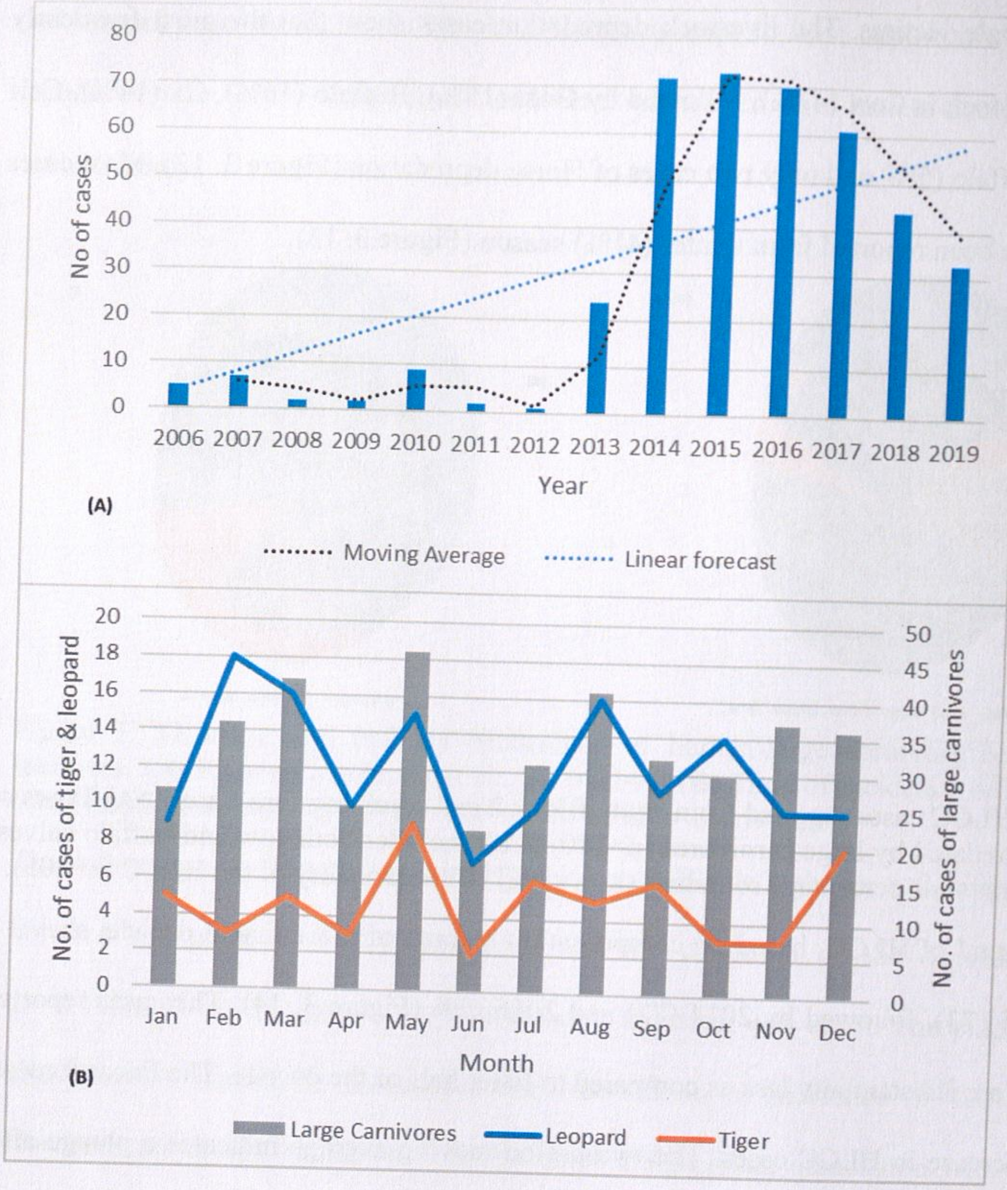


Figure 3. 14 Trend of human-large carnivore conflict cases from 2006 to 2019 in Block 2 around the KKS and BB corridor. **(A)** Yearly trend— number of large carnivores cases (n=405) per year, trendline showing two-period moving average and linear forecast over the years. **(B)** The monthly trend of tiger and leopard cases (lines)— number of cases of tiger (n= 58) and leopard (n=146) in each month over the years in the primary vertical axis; the secondary vertical axis (columns) shows the number of cases of overall large carnivores in each month. [Large carnivores includes all cases related to tiger, leopard, and Unknown– cases of depredation without species name (n=201)]

People's perception of conflict and mitigation

The HH survey revealed that 59% of respondents think conflict with tigers has increased in the last five years, 38% perceive a decrease, and 3% say no change compared to before. Meanwhile, 54% of respondents perceive that human conflict with leopards has increased, and 46% think it has decreased in the last five years. Around 84% of respondents in Block 2 say there are no mitigation measures for HWC, and 10% say there are mitigation measures like solar fencing, 6% refrained from answering. About 50% of respondents are aware of the compensation policy of UKFD, of which 78% think that the current amount of ex-gratia (in 2019-2020) is insufficient and should increase based on market inflation. The carcass dumping of dead livestock has been observed in this area, to which 6% of respondents agree that there are instances of carcass dumping in dry river beds or village-forest boundaries.

The ex-gratia amount disbursed by Kilpura, Khatima and Surai range of TEFD, which constitute the KKS corridor from 2006 to 2019 for HLCC, amounts to a total of Rs. 2138500 (Leopard– Rs.1098000 and Tiger– Rs.1040500). The Sharda range of HFD, which constitutes the BB corridor, paid Rs. 2046500 from 2006 to 2019 as ex-gratia to victims (compensation) of HLCC. The compensation records of the Sharda range lack proper record keeping, as a significant amount of funds (Rs. 2028500) released for HLCC victims does not mention the carnivore species causing the loss. The total amount disbursed by the four forest ranges in Block 2 as ex-gratia to victims of HLCC from 2006 to 2019 is Rs. 4185000.

The potential reasons for HLCC, as per the responses recorded in the HH survey of Block 2, are:

- Lack of prey and degradation of habitats inside the forest areas.
- Abundant availability of domestic and stray livestock is an easy prey for large carnivores.
- Direct encounters with the wildlife species.
- Increased population of large carnivores
- Ageing and injury of large carnivore species.
- Change in animal behaviour – predators don't fear humans.

- Deforestation (illegal tree cutting), anthropogenic disturbances in the forest, and increased degraded forest due to lantana invasion.
- The nearness of villages to the forest.
- Orchards in villages of BB corridor provide conditioning to predators like leopards to hunt in the village areas.
- Ungulates raiding crop fields attract predators towards villages.

Most respondents proposed mechanical or physical fencing (solar fencing) as a mitigation measure for HWC. Few respondents suggested street lighting and removal of shrubs/bushes around the settlements. People perceive lantana as a severe challenge to wildlife pasture lands, as it has invaded most of the small grassland patches in the forest near their villages, so herbivores are raiding their crop fields. Respondents suggested improving the habitat conditions inside the forest area by planting trees and grasses favourable for wildlife and increasing wild prey (food availability for carnivores) in the core habitats of the forest.

Comparative Analysis

The data collected from compensation records show a significant difference between the annual ($p= 0.0009$) and monthly ($p= 0.003$) trend of HLCC cases between study blocks 1 and 2. Meanwhile, the seasonal patterns of HLCC ($p= 0.08$) and the number of cases of different types of livestock ($p= 0.14$) depredated by large carnivores as per the compensation records were not significantly different between blocks 1 and 2. The comparative analysis for the primary source of income ($p= 0.31$), annual income category ($p= 0.22$), and landholding of HH ($p= 0.06$) based on the questionnaire survey shows no significant difference between blocks 1 and 2.

Discussion

Our result clearly shows that HLCC in study block 1 is substantially higher than block 2. In block 1, the cases of tiger are higher than in block 2. On the other hand, the cases of leopards are higher in block 2 than in block 1. The high number of tiger incidences in block 1 can be attributed to the high tiger density in CTR, the highest among India's tiger reserves (Qureshi et al., 2023). The human population density in Block 1 is also less than in Block 2. Broadly, the topography of block 1 is Bhabar, whereas block 2 has Terai (KKS corridor) and Bhabar (BB corridor) topography equally.

The communities in Block 1 are mainly composed of people from the Himalayan region, whereas people in Block 2 are from various origins who migrated and primarily settled in the Terai area, i.e. around the KKS corridor. In areas of the BB corridor, most people are from the Himalayan region who were seasonal migrants to this area. The Terai region of block 2 has villages of Tharu tribes, who are the indigenous community of this region. The encroached settlements of migrants from other areas are a major challenge for habitat integrity and connectivity of corridors as these encroachments form critical bottlenecks. The family size of the households in communities of both the study blocks are similar as most of the HH have cultural similarities. The proportion of recent settlers in the last two decades is slightly higher in block 2, which can be attributed to industrialisation and urbanisation in the Terai region after the formation of Uttarakhand state in 2000.

Socio-economic status

The results highlight that the education level in communities of both the study blocks is low, mostly till schooling and education of women are low priorities. The collection of fodder and fuelwood from the forest is part of the daily routine for most of HH and is more of a cultural habit. Most of the community members regularly travel around 3km inside the forest for collection in both the study blocks (Block 1–63%, Block 2– 56%). However, HH not going to the forest for fodder or fuelwood collection is considerably higher in Block 2 (20%) than in Block 1 (5%), which may be due to the larger number of HH in higher annual family income groups in block 2 (>5–10 lakh – 6%). Even though most of the HH, around 90% in both the study blocks, have LPG connections, over 80% of HH use fuelwood as cooking fuel due to habit and cost of LPG for lower-income families. During the open discussion in communities of both the study blocks, it was observed that older generation women tend to pressure younger women and daughters-in-law in the family to go to the forest to collect firewood as a daily household task. Such practices of collection from forests increase the vulnerability towards negative HWI.

The results show that the primary source of income for most HH in both study blocks is labour work (Block 1–38%, Block 2– 34%). However, the second most primary source of income for HH in Block 1 is ecotourism-related work (30%), whereas the agriculture sector is for Block 2 (33%). The higher share of ecotourism in block 1 is due to the proximity to CTR and the proliferating wildlife tourism industry in this area. The agriculture in Block 2 is more profitable than in Block 1 because the fertile alluvial soil of Terai has high productivity, and fruit orchards in the Bhabar area are low maintenance and have better profit than food crops. The poultry business under private company partnership is popular and profitable in villages of Block 2. Thus, 3% of HH surveyed have primary income from this sector. The annual family income of HHs in Block 2 is better than Block 1, as 86% of HHs have a yearly income of less than 1 lakh in Block 1 as compared to only 51% of HHs with an annual income of less than 1 lakh, which can be attributed to low agricultural productivity in Block 1 areas, low wage job/service, and underpaid jobs in ecotourism sector mostly owned and run by large firms and outsiders. The landholdings are indicative of economic prosperity in the agrarian economy. The proportion of HHs with large land holdings is higher in Block 2 than in Block 1, and landless HHs are slightly higher in Block 1 than in Block 2. However, there is no statistically significant difference between communities of Block 1 and Block 2 based on landholdings, primary source of income, and annual family income.

The type of material with which a house is constructed is indicative of the household's socio-economic conditions, the area's geography, and cultural practices (Hondo et al., 2006; Turrell et al., 2003). The proportion of families living in concrete and cemented houses with permanent reinforced roofs is substantially higher in Block 2 (72%) than in Block 1 (27%), and HH residing in Huts in Block 1 (12%) is double than in Block 2 (6%). The CC type of houses provides safety from any wildlife attacks and damage by large mammals like elephants. It also gives a sense of security in the HWC scenario, a psychosocial benefit for HHs living around forest areas (Barua et al., 2013; Manral et al., 2016). The livestock are vital in the rural agrarian economy for HH needs and dairy-related income. At the same time, livestock density is also a critical factor for HLCC, where livestock depredation is prevalent and affects the livelihood of communities. Most of the HHs in both the study blocks have 1-5 livestock individuals at their home (Block1– 40%, Block2– 67%). However, a considerable proportion of HH in Block 1 have no livestock (31%) due to large carnivores' high livestock depredation rate. The Cow is the most abundant livestock in the study area, reared for milk, and Ox is used for farming purposes. The low dependence on agriculture and allied sectors in Block 1 also explains the high number of HHs without livestock. The livestock rearing is not economical in areas of Block 1 where HLCC is high and agricultural practice is not profitable.

Nature and Aspects of HLCC

The nature of human-large carnivore interaction can be neutral or negative with direct and indirect impacts. Most of the time, the direct encounter of humans with large carnivores does not result in a negative outcome, which can be considered neutral as neither humans nor wild animals are harmed in such interactions. Only when the encounter results in loss of human life or property it is considered a negative interaction and termed as conflict.

The information about the incidences of negative HWI reveals the nature, aspects, patterns and significant factors responsible for conflict in the region. The time of the attack, place of incidence, condition of livestock body that was killed, seasonality, type of livestock depredated, and carnivore species involved provide information crucial for understanding the nature of conflict and their aspects. The perception of people and their understanding of the HLCC problem helps develop potential mitigation and management solutions to the problem.

The results show that most HLCC incidences occurred inside the forest (Block 1– 41%, Block 2– 61%) and during the latter half of the daytime, i.e., noon (Block 1– 34%, Block 2– 31%) and evening (Block 1– 33%, Block 2– 28%), in both the study blocks which can be attributed to livestock grazing in the forest and fuelwood collection from forest during the day. It is also supported by a statistically significant association (p=0.007, X^2=21.03) between place and time of incidence in Block 1, where conflict with the tiger (~90%) is substantially higher than leopard (~10%) as reported in an earlier study as well (Bargali & Ahmed, 2018). However, the association between place and time of incidence is not statistically significant in Block 2, where conflict with tiger and leopard has no substantial difference, which can be attributed to differences and adaptation in spatio-temporal habitat-use patterns and the species' food habits. The statistically significant association between the place of attack on the livestock and the condition of the body of the livestock (Block1– p=0.016, X^2=15.55; Block2– p=0.0003, X^2=20.81) when recovered in both the study blocks and, in most incidences, eaten or partially eaten by the predator suggests that livestock are preyed upon opportunistically as an alternative to wild prey.

Three prominent seasons are observed in the study area as in most parts of India. Seasonality plays a vital role in activity patterns, habitat use, natural food (prey) availability, and animal behaviour of wildlife species, which can affect the nature of HWI (Klees van Bommel et al., 2020; Koziarski et al., 2016; Valeix et al., 2012). Most cases in Block 1 were reported in the monsoon season (43%), whereas in Block 2, most cases were reported in the winter season (41%). The terai area in Block 2 experiences seasonal flooding during monsoon, livestock grazing inside the forest area is minimal, and the fodder requirements are met from crop fields. Forest collection of fuelwoods also decreases considerably during the wet monsoon season. These factors reduce the probability of HWI, particularly inside the forest area where maximum chances of negative interaction are possible. However, the increased HLCC in monsoon in Block 1 may be attributed to the inability of livestock owners to feed their animals at home during the low-income season since ecotourism activities and tourists are less during monsoon, causing seasonal unemployment and slow business as tourism is the lifeline of the local economy in this area. The other reasons for increased large carnivore conflict during monsoon are the fast and dense growth of understory plants and bushes providing a hiding place for large carnivores and sudden encounters with humans. The results also show a significant association between the place of attack and season (Block1– p=0.024, X^2=11.18; Block2– p=0.018, X^2=11.83) in both the study blocks.

The HLCC in this landscape has two direct negative impacts, i.e., livestock depredation and human casualty. The cases of human casualty are less in Block 1 than in Block 2, whereas overall, the HLCC cases are much higher in Block 1, more than double the instances in Block 2. Most human casualty cases are related to tigers in both study blocks. All the cases of women victims are related to tigers because the collection of fodder and fuelwood from the forest is done mainly by female members of the household– a common practice in the Himalayan region, making women more vulnerable to attacks. However, the major aspect of

HLCC is livestock depredation. The secondary data of UKFD highlights six types of livestock depredated by large carnivores (Figure 3. 6, and Figure 3. 13 A), with a maximum of cow cases in both the study blocks, which can be attributed to its high abundance and easier to kill than other large cattle like Buffalo which sometimes successfully defends itself with their herding behaviour.

The annual trends of HLCC cases in both study blocks show an increasing trend with periodic downfall in intermittent years (Figure 3. 7, and Figure 3. 14). As per the trend forecast, the lower number of HLCC cases in 2019 can be seen as an intermittent plunge before the progressive increase in the next few years. The trends of HLCC cases in the landscape are alarming for large carnivore conservation and conflict management in the upcoming years. The yearly trend of HLCC cases in block 2 shows a sudden rise from 2014, which can be attributed to increased reporting of cases due to increased awareness other than ecological reasons for the increase in conflict.

The monthly trends of tiger and leopard HLCC cases show a spike for both species in the same months in block 1, indicating temporal similarity; however, there is a large difference in number of cases between them (Figure 3. 7 B). The temporal similarity is not observed in Block 2 for tiger and leopard cases except in May (summer) (Figure 3. 14 B). The monthly trend of Block 2 shows a decrease in tiger cases during the peak in leopard cases. The trend of large carnivore cases in Block 1 shows an apparent rise during the monsoon months of August and July. On the other hand, cases of large carnivores in Block 2 show the highest peak in the summer month of May, with no clear significant pattern across different months. The yearly (*p*= 0.0009) and monthly (*p*= 0.003) trends of HLCC are significantly different between Block 1 and 2 because of differences in anthropogenic factors, demography, and landscape characteristics. However, the seasonality of HLCC between Block 1 and Block 2 is not significantly different.

Perception and mitigation of conflict

The people's perception of HLCC in the study area is that the HWC due to tiger and leopard has increased in the last five years because of the direct encounter with large carnivores, lack of natural prey for predators in the forest, their increasing population, deteriorating habitat quality, change in animal behaviour and easy and abundant availability of livestock in the forest area and its fringes. A critical observation from Block 1 communities is that excessive and irresponsible wildlife tourism is one of the main reasons for the change in the behaviour of large carnivores, as they have lost the fear of humans and shyness towards humans. Large carnivores have become habituated to human presence. The locals accept that ecotourism is beneficial for their livelihood and finances, but at the same time, their community is facing the brunt of negative HWI at the expense of small financial gains.

Most respondents say there are no mitigation measures for HWC in place, which is invalid. The solar fencing, stone walls, pit trenches and forest patrol teams are deputed and installed at different locations. However, the dynamic nature of conflict, and animals improvising to overcome these physical barriers make these mitigations ineffective in the long term. However, people perceive these mechanical and physical barriers as potential solutions to HWC. The awareness of communities towards HWC and the role of the community in conservation is low. The compensation policy of UKFD is not a mitigation measure; instead, it is a relief mechanism to persuade people to coexist peacefully with wildlife. People perceive large carnivores as a threat to their financial security due to livestock depredation and feel insecure only when in case of human casualty. The communities are still in a coexistence phase due to their traditional and cultural linkage with biodiversity and wildlife and religious tolerance.

Conclusion

The nature of HLCC in the study area is both tangible and intangible. The tangible nature of large carnivore conflict is the direct impacts in the form of human casualty and livestock depredation. The intangible nature of the conflict has imbibed effects with indirect impacts such as psychological– fear of large carnivores and sense of insecurity, social – loss of livelihood and family security. The aspects of HLCC are socio-ecological, with both the social factors of communities residing around the forest like high forest resource dependency due to low income, vulnerability of families living on forest fringe in *Kacha* or semi-pucca houses, and the ecological processes influencing the HWI. In rapidly transforming human-dominated landscapes, anthropogenic activities and disturbances significantly impact the ecological processes and landscape characteristics.

The education and awareness of communities to minimise forest collection practices is essential as it will break down their age-old habit of fuelwood collection. The education of the younger generation will enable them to earn livelihood from other sources than forest which will be safer for both community and wildlife. Policy-level interventions like incentivisation for using clean fuels like LPG and cost-sharing policy can make LPG connections economical for low-income families. Along with social reform and enhanced tolerance for wildlife, it is critical to enhance the ecological status and sanctity of the wildlife corridor habitats at the same time. Prey augmentation and habitat improvement in wildlife corridors and core habitats are crucial for long-term solutions to HWC. Protection of habitats will help increase the wildlife population and wildlife corridors from encroachment, as bottlenecks act as a stressor to wildlife species by affecting their movement and behaviour. Stopping encroachment of forest in densely populated anthropogenic landscape is one of the most challenging task for effective the conservation efforts.

Chapter 4

Habitat Quality: Structure and Composition

Introduction

The habitat concept is fundamental to wildlife management (Krausman, 1999). Odum (1971) defines habitat as the place where an organism lives. Habitat quality is typically described in terms of the resources' contribution to population persistence and individual survival and reproduction (i.e., fitness) (Krausman, 1999; Rachlow, 2008). The quality of a region's habitat is a crucial determinant of its capacity for biodiversity and is essential for maintaining ecological stability and fostering coordinated environmental and economic development (Z. Li et al., 2022).

The habitat comprises physical and biological components and their interaction (Brough et al., 2023). The biological components include both flora and fauna existing in the region. Monitoring habitat characteristics and attributes is vital for conservation (Horne, 1983; Johnson, 2007). Habitat attributes like forest type, structure, and composition are essential to assess along with species diversity and abundance to understand the role of habitat in wildlife management and conservation (Del Vecchio et al., 2016; Horne, 1983; Johnson, 2005). Developing methods for managing wildlife and preserving its habitats requires a thorough understanding of the relationships between animals and their surroundings (Fortin et al., 2008). St. Pierre & Kovalenko (2014) highlighted the positive relationship between habitat complexity and species richness in their study in freshwater coastal wetlands.

Habitat degradation and loss significantly threaten biodiversity conservation and human-wildlife coexistence (Ladue et al., 2021; St. Pierre & Kovalenko, 2014; Tellería, 2016). Assessing the habitat quality by examining the species diversity, structure and composition, and influence of anthropogenic disturbances on habitats of wildlife corridors is crucial to understanding the ecological aspects of negative Human-Wildlife Interaction (HWI) (Demeo et al., 2010; Z. Li et al., 2022; Puri et al., 2022; Teixeira et al., 2021). This chapter assesses the floral diversity, Importance Value Index (IVI) of tree species, tree regeneration, forest types, prey abundance, and an estimated population of the large carnivores, i.e. tigers and leopards, in the three wildlife corridors studied. The chapter also examines the level of anthropogenic disturbance and the extent of invasive plant species in the corridor habitats.

Materials and Methods

Study Area

The study area includes three delineated wildlife corridors, i.e. Kosi, Kilpura-Khatima-Surai (KKS), and Boom-Brahmadev (BB). Kosi corridor is part of study block 1, and KKS and BB are part of study block 2. The Block 1 is located in the Nainital district of Uttarakhand, India. Block 2 lies in the Champawat and Udham Singh Nagar districts of Uttarakhand. The forest habitats of the Kosi corridor comprise areas of Corbett Tiger Reserve (CTR), Ramnagar Forest Division (RFD), and Almora Forest Division (AFD). KKS corridor forest habitat lies in the Terai East Forest Division (TEFD). The forest habitats of the BB corridor are part of the Haldwani Forest Division (HFD) and Champawat Forest Division (CFD).

The river Kosi forms the central zone of the Kosi corridor habitat. The river Sharda flows through the BB corridor, forming the easternmost limit of the BB corridor in the Indian part, connecting forest habitats of Nepal with Nandhaur Wildlife Sanctuary (NWLS) in India. KKS corridor connects NWLS in Uttarakhand state with Pilibhit Tiger Reserve (PTR) in Uttar Pradesh state of India. Sal forest is the most extensive habitat type in all three corridors. The floral and faunal attributes of the habitats and anthropogenic disturbances of the habitats of all three wildlife corridors have been studied distinctly. The topography of the Kosi and BB corridors is primarily Bhabar, and the KKS corridor is Terai. Therefore, the flora and fauna of the KKS and BB corridors have been studied separately, even though they are connected geographically and are part of one study block.

Methodology

Data Collection

Vegetation data was collected using the nested quadrat method with a 10m x 10m quadrat for trees, 5m x 5m for shrubs, tree saplings and seedlings, and 1m x 1m for herbs, sedges and grasses (Peet et al., 1998; Stohlgren et al., 1995; Sutherland, 2006). The quadrats were laid randomly at each Camera Trap (CT) location in every grid and every 400m distance along the trail and forest road transect (Figure 4. 1). The identification of species was done by the research team based on experience and knowledge of local resource persons, and cross verified by expert from Wildlife Institute of India and websites like https://indiabiodiversity.org/, https://www.flowersofindia.net/. The girth of all the trees above 30cm was measured in centimetres at breast height (1.37 m) from the ground, and all the stands of each tree species were counted in each 10m x 10m quadrat. The number of shrubs, weeds/invasive plants, tree species' saplings and seedlings were counted in 5m x 5m quadrat inside 10m x 10m quadrat.

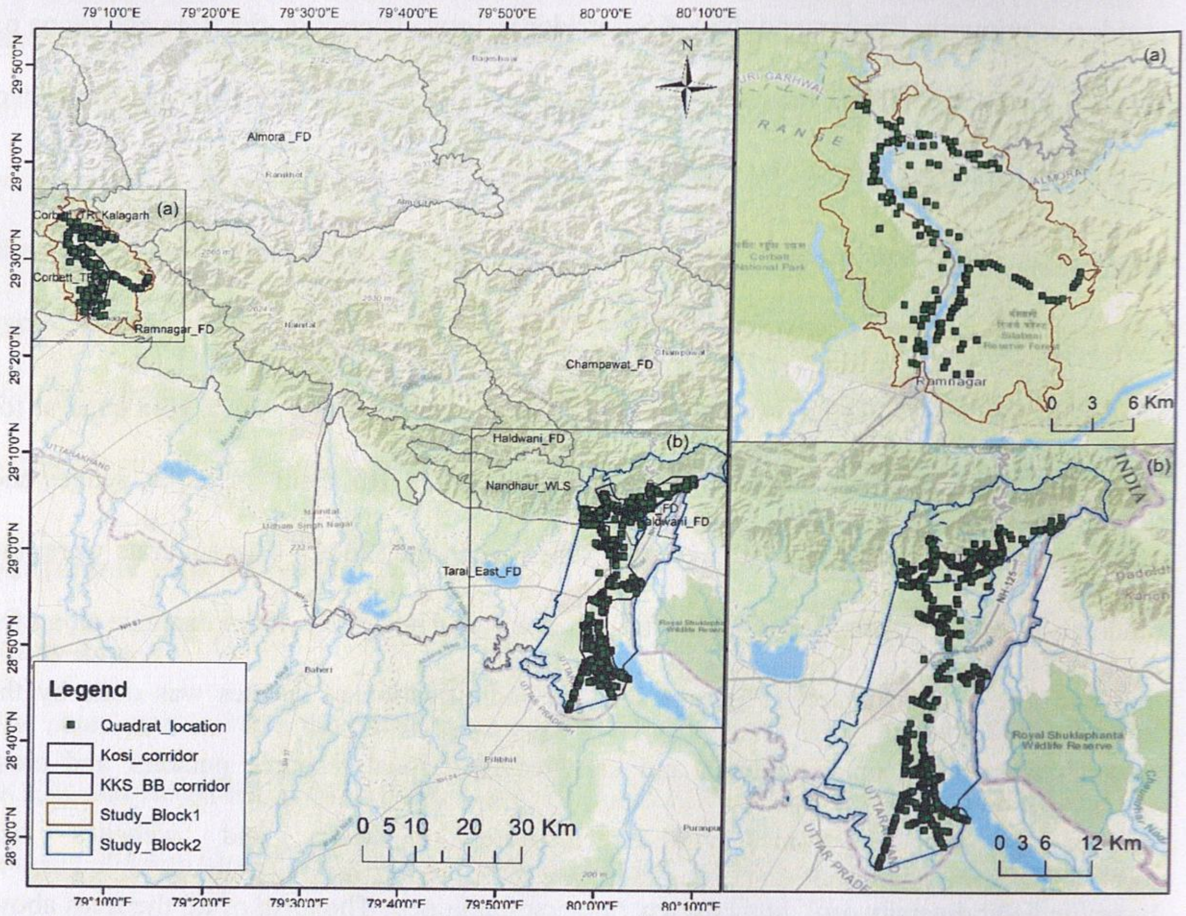


Figure 4. 1: Map of the study area with geocoordinates of the quadrats for vegetation sampling. (a) Study Block 1 is comprised of the Kosi corridor, and (b) Study Block 2 is comprised of the Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridors.

The study blocks were divided into even-sized sampling grids of 2 sq. km for a camera trap-based capture-recapture study (Karanth, 1995). Two CTs were installed at one location per grid in the capture-recapture method at approximate knee height targeted for tigers. The CT location was selected on forest trails and roads based on sign surveys for large carnivores and local information of ground forest staff for maximum detection probability (Figure 4. 2). CT survey was conducted from 2018 to 2020 in different wildlife corridors in a phased manner. Camera trapping exercise was done in winter and summer months with a minimum cycle of 45 days at each location. The CTs were functional for 24 hours continuously with the Fast As Possible (FAP) setting for triggering captures. The effort was made to cover the maximum area/grids of one corridor at once or in one survey cycle. However, due to logistic constraints and the unavailability of CTs in such a large number, parts of the corridors were covered in a phased manner. CT was not deployed in some grids due to higher chances of theft or damage by people. The Cuddeback C1 strobe flash camera traps were used for the survey, and Garmin Etrex 20 and Montana 640 were used for geocoordinates. The data was not collected in some CTs due to the device not functioning and data loss due to camera theft.

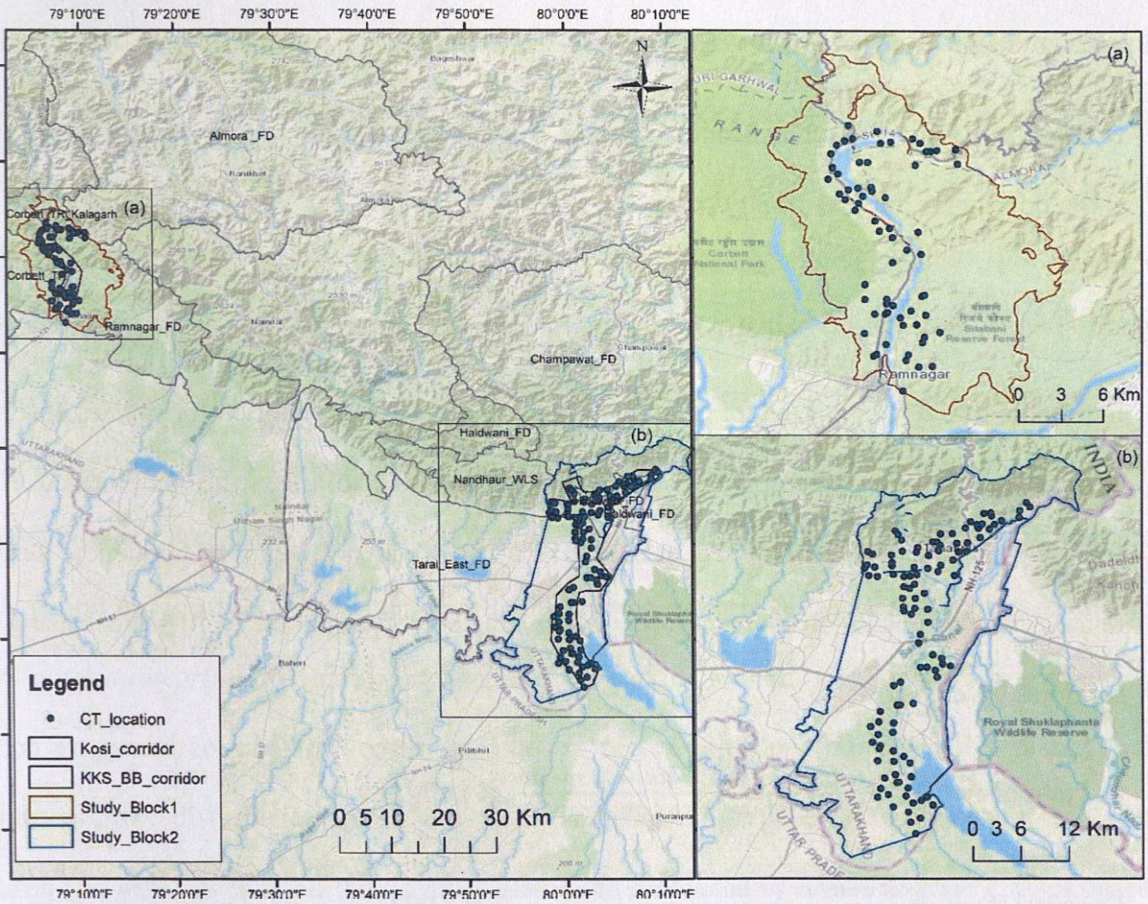


Figure 4. 2: Map of the study area with geocoordinates of the Camera Trap (CT) locations for faunal species sampling. (a) Study Block 1 is comprised of the Kosi corridor, and (b) Study Block 2 is comprised of the Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridors.

Analysis

The vegetation data was entered, processed and analysed in Ms-Excel and PAST 4.03 software. Various diversity indices for tree species in the three corridors were analysed using PAST software. The Shannon diversity (H) index is one of the most widely used diversity indexes (Mouillot & Leprêtre, 1999; Redowan, 2015). The Shannon index also considers the number of individuals and taxa, ranging from 0 for communities with only a single taxon to high values for communities with many taxa, each with few individuals (C. E. Shannon, 1948).

$H = -\sum_i \frac{n_i}{n} \ln \frac{n_i}{n}$ where n_i is number of individuals of taxon i; n is total number of individuals.

Dominance (D) = 1-Simpson index. Ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely)

$$D_m = \sum_i \left(\frac{n_i}{n}\right)^2$$

Individual rarefaction curves for Shannon diversity of trees were plotted for species observed in quadrats from the three corridors in PAST 4.03 software to assess the sampling coverage for diversity assessment (Colwell et al., 2012). The frequency, relative frequency, density, relative density, basal area and relative basal area were calculated in Ms-Excel using the formulas given below:

$$\%\ \text{Frequency (F)} = \frac{\textit{Number of quadrats with species}}{\textit{Total number of quadrats}} \times 100$$

$$\text{Density (D)} = \frac{\textit{Total number of individuals of a species}}{\textit{Total number of quadrats}} \times 100$$

$$\text{Basal Area (BA)} = \frac{(\textit{Girth at Breast Height})^2}{4\pi}$$

$$\text{Relative Frequency (RF)} = \frac{\textit{Frequency of a species}}{\textit{Total frequency of all species}} \times 100$$

$$\text{Relative Density (RD)} = \frac{\textit{Density of a given species}}{\textit{Total density of all species}} \times 100$$

$$\text{Relative Basal Area (RBA)} = \frac{\textit{Total basal area of all individuals of a given species}}{\textit{Total basal area of all the species}} \times 100$$

Importance Value Index (IVI) $= Relative\ Frequency + Relative\ Density + Relative\ Basal\ Area$

The IVI of tree species found in these corridors were also statistically compared using the Kruskal-Wallis and Mann-Whitney U tests in PAST software. It is a non-parametric test to compare two or more independent samples/ groups. The Kruskal-Wallis test can compare more than two samples, while Mann-Whitney U test is limited to only two samples or groups. The habitat types have been categorised based on dominant tree species based on visual interpretation of vegetation where the quadrat was laid. The primary habitat types present in the study area are Sal forest (*Shorea robusta* and its associate tree species), Mix forest (Multiple tree species with co-dominance), Teak forest (*Tectona grandis* plantations), Grassland (Grasses and sedges are dominant plant species), Riparian (Riverine and adjoining areas), Degraded forest (Forest and natural habitats severely disturbed by anthropogenic activities/ invaded by weeds and invasive plant species), Scrubland (Shruby and thorny vegetation are dominant with dry conditions), Jamun forest (*Syzygium cumini* dominant tree plantation or natural), and Plantation patches or monoculture areas of different species like *Holoptelea integrifolia* (Kanju), *Eucalyptus* spp., *Cassia siamea* (Chakundi). The covariates, such as ground cover, shrub cover, herb cover, regeneration potential, invasive plants, and anthropogenic disturbances, were analysed using Ms-Excel. The ground cover, tree cover, shrub and herb cover of all the quadrats have been classified in five histogram classes based on their percent cover of the quadrat (10m*10m): A (1-20%), B (21-40%), C (41-60%), D (61-80%), and E (81-100%).

The percentage frequency, density, and relative density of tree species were calculated for saplings and seedlings to understand the regeneration status and floral community health in the corridor habitats. The relative density of saplings and seedlings was also compared statistically using t-test statistics to understand the variation between successional life stages.

The tree regeneration potential was measured by comparing each species' number/density of trees, saplings, and seedlings (Ballabha et al., 2013; Saxena & Singh, 1984). The regeneration potential has been categorised into five categories (Das et al., 2021; Mohanta et al., 2021; Shankar, 2001) if the number/density of seedlings>number/density of saplings>number/density of trees depicts 'good' regeneration; seedlings≥saplings≤trees depicts 'fair' regeneration (also seedlings>trees with no saplings); seedlings<saplings≤trees depict 'poor' regeneration (or no seedling); absence of both seedling and sapling depicts 'nil' or no regeneration i.e. presence of only mature trees; and presence of seedling/sapling but no mature trees shows 'new' regeneration.

The CT data was segregated and tagged for species using ExifPro 2.1 software with date and time correction. The adult tiger and leopard unique individuals were manually identified by comparing stripes and rosette patterns. The study area primarily lies outside and on boundaries of protected areas (PAs) with high anthropogenic disturbances, where direct sighting is a major limitation for using line transects for density estimation. Increasing CT survey coverage and duration improves relative abundance index (RAI) precision and is a substantive tool for herbivore population estimation (Palmer et al., 2018; Rovero & Marshall, 2009). The RAI of wild prey species and livestock in the natural habitat of corridors was calculated based on CT data of 3 months for each corridor. The RAI is calculated based on captures from CT using multiple methods. However, the most widely used method is RAI per 100 trap nights using independent captures of focal species by selecting captures with a minimum time difference (Bhatt et al., 2022; Chen et al., 2019). The RAI was calculated as the total number of independent captures of a species divided by total camera trap nights and whole multiplied by 100 (Carbone et al., 2001; Jenks et al., 2011; Martin-Garcia et al., 2022). The captures were considered independent if the time difference between two consecutive detections of a species is 30 minutes or more (Bhatt et al., 2022; O'Brien et al., 2003). Data from both CTs at each location was used to increase the detection and captures, as 30-minute criteria automatically filtered out same-time captures in both cameras, considering it to be a single event. Counting individuals of each species per photograph was not feasible due to the large number of captures. The RAI of prey species were statistically compared using the Kruskal-Wallis test between the three corridors.

Result

Vegetation

A total of 581 quadrats were laid in the study area in both the study blocks, with 153 quadrats in Kosi, 291 in KKS, and 137 in BB corridors. Sixty-one species of trees were recorded from all the sampled areas in three corridors, with 35 species from Kosi, 46 species from KKS, and 32 species from the BB corridor (Table 4. 1). However, the Shannon diversity (H) of trees is highest for BB corridor (H=2.538) followed by KKS (H=2.196) and Kosi (H=2.189) corridor with a marginal difference between the latter two (Table 4. 1). The dominance (D_m) of any one taxon is not very high in any of the corridors with a maximum in KKS (0.224) corridor.

Table 4. 1: Different diversity indices for tree species observed in the three wildlife corridors under this study.

Diversity_indices	Kosi	BB	KKS
Taxa_S	35	32	46
Individuals	552	671	1196
Dominance_D_m	0.178	0.116	0.224
Simpson_1-D_m	0.822	0.884	0.776
Shannon_H	2.189	2.538	2.196
Evenness_e^H/S	0.255	0.395	0.195
Brillouin	2.093	2.452	2.132
Menhinick	1.49	1.235	1.33

Margalef	5.385	4.763	6.35
Equitability_J	0.616	0.732	0.574
Fisher_alpha	8.312	6.996	9.497
Berger-Parker	0.266	0.195	0.425
Chao-1	40.63	33.5	68.75

The individual rarefaction curve shows sufficient data (specimens) and sampling depth for estimating the Shannon diversity of trees in all three corridors, with substantively high taxonomical diversity of trees observed in the BB corridor for a similar number of specimens compared to the Kosi and KKS corridor (Figure 4. 3). The study's sampling effort is sufficient for assessing vegetation attributes.

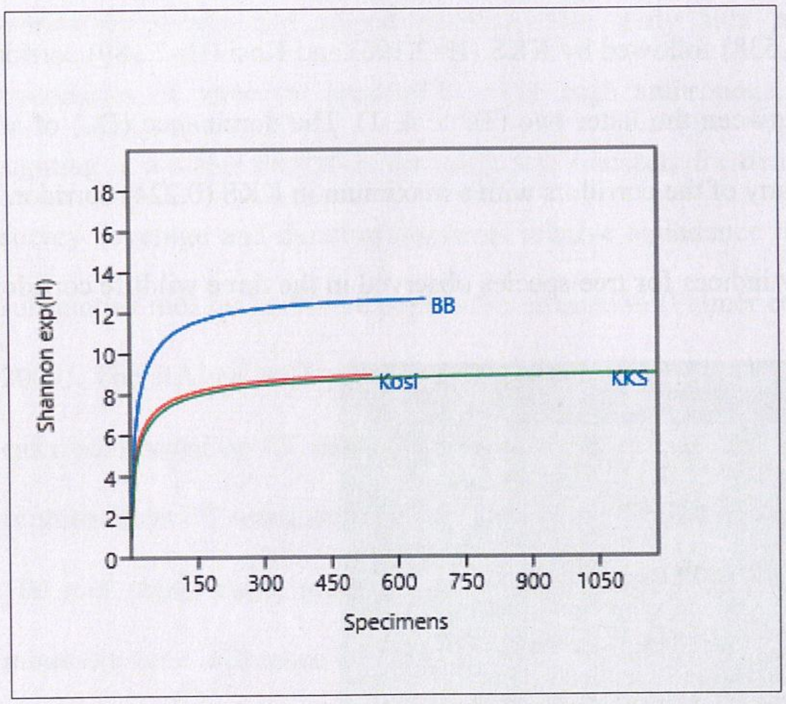


Figure 4. 3: Individual rarefaction curve for tree diversity in all three corridors.

The most important and dominant tree species of vegetation communities in Kosi corridor habitats is *Shorea robusta* (Sal, IVI=78.71), followed by *Tectona grandis* (Teak, IVI=56.04), *Mallotus phillipensis* (Rohini, IVI=44.89), *Syzygium cumini* (Jamun, IVI=29.10), and *Adina* *cordifolia* (Haldu, IVI=13.24). However, the most frequently observed tree in the Kosi corridor was Rohini, followed by Sal, then Teak (Supplementary Table 4. 1). Most densely available tree species was Teak, then Sal and then Rohini in the Kosi corridor.

In forest habitats of the KKS corridor, the most dominant tree species and important in plant community based on IVI is *Shorea robusta* (123.12), followed by *Tectona grandis* (33.42), *Mallotus phillipensis* (32.18), *Syzygium cumini* (17.55), and *Terminalia elliptica* (vernacular name- Asan, 16.48). The most frequently and densely observed tree species was Sal in the KKS corridor (Supplementary Table 4. 2). The frequency of the Rohini tree is more than that of the Teak, whereas the Teak's density is higher than the Rohini in the KKS forest.

The most dominant species of tree based on IVI in the habitats of the BB corridor is *Tectona grandis* (48.89), closely followed by *Shorea robusta* (46.91), *Mallotus phillipensis* (40.13), *Holoptelea integrifolia* (36.16), and *Syzygium cumini* (23.84). The most frequently observed tree is Rohini, followed by Teak, and the most densely distributed trees are Teak and Rohini in the forest of the BB corridor (Supplementary Table 4. 3). The comparison of IVI for trees between the three corridors using Kruskal-Wallis test shows significant difference (p =0.0131, χ^2 =8.67). The Mann-Whitney U test shows a significant difference in the dominance of trees between the KKS and BB corridors (p =0.0051). There is no significant difference between the Kosi–KKS and Kosi–BB corridors.

The quadrats were laid randomly in the study areas; seven habitat types were observed in the Kosi corridor, eight in KKS and ten in the BB corridor (Figure 4. 4). The percentages expressed as 0% in Figure 4. 4(B) is not null but very small (1 quadrat per habitat type) thus rounded as 0 and 1% is 1–2 quadrats per habitat type. The most common habitat type in the Kosi and BB corridors is mixed forest habitats, and in the KKS corridor, it is Sal forest. More than 50% of the forest habitat in the KKS corridor is under the Sal forest habitat type. Teak forest habitat is prevalent in all three corridors. The degraded habitat due to anthropogenic disturbance and invasive plants is noticeable in the KKS (4%) and BB (6%) corridors.

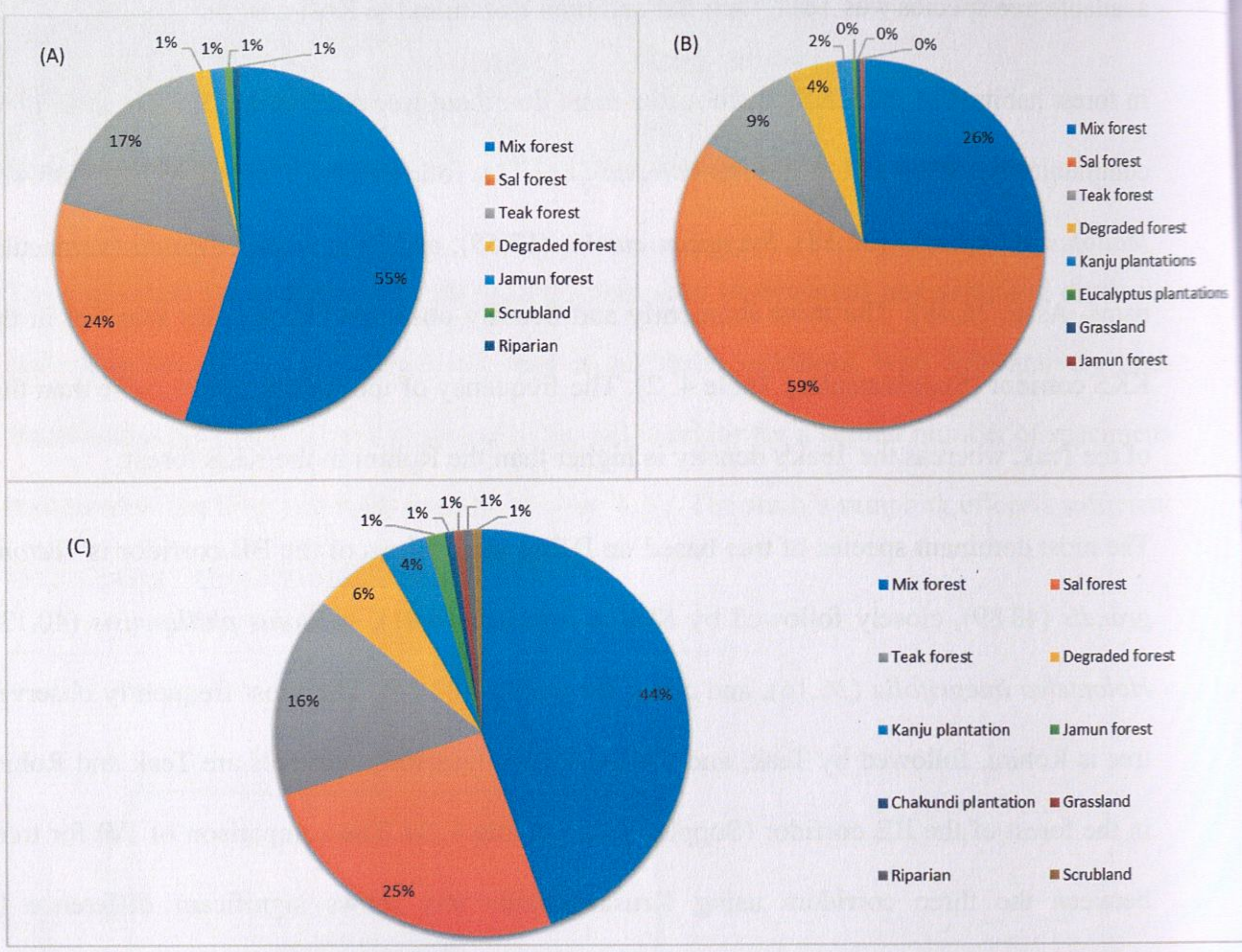


Figure 4. 4: Forest habitat types based on dominant vegetation recorded in the three corridors (percentage of quadrats in different habitat types). (A) Kosi corridor (n=153) (B) KKS corridor (n=291), 0% is 1 quadrat per habitat type (C) BB corridor (n=137).

The ground cover is low in the KKS and Kosi corridor and higher in the BB corridor. Most quadrats in all three corridor habitats have shrub cover and herb cover in the lowest frequency class, i.e. class A with the lowest per cent cover (Figure 4. 5). Tree cover is the maximum for class D in the Kosi corridor, class C in the KKS corridor, and classes E and D are almost equivalent in the BB corridor. Tree cover is at the intermediate level in most Kosi and KKS habitats. However, BB corridor areas have either high or very low tree cover.

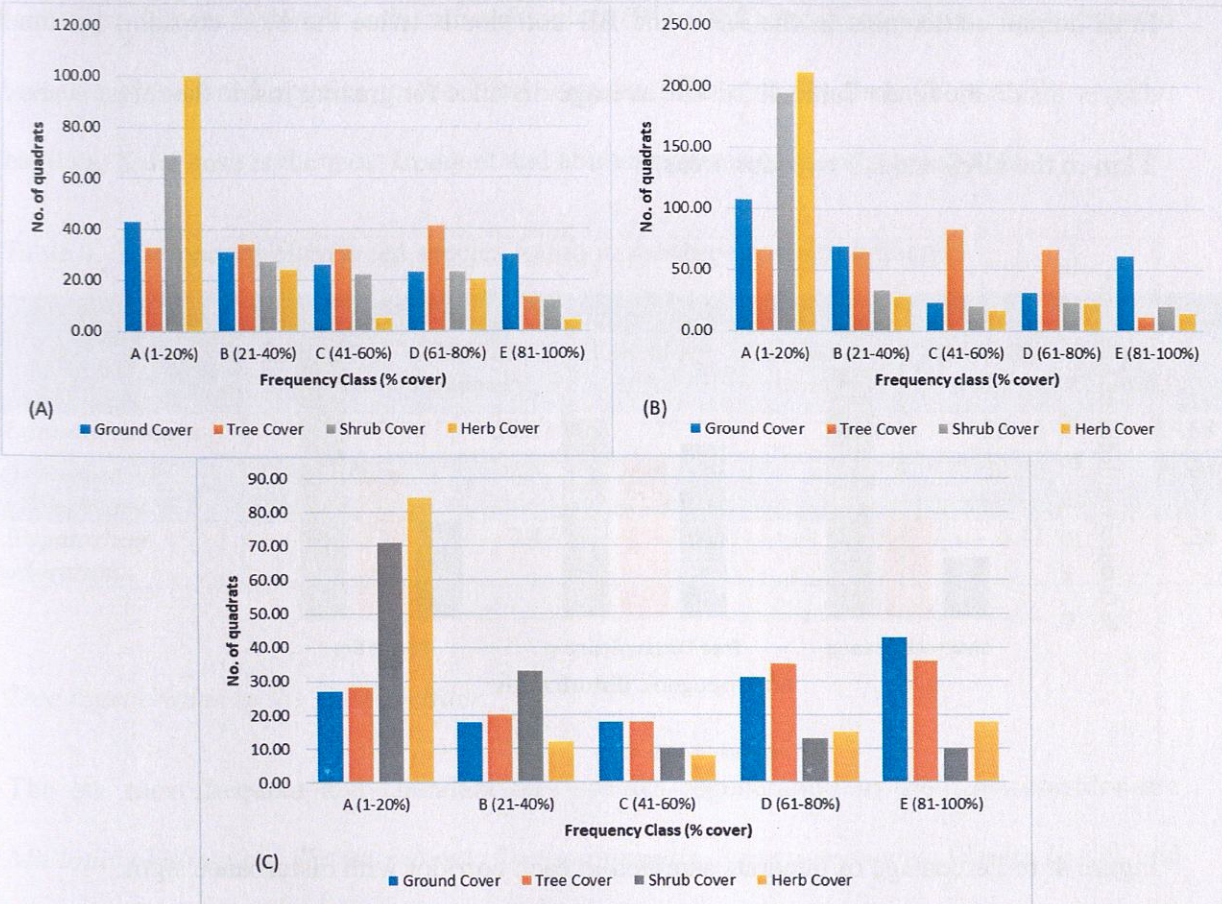


Figure 4. 5: Quadrats in different frequency classes for per cent cover of quadrat areas under the ground, tree, shrub, and herb cover in the sampled corridor areas. (A) Kosi corridor (n=153) (B) KKS corridor (n=291) (C) BB corridor (n=137). [Percent cover of different classes A<B<C<D<E].

The anthropogenic disturbances were recorded based on signs observed in the quadrats. Direct sighting, hoof marks, and cattle dung were considered signs of livestock grazing. Other anthropogenic disturbance signs were lopping and cutting (stumps) of trees. Forest fire signs were also documented; however, forest fire is also due to natural conditions, but it is mainly triggered and aggravated by human activities. The disturbance in the BB corridor habitat is higher than in the KKS and Kosi corridor habitats (Figure 4. 6). The grazing pressure (~32%) and forest fire (~40%) are substantially higher in the BB corridor than in the other two corridors. Tree lopping and cutting are the most common anthropogenic disturbances observed in all the corridors studied. The average distance of disturbance signs from human settlements in the KKS and BB corridor is twice the Kosi corridor, i.e. much deeper inside the forest Table 4. 2). The average distance for grazing inside the forest is above 2 km in the KKS and BB corridor areas.

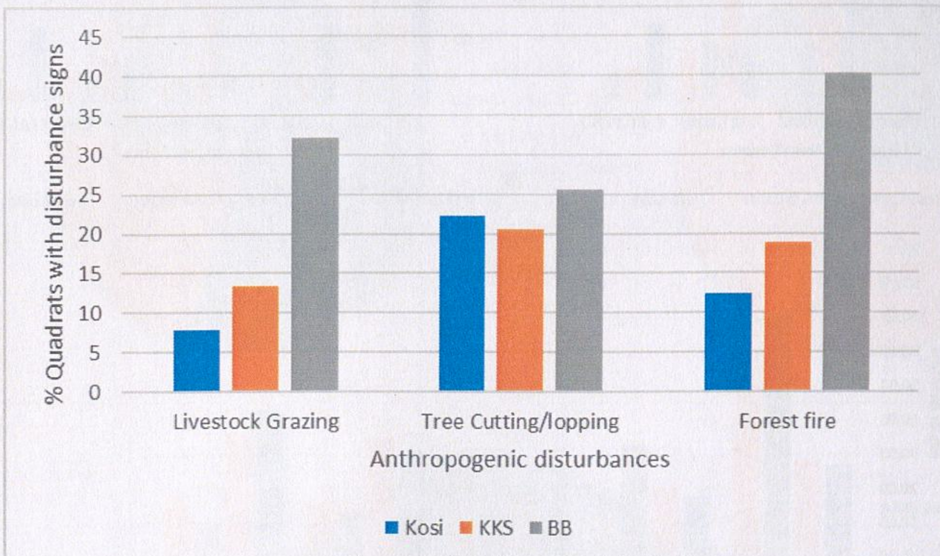


Figure 4. 6: Percentage of quadrats sampled in each corridor with disturbance signs.

Table 4. 2: Average distance (m) of recorded disturbance signs in quadrats from human settlements.

Anthropogenic disturbances	Kosi (m)	KKS (m)	BB (m)
Forest Fire	1552	2053	4573
Livestock Grazing	874	2543	2365
Tree Cutting	1250	2988	2516
Tree Lopping	1721	2371	1673

Three prominent plant weed species found in the wildlife corridor landscape of the study area are *Lantana camara* (Kurri/lantana), *Ageratina adenophora* (Kalabansa), and *Eupatorium odoratum* (Safedbansa). *Eupatorium odoratum* has had a low spatial spread till now in the forest habitats of wildlife corridors in the study area. However, *Ageratina adenophora* and *Lantana camara* are widespread and aggressively spreading in the forest habitats in the landscape. *Lantana camara* is the most abundant (RD= ~59) and frequently (~58%) observed invasive plant weed species in the Kosi corridor (Table 4. 3). In KKS and BB corridor habitats, Kalabansa is the most frequent and abundant invasive plant weed species.

Table 4. 3: Important plant weed species found in the three corridor habitats.

Weed Species	Kosi		KKS		BB	
	Frequency (%)	Relative density	Frequency (%)	Relative density	Frequency (%)	Relative density
Lantana camara	58.17	59.11	13.75	25.80	25.55	23.68
Ageratina adenophora	39.87	37.42	41.24	70.57	50.36	71.04
Eupatorium odoratum	3.27	3.47	1.72	3.63	5.11	5.28

Tree regeneration in the Kosi corridor

The six most frequent and abundant tree species regeneration in the Kosi corridor are *Mallotus phillipensis, Shorea robusta, Tectona grandis, Syzygium cumini, Ehretia laevis,* and *Holorrhena pubescens.* However, only three species i.e. *Shorea robusta, Aegle marmelos,* and *Holorrhena pubescens* show good regeneration potential. *Mallotus phillipensis* has the highest frequency of saplings (~54%) and seedlings (~49%) and the relative density of saplings (~41) (Supplementary Table 4. 4) but has poor regeneration potential. The relative density of *Shorea robusta* seedlings (~43) is highest in the Kosi corridor. The frequency of Sal seedlings (~40%) is higher than that of Teak (~15%), but the frequency of Teak saplings (~25%) is higher than that of Sal (~23%) saplings. The relative density of Teak (~8) and Jamun (*Syzygium cumini*, ~8) seedlings is similar. However, Jamun has fair, and Teak has poor regeneration potential. The relative density of Sal saplings (~22) also decreases by ~50% of its seedling level (~42).

Tree regeneration in the KKS corridor

The tree species with high regeneration frequency and abundance observed in the KKS corridor are *Mallotus phillipensis, Shorea robusta, Syzygium cumini, Tectona grandis, Miliusa velutina,* and *Terminalia elliptica.* Saplings of *Mallotus phillipensis* have the highest frequency (~47%) and relative density (~33) (Supplementary Table 4. 5) with good regeneration potential. Other species with good regeneration potential are *Aegle marmelos*, *Albizia procera*, *Diospyros melanoxylon*, *Holorrhena pubescens*, *Schleichera oleosa*, and *Syzygium cumini*. Sal seedlings have the highest frequency (~51%) and relative density (~47) with fair regeneration potential. The sapling frequency of Sal (~26%) and Jamun (~15%) decreases by almost half its seedling stage frequency (Sal = 51%, Jamun =32%). The relative density of Teak saplings (~9) increases almost thrice from the seedling stage (~3) with poor regeneration. The frequency and relative density of *Miliusa velutina* saplings (~9%, ~3) also show approximately three times increase from the seedling (~3%, ~1) stage, respectively showing poor regeneration (Supplementary Table 4. 5).

Tree regeneration in BB corridor

In forest habitats of the BB corridor, *Mallotus phillipensis, Shorea robusta, Tectona grandis, Syzygium cumini, Ehretia laevis, Holorrhena pubescens,* and *Cassia fistula* are some of the major tree species with higher sapling and seedling abundance than other species of trees. *Shorea robusta*, *Holorrhena pubescens,* and *Cassia fistula* show good regeneration potential. *Mallotus phillipensis* shows the highest sapling (~50%) and seedling frequency (~50%) and sapling relative abundance (~41) with poor regeneration potential. In contrast, the maximum relative abundance of seedlings is of *Shorea robusta* (~38) with good regeneration (Supplementary Table 4. 6). The relative abundance of Sal saplings (~18) decreases by more than 50% from the seedling stage. The frequency and relative density of Jamun saplings (~4%, ~1) decrease more than three times from the seedling stage (~14%, ~7) with fair regeneration potential. *Ehretia laevis* shows an increase of more than three times in frequency and relative abundance of saplings (~24%, ~7) from the seedling stage (~7%, ~2), indicating poor regeneration. The frequency of *Holorrhena pubescens* is the same at the seedling and sapling stages (~14%). The frequency of *Cassia fistula* seedlings (~14%) is the same as that of *Holorrhena pubescens* seedlings, and both species show good regeneration.

The KKS corridor (47) has the highest number of species recorded at the seedling or sapling stage, followed by BB (36) and lowest for the Kosi (27) corridor. However, some species have not been observed in the sampled quadrats at both seedling and sapling stages (Supplementary Table 4. 4, 4.5, 4.6). The statistical comparison of tree species' relative density and frequency at the seedling and sapling stages shows no significant difference between the two stages in all three corridors (p = >0.05 in all three corridors). The regeneration potential of tree species is poor to no regeneration for approx. 70% of species in the Kosi corridor, and only 7% show good regeneration (Figure 4. 7). The regeneration in the KKS corridor is maximum amongst all three, with 13% of species with good regeneration potential and only 15% of species showing no regeneration. In the BB corridor, 27% of species are new colonisers (only seedling or sapling stage plants were recorded), with no mature trees sampled in the area of that species. The most significant proportion of tree species in all three corridors shows Poor regeneration.

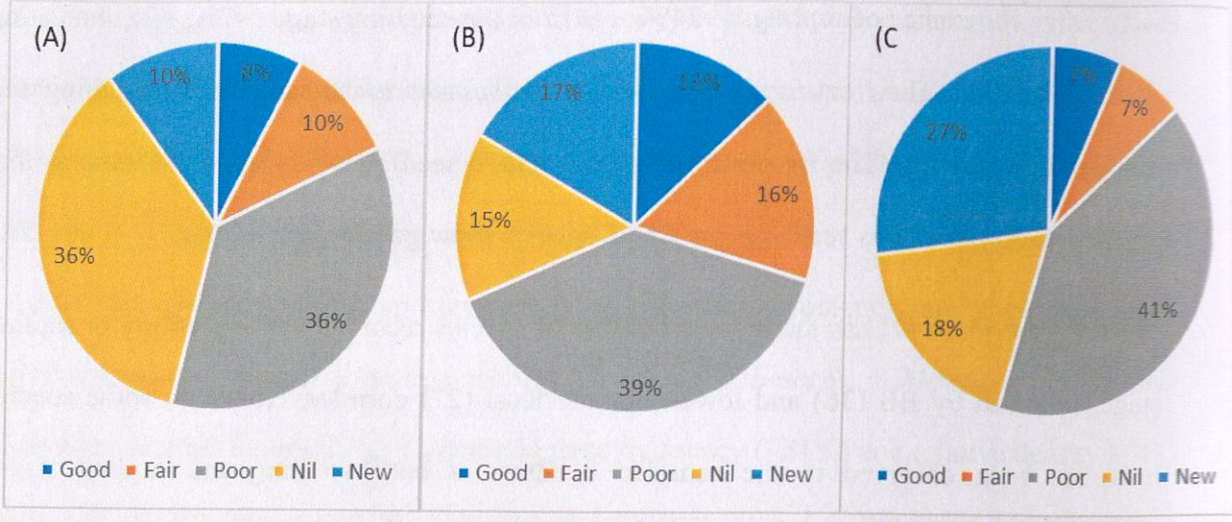


Figure 4. 7: Regeneration potential of percent of tree species in the three corridors. (A) Kosi corridor (B) KKS corridor (C) BB corridor. [Regeneration potential- Good, Fair, Poor, Nil, and New]

Fauna

The CTs were deployed in 180 locations, and data was retrieved from 169 locations in three corridors, with the loss of CTs at 11 locations due to theft and damage. Out of 169 locations, 64 are in Kosi, 59 are in KKS, and 46 are in the BB corridor. The data was retrieved from 336 CTs, of which 128 were in Kosi, 117 in KKS, and 91 in the BB corridor. The data of the Kosi corridor used for RAI calculation is from April–June 2019. The data of the KKS corridor used for RAI calculation is from November 2019–January 2020 and May 2020 for the Kilpura forest range, and February–April 2020 for the Khatima and Surai Forest range. In the BB corridor, CT data from November 2019–February 2020 was used to calculate RAI. The total trap night effort in the Kosi corridor is 9664 nights; in the KKS corridor, it is 9484 nights, and in the BB corridor, it is 5814 nights. The total captures from all the CTs during the analysed data period are 279272 in the Kosi corridor, 115846 in KKS, and 89100 in the BB corridor. The total captures of targeted species for this study, including large carnivores, livestock and prey species of tigers and leopards, is 47565 in Kosi, 48397 in KKS and 18905 in the BB corridor during the analysed data period.

The average RAI per 100 trap nights of medium prey is the maximum for the Kosi (6.46), then KKS corridor (4.27) and large prey for the BB corridor (3.33). The RAI of spotted deer (~23) is highest in the Kosi corridor, followed by sambar deer (~10), peafowl (~9), and Northern Red Muntjac (~6) (Figure 4. 8, **Supplementary Table 4. 7**). The RAI in KKS corridor habitat is highest for peafowl (~11) and spotted deer (~11) in wild ungulates, followed by livestock (~10) and then Wild boar (~8) (Figure 4. 8). In the BB corridor, sambar deer (~10) has the maximum RAI, followed by livestock (~5), Wild boars (~4), and Northern Red Muntjac (~4) (**Supplementary Table 4. 7**). Himalayan Serow and Himalayan Goral was captured in Kosi and BB corridor, few capture only (**Supplementary Table 4. 7**). Hog deer was captured in KKS corridor at one instance only (**Supplementary Table 4. 7**). The average RAI for small sized prey is lowest in all the three corridors sampled. Livestock RAI is at its maximum in the KKS corridor, followed by BB and the Kosi corridor. Nilgai observance is low in all the corridors, with minimal in the Kosi corridor with only 4 independent captures. The statistical comparison of prey abundance between three corridors based on RAI per 100 trap nights for all the species showed no significant difference (p =0.75).

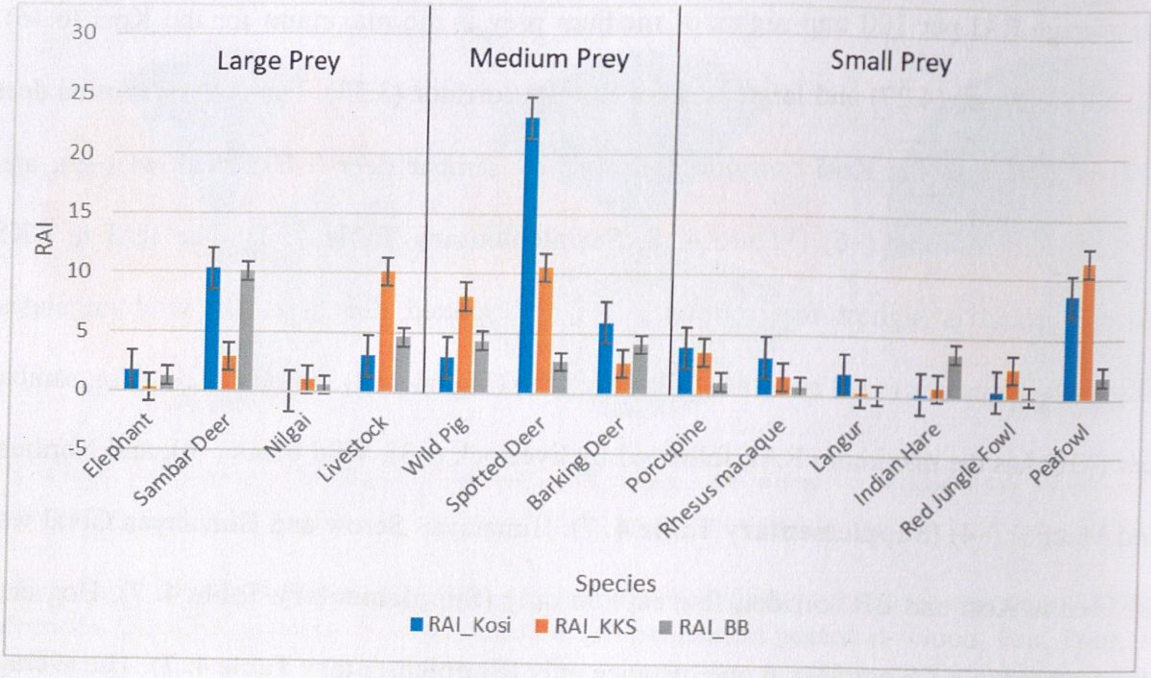


Figure 4. 8: Relative Abundance Index (RAI) per 100 trap nights of key prey species of tiger and leopard in the three corridors and adjoining habitats. (KKS: Kilpura-Khatima-Surai corridor, BB: Boom-Brahmadev corridor)

All the captures of tigers and leopards over the complete survey duration were analysed to identify unique adult individuals. The total number of tiger captures was 824 from the Kosi corridor, 514 from KKS, and 180 from the BB corridor. A total of 16 unique adult tiger individuals were identified from the Kosi corridor, comprising six males, eight females, and two unconfirmed genders. In the KKS corridor, 18 adult tiger individuals have been identified, with six males, 11 females, and one unconfirmed gender. The BB corridor has 13 unique adult tiger individuals and one common male individual with the KKS corridor. Amongst 13 adult tiger individuals in the BB corridor, seven are male, four are female, and two are unconfirmed genders. The total number of adult tiger individuals in Study Block 2 is 31, and in Study Block 1, it is 16 (Annexure 4.1).

The total number of leopards captures in the Kosi corridor is 182, 586 in KKS, and 358 in the BB corridor. The number of adult unique leopard individuals in the Kosi corridor is 22, with

11 males, 4 females, and 7 unconfirmed genders. In the KKS corridor, the total number of adult leopard individuals is 23, with 12 males, six females, and five unconfirmed genders. In the BB corridor, one adult leopard individual is common with KKS, and 17 unique adult leopard individuals comprising seven males, 10 females, and one unconfirmed gender have been recorded (Annexure 4.2). The total number of adult leopards in Study Block 1 is 22, and Study Block 2, it is 40.

Discussion

The diversity of trees is higher in the BB corridor, which also has the maximum types of habitats among the three corridors studied. The mosaic of habitat types supports a higher species diversity with multiple ecotone habitats (Anchorena & Cingolani, 2002; Kark, 2013; Senft, 2009). Sal is the most dominant tree species in both the study blocks, native to the region. However, Teak has slightly higher dominance in the BB corridor than Sal, possibly due to the monoculture plantation of timber species during the 1970s–90s as large forest patches felled for timber were replanted with Teak. There is also a significant difference between the tree dominance of KKS and BB (Mann-Whitney U test p =0.0051) due to topographic differences and soil characteristics, as BB lies primarily in the Bhabar region and KKS in the Terai region. The area under the Sal forest type is also higher in the KKS (59%) than in the BB (25%) corridor.

Teak has allelopathic effects and limits the growth of the understory species, causing low shrub and herb cover, which has also been observed in the study area (Ikhajiagbe et al., 2020; Kato-Noguchi, 2021; Udayana et al., 2020). The tree canopy cover is mainly medium to high in all three corridors, typical of broadleaf forests. The shrub and herb cover is mainly in the lowest frequency class A in all the sampled corridors, which may be attributed to natural causes like dense canopy cover (S. Baral & Ghimire, 2020; Wulf & Naaf, 2009), the presence of Teak plantations with negligible undergrowth and human factors like extensive grazing by livestock, recurring forest fire and invasion of weed species outcompeting the native vegetation. KKS corridor has the highest proportion of sampled quadrats with class A (<20%) shrub and herb cover and the lowest in the Kosi corridor. The grazing pressure is also highest in KKS, with the highest livestock RAI and the lowest in Kosi. Earlier studies have also linked grazing with reduced lower taxa plant diversity (Chillo et al., 2017; McIntyre et al., 2003; Pandey & Singh, 1991). Most parts of the habitats lack lower structure in the vegetation community in all three corridors.

The anthropogenic disturbance is a critical factor influencing the diversity and invasion of weed species (Kaushik, 2014; Malik et al., 2016). The anthropogenic disturbance indicators, like livestock grazing, tree cutting and lopping in the study area (Arnan et al., 2018; Liira et al., 2007), indicate higher disturbance in the BB corridor than in KKS and lowest in the Kosi corridor, which is understandable as most parts of the BB and KKS corridors are under reserved forest. In contrast, the western part of Kosi is under CTR, and only the eastern part is under the reserved forest area of RFD. The grazing and cutting/lopping signs have been observed in deeper parts of the forest habitats in BB and KKS (above 2 Km average distance from human settlements inside the forest) than in Kosi (average distance of grazing ~0.9 km and lopping/cutting above 1 km). Anthropogenic activities like grazing, fodder and fuelwood collection are restricted in tiger reserves. The other reason for low anthropogenic disturbance in the Kosi corridor is the development of alternate livelihoods for local communities in the eco-tourism sector, awareness towards wildlife, and policy support for human-wildlife coexistence. As highlighted in the previous chapter, livestock rearing is also lower in the Kosi corridor than in the KKS and BB corridor areas, thus lowering grazing pressure in the wildlife habitats.

The presence of weed species also indicates habitat disturbance due to anthropogenic activities (Bonilla-Valencia et al., 2021; Frenot et al., 2001). The invasive plant species significantly impact the structure and composition of vegetation communities, severely affecting the habitat dynamics (Fried et al., 2014; Mungi et al., 2018; Pyšek et al., 2012). *Lantana camara* is most frequently and abundantly spread in the Kosi corridor and *Ageratina adenophora* in the KKS and BB corridor, which may be attributed to varied soil conditions, moisture content, and intensity of disturbances. *Lantana* is more hardy and shrubby and prefers drier conditions than *A. adenophora,* which prefers moist conditions and has herbaceous characteristics (Changjun et al., 2021; Mungi et al., 2018). Local pastoralist communities also clear/ remove the *Lantana* patches for pasture lands for their livestock. However, their way of clearing these patches is unscientific and leads to more aggressive growth in the subsequent years. The seasonal flooding and raised surface water level in terai areas also act as limiting factors for the growth of *Lantana* in low-lying areas with low sunlight (Prasad, 2007)*;* thus, the lowest frequency and density are observed in the KKS corridor. On the other hand, moist conditions support *A. adenophora* proliferating more profoundly in the absence of *Lantana*. The extant of the *Eupatorium odoratum* is ubiquitous in three corridors and is not as extensive as *Lantana* and *A. Adenophora. E. odoratum* is mainly observed with *A. adenophora*, which prefers similar habitat conditions and is mainly observed on stream banks and roadsides. The relatively lower spread of Lantana in BB than Kosi, both having Bhabar topography, may be attributed to the higher dominance of Teak in BB as Teak also limits the growth of *Lantana* as well under its canopy (Ikhajiagbe et al., 2020; Udayana et al., 2020) and higher livestock grazing, thus clearing patches for pasture land. Invasive species invade the abandoned croplands rapidly in the villages adjoining forest areas, creating dense undergrowth and intermixed forest-village boundaries (K. Baral et al., 2021). Such dense bushes around settlements in large carnivore-populated forest areas increase the chances of negative encounters with humans by influencing animal behaviour or while manoeuvring through the human landscape (Duncan et al., 2004; Stewart et al., 2021).

The regeneration ability of the tree species is critical for the long-term viability and health of the ecosystem and habitats (Malik & Bhatt, 2016; Parkes et al., 2003; Shahabuddin & Prasad, 2004; Shankar, 2001). It also indicates the quality and lower structure of the forest habitats (Das et al., 2021; Mohanta et al., 2021). Saplings and seedlings of the plants are essential for the multi-level vegetation community structuring and understory diversity, which is critical for faunal diversity and ecosystem functioning (Bowd et al., 2021; Jakobsson et al., 2020; Omeja et al., 2016). *Holorrhena pubescencs* (Dudhi) shows good regeneration potential in all three corridor habitats. Sal also shows good regeneration potential in the Kosi and BB corridors and fair in the KKS corridor. However, Teak shows poor regeneration potential, possibly due to the policy decision to remove Teak plantations with native species favourable for biodiversity and wildlife habitats. Thus, Teak is dominant and abundant in the mature tree stage, resulting from earlier monoculture practices for timber production but not at the regenerative stage.

The regeneration potential status of tree species in the Kosi corridor is in a poor state (34% poor regeneration and 34% species with no regeneration), which may be attributed to the mature stage of the vegetation community, invasive species like *Lantana,* dense canopy, and low diversity of habitat types than KKS and BB corridor. The KKS corridor shows maximum regeneration potential among three corridors, with seven species showing good regeneration potential. It also has the highest number of species (KKS= 47, Kosi = 27, BB= 36) in the regenerative stage. Invasive plant species also affect the regeneration of native species by outcompeting and depleting available resources for native vegetation to grow and germinate, like *Lantana,* which alters the soil characteristics, proliferates aggressively and can withstand unfavourable conditions (Fried et al., 2014; Mungi et al., 2018; Prasad, 2007; Pyšek et al., 2012). The extensive spread of *Lantana* in the Kosi corridor is one of the important factors for poor regeneration status.

Anthropogenic disturbances also influence the regeneration ability of species like lopping of leaves from saplings diminishes their chance of survival to healthy mature trees, or extensive grazing reduces the percentage of seedlings turning into saplings (Chillo et al., 2017; McIntyre et al., 2003) as observed in KKS and BB corridor where frequency and relative density of Sal and Jamun seedlings was decreased by two to three times at sapling stage and have high grazing (high livestock RAI) (Figure 4. 8) and lopping/cutting (Figure 4. 6). However, the KKS and BB corridors have higher anthropogenic disturbance than the Kosi corridor, yet they have better regeneration. Thus, it can be inferred that not only direct impacts of anthropogenic disturbance influence the regeneration, but other factors like climate, hydrology, and soil, along with long-term indirect impacts of anthropogenic activities, invasive species and natural succession, influence the plant community structure, composition and regeneration ability (Dash et al., 2021; Malik et al., 2016; Mandal & Joshi, 2014; Mungi et al., 2021).

The topography and vegetation of the region influence the distribution and assemblage of herbivore prey species (Bhola et al., 2012; Lahkar et al., 2020; Namgail et al., 2009). Sambar deer is an important large-sized wild prey present in the study area. The RAI per 100 trap nights of sambar deer is high in the Kosi (~10) and BB (~10) corridor, which may be attributed to its preference for undulating topography as in the Bhabar areas and avoiding the presence of livestock highest in the KKS (RAI= ~10) corridor (Figure 4. 8). Spotted deer, Wild boar, and Northern Red Muntjac are the important medium-sized wild prey species in the study area with relatively higher abundance than other species. The high abundance of spotted deer in the Kosi corridor can be attributed to its proximity to CTR, where prey base density is good and protection is high with minimal disturbance. The CTR also acts as a source population for tigers and other wildlife species (Bisht et al., 2019; Qureshi et al., 2023). CTR is India's densest tiger population PA (Qureshi et al., 2023). The river Kosi forms the central part of the Kosi corridor and is a perennial water source; thus, animals' movement towards the river from CTR and RFD is high in the dry season, so higher captures also. However, the relative abundance of primary prey species in the Kosi corridor has decreased from 2013-14, as reported by an earlier study on the Kosi corridor (Anwar et al., 2014).

The RAI of elephants in KKS is low as there is no presence of elephants in the Surai forest range of the KKS corridor. Elephants are restricted to the Kilpura and Khatima forest range in the KKS corridor as further movement through PTR is blocked due to obstruction of the corridor due to dense human settlements (Anwar & Borah, 2020; Ranjan et al., 2021). KKS corridor is functional for large carnivores and other mammalian species but non-functional for elephants south of Khatima (only in Kilpura and Khatima). The RAI of prey species from the KKS and BB corridor will provide a baseline for the prey base, as no prey baseline information was available for the KKS and BB corridor.

The tiger and leopard population are highest in KKS (tiger=18, leopard=23), followed by Kosi (tiger=16, leopard= 22) and BB (tiger=13, leopard=17) corridor. The tiger and leopard populations use the wildlife corridors as movement paths and home territory, breeding and foraging in the corridor habitats. We have recorded tiger and leopard females with cubs in all three corridors. The increased protection by law and ground-level efforts have yielded positive results by increasing the tiger population compared to earlier studies in the Kosi (Anwar et al., 2014) and KKS (Anwar & Borah, 2020) corridor. The increasing population trend of tigers and leopards in the study area forest divisions of Uttarakhand has also been observed in the latest All India Tiger Estimation (AITE) report 2022 (Qureshi et al., 2023). However, the increasing population of wide-ranging large carnivores, decreasing prey base, and deteriorating wildlife corridor habitats are alarming situations for long-term conservation and the future peaceful coexistence of humans and wildlife. It requires immediate scientific planning and management intervention to sustain wildlife conservation in human-dominated mosaic landscapes.

Conclusion

The wildlife habitats of the three corridor areas studied have good tree diversity and complexity. However, the regeneration of tree species is poor for most species like *Adina cordifolia, Ehretia laevis* and *Terminalia chebula* etc. The shrub and herb cover are also low for most areas in all three corridors, affecting the lower structure of forest habitats. The extensive growth of weed species like *Lantana camara* and *Ageratina adenophora* also affects understory species' composition, structure, and tree regeneration. The poor regeneration and deteriorated lower strata vegetation with sparse undergrowth are unfavourable conditions for breeding large carnivores, which requires dense patches for hiding their offspring. The lack of such patches and high human disturbance forces them out of the forest to use sugarcane farm fields to raise and hide their young ones, as has been observed in many instances in the Terai-Bhabar landscape. Using human-modified landscapes by large carnivores for their life cycle stages is unsuitable for human-wildlife coexistence and increases the vulnerability of negative HWI.

Restoring habitat in wildlife corridors with assisted management strategies is the need of the hour. Few strategies like plantation of wildlife anchoring species providing foraging and sheltering places, water availability in the forested areas is critical especially during lean season, ANR of native species, and stringent protection from poaching and illegal extraction of resources will prove instrumental in restoring the habitat. The multilayered structured forest habitats and diversity of habitat types are required in the studied wildlife corridors through controlled and regulated grazing, fodder, fuelwood and NTFP collection. The habitats of the studied wildlife corridors lack grassland patches, and management interventions are required to secure existing small grasslands from being invaded by weeds and natural succession by removing tree species. Grasslands are critical habitat areas for large carnivores and ungulates. Planting wildlife anchoring species (*Ficus* spp., *Ziziphus* spp., native fruiting trees, annuals and seasonal native grasses etc.) in the core forest habitats to cater to the needs of herbivores and provide all-season safe foraging areas inside the natural habitat will lure them away from farm fields, avoiding HWC. The augmentation of wild prey through passive addition and their protection from hunting is paramount for increasing prey base and subsequently reducing negative HWI with large carnivores.

Supplementary Tables

Supplementary Table 4. 1: Tree species of Kosi corridor in descending order based on Importance Value Index (IVI), showing frequency in percentage, and density.

S. No.	Species	IVI	Frequency (%)	Density
1	***Shorea robusta***	78.71	33.33	0.88
2	***Tectona grandis***	56.04	26.80	0.96
3	***Mallotus phillipensis***	44.89	37.25	0.72
4	***Syzygium cumini***	29.10	18.95	0.26
5	***Adina cordifolia***	13.24	7.19	0.10
6	***Terminalia elliptica***	12.76	7.19	0.08
7	***Ehretia laevis***	9.62	9.15	0.12
8	***Ficus religiosa***	8.28	1.31	0.01
9	***Holoptelea integrifolia***	7.56	5.23	0.07
10	***Lagerstroemia parviflora***	5.74	4.58	0.06
11	***Cassia fistula***	3.26	3.27	0.03
12	***Anogeissus latifolia***	2.56	1.31	0.02
13	***Terminalia bellirica***	2.38	1.96	0.02
14	***Aegle marmelos***	2.20	1.96	0.02
15	***Sapindus mukorossi***	1.92	1.31	0.02
16	***Lannea coromondelica***	1.83	1.96	0.02
17	***Emblica officinalis***	1.77	1.31	0.01
18	***Sapium insigne***	1.73	0.65	0.01
19	***Melia azadirachta***	1.66	1.31	0.02
20	***Madhuca latifolia***	1.56	1.31	0.01
21	***Senegalia catechu***	1.48	1.31	0.02
22	***Allangium lamarckii***	1.45	1.31	0.01
23	***Schleichera oleosa***	1.45	0.65	0.03
24	***Eucalyptus spp.***	1.40	1.31	0.01
25	***Ziziphus mauritiana***	1.15	1.31	0.01
26	***Terminalia chebula***	0.76	0.65	0.01
27	***Cordia dichotoma***	0.74	0.65	0.01
28	***Pithecellobium dulce***	0.71	0.65	0.01
29	***Strebulus asper***	0.62	0.65	0.01
30	***Garuga pinnata***	0.60	0.65	0.01
31	***Grewia asiatica***	0.58	0.65	0.01
32	***Semecarpus anacardium***	0.57	0.65	0.01
33	***Holorrhena pubescens***	0.56	0.65	0.01
34	***Psidium guajava***	0.56	0.65	0.01
35	***Trewia nudiflora***	0.55	0.65	0.01

Supplementary Table 4. 2: Tree species of KKS corridor in descending order based on Importance Value Index (IVI), showing frequency in percentage, and density.

S. No.	Species	IVI	Frequency (%)	Density
1	*Shorea robusta*	123.12	54.30	1.746
2	*Tectona grandis*	33.42	18.56	0.577
3	*Mallotus phillipensis*	32.18	27.15	0.533
4	*Syzygium cumini*	17.55	14.78	0.199
5	*Terminalia elliptica*	16.48	12.37	0.182
6	*Holoptelea integrifolia*	12.14	4.81	0.117
7	*Lagerstroemia parviflora*	6.71	6.53	0.079
8	*Eucalyptus spp.*	6.29	3.78	0.065
9	*Miliusa velutina*	5.17	5.84	0.072
10	*Lannea coromondelica*	4.74	4.47	0.055
11	*Ehretia laevis*	3.52	4.12	0.041
12	*Eugenia operculata*	3.09	3.09	0.041
13	*Terminalia bellirica*	3.09	3.44	0.034
14	*Adina cordifolia*	2.99	2.06	0.024
15	*Trewia nudiflora*	2.66	2.41	0.034
16	*Bombax ceiba*	2.66	1.72	0.017
17	*Senegalia catechu*	1.96	1.72	0.031
18	*Cassia fistula*	1.81	1.72	0.017
19	*Madhuca latifolia*	1.78	1.37	0.017
20	*Grewia asiatica*	1.57	1.72	0.021
21	*Dalbergia sissoo*	1.44	1.03	0.014
22	*Allangium lamarckii*	1.43	1.37	0.021
23	*Wrightia tomentosa*	1.38	1.72	0.017
24	*Sapindus mukorossi*	1.34	1.03	0.024
25	*Ficus virens*	1.29	1.03	0.017
26	*Litsea glutinosa*	1.13	1.37	0.014
27	*Ougeinia oojeinensis*	0.85	1.03	0.010
28	*Schleichera oleosa*	0.84	0.69	0.007
29	*Bauhinia racemosa*	0.83	1.03	0.010
30	*Albizia procera*	0.69	0.69	0.007
31	*Garuga pinnata*	0.64	0.34	0.010
32	*Terminalia chebula*	0.60	0.69	0.007
33	*Albizia lebbeck*	0.44	0.34	0.003
34	*Pongamia pinnata*	0.43	0.34	0.003
35	*Melia azadirachta*	0.39	0.34	0.003
36	*Butea monosperma*	0.37	0.34	0.003
37	*Holorrhena pubescens*	0.32	0.34	0.003
38	*Chukrasia tabularis*	0.32	0.34	0.003
39	*Diospyros melanoxylon*	0.31	0.34	0.003
40	*Emblica officinalis*	0.30	0.34	0.003
41	*Fernandoa adenophylla*	0.30	0.34	0.003
42	*Grewia tiliifolia*	0.30	0.34	0.003
43	*Flacourtia indica*	0.29	0.34	0.003
44	*Ficus hispida*	0.27	0.34	0.003
45	*Aegle marmelos*	0.27	0.34	0.003
46	*Ficus racemosa*	0.27	0.34	0.003

Supplementary Table 4. 3: Tree species of BB corridor in descending order based on Importance Value Index (IVI), showing frequency in percentage, and density.

S. No.	Species	IVI	Frequency (%)	Density
1	***Shorea robusta***	123.12	54.30	1.746
2	***Tectona grandis***	33.42	18.56	0.577
3	***Mallotus phillipensis***	32.18	27.15	0.533
4	***Syzygium cumini***	17.55	14.78	0.199
5	***Terminalia elliptica***	16.48	12.37	0.182
6	***Holoptelea integrifolia***	12.14	4.81	0.117
7	***Lagerstroemia parviflora***	6.71	6.53	0.079
8	***Eucalyptus spp.***	6.29	3.78	0.065
9	***Miliusa velutina***	5.17	5.84	0.072
10	***Lannea coromondelica***	4.74	4.47	0.055
11	***Ehretia laevis***	3.52	4.12	0.041
12	***Eugenia operculata***	3.09	3.09	0.041
13	***Terminalia bellirica***	3.09	3.44	0.034
14	***Adina cordifolia***	2.99	2.06	0.024
15	***Trewia nudiflora***	2.66	2.41	0.034
16	***Bombax ceiba***	2.66	1.72	0.017
17	***Senegalia catechu***	1.96	1.72	0.031
18	***Cassia fistula***	1.81	1.72	0.017
19	***Madhuca latifolia***	1.78	1.37	0.017
20	***Grewia asiatica***	1.57	1.72	0.021
21	***Dalbergia sissoo***	1.44	1.03	0.014
22	***Allangium lamarckii***	1.43	1.37	0.021
23	***Wrightia tomentosa***	1.38	1.72	0.017
24	***Sapindus mukorossi***	1.34	1.03	0.024
25	***Ficus virens***	1.29	1.03	0.017
26	***Litsea glutinosa***	1.13	1.37	0.014
27	***Ougeinia oojeinensis***	0.85	1.03	0.010
28	***Schleichera oleosa***	0.84	0.69	0.007
29	***Bauhinia racemosa***	0.83	1.03	0.010
30	***Albizia procera***	0.69	0.69	0.007
31	***Garuga pinnata***	0.64	0.34	0.010
32	***Terminalia chebula***	0.60	0.69	0.007
33	***Albizia lebbeck***	0.44	0.34	0.003
34	***Pongamia pinnata***	0.43	0.34	0.003
35	***Melia azadirachta***	0.39	0.34	0.003
36	***Butea monosperma***	0.37	0.34	0.003
37	***Holorrhena pubescens***	0.32	0.34	0.003
38	***Chukrasia tabularis***	0.32	0.34	0.003
39	***Diospyros melanoxylon***	0.31	0.34	0.003
40	***Emblica officinalis***	0.30	0.34	0.003
41	***Fernandoa adenophylla***	0.30	0.34	0.003
42	***Grewia tiliifolia***	0.30	0.34	0.003
43	***Flacourtia indica***	0.29	0.34	0.003
44	***Ficus hispida***	0.27	0.34	0.003
45	***Aegle marmelos***	0.27	0.34	0.003
46	***Ficus racemosa***	0.27	0.34	0.003

Supplementary Table 4. 4: Tree species regeneration in the Kosi corridor.

S. No.	Species	Sapling frequency (%)	Sapling relative density	Seedling frequency (%)	Seedling relative density
1	*Senegalia catechu*	0.00	0.00	0.65	0.45
2	*Adina cordifolia*	1.31	0.26	0.00	0.00
3	*Aegle marmelos*	1.31	0.93	1.96	1.88
4	*Buchanania cochinchinensis*	0.00	0.00	0.65	0.18
5	*Cassia fistula*	7.19	2.25	5.88	1.52
6	*Dalbergia sissoo*	0.65	0.13	0.00	0.00
7	*Diospyros melanoxylon*	1.31	0.66	0.00	0.00
8	*Emblica officinalis*	0.65	0.26	0.00	0.00
9	*Ehretia laevis*	11.76	4.11	9.80	2.33
10	*Eucalyptus* spp.	0.65	0.79	0.65	0.18
11	*Holorrhena pubescens*	5.88	3.05	10.46	5.11
12	*Lagerstroemia parviflora*	0.65	0.26	0.00	0.00
13	*Mallotus phillipensis*	53.59	40.00	49.02	26.73
14	*Mangifera indica*	0.00	0.00	0.65	0.09
15	*Melia azadirachta*	0.65	0.53	0.00	0.00
16	*Miliusa velutina*	1.96	1.32	0.65	0.27
17	*Psidium guajava*	0.65	0.13	0.00	0.00
18	*Schleichera oleosa*	1.96	0.53	1.96	0.63
19	*Shorea robusta*	22.88	21.72	39.87	42.24
20	*Syzygium cumini*	11.76	5.03	17.65	7.98
21	*Tectona grandis*	24.84	16.16	15.03	7.53
22	*Terminalia bellirica*	0.00	0.00	0.65	0.18
23	*Terminalia chebula*	0.65	0.13	0.00	0.00
24	*Terminalia elliptica*	0.00	0.00	2.61	0.45
25	*Trewia nudiflora*	0.00	0.00	0.65	0.09
26	*Ziziphus mauritiana*	0.00	0.00	0.65	0.18

Supplementary Table 4. 5: Tree species regeneration in the KKS corridor.

S. No.	Species	Sapling frequency (%)	Sapling relative density	Seedling frequency (%)	Seedling relative density
1	*Senegalia catechu*	1.03	0.21	0.69	0.22
2	*Adina cordifolia*	0.69	0.28	0.00	0.00
3	*Aegle marmelos*	1.72	0.56	2.75	0.80
4	*Albizia procera*	2.06	0.77	0.34	0.62
5	*Allangium lamarckii*	1.37	0.84	1.03	0.40
6	*Bombax ceiba*	0.34	0.07	0.34	0.04
7	*Bridelia retusa*	1.03	0.28	0.34	0.09
8	*Buchanania cochinchinensis*	1.37	1.05	1.37	0.67
9	*Butea monosperma*	0.34	0.07	0.00	0.00
10	*Cassia fistula*	7.22	2.02	3.44	0.89
11	*Dalbergia sissoo*	0.34	0.14	0.34	0.22
12	*Diospyros melanoxylon*	1.03	0.35	3.78	1.07
13	*Emblica officinalis*	0.00	0.00	0.34	0.09
14	*Ehretia laevis*	4.81	1.39	3.44	0.71
15	*Eucalyptus* spp.	0.34	0.14	0.69	0.18
16	*Eugenia operculata*	0.69	0.35	0.34	0.27
17	*Fernandoa adenophylla*	1.03	0.56	0.00	0.00
18	*Ficus benghalensis*	0.34	0.07	0.00	0.00
19	*Ficus hispida*	0.34	0.14	0.00	0.00
20	*Ficus racemosa*	0.34	0.07	0.00	0.00
21	*Ficus religiosa*	0.00	0.00	0.34	0.04
22	*Garuga pinnata*	1.72	0.63	0.00	0.00
23	*Grewia tiliifolia*	0.00	0.00	0.34	0.04
24	*Holoptelea integrifolia*	1.37	0.63	1.03	0.36
25	*Holorrhena pubescens*	2.75	0.91	6.53	1.91
26	*Lagerstroemia parviflora*	3.44	1.12	2.41	0.67
27	*Lannea coromondelica*	0.34	0.07	0.00	0.00
29	*Madhuca latifolia*	0.00	0.00	0.34	0.36
30	*Mallotus phillipensis*	46.74	33.26	44.67	21.60
31	*Mangifera indica*	0.00	0.00	0.69	0.09
32	*Melia azadirachta*	0.69	0.28	0.34	0.18
33	*Michelia champaca*	0.00	0.00	0.34	0.04
34	*Miliusa velutina*	8.59	3.35	2.75	0.93
35	*Populus ciliata*	0.34	0.07	0.00	0.00
36	*Psidium guajava*	0.00	0.00	0.34	0.04
37	*Sapindus mukorossi*	0.34	0.14	0.00	0.00
38	*Saraca ashoca*	0.34	0.07	0.00	0.00
39	*Schleichera oleosa*	0.34	0.14	1.37	0.40
40	*Shorea robusta*	26.46	30.06	50.86	47.29
41	*Syzygium cumini*	15.46	8.72	32.30	14.49
42	*Tectona grandis*	13.40	9.14	9.28	2.62
43	*Terminalia bellirica*	1.03	0.28	2.06	0.84
44	*Terminalia chebula*	1.03	0.21	0.69	0.09
45	*Terminalia elliptica*	3.78	1.26	6.19	1.73
46	*Trewia nudiflora*	0.69	0.21	0.00	0.00
47	*Wrightia tomentosa*	0.69	0.14	0.00	0.00

Supplementary Table 4. 6: Tree species regeneration in BB corridor.

S. No.	Species	Sapling frequency (%)	Sapling relative density	Seedling frequency (%)	Seedling relative density
1	*Senegalia catechu*	5.11	2.48	1.46	0.69
2	*Adina cordifolia*	2.19	0.90	2.19	0.40
3	*Aegle marmelos*	4.38	1.01	4.38	1.09
4	*Allangium lamarckii*	6.57	3.04	1.46	0.20
5	*Bombax ceiba*	2.19	0.34	0.00	0.00
6	*Bridelia retusa*	1.46	0.34	0.73	0.10
7	*Buchanania cochinchinensis*	0.73	0.23	0.00	0.00
8	*Cassia fistula*	7.30	1.92	13.87	2.58
9	*Dalbergia sissoo*	1.46	1.01	0.00	0.00
10	*Diospyros melanoxylon*	0.73	0.11	0.00	0.00
11	*Ehretia laevis*	24.09	6.99	6.57	1.69
12	*Eucalyptus* spp.	0.73	0.11	0.00	0.00
13	*Fernandoa adenophylla*	0.73	0.11	1.46	0.30
14	*Holoptelea integrifolia*	6.57	2.37	2.19	0.79
15	*Holorrhena pubescens*	13.87	5.30	13.87	4.96
16	*Jacaranda mimosifolia*	0.00	0.00	0.73	0.10
17	*Lagerstroemia parviflora*	1.46	0.23	1.46	0.20
18	*Mallotus phillipensis*	49.64	41.15	50.36	30.95
19	*Mangifera indica*	0.73	0.23	1.46	0.20
20	*Melia azadirachta*	0.00	0.00	2.92	2.58
21	*Michelia champaca*	0.00	0.00	0.73	0.30
22	*Miliusa velutina*	2.92	0.90	0.73	0.10
23	*Ougenia oojensis*	0.73	0.45	0.00	0.00
24	*Pongamia pinnata*	0.73	0.11	0.73	0.10
25	*Psidium guajava*	0.00	0.00	1.46	0.30
26	*Saraca asoca*	0.73	0.11	0.73	0.10
27	*Schleichera oleosa*	2.19	0.34	1.46	0.20
28	*Shorea robusta*	21.17	18.26	33.58	38.10
29	*Syzygium cumini*	4.38	1.24	13.87	6.55
30	*Tectona grandis*	19.71	9.81	16.06	6.05
31	*Terminalia chebula*	1.46	0.23	0.00	0.00
32	*Terminalia elliptica*	1.46	0.23	3.65	1.09
33	*Trewia nudiflora*	0.73	0.11	0.00	0.00
34	*Woodfordia fruticosa*	0.73	0.11	0.73	0.10
35	*Wrightia tomentosa*	0.73	0.11	0.00	0.00
36	*Ziziphus mauritiana*	0.73	0.11	0.73	0.20

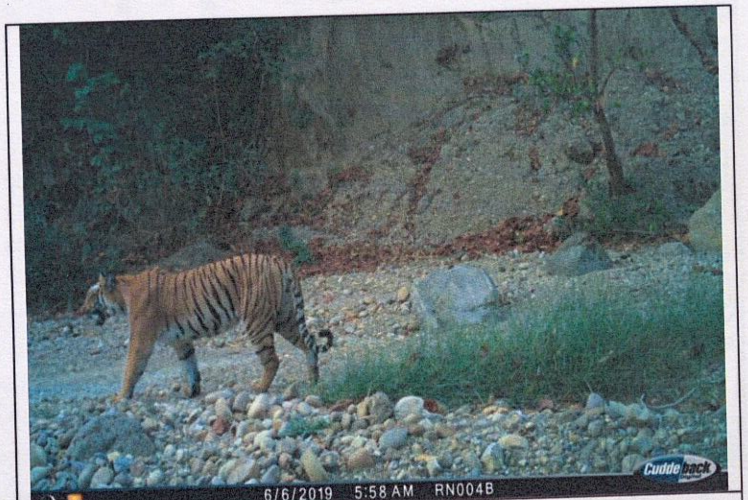
Supplementary Table 4. 7: Relative Abundance Index (RAI) per 100 trap nights of key prey species of tiger and leopard in three corridors. (Independent Events are independent image captures/occurrence of each species at 30-minute or above interval)

Prey Body size	Species	Kosi_Independent Events	RAI_Kosi	KKS_Independent Events	RAI_KKS	BB_Independent Events	RAI_BB
Large Prey	Elephant	166	1.72	30	0.32	74	1.27
	Sambar Deer	997	10.32	272	2.87	588	10.11
	Nilgai	4	0.04	99	1.04	34	0.58
	Livestock	299	3.09	962	10.14	270	4.64
	Himalayan Serow	2	0.02	0	0.00	1	0.02
Medium Prey	Wild boar	290	3.00	768	8.10	257	4.42
	Spotted Deer	2225	23.02	1005	10.60	158	2.72
	Northern Red Muntjac	576	5.96	250	2.64	242	4.16
	Himalayan Goral	32	0.33	0	0.00	2	0.03
	Hog Deer	0	0.00	1	0.01	0	0.00
Small Prey	Porcupine	381	3.94	339	3.57	62	1.07
	Rhesus macaque	306	3.17	148	1.56	44	0.76
	Langur	178	1.84	28	0.30	6	0.10
	Indian Hare	28	0.29	80	0.84	214	3.68
	Peafowl	836	8.65	1077	11.36	111	1.91
	Red Jungle Fowl	60	0.62	240	2.53	13	0.22

Annexure 4.1: Adult Tiger Individual Photo Album

T: Tiger, K: Kosi, KKS: Kilpura-Khatima-Surai, BB: Boom-Brahmadev

Tigers of Kosi corridor (16 individual plates).



T-K_1 (Female)

T-K_1 (Female)

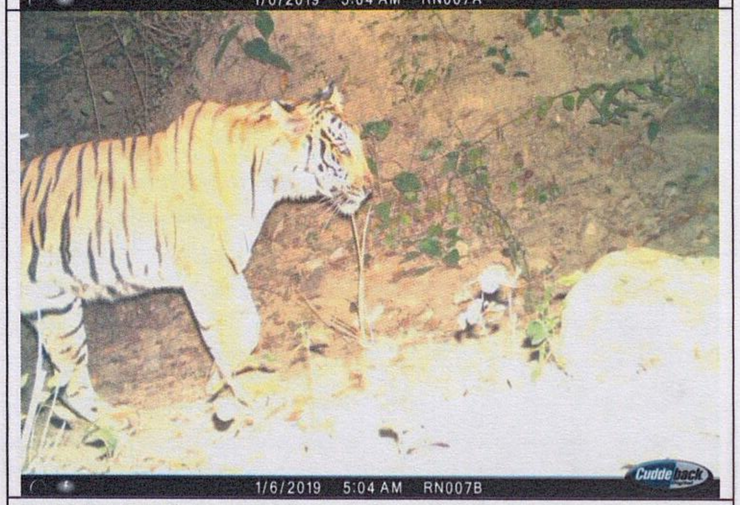
T-K_2 (Male) (Individual recorded from CTR and Ramnagar FD)

T-K_3 (Male)

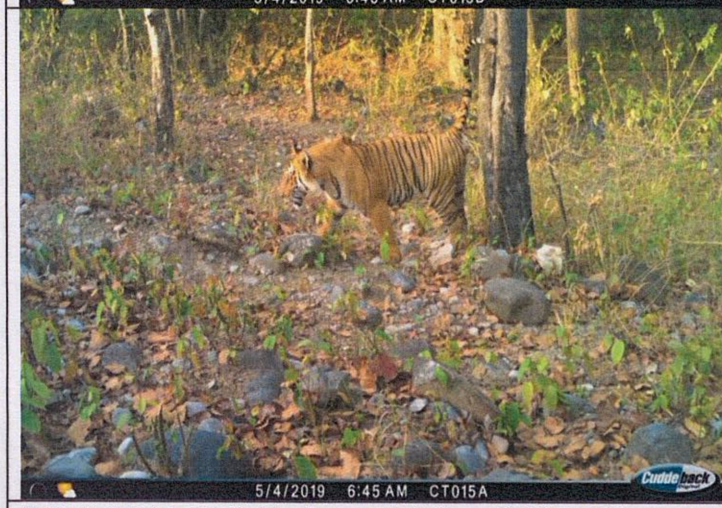
T-K_4 (Female) (Individual recorded from CTR and Ramnagar FD)

T-K_5 (Female)

T-K_6

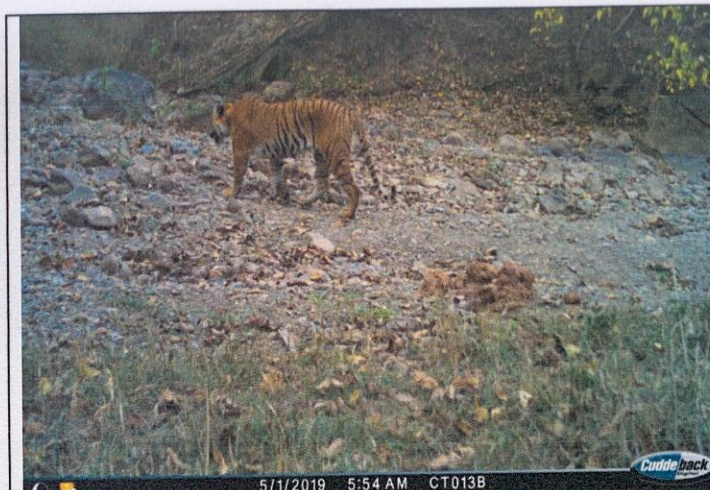


T-K_7 (Female)



T-K_8 (Male) (Individual recorded from CTR and Ramnagar FD)

T-K_9 (Male) (Individual recorded from CTR and Ramnagar FD)



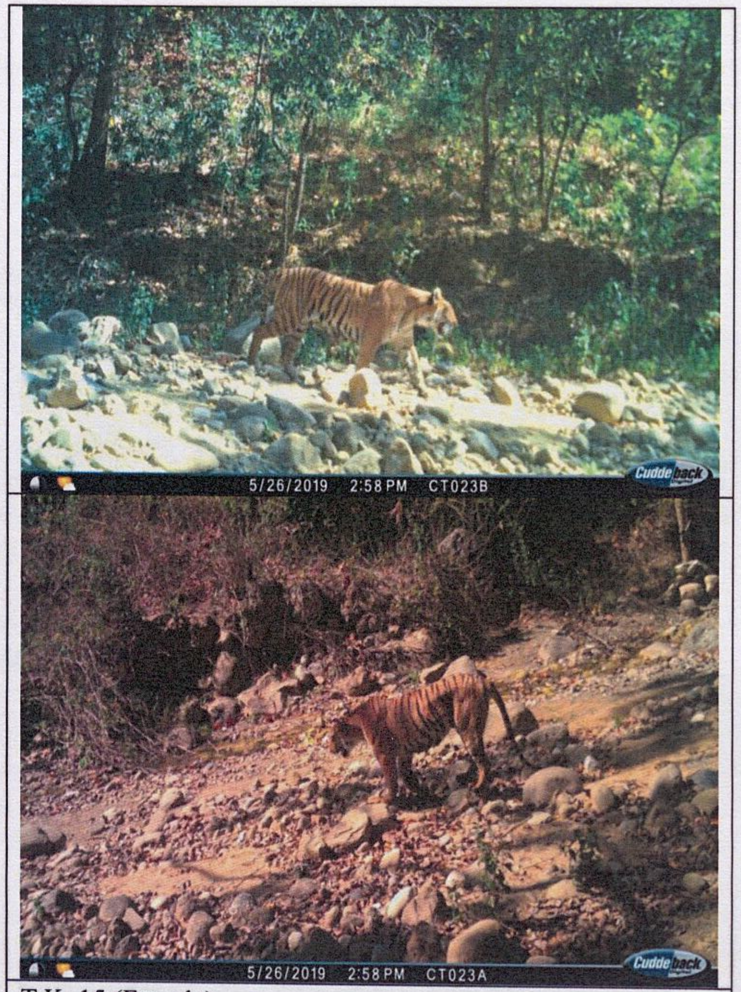
T-K_10

T-K_11 (Female)

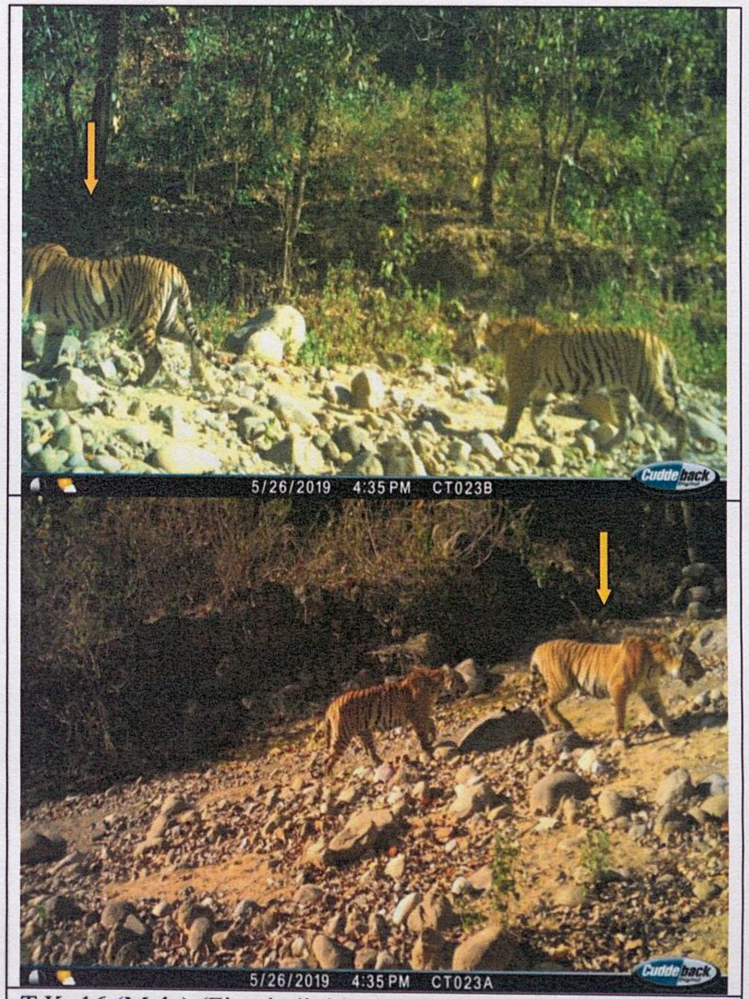
T-K_12 (Male) (Individual recorded from CTR and Ramnagar FD)

T-K_13 (Female)

T-K_14 (Female)



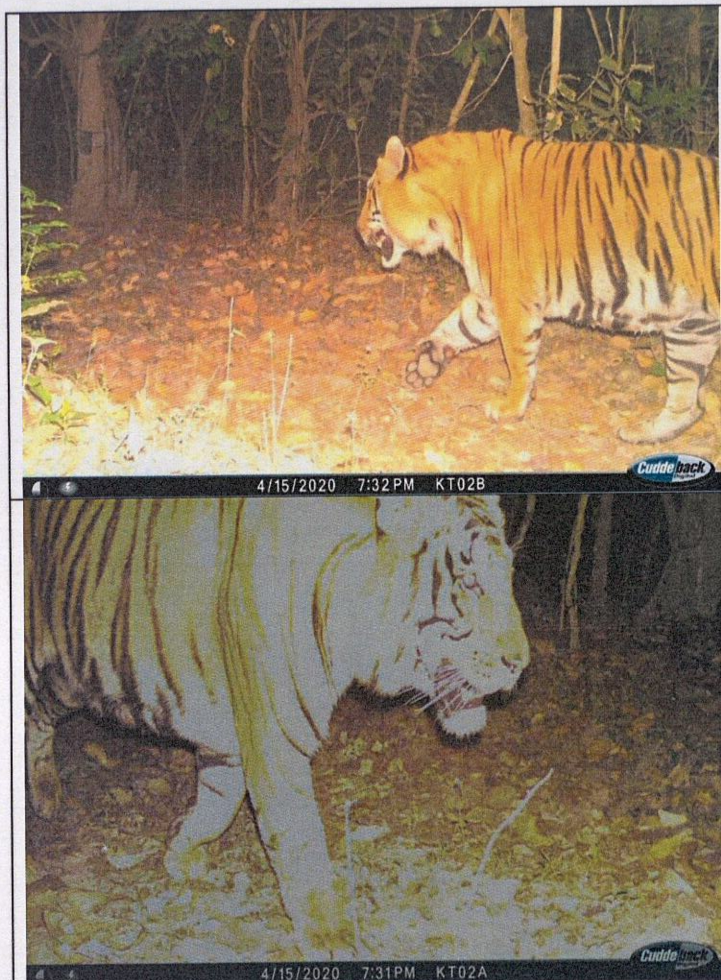
T-K_15 (Female)



T-K_16 (Male) (First individual-Anterior position)

Tigers of KKS corridor (18 individual plates)

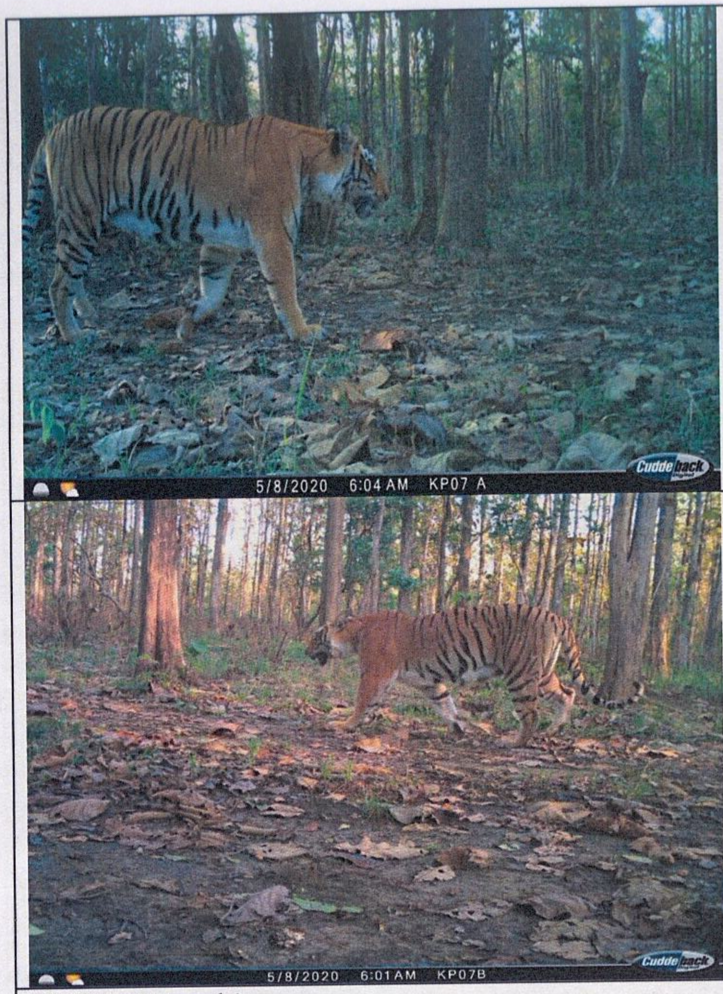
T-KKS_1 (Female)



T-KKS_2 (Male)

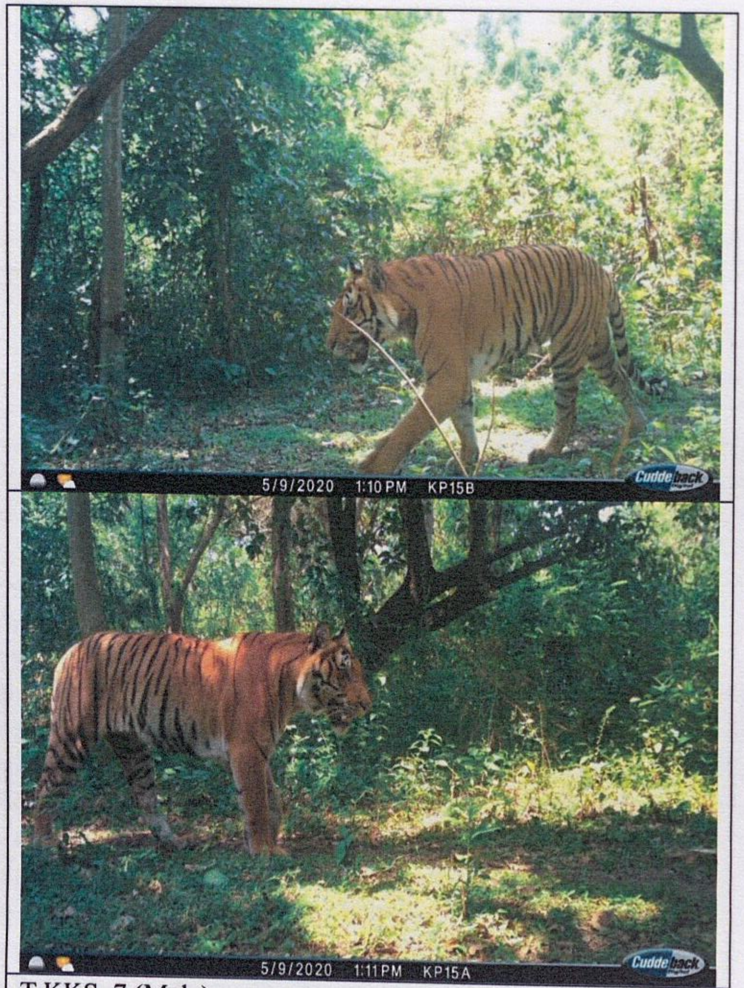
T-KKS_3 (Female) (Movement in both Khatima and Kilpura forest range)

T-KKS_4 (Female)



T-KKS_5 (Female)

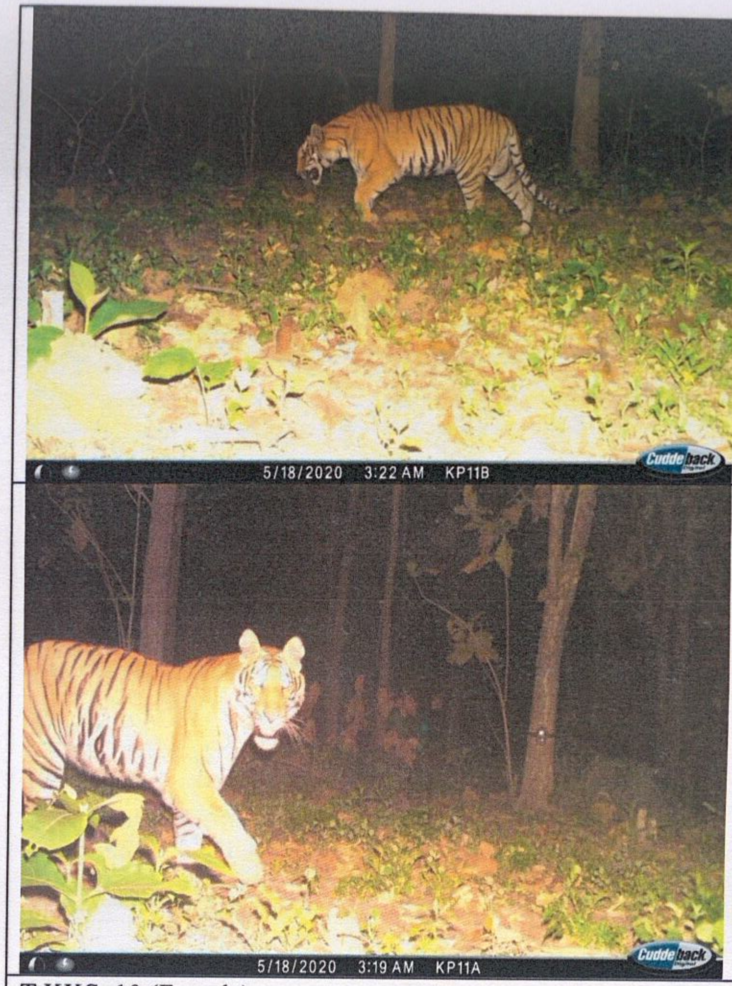
T-KKS_6 (Female)



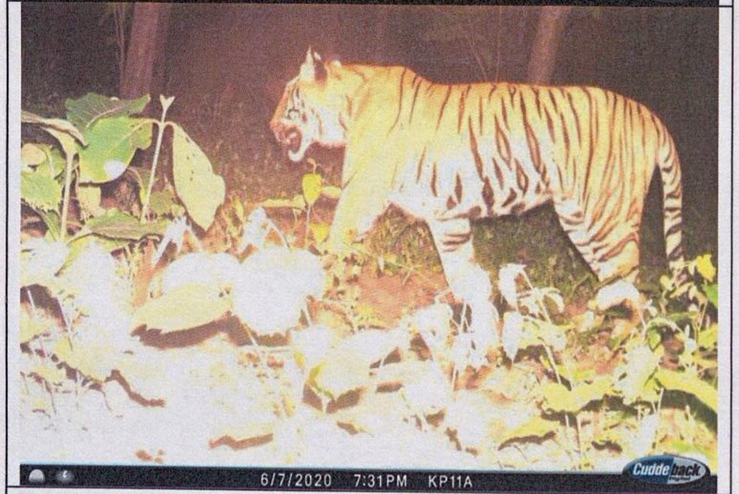
T-KKS_7 (Male)

T-KKS_8 (Male) (Common in KKS and BB corridor)

T-KKS_9 (Male)

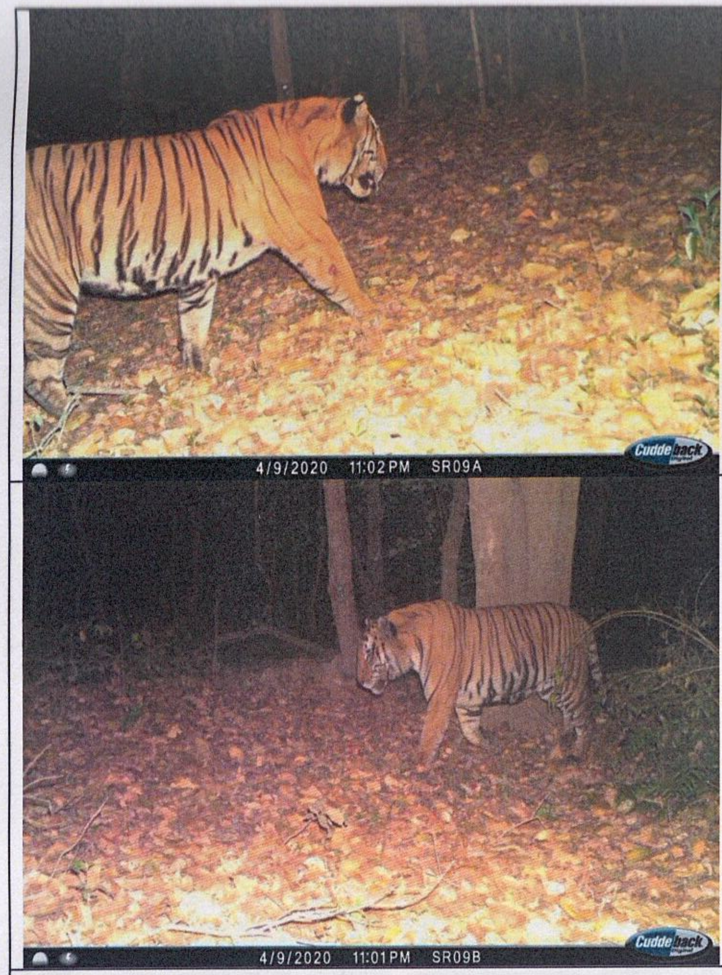


T-KKS_10 (Female)



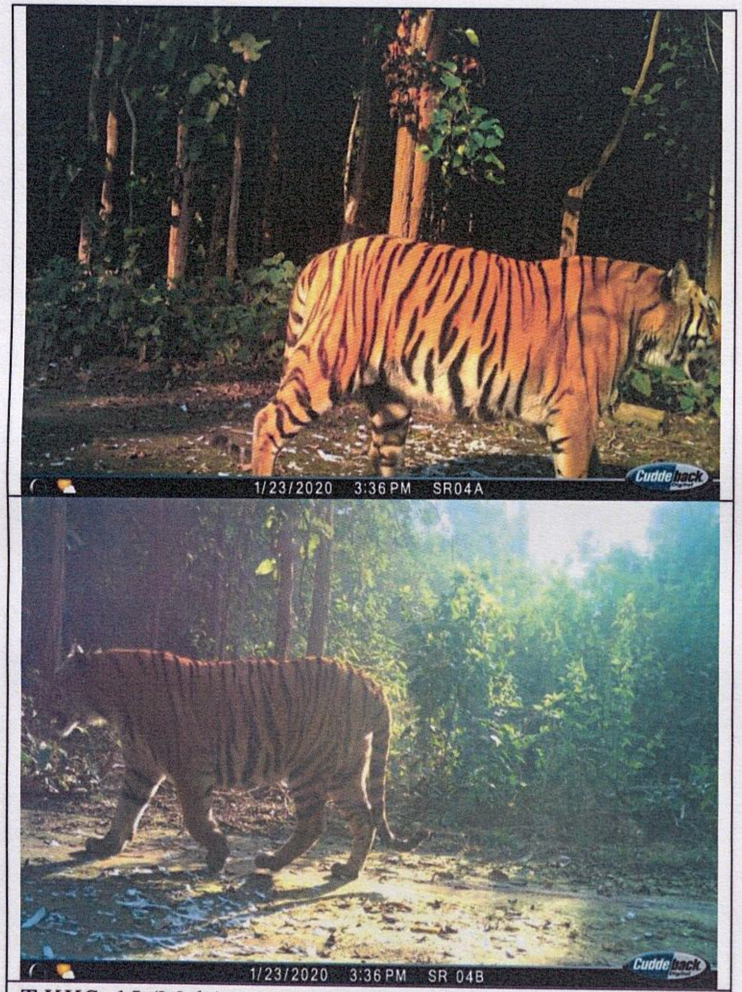
T-KKS_11 (Female)

T-KKS_12 (Female)



T-KKS_13 (Male)

T-KKS_14 (Female)



T-KKS_15 (Male)

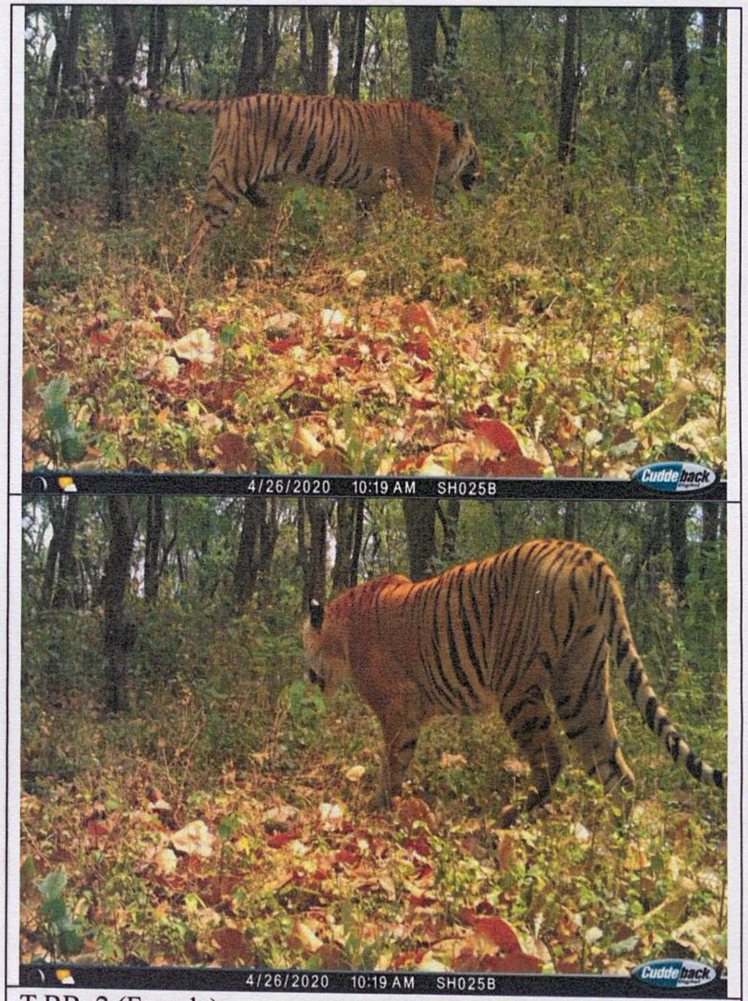
T-KKS_16 (Female)

T-KKS_17

T-KKS_18 (Female)

Tigers of BB corridor, India (13 unique individual plates).

T-BB_1 (Male)



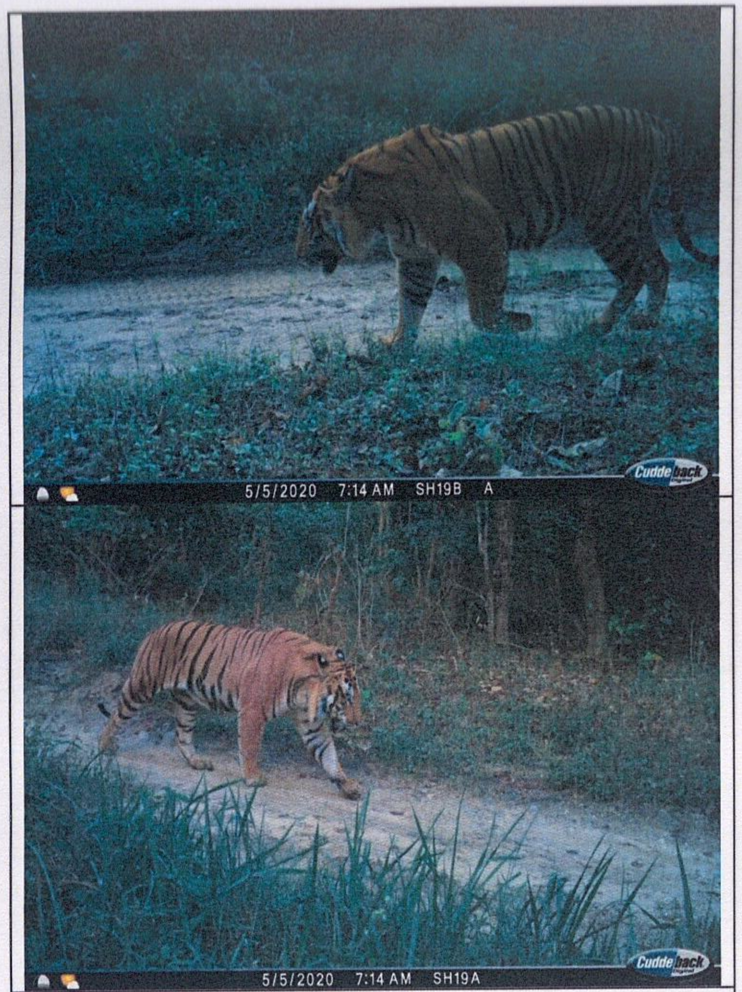
T-BB_2 (Female)

T-BB_3 (Female)

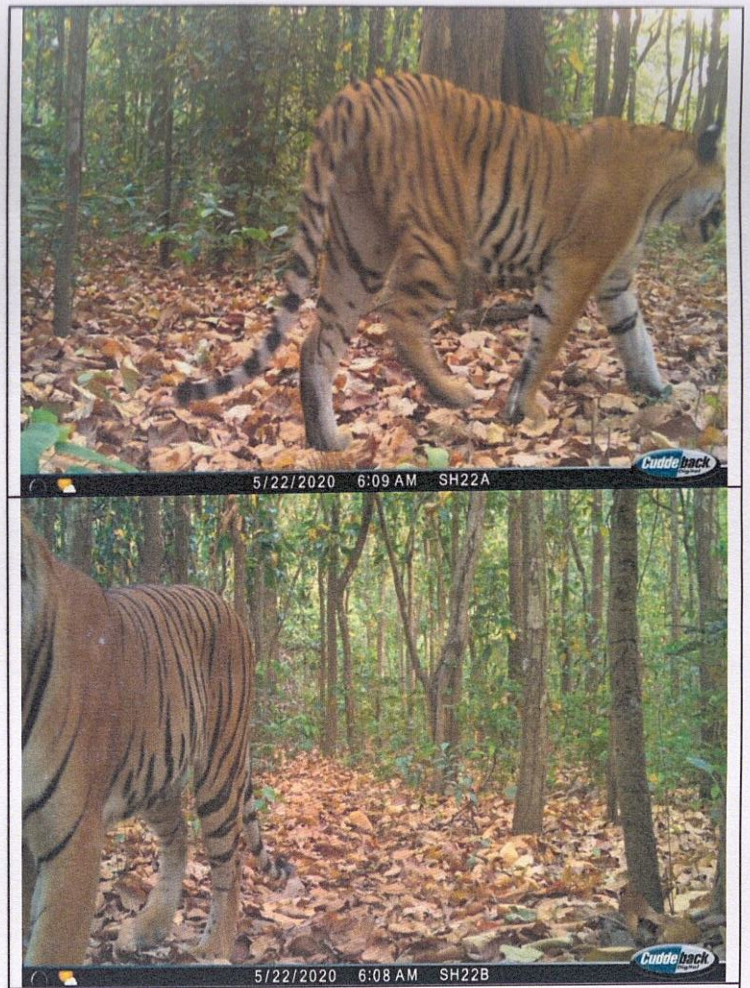
T-BB_4 (Male)

T-BB_5 (Female)

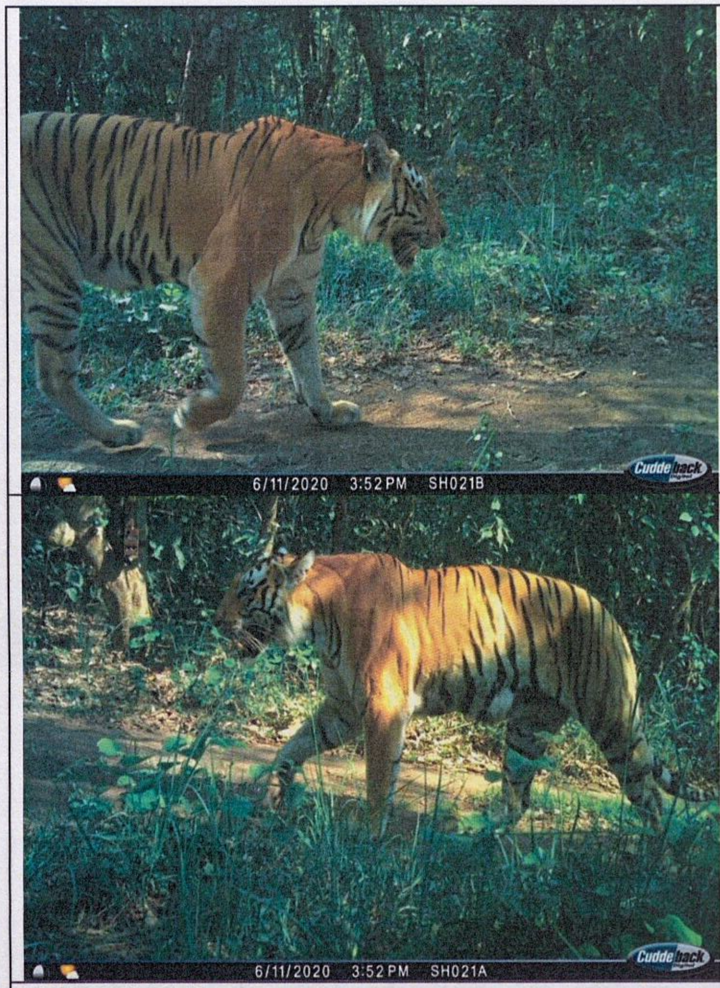
T-BB_6 (Male)



T-BB_7 (Male)

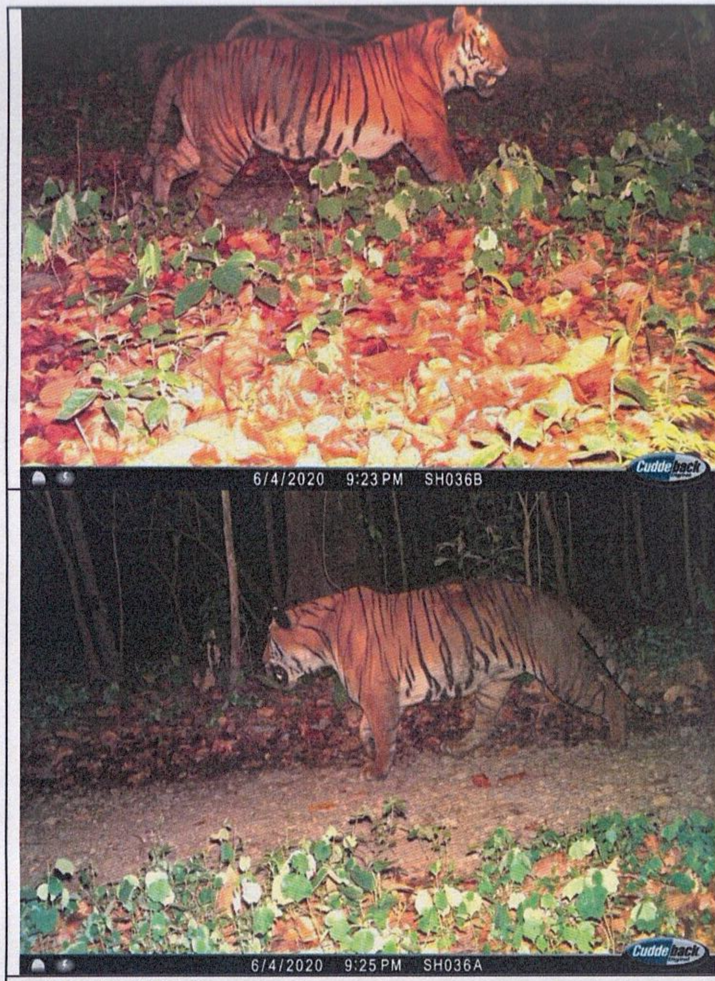


T-BB_8 (Male)



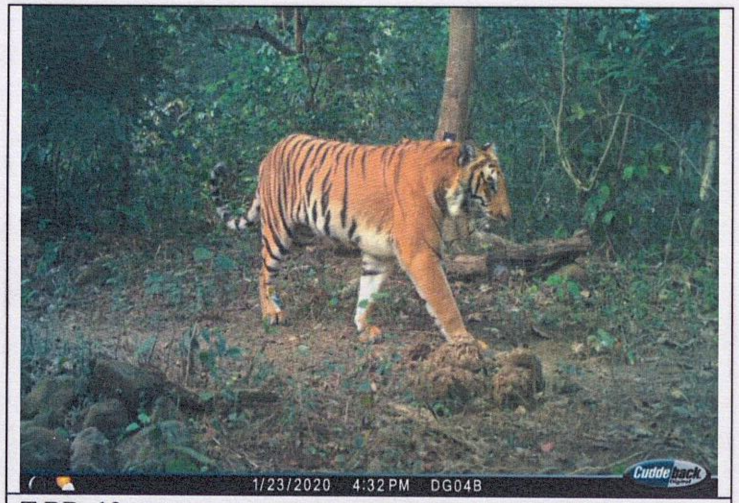
T-BB_9 (Male)

T-BB_10



T-BB_11 (Male)

T-BB_12 (Female)



T-BB_13

Annexure 4.2: Adult Leopard Individual Photo Album

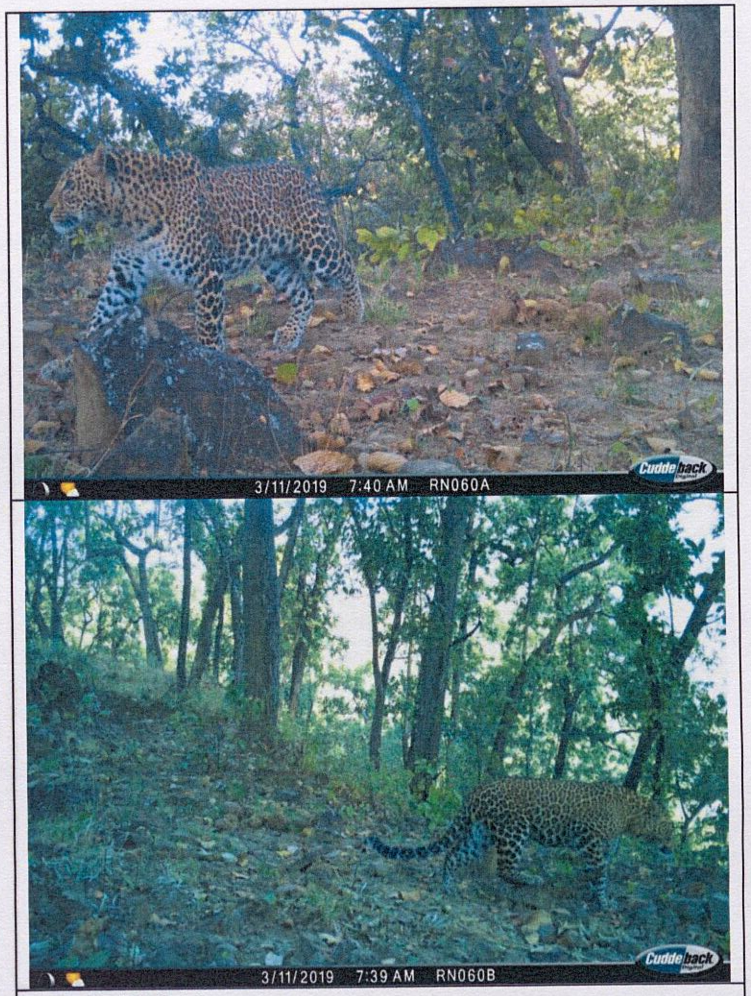
L: Leopard, K: Kosi, KKS: Kilpura-Khatima-Surai, BB: Boom-Brahmadev

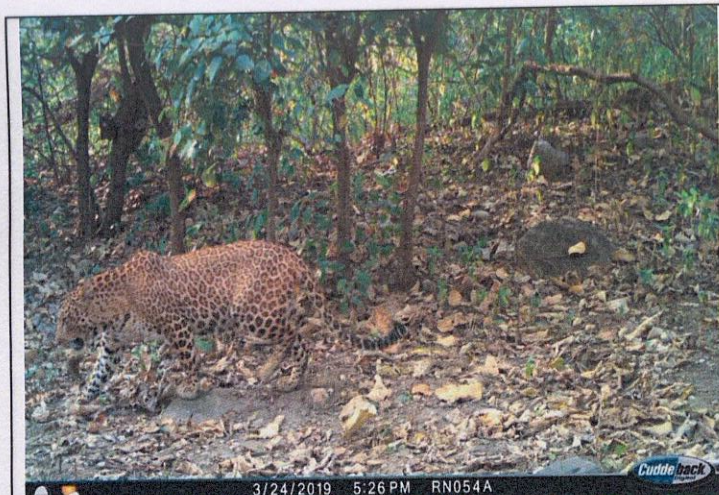
Leopards of Kosi corridor (22 individual plates).

L-K_1 (Male)

L-K_1 (Male)

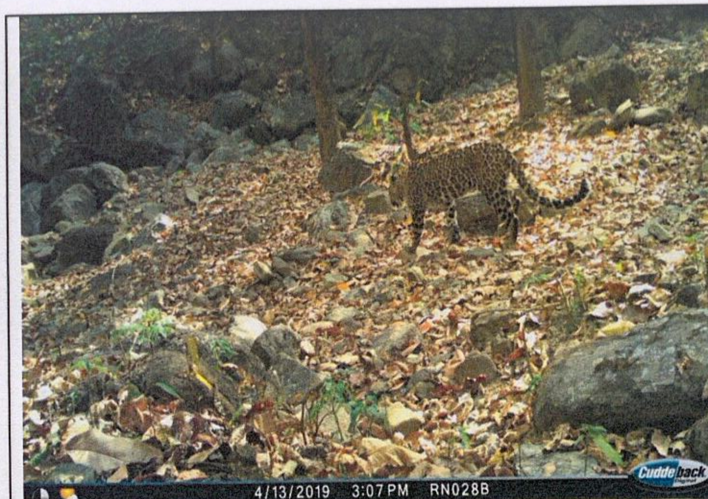

2/24/2019 3:26 AM RN044A
2/24/2019 3:28 AM RN044B
L-K_2


3/11/2019 7:40 AM RN060A
3/11/2019 7:39 AM RN060B
L-K_3 (Male)


3/24/2019 5:26PM RN054A

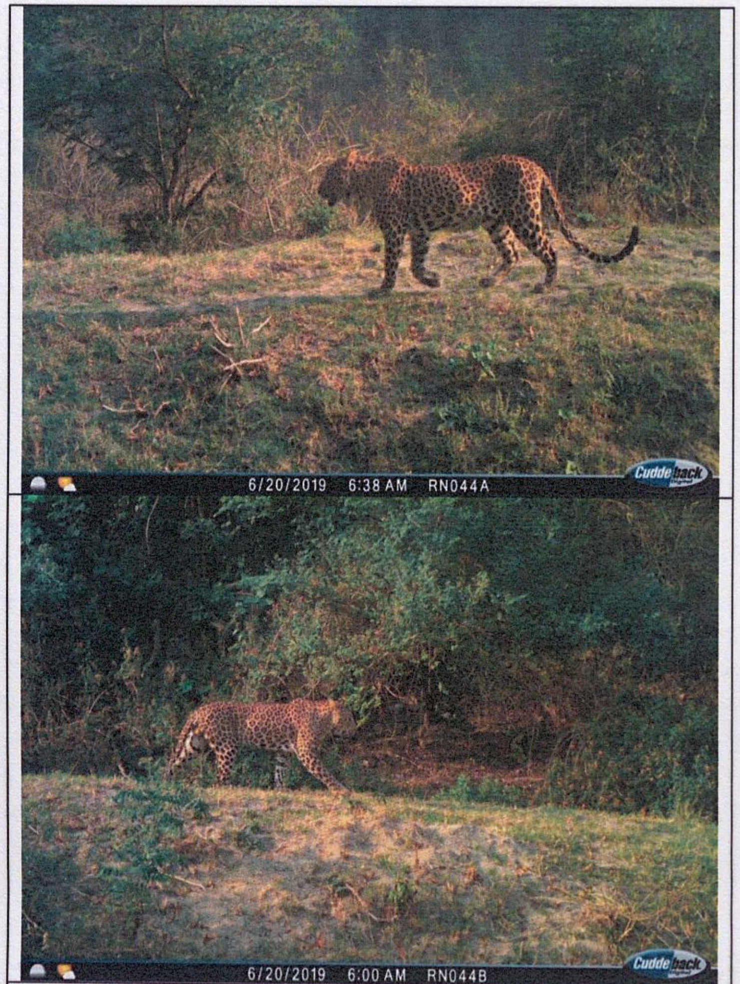

3/24/2019 5:27PM RN054B

L-K_4 (Male)


4/13/2019 3:07PM RN028B

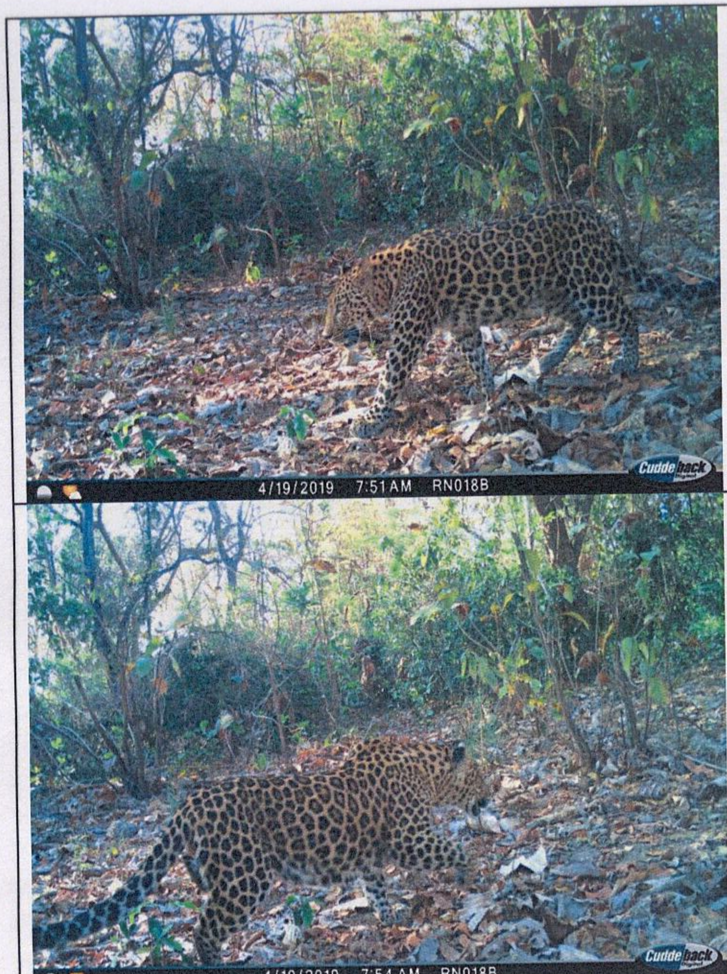

3/25/2019 8:15 AM RN028B

L-K_5



L-K_6 (Male)

L-K_7 (Female)

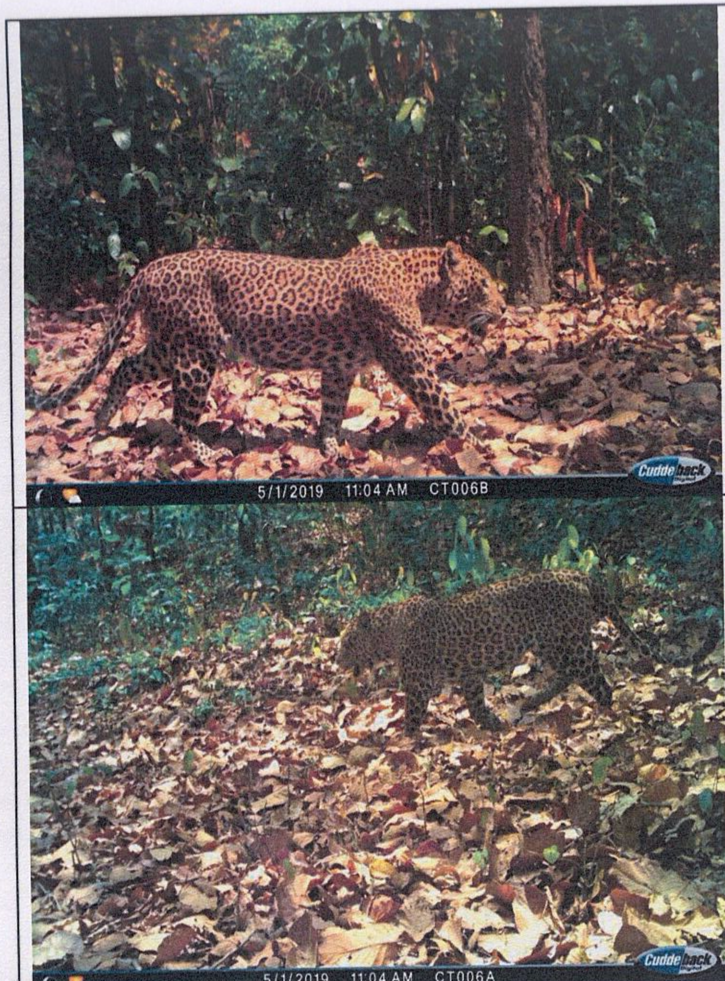


L-K_8 (Male)

L-K_9 (Female)

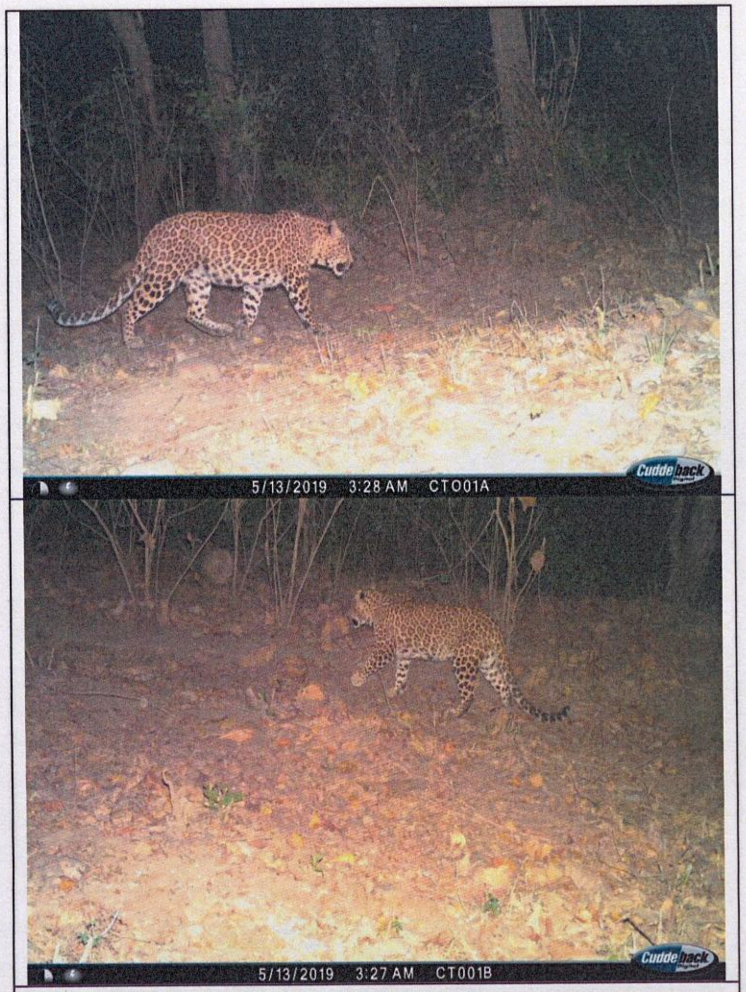
L-K_10 (Male)

L-K_11 (Female)



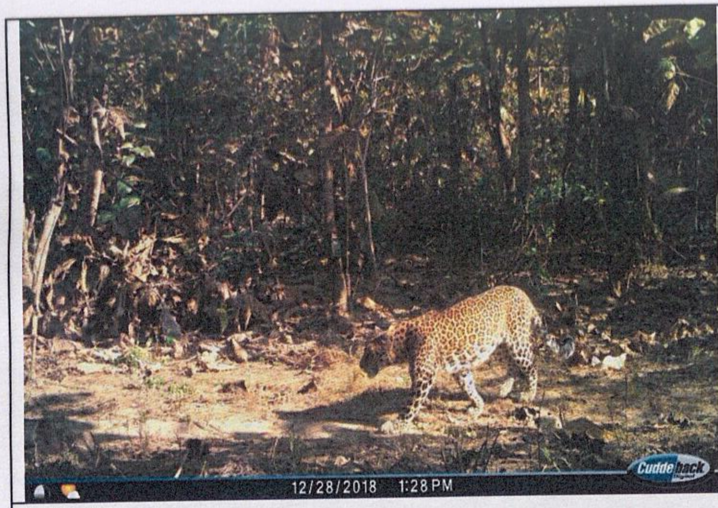
L-K_12 (Male)

L-K_13 (Male)



L-K_14 (Male)

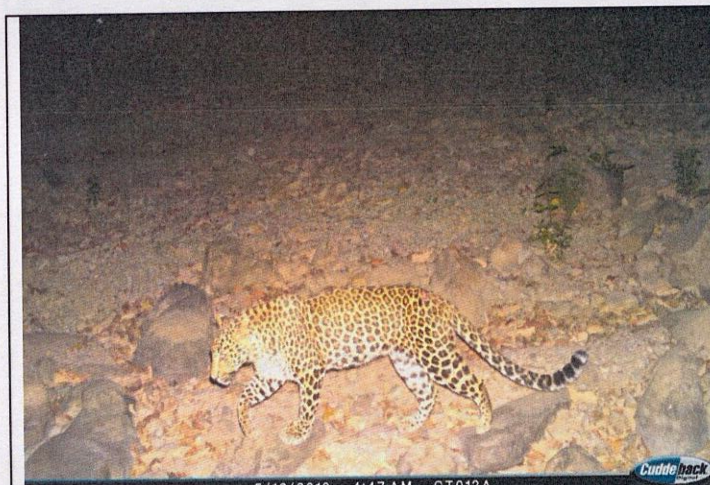
L-K_15



L-K_16

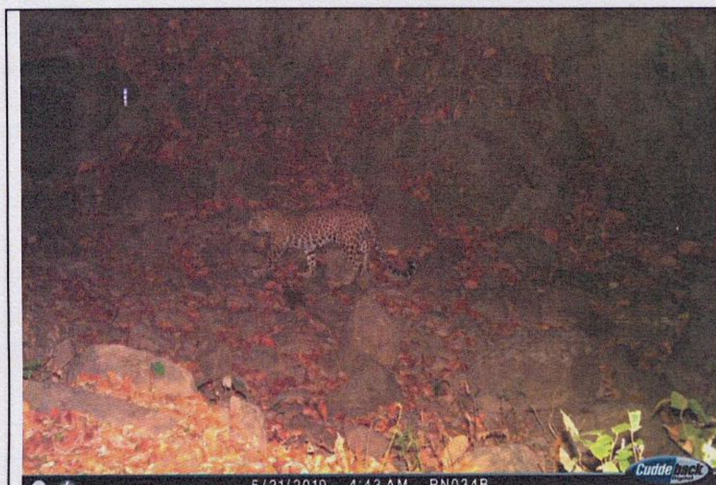
L-K_18 (Female)

L-K_17 (Male)



L-K_19 (Female)

L-K_20



L-K_21 (Male)

L-K_22

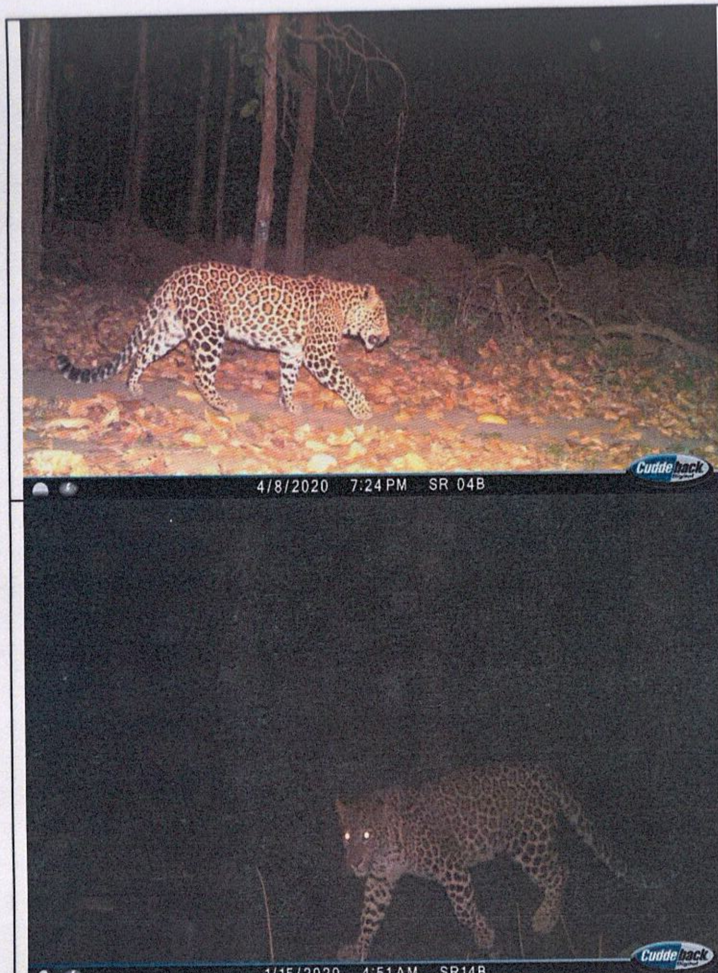
Leopards of Kilpura-Khatima-Surai corridor (23 individual plates).

L-KKS_1 (Male)

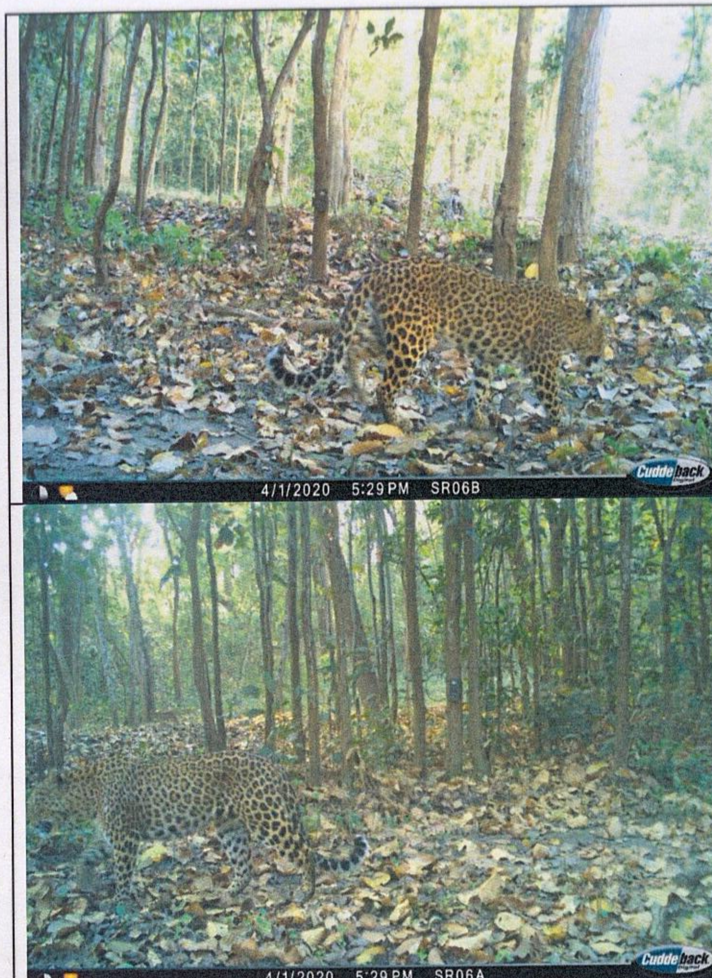
L-KKS_2 (Female)

L-KKS_3 (Male)

L-KKS_4 (Female)

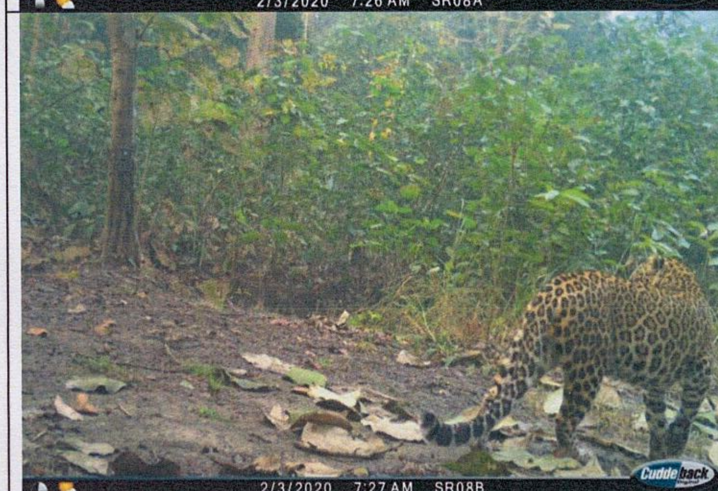


L-KKS_5 (Male)



L-KKS_6 (Female)

L-KKS_7 (Female)

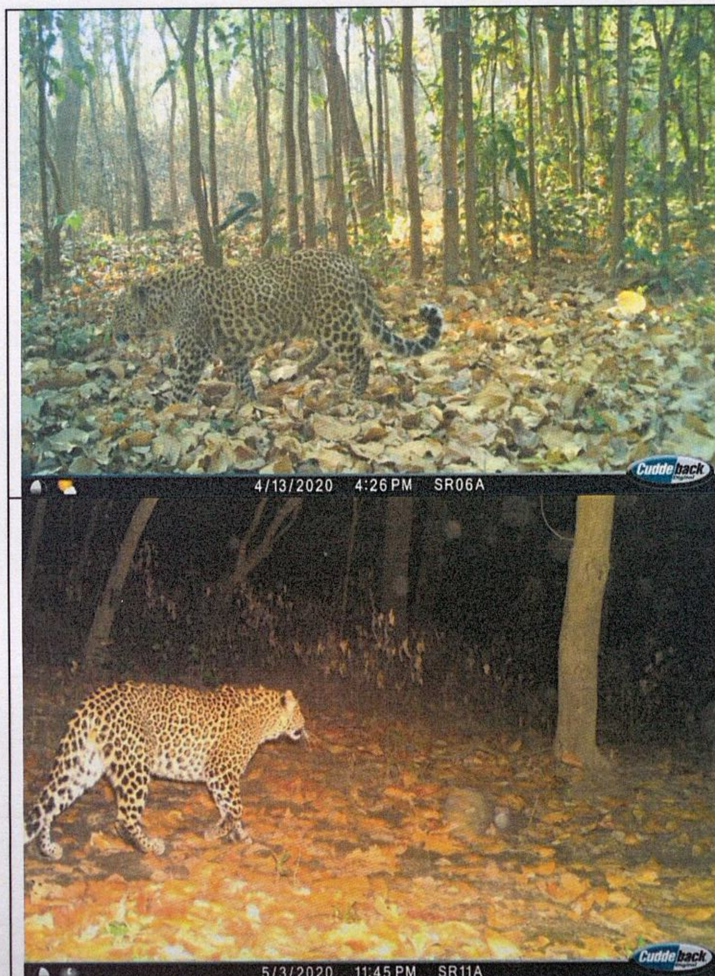


L-KKS_8 (Male)

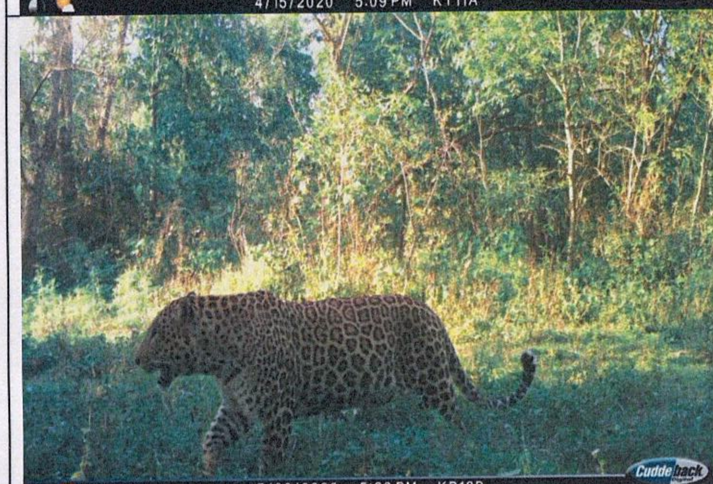
L-KKS_9 (Female)

L-KKS_10 (Male)

L-KKS_11 (Male)



L-KKS_12 (Male)



L-KKS_13 (Male)

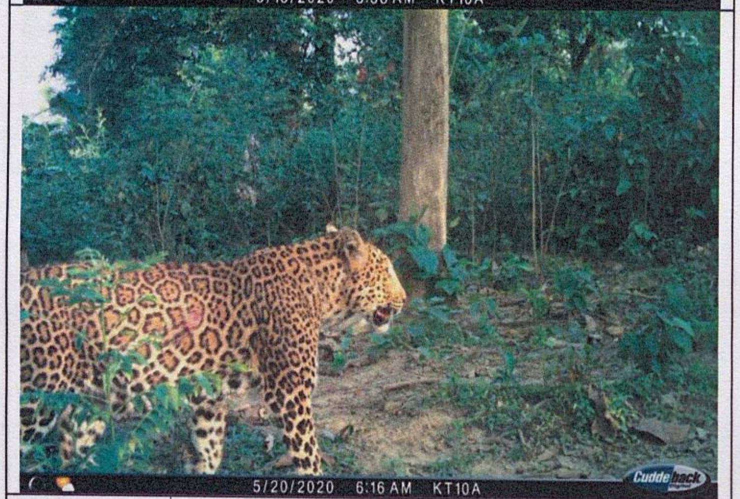
L-KKS_14 (Female)

L-KKS_15 (Male)

L-KKS_16

L-KKS_17

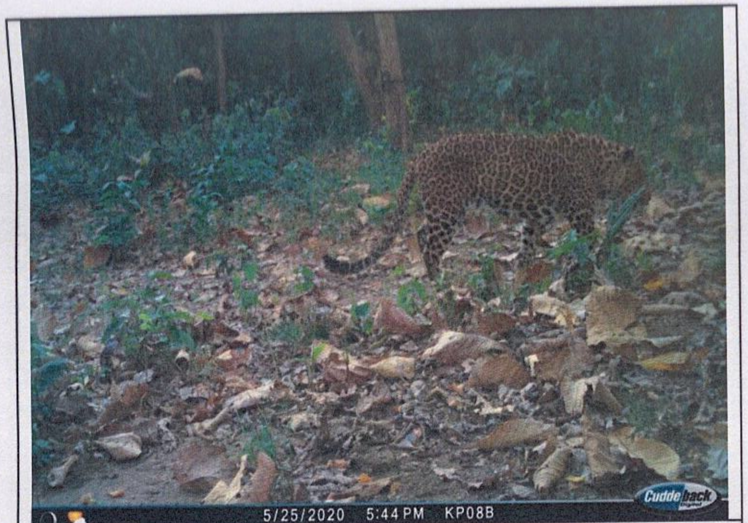
L-KKS_18 (Male)



L-KKS_19 (Female)

L-KKS_20

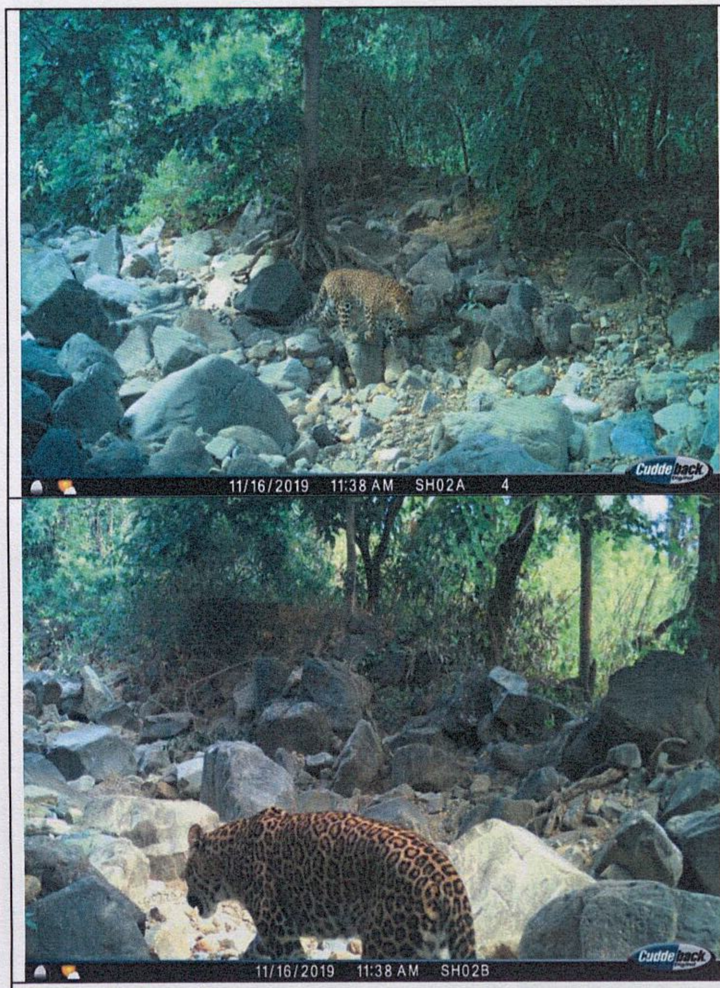
L-KKS_21



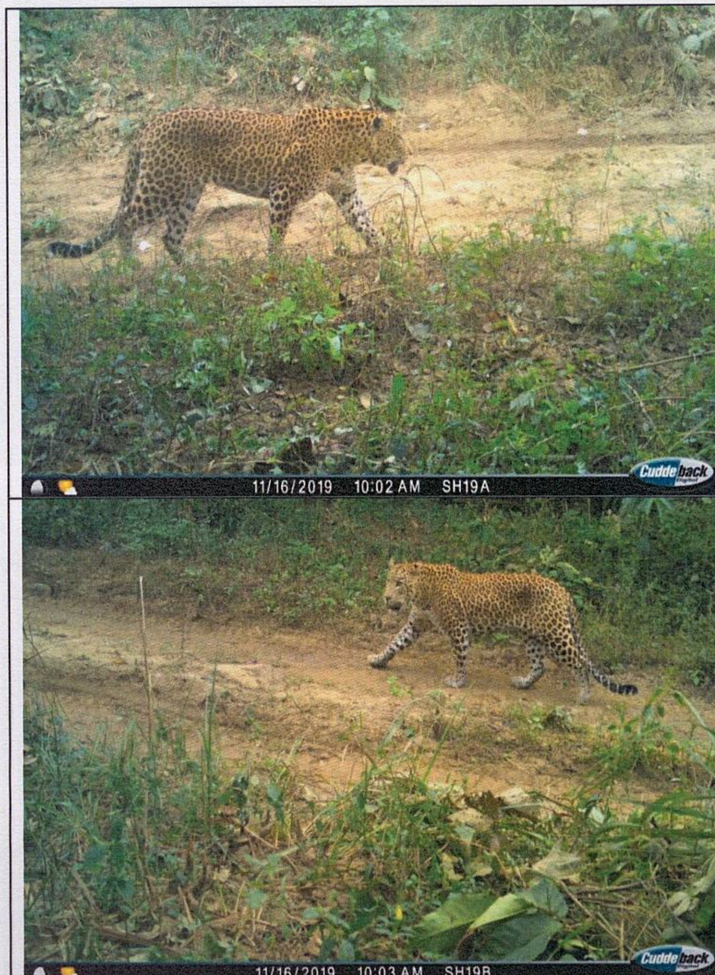
L-KKS_22 (Male) Common in KKS and BB corridor

L-KKS_23 (Male)

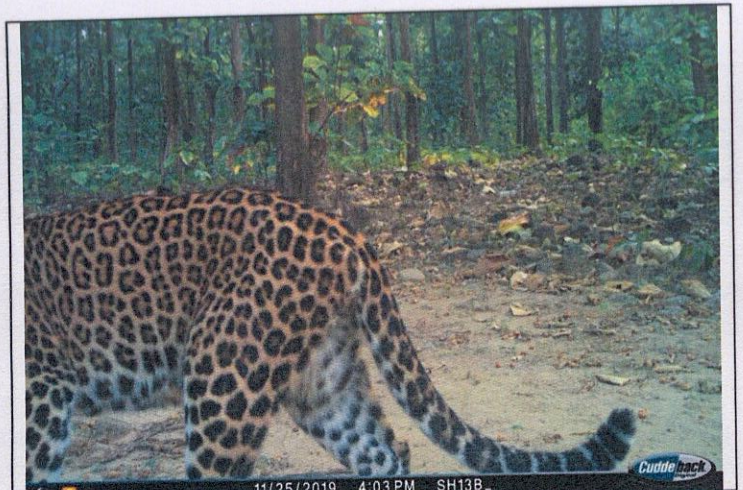
Leopards of Boom-Brahmadev corridor (17 individual plates).



L-BB_1 (Female)

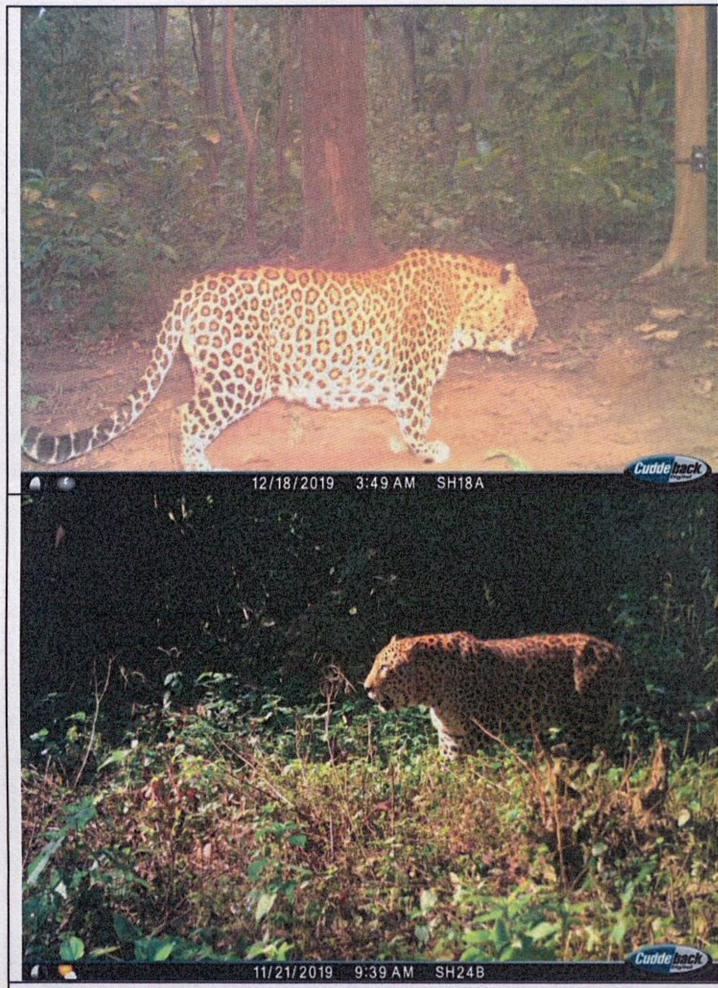


L-BB_2 (Male)

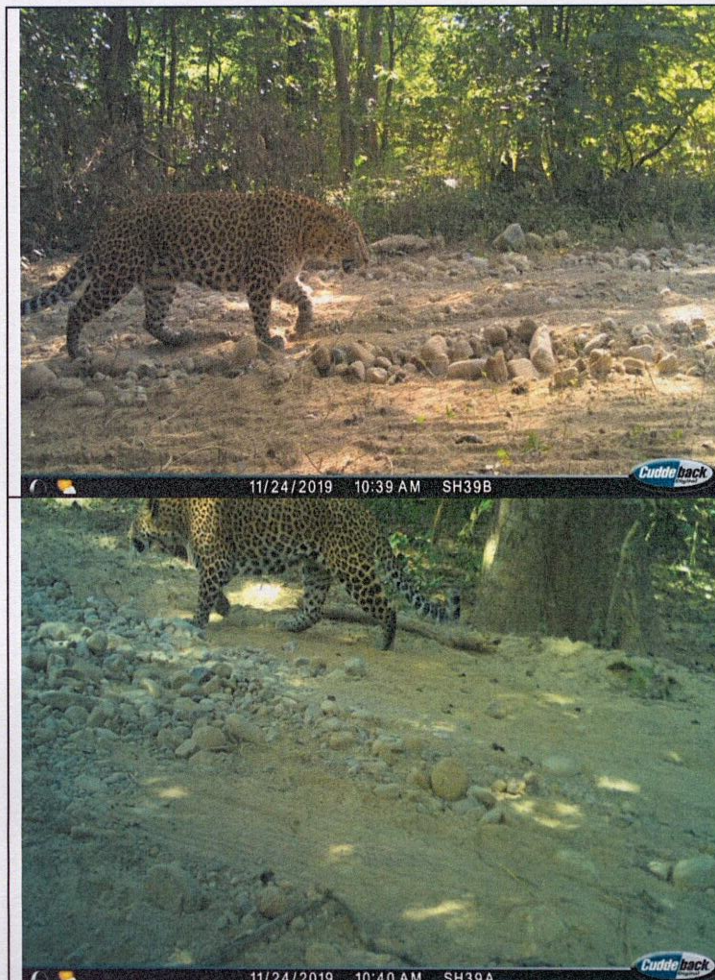


L-BB_3 (Female)

L-BB_4 (Female)



L-BB_5 (Male)



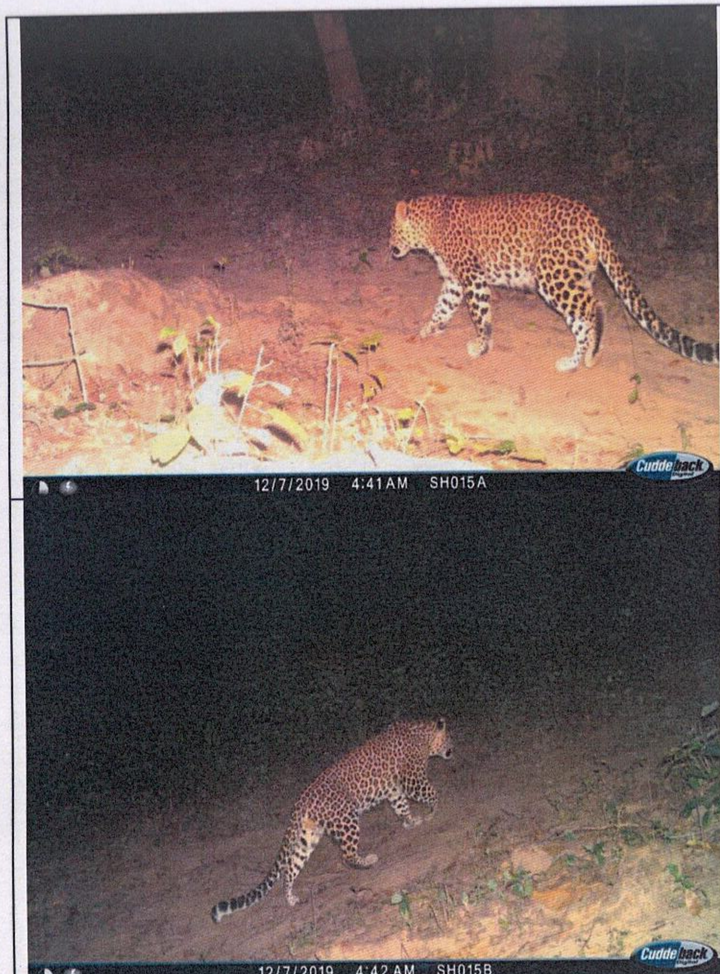
L-BB_6 (Male)

L-BB_7 (Female)

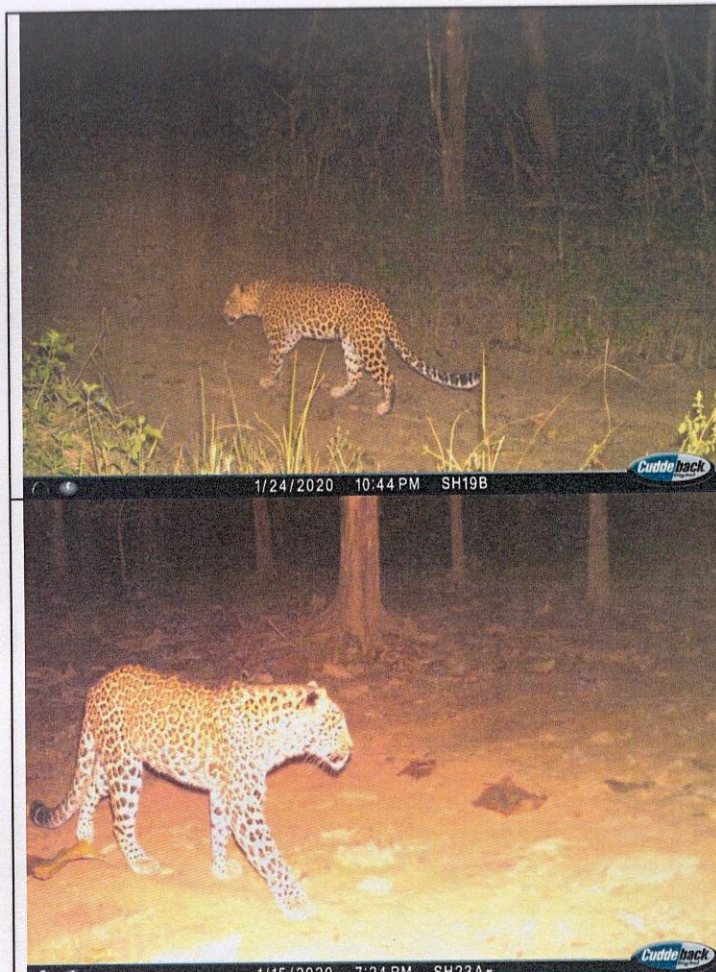
L-BB_8 (Female)

L-BB_9 (Female)

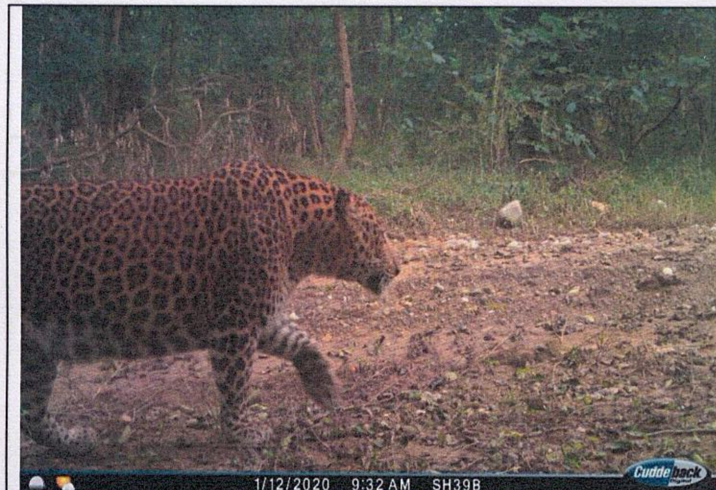
L-BB_10 (Male)



L-BB_11 (Male)

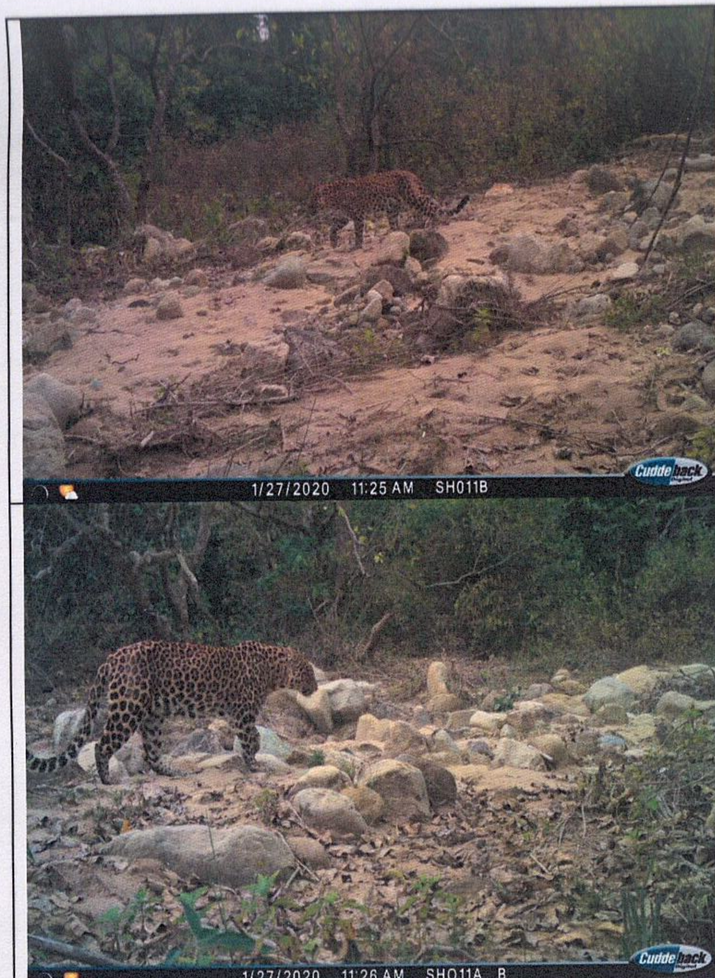


L-BB_12



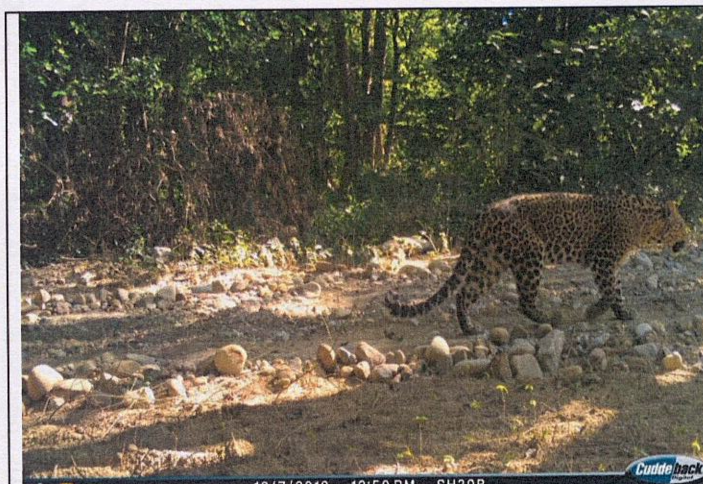
L-BB_13 (Male)

L-BB_14 (Female)



L-BB_15 (Female)

L-BB_16 (Female)



L-BB_17 (Female)

Chapter 5

Assessing the Implications of Habitat Transformations on Human-Large Carnivore Interaction Outside the Protected Areas

Introduction

Humans and wildlife have been co-existing and sustaining their life cycles close to each other since time immemorial. The nature of human-wildlife coexistence depends upon their interaction, which may range from positive to neutral to negative (Frank et al., 2019). It is the negative interaction where anthropogenic losses or loss of wildlife species occur, generally referred to as conflict or Human-Wildlife Conflict (HWC) (Bhatia et al., 2020; Nyhus, 2016; Peterson et al., 2010). It has been considered one of the most significant conservation challenges of the 21st century (Acharya et al., 2016; Barua et al., 2013; Distefano, 2005). The communities living close to the forest habitats have a high probability of Human-Wildlife Interaction (HWI). The rapidly changing demography, socioeconomic context, and environmental factors significantly influence the occurrence and patterns of HWI (Pop et al., 2023).

Rapidly increasing human population and their needs lead to large-scale land-use changes. The landscape level changes and transformation of habitats is a significant concern for large and wide-ranging mammals like tigers, leopards, and elephants. One vital tool for their long-term conservation is establishing Protected Areas (PAs) as secured natural systems to conserve flora and fauna (Kshettry et al., 2017). The global network of PAs amounts to 17% of the total terrestrial surface (UNEP-WCMC, 2023). However, these PAs are often fragmented, isolated, and disconnected from adjoining non-protected forest areas in a human-dominated mosaic landscape (Kshettry et al., 2017; Treves et al., 2006). Assuring the prosperity and peaceful coexistence of communities living with wildlife and on the fringe of these PAs is a significant challenge for sustainable development (Braczkowski et al., 2023; Ogra & Badola, 2008).

Protecting wide-ranging large carnivores is difficult because they frequently prey on valuable livestock on community lands and areas close to protected areas (Braczkowski et al., 2023; Holland et al., 2018; Mustățea & Pătru-Stupariu, 2021). Large carnivores are territorial species and occur at low population densities, requiring vast extant habitats, thus becoming more vulnerable to habitat loss (Poor et al., 2020). Studies highlighted the importance of multi-use landscapes for conserving large carnivores, especially in regions where carnivore ranges overlap with high human-density areas (Kshettry et al., 2017; Naha et al., 2020). One of the critical tasks in carnivore conservation is identifying priority human-carnivore conflict sites and their underlying reasons for effective mitigation strategies (Miller, 2015).

This paper investigates the implications of habitat transformations on the Human-Large Carnivore Conflict (HLCC). It focuses on the changes in habitat attributes of the wildlife corridors and adjoining areas and their influence on large carnivore conservation. The study identifies the priority hotspot sites for large carnivores, i.e. tiger (*Panthera tigris*) and leopard (*Panthera pardus*) conflict, based on the reoccurrence of negative HWI events. We examine the association and effects of the Land-use Land Cover (LULC) changes and other habitat modifications over the years on HLCC hotspots. Habitat transformations affect the ecology of the species in various ways (Carrete et al., 2009; Choi et al., 2017; Medan et al., 2011). Even sympatric species with similar size and behaviour respond differently to human stressors (De Angelo et al., 2011). Understanding the inter-relationship of habitat modifications and HWI is essential to strategize the effective and efficient long-term conservation and coexistence of humans and large mammals.

Materials and Methods

Study Area

The study area is wildlife corridors for large mammals and adjoining forests in the Terai Bhabhar landscape, part of the broader Shivalik corridors (Qureshi et al., 2014, 2023; K. Thapa et al., 2017). It lies in the Terai Arc Landscape (TAL) (Semwal, 2005), east of the Corbett Tiger Reserve (CTR) and west of the Indo-Nepal border in Uttarakhand, India. It is also part of Tiger Conservation Landscape (TCL) Tx2 (TCL_ID: 44) (Dinerstein et al., 2010; WWF & RESOLVE, 2015) and Tiger Habitat Block (THB) II and III (Johnsingh et al., 2004). Three wildlife corridors, i.e., Kosi, Kilpura-Khatima-Surai (KKS), and Boom-Brahmadev (BB) corridor, have been included in the study. The study sites are categorized in the two study blocks for convenience based on spatial location: Block 1- Kosi corridor; Block 2- KKS and BB corridor (Figure 5. 1). Kosi corridor connects CTR with Ramnagar Forest Division (FD) and Pawalgarh Conservation Reserve along the river Kosi east of CTR in Uttarakhand. KKS corridor connects Nandhaur Wildlife Sanctuary (NWLS) in Uttarakhand with Pilibhit Tiger Reserve (PTR) in Uttar Pradesh and the Indo-Nepal border in the Khatima forest range. BB corridor connects NWLS to Kanchanagar FD in Nepal, a transboundary landscape which expands to Sukhlaphanta National Park in Nepal (Qureshi et al., 2023; Semwal, 2005). KKS and BB corridors have interconnected habitats, thus considered together as Block 2 for this study. Kosi corridor comprises parts of the Kosi and Kota Forest ranges in Ramnagar FD, Bijrani, Sarpduli, and Mandal Forest ranges of CTR and the Mohan range of Almora FD. KKS corridor consists of the Kilpura, Khatima, and Surai Forest ranges of Terai East FD, Uttarakhand. BB corridor consists of the Sharda Forest range of Haldwani FD, parts of the Kilpura forest range, and the Dogadi and Boom Forest ranges of Champawat FD in Uttarakhand, India.

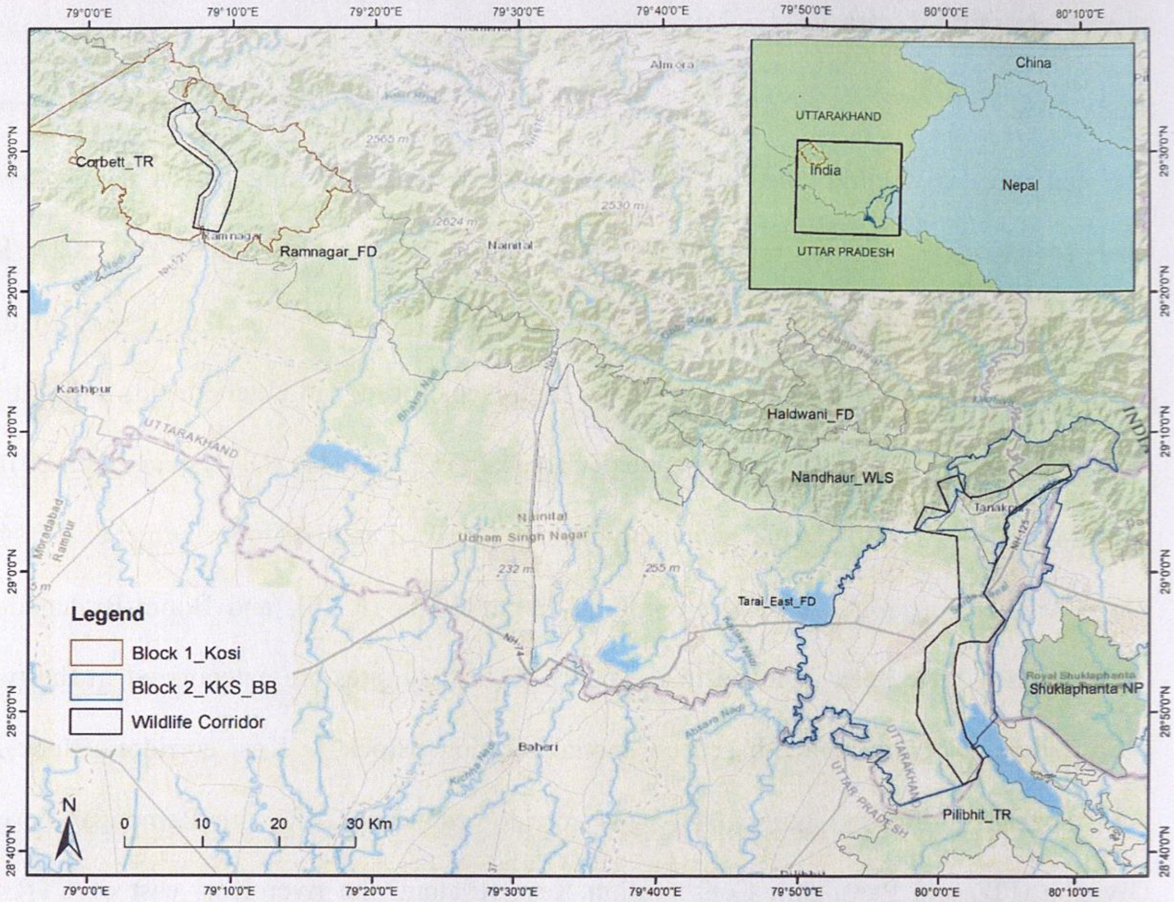


Figure 5. 1: Study area map of the focal wildlife corridors, Kosi and KKS_BB, in the terai arc landscape in Uttarakhand east of Corbett Tiger Reserve to Indo-Nepal border. (KKS: Kilpura-Khatima-Surai, and BB: Boom-Brahmadev)

The major forest types are moist and dry deciduous forests interspersed with alluvial and riverine grasslands (Harihar & Pandav, 2012; Ranjan et al., 2021). Sal forest, Teak forest, and mix forest are majorly found in the landscape comprising of tree species such as *Terminalia alata, Anogeissus latifolia, Lagerstroemia parviflora, Holoptelia integrifolia, Ehretia laevis* and *Aegle marmelos* (Harihar et al., 2014). The crucial large mammal species in the region are Asiatic Elephant (*Elephas maximus), Panthera tigris, Panthera pardus,* Sloth Bear *(Melursus ursinus),* Sambar deer (*Rusa unicolor),* Spotted deer (*Axis axis),* and Northern Red Muntjac (*Muntiacus muntjac*). The study area falls in 2B Himalaya-West Himalaya and 7A Gangetic Plain- Upper Gangetic Plain biogeographic provinces of India (Rodgers et al., 2000). The landscape is also a densely human-populated area with rapid growth and urbanization. The natural vegetation is interspersed with agricultural land and human settlements.

Methodology

Data Collection

The data was collected during the fieldwork under the project funded by the National Mission on Himalayan Studies. We collected the ex-gratia payment records for Human-Wildlife Conflict (HWC) between 2006 and 2020 from the field offices of the Uttarakhand Forest Department (UKFD), with data gaps between 2006 and 2009 at some locations. The data format and details were inconsistent in all the documents; thus, we had to scrutinize and reorganize the data as per the requirements of the study. The record registers contained information such as the incident date, the species involved, the number and type of livestock killed, human casualty/death, victim name or name of livestock owner, and the village/ locality/ forest beat or compartment where the incident occurred (in cases where the incident happened in forest-village fringe areas, only the name of the village was mentioned). We cross-checked the records with forest officials and community members during household surveys. We filtered the data related to large carnivores (tiger and leopard) from the ex-gratia records.

Spatial risk mapping

The number of incidents related to tigers and leopards at each location in each study block was statistically compared using a t-test analysis. This study uses geostatistical techniques to analyze point data in terms of spatial statistics and spatial analysis for risk assessment of their spatial patterns. First, we examined the spatial autocorrelation using Moran's Index (Global Moran's I) through the spatial analyst tool in ArcGIS 10.7 software. The spatial autocorrelation was measured using the global Moran's I statistic, which assesses whether the pattern expressed is clustered, scattered, or random. In the spatial autocorrelation, Global

Moran's I statistic in Block 1, the *p*-value of 0.59 meant we could not reject the null hypothesis, and the *z*-score = 0.53 and Moran's I = 0.04 proves that the distribution of HLCC incidents is not significantly different than random. The Global Moran's I statistic in Block 2 with the *p*-value = 0.75, *z*-score = 0.31, and Moran's I = 0.05 confirmed that incidents are random and have no significant clustering. Similarly, spatial autocorrelation was not significant ($p > 0.05$) for tiger and leopard incidents in both the study blocks. Additionally, incremental spatial autocorrelation failed to identify the distances at which spatial mechanisms favouring clustering were most prominent. Hence, we did not use Hot Spot analysis based on the Getis-Ord Gi* statistic.

Kernel density is an effective GIS analysis that helps identify event hotspots (Ruda et al., 2018; Varghese et al., 2022). We used the Kernel Density Estimation (KDE) technique in ArcGIS 10.7 for mapping the spatial HLCC hotspot based on the intensity and magnitude of the incidence in an area or village (Chamling & Bera, 2020; Ruda et al., 2018). We populated the field with the number of incidences at each location. The geocoordinates of the location of incidence were not available for most of the cases; thus, we used one central geolocation for each village or forest compartment/ beat. Kernel density highlights the area of high intensity and magnitude of the HLCC. The kernel is an estimator that functions by generalizing or smoothing discrete point data into a continuous surface area (Hart & Zandbergen, 2014; Silverman, 2018). The KDE hotspot map was reclassified into five categories: very low, low, moderate, high, and very high-risk zones based on the magnitude and intensity of HLCC incidents (Figure 5.2). The areas with null values have not been mapped in the spatial risk zone maps.

LULC

Analyzing changes in LULC is essential for examining worldwide urban development (Akbar et al., 2019). LULC maps for 2002 and 2022 were prepared using Landsat 7 and 9 satellite images acquired from the USGS Earth Explorer to assess the changes over two decades. We selected 2002 as a reference year because the state of Uttarakhand was formed in 2000, significantly impacting the study area's developmental activities and demography. We considered the satellite images of May month for both years, when the majority of croplands are harvested. The croplands devoid of vegetation make the distinction convenient between grassland, cropland and degraded invasive species forest (Lucas et al., 2007; Prishchepov et al., 2012; Wang et al., 2018), and the cloud cover is minimal during this period. Landsat 9 level 2 product for 2022 and Landsat 7 ETM level 2 product for 2002 WRS_PATH = 145 WRS_ROW = 40 with less than 10% cloud cover were used. LULC classification was done using the Supervised Maximum Likelihood Classification tool in ArcGIS 10.7. The classification was assessed for accuracy based on the kappa coefficient (κ) using random accuracy points (Howard et al., 2023; Rwanga & Ndambuki, 2017). We used the field data on co-variates and location details of vegetation plots and habitat types for the accuracy of training samples. A minimum of 50 data point locations of each class type was used in the training sample.

The study area was classified into eight LULC classes, i.e. 1) Sal_Mix forest comprising of sal, mix, and other broadleaf forest except Teak, (2) Teak forest, (3) Grassland inclusive of riverine grasslands, (4) Degraded forest includes barren forest land due to landslides or erosion or any natural hazards, area under invasive species like lantana, and forest areas disturbed due anthropogenic activities in past, (5) Waterbodies includes all natural and artificial water bodies and canals, (6) Cropland, (7) Built-up, (8) Floodplain and seasonal streams includes monsoon streams, river banks, and dry riverbeds. The classes are based on habitat type use and preference of large carnivores (Habib et al., 2021; Miller, 2015; Mkonyi et al., 2018).

Change Analysis

Transformation of habitat characteristics and composition significantly affect wildlife behaviour and activity (Naha et al., 2020; Poor et al., 2020). All the change analysis has been performed in ArcGIS 10.7. We examined the change in LULC, Enhanced Vegetation Index (EVI), and Night-time Light (NTL) in the wildlife corridor and its adjoining areas. The Change detection in LULC was assessed between 2002 and 2022 over twenty years. The change in EVI was also examined between 2002 and 2022 using MODIS data global 250m (MOD13Q1 V6.1). The EVI minimizes canopy-soil variations and improves sensitivity over dense vegetation conditions. It is crucial to assess the change in the corridor habitat – Greening (improvement in vegetation health) or Browning (degradation of healthy vegetation) (Mallegowda et al., 2015). The NTL change analysis was done between 2012 and 2022 due to the limitation of NTL data availability. We used the annual VIIRS Night-time Lights (VNL) V2.2 for 2022 and V2.1 for 2012 average masked for change analysis (Elvidge et al., 2021). NTL data have been used as a proxy measure for urbanization, human settlements, density and economic growth (Anand & Kim, 2021; Mellander et al., 2015). NTL data records nocturnal emissions of human activities and can be used to measure the urban spatial extent and changes over time (Xi et al., 2022).

Impact analysis

The HLCC hotspot map was overlayed and superimposed over change analysis maps to understand the underlying changes in the area of high conflict frequency and spatial association. Using the data management tool in ArcGIS, we plotted 1000 random points in each study block. Then, we used the Extract Multi values to Point spatial analyst tool in ArcGIS to extract point data for each variable, i.e. EVI, NTL, LULC changes, cattle density using the GLW layer, Leopard conflict intensity, Tiger conflict intensity, and overall HLCC intensity using KDE Hotspot layer. The extracted multiple values for each point were analyzed using a Generalized Linear Model (GLM) to examine the role and implications of EVI change, NTL change, LULC change, and cattle density on HLCC, as well as the effect of sympatric large carnivore species. The GLM was run with Gamma distribution and log link function with KDE hotspot of specific species (Leopard, Tiger, and Large Carnivore combined) as the dependent variable and EVI, NTL, LULC changes, cattle density (GLW) and other sympatric species KDE hotspot as independent variables in IBM SPSS Statistics 23 software to examine their effects on HLCC. The EVI change was categorized as Browning (minimum to -0.1), Greening (0.1 to maximum), and None (-0.1 to 0.1); NTL change was categorized into Increase (1 to maximum), Decrease (-1 to minimum), and No Change (-1 to 1), and these two nominal variables were used as Factors whereas cattle density, LULC change and species KDE hotspot values was used as Covariates in the model. The model with the lowest corrected Akaike's Information Criterion (AICC) was selected to observe the effects of different variables. The model was built with the main effects of EVI change, NTL change, LULC change, cattle density (GLW) as habitat variables, and species KDE hotspots to understand the implication of the sympatric species in tandem with the habitat parameters (Table S 5.7- S 5.14).

Result

The data listed five species (Tiger, Leopard, Elephant, Wild Boar, Sloth Bear) and two taxa (deer and snakes) of wildlife species involved in the human-wildlife conflict as per the incidents reported to the UKFD. The incidents reported for large carnivores, i.e., tiger and leopard, amounted to 1466 from 2006 to 2020, where Block1 had 1060 incidents from 2009–20, and Block2 had 406 incidents reported from 2006–20. Two types of conflict were observed in large carnivores: livestock depredation and human casualty (injury and killing). In Block 1, 48% of cases were of tiger, 7% of leopard, and 45% did not mention species due to lack of confirmed identification. In Block 2, 14% of cases were of tiger, 36% were leopard, and 50% were without confirmed species. In study Block 1, 14 cases of human casualty were reported, of which 10 were due to tigers, and four were due to leopards. In study Block 2, there were 25 cases of human casualty, 19 cases due to tiger and six to leopard. Livestock depredation incidents involve five livestock species, i.e., cow, buffalo, ox, goat, and horse. Leopards also kill domestic or stray dogs, but such cases were not compensated and thus were out of the purview of this study. The lack of awareness and inconsistency in reporting the species involved in incidents pose a serious issue in the comparative analysis of data between tiger and leopard conflict patterns.

Spatial Risk Mapping

For spatial risk mapping, we had 125 input geocoordinate locations of HLCC incidents in Block 1 and 97 locations in Block 2. The number of incidents in these locations significantly differed for tigers and leopards in each study block ($p<0.05$). The density of HLCC events in the KDE hotspot map of Block 1 ranged from 0 to 61.6, and Block 2 ranged from 0 to 6.6 (**Error! Reference source not found.**). The KDE value of leopard-related conflict incidents r anges from 0 – 4.9, and tiger ranges from 0 – 22.8 in Block 1. In Block 2, the leopard KDE ranges from 0 – 2.5, and tiger incidents range from 0 – 0.4. The magnitude of tiger-related negative HWI is substantially low in Block 2. However, the spatial spread of tiger-related priority conflict areas is higher than leopard in both the study blocks (Figure 5.3 and 5.4). The high-risk spatial zones for leopard-related conflict are restricted towards the eastern flank of Block 1 in human-dominated areas away from the Kosi corridor (Figure 5.3). Whereas the tiger high-risk zone covers both the Kosi corridor and eastern flank of study Block 1. In Block 2, the leopard high-risk zone is restricted to the Khatima-Kilpura segment of the KKS corridor and BB corridor areas (Figure 5.4). The number of tiger incidents is significantly higher than the leopard in Block 1. Hence, the overall HLCC hotspot map resembles the tiger hotspot map. However, in Block 2, the HLCC hotspot map is more similar to the leopard hotspot map due to its higher number of incidents than tigers.

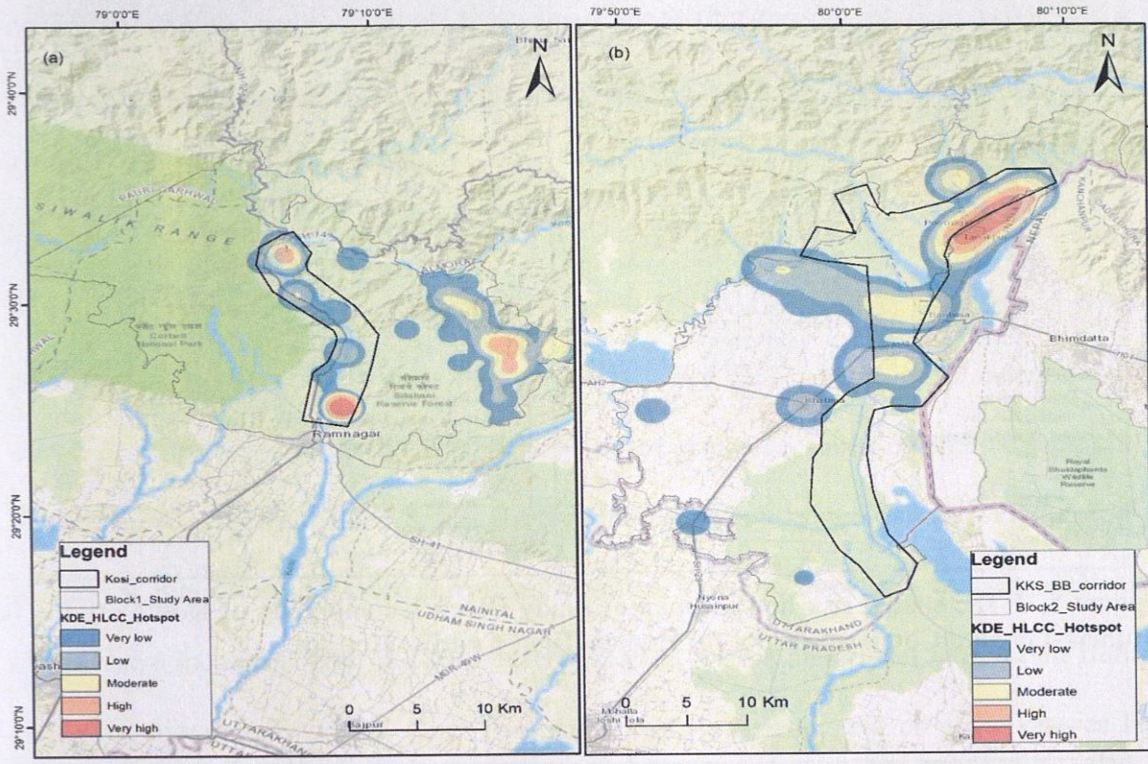


Figure 5. 2 The spatial risk hotspot map of HLCC with five risk zone categories in the study area. (a) Study Block 1 constitutes the Kosi corridor connecting CTR to Ramanagar FD and Pawalgarh Conservation Reserve. (b) Study Block 2 comprises the KKS and BB wildlife corridor network. (HLCC: Human Large Carnivore Conflict, CTR: Corbett Tiger Reserve, FD: Forest Division, KKS: Kilpura-Khatima-Surai, and BB: Boom-Brahmadev)

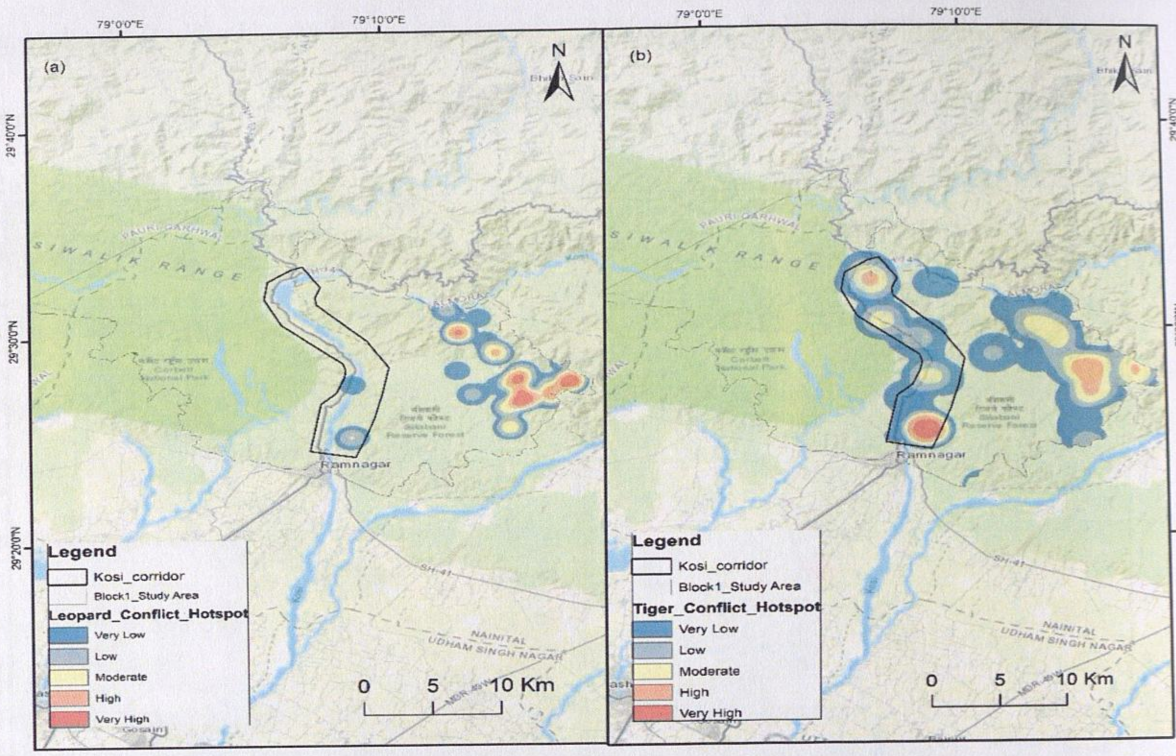


Figure 5. 3 The spatial risk hotspot map of Study Block 1 comprising of Kosi Corridor. (a) Human-Leopard Conflict Hotspot (b) Human-Tiger Conflict Hotspot.

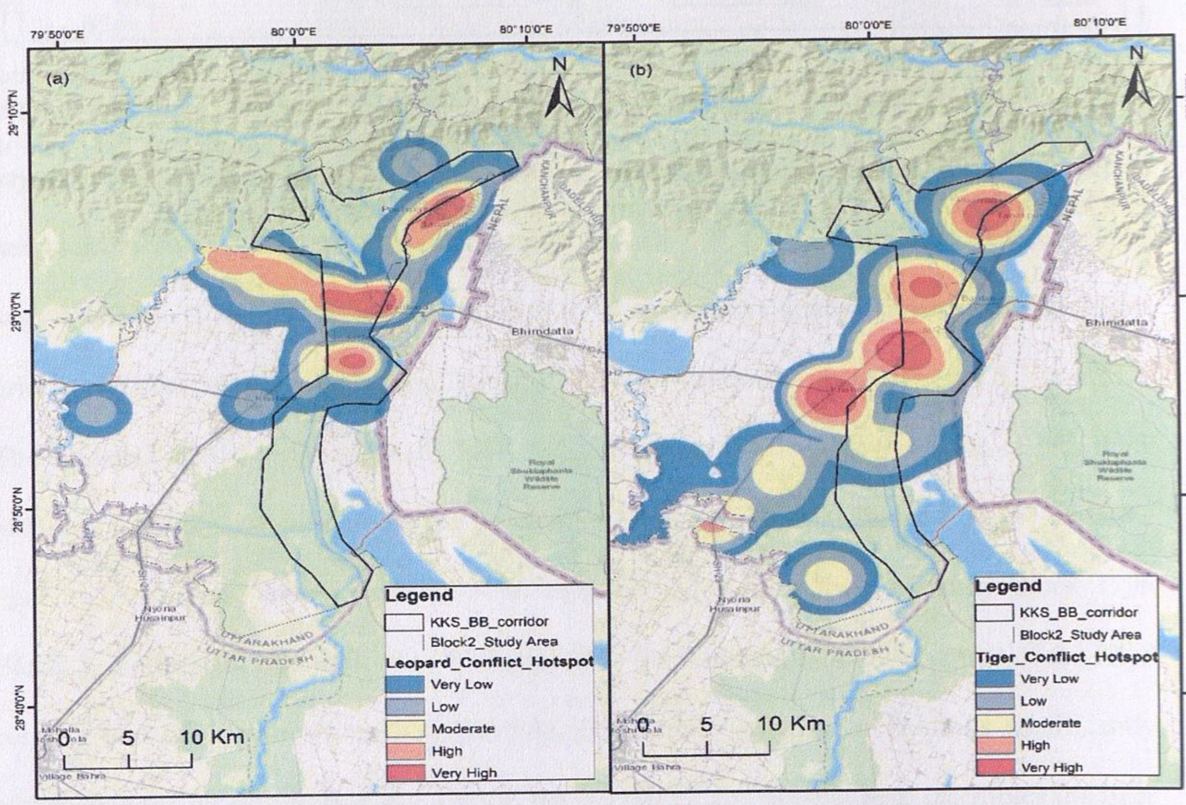


Figure 5. 4 The spatial risk hotspot map of Study Block 2 comprising of Kosi Corridor. (a) Human-Leopard Conflict Hotspot (b) Human-Tiger Conflict Hotspot

LULC Classification

LULC classification was done for 2002 and 2022 to evaluate the habitat transformation in the delineated wildlife corridor and adjoining areas. Eight LULC classes were selected based on habitat preferences and their influence on the wildlife movement of large carnivores. The user accuracy, producer accuracy, overall accuracy, and kappa coefficient for LULC classification of Block 1 and 2 for 2022 is 81% (Table S 5.1 and S 5.2). The dominant class is the Sal_Mix forest in the landscape, which includes all types of woodlands other than teak forests. In Block 1, the sal_mix forest class has decreased since 2002, while other categories have shown an increase, with the highest increase in the degraded forest of approximately 8 sq. Km from 2002 to 2022 (Table S 5.3, **Error! Reference source not found.**). However, in B lock 2, sal_mix forest, degraded forest, waterbodies, built-up, floodplain and seasonal stream classes have increased from the 2002 reference year, with a significant increase in Built-up area of approximately 50 sq. Km. The teak forest, grassland, and cropland classes have decreased, with the highest decrease in teak forest area of approx. 41 sq. Km in Block 2 (Table S 5.4, **Error! Reference source not found.**). The LULC classes change detection b etween 2002 and 2022 in Block 1 and 2 are given in Table S 5.5 and S 5.6, respectively.

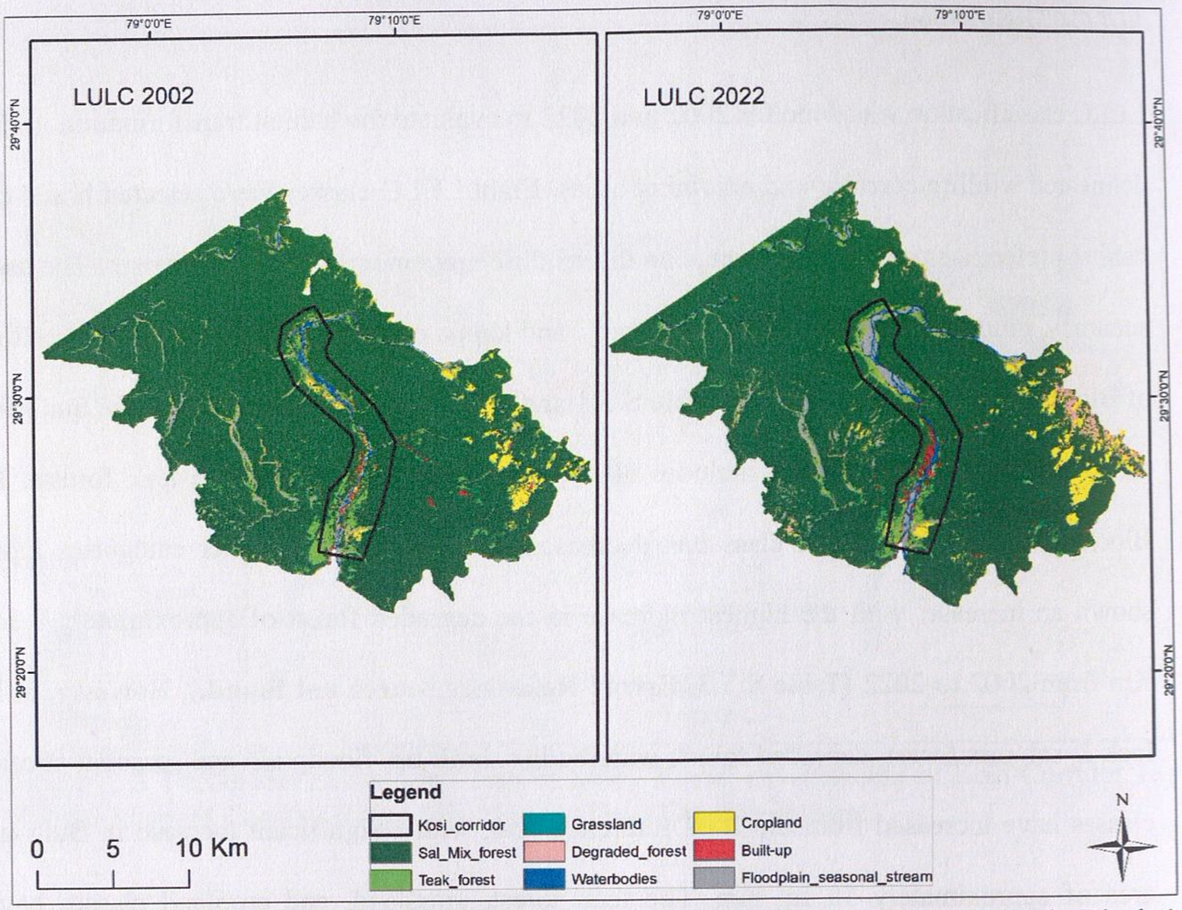


Figure 5. 5 The Land-Use Land-Cover (LULC) map of 2002 and 2022 of the study Block 1 with Kosi corridors.

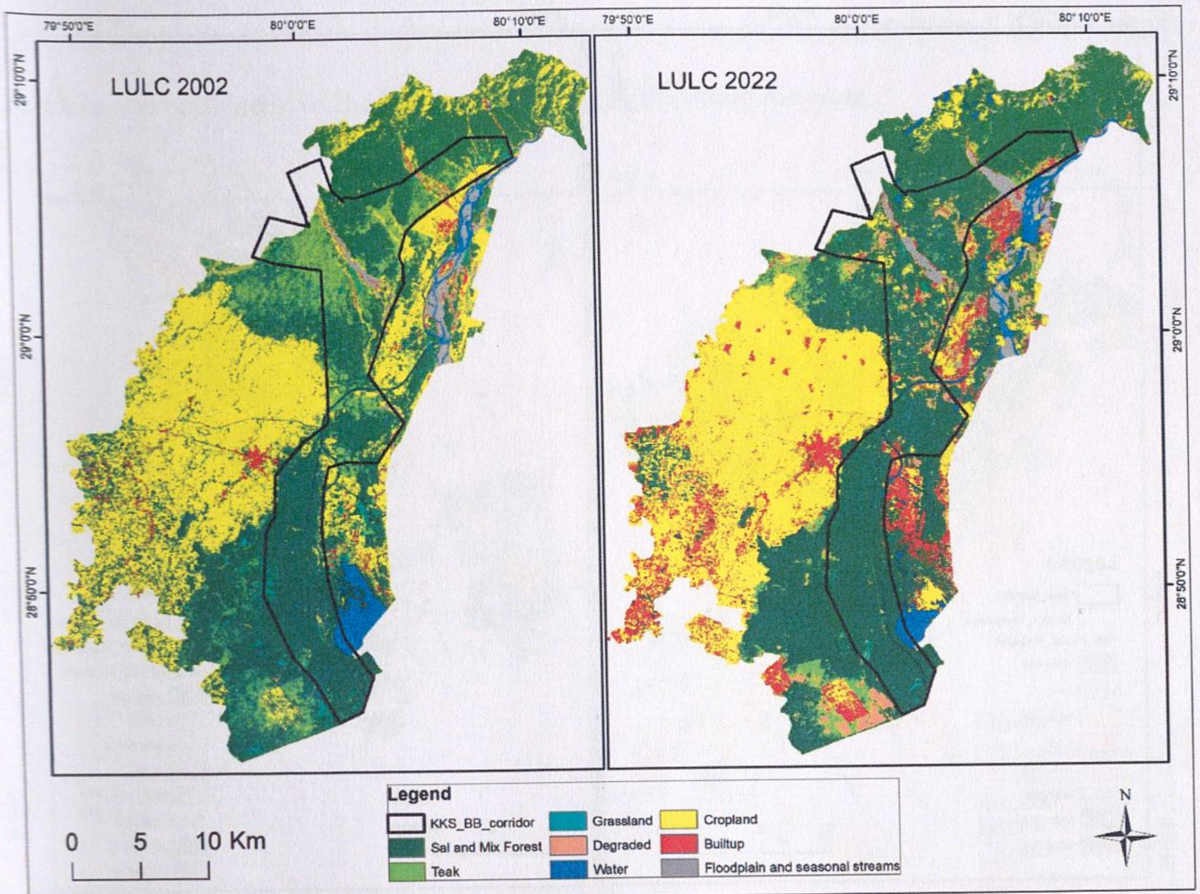


Figure 5. 6 The Land-Use Land-Cover (LULC) map of 2002 and 2022 of the study Block 2 with Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridor

EVI change

The Enhanced Vegetation Index (EVI) change highlights the vegetation cover transformation from 2002 to 2022. The EVI change ranged from -0.21 to 0.35 in Block 1 and -0.22 to 0.3 in Block 2. The EVI change observed in the study area over the twenty-year period is low. The EVI ranges from -1 to +1, and for healthy vegetation, it ranges from 0.2 to 0.8. We remapped the range into Greening (maximum to 0.1) and Browning (minimum to -0.1) areas, overlaying the KDE hot spot map to understand better and assess the vegetation transformation in the high-risk zones and its effects (**Error! Reference source not found.**).

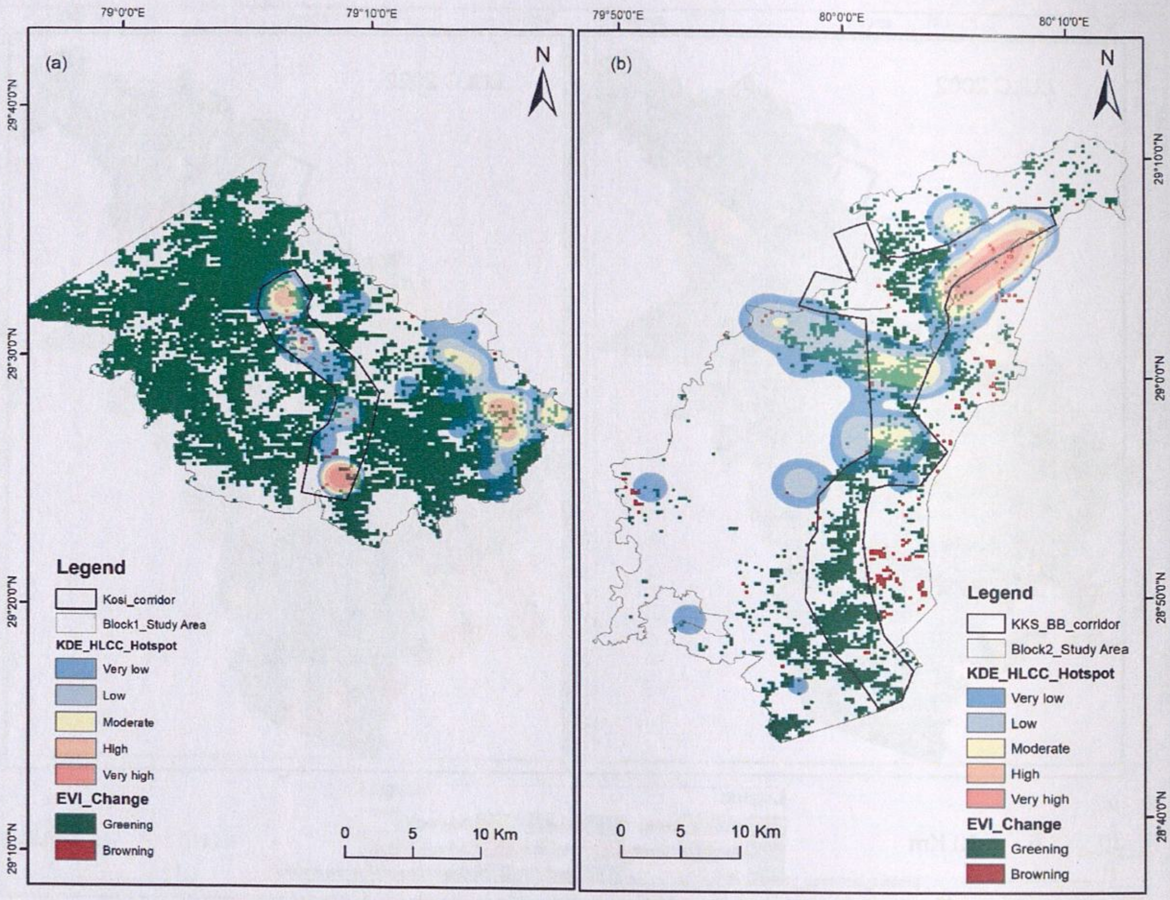


Figure 5. 7 The Enhanced Vegetation Index (EVI) change in the study area shows the Greening and Browning of vegetation over two decades between 2002 and 2022 superimposed with spatial risk zones (HLCC) and delineated wildlife corridors. (a) Study Block 1 with Kosi corridor (b) Study Block 2 with Kilpura-Khatima-Surai and Boom-Brahmadev corridor

NTL change

The change in NTL from 2012 to 2022 shows an increase in light emissions near the high and very high-risk HLCC zones (**Error! Reference source not found.**). The difference in NTL in B lock 1 ranges from 3.71 to -5.44, and 5.11 to -5.51 in Block 2 between 2012 and 2022. We reclassified the NTL change from -1 to +1 for no change, ranging from -1 to minimum as lights out, representing the decreased intensity of light, and 1 to maximum as new lights represent increased light intensity. The decadal change in NTL in the study area is moderate. The NTL increase indicates the expansion and growth of human settlements, activities and development. The increase in night light affects the movement path of wildlife, further squeezing the bottleneck areas. Study block 1 shows increased light, i.e. new lights around the corridors. Study block 2 shows a high increase in lights around the Khatima range, forming the bottleneck of the KKS corridor and areas along the river.

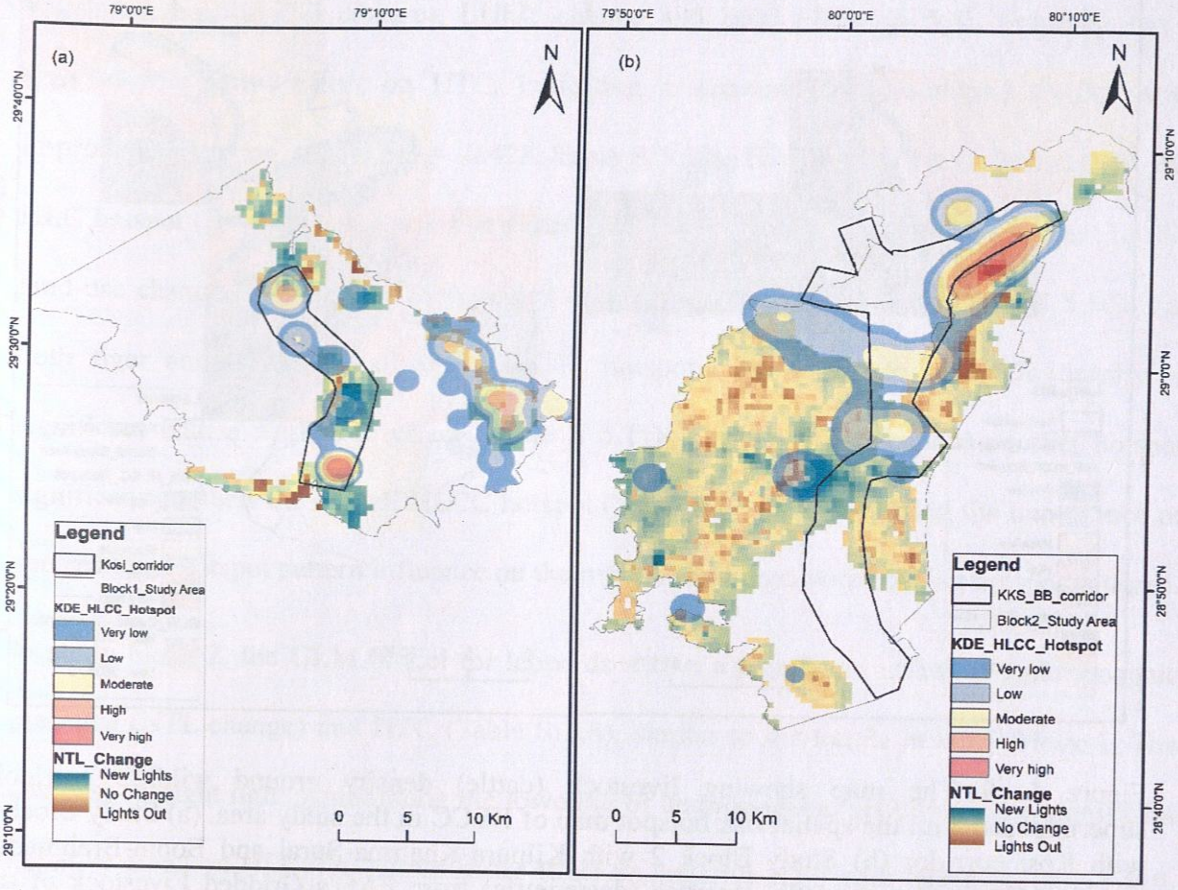


Figure 5. 8 The Night Time Light (NTL) decadal change between 2012 and 2022 in the study area shows the expansion of human activity centres with overlayed spatial risk zone map of HLCC for spatial comparison. (a) Study Block 1 (b) Study Block 2

Cattle distribution in HLCC hotspots

We extracted the study area mask from Gridded Livestock of the World (GLW) v4 with the dasymetric method (DA) for the cattle distribution map. The cattle density (animals per sq. Km) in Block 1 area ranges from 176.51 to 3077.03 and 2539.72 to 5191.98 in study Block 2 (**Error! Reference source not found.**). The livestock density and wildlife incidence sites h ave no statistically significant linear correlation ($p > 0.05$). Spatially, the high-risk zones of HLCC have the highest cattle density in adjoining areas. The GLM analysis also shows no significant effect of cattle density on HLCC hotspot.

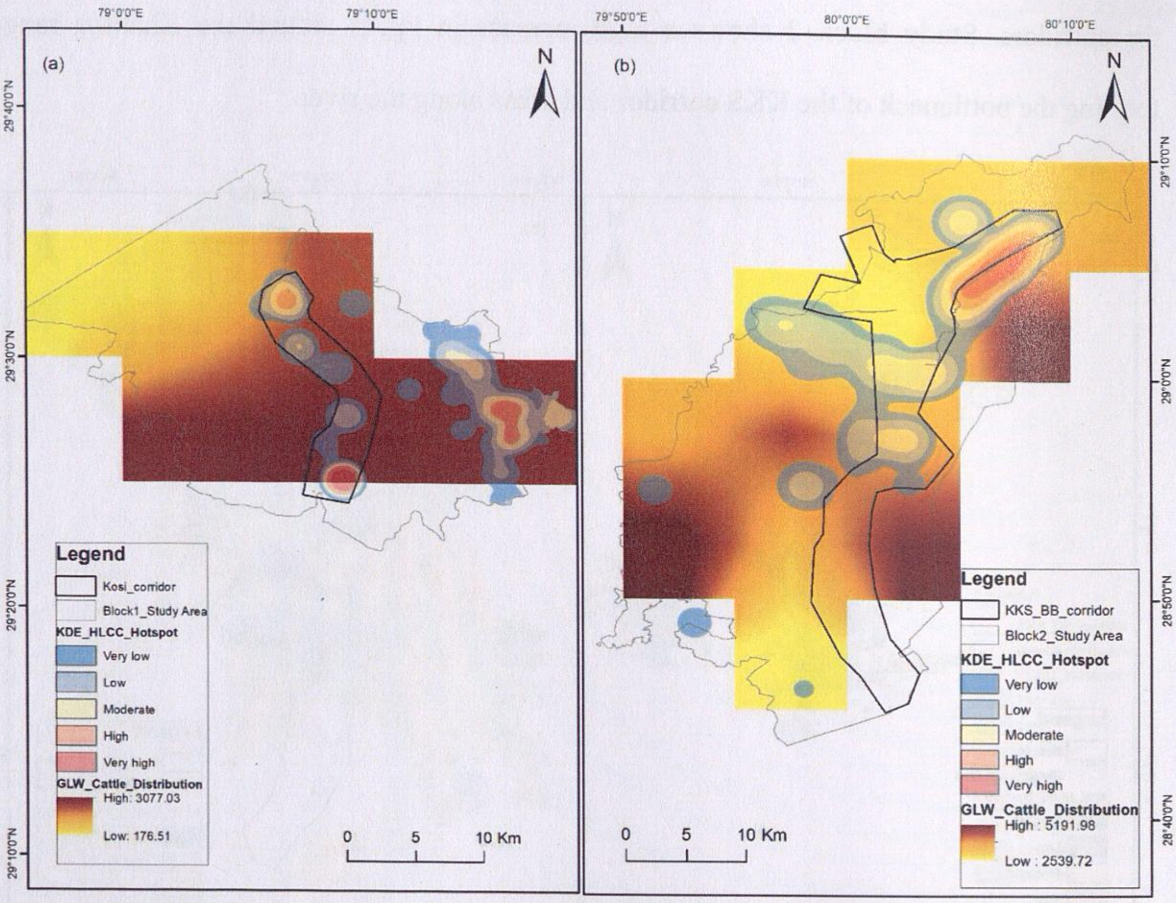


Figure 5. 9 The map showing livestock (cattle) density around wildlife corridors superimposed with the spatial risk hotspot map of HLCC in the study area. (a) Study Block 1 with Kosi corridor (b) Study Block 2 with Kilpura-Khatima-Surai and Boom-Brahmadev corridor. *Data sources* cattle densities (dasymetric) from FAO's Gridded Livestock of the World.

Impact analysis

The models with both habitat and sympatric species effect show better goodness-of-fit with lower AICC than without sympatric species effect, attributing to the influence of species-specific pattern has an important role in shaping spatial HLCC patterns (Table S 5.7). The GLM model in study block 1 for leopards shows a significant ($p<0.05$) effect of anthropogenic activity presence (NTL change) and Human-Tiger Conflict (HTC) hotspot on the Human-Leopard Conflict (HLC) hotspot (Table S 5.8). The decrease in night light shows a significant negative effect on the HLC, indicating the decrease in leopard conflict with the removal of anthropogenic settlements and disturbance in the forested habitats (B = -1.266,

Table S 5.9). The HTC hotspot showed a significant positive effect on HLC (B = 0.114, Table S 5.9). The tiger-related conflict model in study block 1 shows a significant effect of vegetation health (EVI change), LULC change and HLC (Table S 5.8). Greening has a significant negative effect on HTC, indicating a decrease in tiger-related conflict with improved vegetation quality (B = -0.428, Table S 5.10). The LULC change (B = 0.012) and HLC hotspot (B = 0.871) show a significant positive effect on the tiger conflict sites, i.e. the land-use change has an incremental effect on the tiger conflict hotpots (Table S 5.10). For both tiger and leopard combined (HLCC) hotspots, the influence of cattle density is significant with a negligible effect (Table S 5.11). The tiger and leopard conflict hotspot significantly affects the overall HLCC hotspot (Table S 5.11), highlighting the importance of species-level hotspot pattern influence on the overall large carnivore conflict hotspot patterns. In study block 2, the GLM model for leopards shows a significant effect of anthropogenic presence (NTL change) and HTC (Table S 5.8), similar to the trends in study block 1. The decrease in night light symbolizing the lowering of anthropogenic activities has a significant negative effect on HLC, i.e., diminishing effect on negative HWI with leopards (B = -1.119, Table S 5.12). The HTC hotspot shows a significant positive effect on the HLC hotspot (Table S 5.12). The model for the tiger in study block 2 shows a significant positive effect of the decrease in night light, indicating higher HTC in areas with lower anthropogenic activity (B= 0.569, Table S 5.13). The HLC hotspot also has a significant positive effect on HTC in study block 2 (B= 0.668). The cattle density also shows a significant negligible effect on HTC (Table S 5.13). The model for overall HLCC (combined tiger and leopard) in study block 2 shows a significant effect of vegetation quality improvement (Greening), HLC and cattle density (Table S 5.8 & S 5.14). The improvement in vegetation quality (Greening) has a significant negative effect on HLCC (B= -0.441), indicating that healthy vegetation areas have low HLCC intensity. The HLC had a significant positive effect on HLCC (B= 2.412), whereas the effect of HTC was not significant on HLCC in study block 2. The effect of cattle density on HLCC is significant but negligible (Table S 5.14).

Discussion

Our results highlight the significant implications of habitat transformations on large carnivore conflict spatial hotspots, which also vary with species and region. The study blocks had varied effects of habitat change on tiger and leopard conflict hotspots. The habitat implications on HLC hotspots show a similar trend in both the study blocks for leopards, where the HLC is lower in areas where anthropogenic activities have decreased from the past (decrease in NTL change), highlighting that a decrease in anthropogenic disturbance can improve the coexistence (Table S 5.9 & S 5.12). An earlier study on leopards also shows that animals residing in sparsely human-populated areas tend to avoid proximity to human settlements, while animals living in densely populated areas come closer to the settlements for food during the night (temporal partitioning), avoiding encounters with humans (Odden et al., 2014). The sparse human settlements in wildlife corridor areas provide better permeability for safe wildlife movement, which is critical for minimizing the negative HWI (Theobald et al., 2012). The significant positive effect of HTC hotspots on HLC hotspots and vice-versa in both the study blocks infers spatial overlap and common critical (high-risk zones) conflict hotspot areas of these two sympatric species in the landscape, which is also clearly visible in the species hotspot map (Figure 5.3 & 5.4).

Our findings show that the vegetation quality is crucial for minimizing the negative HWI, as highlighted by the model for HTC in study block 1, which indicates that improvement of vegetation health (Greening) has a diminishing effect on tiger-related conflict hotspots (Table S 5.10). This model also reveals the importance of land-use changes, which have an incremental effect on negative HWI, possibly due to rapid development to which species cannot adapt and reduced habitat permeability. Land use changes affect habitat quality, cascading over the natural prey base of large carnivores (Coon et al., 2019; Dorresteijn et al., 2015; Yang, 2021). The growth of hotel and resort businesses in Kosi corridor areas in the last decade was rapid, substantially reducing the permeability of the corridor and increasing night traffic and human presence.

In study block 2, the model reveals that the HTC increases in areas where anthropogenic activity (NTL change) has decreased (Table S 5.13), which may be attributed to the location of tiger-related incidents, mainly inside the forest areas. Most of the negative HWI with tigers in KKS and BB corridor areas have been reported from the forested habitats while grazing or fuelwood collection (Ranjan, Unpubl.). The effect of cattle density is significant, with near-zero values in the HTC and HLCC model, which may have a small-scale direct impact on the negative HWI (Table S 5.11, S 5.13, & S 5.14). However, the indirect impact of livestock through habitat degradation and resource competition with wildlife may have far-reaching implicit consequences affecting the structural and functional level of prey-predator dynamics with anthropogenic elements acting as a third pillar (de Souza et al., 2018; Dorresteijn et al., 2015; Lee et al., 2024; Nickel et al., 2020). The improvement of vegetation health has a diminishing effect on HLCC, as shown in study block 2 (Table S 5.14), as the human sprawl in this area is extensive, affecting the quality of forest and habitat. Hence, enhancing vegetation health provides a conducive environment for elusive large carnivore species. The demographic conditions of Block 2 are different from Block 1, with more dense human habitation, industries and high anthropogenic pressure on forest-like grazing and Non-Timber Forest Produce (NTFP) collection.

The models for which implications of habitat changes like deterioration of vegetation health (Browning), increase in human activity (increase in NTL), and LULC change are not significant does not mean that they do not influence the HWI. It might be statistically nonsignificant due to variations, but the coefficient value indicates its positive and negative impacts on HLCC, which is true in an ecological sense. The impact of habitat changes on wildlife is not always direct and perceivable in a short duration (Nielsen et al., 2010; Shannon et al., 2016). Studies have tried to establish the relationship between HWC and habitat characteristics, socioecological factors, and anthropogenic disturbances, which are not always strongly and linearly correlated (Dickman, 2010; Linuma et al., 2022; Miller, 2015; Treves et al., 2006; van Eeden et al., 2018). The species' relationship to their habitat in a natural ecosystem is complex, direct, indirect, non-linear, and multi-faceted. The study also highlights the importance of considering the role of sympatric species while understanding and determining the underlying factors and patterns of HWI, as all the models show better fitness and significant effects of sympatric large carnivore species.

Our study found that the HLCC in the eastern terai landscape of Uttarakhand is mainly due to tiger and leopard, which have the major share of livestock depredation. Human casualties are chiefly related to tigers, with most incidents happening in forest areas during NTFP collections or due to sudden encounters. Higher tiger incidents in Block 1 can be attributed to high tiger density in Corbett Tiger Reserve (CTR) and adjoining areas (Bargali & Ahmed, 2018; Qureshi et al., 2023). The tiger density in CTR is the highest in India amongst all the PAs (Qureshi et al., 2023). The tiger density in study Block 2 is lower than in Block 1; however, the density has recently increased (Qureshi et al., 2023). The buffer areas of NWLS and PTR around the KKS and BB corridor are dotted with human settlements, both legal and encroachment, and are frequently fragmented due to anthropogenic disturbances, which may be crucial factor for higher human casualties in Block 2 than in Block 1. The higher human casualties related to tigers than leopards may also be attributed to the different behavioural attributes of these two sympatric predators (Löe & Röskaft, 2009; Naha et al., 2021). Generally, leopards avoid direct human confrontation (Naha et al., 2021; Odden et al., 2014).

Leopards are more adaptable and conveniently manoeuvre the human-dominated landscape than tigers (Corlett, 2011; Puri et al., 2022). The increased anthropogenic disturbances in the natural ecosystem of wildlife species also affect their behaviour and nature of response towards human presence (Gaynor et al., 2018; X. Li et al., 2022).

Communities living around forest areas depend on forest resources for fuelwood, fodder, livestock grazing, and other domestic needs of the household where socioeconomic conditions are not good (Malik et al., 2014; Manral et al., 2016; S. Thapa & Chapman, 2010). The increasing human population and expansion lead to habitat encroachment, sometimes favoured by political scenarios (Dickman, 2010), as in the case of our study area. The livestock herding and rearing are majorly dependent on forest resources, and few pastoralist communities in our landscape, like *Van Gujjars,* depend entirely on forest fodder for their livestock and *Bakrawal* (Sheep and mountain goat herders) in the winter season move to lower elevations of Shivaliks and Terai. It significantly increases the foraging competition between wild ungulates and livestock, restricting the availability of natural forage for wildlife species (Ranjan et al., 2024). It also affects the prey base availability and preference of available prey for top predators like tigers and leopards (Bhattarai & Kindlmann, 2018; Roberts et al., 2021). These anthropogenic interference and disturbances are very high outside PAs and affect the habitat use patterns of wildlife species (Lee et al., 2024; Nickel et al., 2020). The increased livestock pressure decreases the availability of foraging pasture grounds for wild prey populations in the forest habitats, forcing prey species to move towards agricultural fields and villages for food (Athreya et al., 2013b; Naha et al., 2021; Odden et al., 2014).

The study shows land-use changes over two decades, and we have observed low to moderate changes in vegetation cover and LULC patterns in our study blocks. The built-up land-use class has increased significantly in Block 2, highlighting the increase in human footprint and population in the Terai. In Block 1, the sal and mix forest has declined since 2002, with a significant rise in degraded forest. The degradation of habitat quality is mainly due to erosion, invasive plant species like *Lantana camara* and *Ageratina adenophora,* and vegetation loss due to anthropogenic disturbances, which are significant problems for the sanctity of wildlife habitats (Miller et al., 2016; Naha et al., 2020). The diversity of habitats is favourable for wildlife species, especially large mammals like tigers and leopards, which also provides resilience to the ecosystem to sudden changes (Bhattarai & Kindlmann, 2018; Pillay et al., 2011). However, the increasing human population and rapid change in LULC patterns in the terai landscape are concerns about wildlife conservation outside PAs in a human-dominated mosaic landscape. Land-use changes, degrading vegetation quality or health, and growth in human footprints negatively affect the wildlife corridor and movement, acting as stressors for wildlife species (Frey et al., 2017; Nyhus, 2016). Abundant livestock around wildlife habitats and corridors also induce behavioural plasticity of large carnivores for easy livestock prey, especially in areas with low natural prey bases (Bhattarai & Kindlmann, 2018). The increasing human-induced pressure on wildlife habitats and corridors has a funnelling effect, creating tight bottlenecks (Rudnick et al., 2012; Zhuo et al., 2022). It affects the permeability of the corridors and hinders free and safe wildlife movements.

Conclusion

Our research focuses on the issues and spatial factors responsible for negative human-large carnivore interaction outside PAs in the wildlife corridor habitats of human-dominated landscapes. The study has clearly highlighted that the implications of habitat changes are significant for HLCC and the role of sympatric species in shaping these patterns. The implications of habitat changes vary with the landscape and regional attributes, as observed in our study at two sites with varied underlying factors other than habitats. The study identifies the priority sites for HLCC risk based on the wildlife attacks over the last ten years. The landscape is rich in biological diversity and human population, which presents a challenging scenario for long-term conservation and coexistence. The efforts of governments, organizations, researchers, institutions, and conservationists have yielded positive results for wildlife protection and conservation in India, with the increase in the population of tigers and co-predators like leopards. However, it has also brought a more significant challenge of accommodating conservation needs with human needs in a sustainable way with the peaceful coexistence of man and the species.

Using wildlife attack data for the study provides a better and more empirical understanding of the issues of HWC on local and regional scales. However, the lack of precise location of incidence affects the accuracy of analysis and hotspot identification. The study goes beyond the statistical methods to explore and examine the factors playing a vital role in the negative HWI. It highlights the significance of wildlife corridors and their ecological sanctity for long-term conservation. Maintaining the balance between development and habitat protection should be our utmost priority for conserving large mammals. We recommend:

- Proper documentation and more detailed record keeping of HWC cases using technology with the precise location of incidents to assess spatial factors and variables responsible for HWC. Documentation and long-term data regarding HWC can reveal key variables for conflict.
- To safeguard and restore the habitats in wildlife corridors and adjoining areas, maintaining the ecological integrity of the wildlife corridors through protecting forest habitats from encroachment and diversion towards non-forestry land use.
- To check the construction and concrete spread near wildlife corridor habitats is critical.

- Awareness of local communities and stakeholders involved in conservation to adapt to sustainable lifestyle choices and livelihood activities reducing pressure on forest resources and decreasing the vulnerability of communities towards HWC.
- To provide legal protection status to delineated wildlife corridors like PAs.
- The plantation schemes being implemented in the wildlife corridor areas should also focus on the wildlife values while selecting the plant species and planning of harvest cycle to minimize the disturbance and displacement of wild species from the forest areas during harvesting operation. The habitat improvement or management plan should be aligned and coordinated with the revenue-oriented timber extraction and plantations like Sal Assisted Natural Regeneration (ANR) plots which is prevalent in the study area and provides safe habitats for breeding individuals of large carnivores and other fauna.
- Grazing in the grasslands and natural succession should be strategically regulated and managed to protect and restore the grassland habitats.
- Forest fire management is also crucial in the wildlife corridors which lies mostly outside the PAs. Forest fire can prove critically detrimental for habitats in bottleneck areas of the corridors causing seasonal or long-term displacement and change in movement routes of the wildlife species. This can lead to increased chance of negative HWI in nearby forested habitats where displaced wildlife will be forced to move.

Supplementary Information

Table S 5. 1 Confusion matrix of the 2022 LULC map of the study Block 1 showing the overall accuracy and Kappa statistics. (C_1- Sal_Mix forest, C_2 - Teak forest, C_3 - Grassland, C_4 - Degraded forest, C_5 - Waterbodies, C_6 - Cropland, C_7 - Built-up, C_8 – Floodplain and seasonal streams)

Class Value	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total	U_Accuracy
C_1	196	2	3	3	0	0	0	0	204	0.960784
C_2	0	9	1	0	0	0	0	0	10	0.9
C_3	1	2	7	0	0	0	0	0	10	0.7
C_4	1	0	0	9	0	0	0	0	10	0.9
C_5	1	0	1	0	8	0	0	0	10	0.8
C_6	0	0	0	1	0	9	0	0	10	0.9
C_7	0	0	0	0	0	0	6	4	10	0.6
C_8	1	0	1	0	0	1	1	10	14	0.714286
Total	200	13	13	13	8	10	7	14	278	0
P_Accuracy	0.965517	0.692308	0.538462	0.692308	1	0.9	0.75	0.642857	0	
Overall Accuracy	**0.913669**									
Kappa	**0.812837**									

Table S 5. 2 Confusion matrix of the 2022 LULC map of the study Block 2 showing the overall accuracy and Kappa statistics. (C_1- Sal_Mix forest, C_2 - Teak forest, C_3 - Grassland, C_4 - Degraded forest, C_5 - Waterbodies, C_6 - Cropland, C_7 - Built-up, C_8 – Floodplain and seasonal streams)

Class Value	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total	U_Accuracy
C_1	117	5	3	2	0	3	2	1	133	0.8796992
C_2	0	12	0	2	0	1	0	0	15	0.8
C_3	2	0	8	0	0	0	0	0	10	0.8
C_4	0	0	0	10	0	0	0	0	10	1
C_5	1	0	0	0	9	0	0	0	10	0.9
C_6	4	0	0	1	2	81	3	2	93	0.8709677
C_7	0	0	0	0	0	3	18	1	22	0.8181818
C_8	0	0	0	2	0	1	0	12	15	0.8
Total	128	12	11	17	12	96	15	12	308	0
P_Accuracy	0.965517	0.692308	0.538462	0.692308	1	0.9	0.75	0.642857	0	
Overall Accuracy	**0.866883117**									
Kappa	**0.813806729**									

Table S 5. 3 The area distribution of LULC in Block 1 in the 2002 and 2022 data sets and change over 20 years (in sq. Km and percentage)

Class Name	Area 2002 (sq. Km)	Area 2022 (sq. Km)	Area change (2002 - 2022)	Percent Change (%)
Sal_Mix forest	440.41	425.99	-14.419763	-3.27
Teak_forest	11.02	12.63	1.612992	14.64
Grassland	0.10	0.54	0.441022	462.98
Degraded_forest	0.02	8.42	8.391567	33767.52
Waterbodies	6.95	7.27	0.31905	4.59
Cropland	12.97	13.84	0.874848	6.75
Built-up	2.14	3.09	0.949291	44.34
Floodplain_seasonal_stream	25.82	27.64	1.813959	7.02

Table S 5. 4 The area distribution of LULC in Block 2 in the 2002 and 2022 data sets and change over 20 years (in sq. Km and percentage)

Class Name	Area 2002 (sq. Km)	Area 2022 (sq. Km)	Area change (2002 - 2022)	Percent Change (%)
Sal_Mix forest	398.54	401.56	3.01	0.76
Teak_forest	70.78	28.84	-41.93	-59.25
Grassland	13.26	2.11	-11.15	-84.10
Degraded_forest	0.32	17.97	17.65	5546.62
Waterbodies	25.61	29.04	3.42	13.37
Cropland	316.46	280.53	-35.92	-11.35
Built-up	12.97	63.15	50.18	386.93
Floodplain_seasonal_stream	26.72	41.45	14.73	55.10

Table S 5. 5 The LULC classes change matrix between 2002 and 2022 in Block 1. (all values are in sq. Km)

LULC Classes	Built-up	Cropland	Degraded forest	Floodplain or seasonal_stream	Grassland	Sal and Mix Broadleaf forest	Teak forest	Water bodies
Built-up	0.328	0.408	-	0.659		1.343	0.130	0.219
Cropland	0.201	6.648	0.002	1.828	0.000	4.957	0.132	0.068
Degraded forest	0.017	0.669	0.004	0.887	0.001	6.450	0.205	0.163
Floodplain or seasonal_stream	0.318	1.643	0.010	11.668	0.006	9.824	1.701	2.439
Grassland	0.001	0.002	0.001	0.077	0.005	0.284	0.163	0.003
Sal and Mix Broadleaf forest	0.954	2.645	0.006	5.547	0.074	410.915	4.252	1.460
Teak forest	0.090	0.675	0.003	2.429	0.010	5.021	4.269	0.123
Waterbodies	0.229	0.263		2.693		1.450	0.157	2.464

Table S 5. 6 The LULC classes change matrix between 2002 and 2022 in Block 2. (all values are in sq. Km)

LULC classes	Built-up	Cropland	Degraded forest	Floodplain or seasonal streams	Grassland	Sal and Mix Broadleaf forest	Teak forest	Water bodies
Built-up	4.126	37.402	0.047	2.332	1.080	14.779	1.717	1.519
Cropland	3.265	213.952	0.078	5.333	1.803	46.503	5.023	4.324
Degraded forest	0.052	2.109	0.029	0.106	0.897	7.433	7.227	0.107
Floodplain or seasonal streams	2.117	14.686	0.012	10.682	0.643	9.714	2.053	1.451
Grassland	0.004	0.148	0.000	0.003	0.235	1.182	0.532	0.002
Sal and Mix Broadleaf forest	2.620	39.468	0.113	2.747	7.109	300.162	43.711	5.397
Teak forest	0.115	4.063	0.020	0.307	0.719	13.304	10.174	0.114
Waterbodies	0.647	4.262	0.019	5.164	0.749	5.206	0.296	12.658

Table S 5. 7 Goodness of Fit of GLM models for implications on different species hotspot (dependent variable) in both the study blocks. [Model variables: Habitat = (intercept), EVI_Change, NTL_Change, LULC_Change, and GLW_Cattle_density; Leopard = KDE_Hostpot of Leopard only; Tiger = KDE_Hostpot of tiger only; Large Carnivore = combined leopard and tiger KDE_Hostpot]

Study Blocks	Species (Dependent variable)	Models	Akaike's Information Criterion (AIC)	Finite Sample Corrected AIC (AICC)	Bayesian Information Criterion (BIC)
Block 1	Leopard	Habitat	175.365	175.788	190.351
		Habitat+Tiger	162.544	163.14	180.527
	Tiger	Habitat	1376.599	1376.809	1400.637
		Habitat+Leopard	1014.819	1015.181	1046.869
	Large Carnivore	Habitat	1619.672	1619.956	1647.665
		Habitat+Tiger+Leopard	1377.354	1377.812	1413.345
Block 2	Leopard	Habitat	88.032	88.321	115.884
		Habitat+Tiger	47.765	48.138	79.596
	Tiger	Habitat	-2196.471	-2196.27	-2159.804
		Habitat+Leopard	-2249.538	-2249.286	-2208.288
	Large Carnivore	Habitat	218.288	218.508	254.274
		Habitat+Tiger+Leopard	-128.684	-128.347	-83.702

Table S 5. 8 Tests of model effects (selected GLM) of different factors and covariates in both the Study Blocks on conflict hotspot of leopard, tiger, and large carnivore (both tiger and leopard). (GLW_cattle_D denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Study Blocks	Species (Dependent variable)	Models	Type-III	EVI_Change	NTL_Change	Tiger_KDE	Leopard_KDE	LULC_Change	GLW_Cattle_D
Block 1	Leopard	Habitat+Tiger	Wald Chi-Square	0.004	4.688	13.247	N/A	3.255	.a
			p-Value	0.948	**0.030**	**0.000**	N/A	0.071	.
	Tiger	Habitat+Leopard	Wald Chi-Square	6.669	1.026	N/A	31.393	5.691	1.466
			p-Value	**0.036**	0.311	N/A	**0.000**	**0.017**	0.226
	Large Carnivore	Habitat+Tiger+Leopard	Wald Chi-Square	0.495	0.568	106.989	10.232	0.032	8.027
			p-Value	0.781	0.451	**0.000**	**0.001**	0.857	**0.005**
Block 2	Leopard	Habitat+Tiger	Wald Chi-Square	1.878	18.128	41.654	N/A	1.438	0.307
			p-Value	0.171	**0.000**	**0.000**	N/A	0.230	0.579
	Tiger	Habitat+Leopard	Wald Chi-Square	0.174	7.406	N/A	46.806	3.138	30.807
			p-Value	0.917	**0.025**	N/A	**0.000**	0.077	**0.000**
	Large Carnivore	Habitat+Tiger+Leopard	Wald Chi-Square	5.457	0.328	2.820	265.168	0.976	14.625
			p-Value	0.065	0.849	0.093	**0.000**	0.323	**0.000**

a. Unable to compute due to numerical problems

Table S 5. 9 Generalized Linear Model (GLM) parameter estimates of independent variables whose effects have been tested on Human-Leopard Conflict hotspot in Study Block 1. (B is coefficient, sig. is p value for significance, df is degree of freedom, GLW_cattle denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval Lower	95% Wald Confidence Interval Upper	Hypothesis Test Wald Chi-Square	Hypothesis Test df	Hypothesis Test Sig.
(Intercept)	-1.070	.2152	-1.492	-.648	24.733	1	.000
[EVI_Change_block1=Greening]	.015	.2251	-.427	.456	.004	1	.948
[EVI_Change_block1=None]	0[a]	.	.	.	.	.	.
[NTL_Change_block1=Decrease]	-1.266	.5848	-2.412	-.120	4.688	1	**.030**
[NTL_Change_block1=No Change]	0[a]	.	.	.	.	.	.
Tiger_KDE_block1	.114	.0314	.053	.176	13.247	1	**.000**
LULC_Change_block1	.011	.0061	-.001	.023	3.255	1	.071
GLW_Cattle_D_block1	0[a]	.	.	.	.	.	.
(Scale)	1.619[b]	.1585	1.336	1.961			

Dependent Variable: Leopard_KDE_block1

Model: (Intercept), EVI_Change_block1, NTL_Change_block1, Tiger_KDE_block1, LULC_Change_block1, GLW_Cattle_D_block1

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Table S 5. 10 Generalized Linear Model (GLM) parameter estimates of independent variables whose effects have been tested on Human-Tiger Conflict hotspot in Study Block 1. (B is coefficient, sig. is p value for significance, df is degree of freedom, GLW_cattle denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.300	.1436	.019	.582	4.377	1	.036
[EVI_Change_block1=Browning]	-.347	1.0999	-2.503	1.809	.100	1	.752
[EVI_Change_block1=Greening]	-.428	.1668	-.755	-.101	6.591	1	**.010**
[EVI_Change_block1=None]	0[a]	.	.	.	.	.	.
[NTL_Change_block1=Decrease]	.582	.5750	-.544	1.709	1.026	1	.311
[NTL_Change_block1=No Change]	0[a]	.	.	.	.	.	.
Leopard_KDE_block1	.871	.1554	.566	1.175	31.393	1	**.000**
LULC_Change_block1	.012	.0051	.002	.022	5.691	1	**.017**
GLW_Cattle_D_block1	.000	.0001	-8.184E-5	.000	1.466	1	.226
(Scale)	2.246[b]	.1288	2.008	2.513			

Dependent Variable: Tiger_KDE_block1

Model: (Intercept), EVI_Change_block1, NTL_Change_block1, Leopard_KDE_block1, LULC_Change_block1, GLW_Cattle_D_block1

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Table S 5. 11 Generalized Linear Model (GLM) parameter estimates of independent variables whose effects have been tested on HLCC hotspot in Study Block 1. (B is coefficient, sig. is p value for significance, df is degree of freedom, GLW_cattle denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-.141	.1369	-.409	.127	1.060	1	.303
[EVI_Change_block1=Browning]	.374	.9421	-1.4 72	2.221	.158	1	.691
[EVI_Change_block1=Greening]	-.083	.1428	-.362	.197	.334	1	.563
[EVI_Change_block1=None]	0[a]	.	.	.	.	.	.
[NTL_Change_block1=Decrease]	.328	.4357	-.526	1.182	.568	1	.451
[NTL_Change_block1=No Change]	0[a]	.	.	.	.	.	.
Tiger_KDE_block1	.337	.0326	.273	.401	106.989	1	**.000**
Leopard_KDE_block1	.400	.1249	.155	.645	10.232	1	**.001**
LULC_Change_block1	.001	.0044	-.008	.009	.032	1	.857
GLW_Cattle_D_block1	.000	.0001	9.729E-5	.001	8.027	1	**.005**
(Scale)	1.622[b]	.0962	1.444	1.822			

Dependent Variable: LC_KDE_block1

Model: (Intercept), EVI_Change_block1, NTL_Change_block1, Tiger_KDE_block1, Leopard_KDE_block1, LULC_Change_block1, GLW_Cattle_D_block1

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Table S 5. 12 Generalized Linear Model (GLM) parameter estimates of independent variables whose effects have been tested on Human-Leopard Conflict hotspot in Study Block 2. (B is coefficient, sig. is p value for significance, df is degree of freedom, GLW_cattle denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval Lower	95% Wald Confidence Interval Upper	Hypothesis Test Wald Chi-Square	Hypothesis Test df	Hypothesis Test Sig.
(Intercept)	-1.295	.1396	-1.568	-1.021	86.035	1	.000
[EVI_Change_block2=Greening]	.341	.2487	-.147	.828	1.878	1	.171
[EVI_Change_block2=None]	0[a]	.	.	.	.	.	.
[NTL_Change_block2=Decrease]	-1.119	.2729	-1.654	-.585	16.830	1	**.000**
[NTL_Change_block2=Increase]	.301	.3787	-.441	1.043	.632	1	.427
[NTL_Change_block2=No Change]	0[a]	.	.	.	.	.	.
Tiger_KDE_block2	4.620	.7158	3.217	6.023	41.654	1	**.000**
LULC_Change_block2	-.004	.0032	-.010	.002	1.438	1	.230
GLW_Cattle_D_block2	2.174E-5	3.9224E-5	-5.514E-5	9.861E-5	.307	1	.579
(Scale)	1.597[b]	.0958	1.419	1.796			

Dependent Variable: Leopard_KDE_block2

Model: (Intercept), EVI_Change_block2, NTL_Change_block2, Tiger_KDE_block2, LULC_Change_block2, GLW_Cattle_D_block2

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Table S 5. 13 Generalized Linear Model (GLM) parameter estimates of independent variables whose effects have been tested on Human-Tiger Conflict hotspot in Study Block 2. (B is coefficient, sig. is p value for significance, df is degree of freedom, GLW_cattle denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-2.897	.0702	-3.035	-2.760	1702.249	1	.000
[EVI_Change_block2=Browning]	.428	1.0997	-1.728	2.583	.151	1	.697
[EVI_Change_block2=Greening]	.024	.1576	-.284	.333	.024	1	.877
[EVI_Change_block2=None]	0[a]	.	.	.	.	.	.
[NTL_Change_block2=Decrease]	.569	.2115	.155	.983	7.239	1	**.007**
[NTL_Change_block2=Increase]	-.084	.2807	-.634	.466	.090	1	.764
[NTL_Change_block2=No Change]	0[a]	.	.	.	.	.	.
Leopard_KDE_block2	.668	.0976	.476	.859	46.806	1	**.000**
LULC_Change_block2	-.004	.0022	-.008	.000	3.138	1	.077
GLW_Cattle_D_block2	.000	2.4162E-5	8.675E-5	.000	30.807	1	**.000**
(Scale)	1.206[b]	.0549	1.103	1.318			

Dependent Variable: Tiger_KDE_block2

Model: (Intercept), EVI_Change_block2, NTL_Change_block2, Leopard_KDE_block2, LULC_Change_block2, GLW_Cattle_D_block2

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Table S 5. 14 Generalized Linear Model (GLM) parameter estimates of independent variables whose effects have been tested on HLCC hotspot in Study Block 2. (B is coefficient, sig. is *p* value for significance, df is degree of freedom, GLW_cattle denote cattle density) [EVI- Enhanced Vegetation Index, NTL- Night Time Light, GLW- Gridded Livestock of the World, LULC- Land Use Land Cover]

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-1.833	.0972	-2.024	-1.643	355.591	1	.000
[EVI_Change_block2=Browning]	-.753	1.2422	-3.188	1.682	.367	1	.544
[EVI_Change_block2=Greening]	-.441	.1949	-.823	-.059	5.131	1	**.024**
[EVI_Change_block2=None]	0[a]	.	.	.	.		.
[NTL_Change_block2=Decrease]	-.026	.2540	-.524	.471	.011	1	.917
[NTL_Change_block2=Increase]	-.194	.3409	-.862	.474	.325	1	.569
[NTL_Change_block2=No Change]	0[a]	.	.	.	.		.
Tiger_KDE_block2	-1.064	.6338	-2.306	.178	2.820	1	.093
Leopard_KDE_block2	2.412	.1481	2.122	2.703	265.168	1	**.000**
LULC_Change_block2	.002	.0024	-.002	.007	.976	1	.323
GLW_Cattle_D_block2	.000	2.9760E-5	5.548E-5	.000	14.625	1	**.000**
(Scale)	1.537[b]	.0714	1.403	1.683			

Dependent Variable: LC_KDE_block2

Model: (Intercept), EVI_Change_block2, NTL_Change_block2, Tiger_KDE_block2, Leopard_KDE_block2, LULC_Change_block2, GLW_Cattle_D_block2

a. Set to zero because this parameter is redundant.

b. Maximum likelihood estimate.

Chapter 6

Diet Profile of Sympatric Large Carnivores in Wildlife Corridors of Terai, India

Introduction

Large carnivores are wide-ranging species inhabiting variable habitats and serving as flagship species for biodiversity conservation (Harihar et al., 2011). Although energy restrictions limit their population sizes in the wild, large predators significantly influence the organisation of communities through trophic cascades (Lamichhane et al., 2019). Predation is a phenomenon that connects trophic levels and is essential to many ecological and evolutionary processes (Fryxell et al., 2007). When sympatric species share a trophic level, niche differentiation and resource partitioning are evident (Schoener, 1986). Differential use of food resources is an essential mode of resource partitioning in ecological communities (Karanth & Sunquist, 2000) in addition to prey size (Gittleman 1985), activity patterns (Fedriani et al., 1999), space use patterns and habitat use preference (Palomares et al., 1996). Thus, understanding the dietary niche overlap and patterns of sympatric carnivores is crucial for their long-term conservation and the ecosystem/habitat as a whole.

The dietary profile of animals could be studied easily with the most widely used non-invasive method of scat or faecal analysis (Ackerman et al., 1984; Karanth and Sunquist, 1995; Klare et al., 2011). This method is very effective for elusive species, such as large feline carnivores (Biswas et al., 2023; Chakrabarti et al., 2016; Karanth and Sunquist, 1995). India harbours more than 75% of the world's wild tiger population, with a population growth of 6.1% (Qureshi et al., 2023). Tigers are distributed across India along with their co-predators, i.e., leopards and dholes (*Cuon alpinus*). These three large carnivores inhabit the forest of India, coexisting across various landscapes. However, the distribution of dholes in the terai landscape of India has declined extensively due to persecution in the past and is now restricted to a few PAs (Qureshi et al., 2023). Recently, the presence of dholes from the Terai landscape in Uttarakhand has been reported from the Nandhaur Wildlife Sanctuary (NWLS) and adjoining wildlife corridors (Ranjan & Dhakate, 2021). The dietary habits of tigers and leopards have been studied extensively in India, both as individuals and as sympatric, mainly in the PAs (Andheria et al., 2007; Athreya et al., 2013; Basak et al., 2018; Biswas et al., 2023; Majumder, 2011). However, limited studies are available on the diet of the two species outside PAs in India, such as food habits and characteristics of livestock predation in the human-dominated landscape (Dahya et al., 2023).

In tropical forests, the relative densities of various size classes of prey can vary naturally and due to human activity, affecting or influencing the community structures of large carnivores (Karanth & Sunquist, 1995). The abundance and availability of prey species are critical to the sympatry of large carnivores (Andheria et al., 2007). The high density of wild prey limits/reduces livestock depredation and negative human–wildlife interactions (Basak et al., 2018; Upadhyaya et al., 2018). However, prey abundance does not necessarily affect prey selection (Bagchi et al., 2003; Lovari et al., 2015). Sometimes, the human-large carnivore conflict scenarios are exaggerated due to the political and social attributes of the region. Thus, the diet profile of large carnivores will also reveal the true nature and picture of conflict situations. Our study focuses on the feeding habits and dietary overlap of tigers and leopards in a multi-use landscape outside the PAs encompassing the critical wildlife corridors in the Terai-Bhabar region of northern India at the foothills of the Himalayas, a critical Tiger Conservation Landscape (TCL) (Dinerstein et al., 2010). The study also explores the dependence of the large carnivores on livestock for food outside PAs with lower wild prey populations and higher anthropogenic disturbances.

Materials and Methods

Study Area

The study area is part of the Terai Arc Landscape (Semwal, 2005), which lies in the Terai-Bhabar topography at the foothills of the Himalayas. The study area is located between the Corbett Tiger Reserve (CTR) and the Indo-Nepal border in the eastern and southern parts of the state of Uttarakhand, bordering the state of Uttar Pradesh in India. The study area is divided into two blocks (Figure 6. 1). Block 1 constitutes the Kosi corridor with adjoining areas of CTR, Ramnagar Forest Division (FD), and Almora FD of Uttarakhand. Block 2 encompasses the Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridors with adjoining forest habitats of the Terai East FD, Haldwani FD, and Champawat FD of Uttarakhand. The Kosi corridor connects CTR with the Ramnagar FD and Pawalgarh Conservation Reserve along the Kosi River east of CTR in Uttarakhand. The KKS corridor connects the NWLS in Uttarakhand with the Pilibhit Tiger Reserve (PTR) in Uttar Pradesh and the Indo-Nepal border in the Khatima forest range of the Terai East FD. The BB corridor connects NWLS to the Kanchanagar FD in Nepal, a transboundary landscape that expands to Sukhlaphanta National Park in Nepal (Qureshi et al., 2014, 2023; Semwal, 2005).

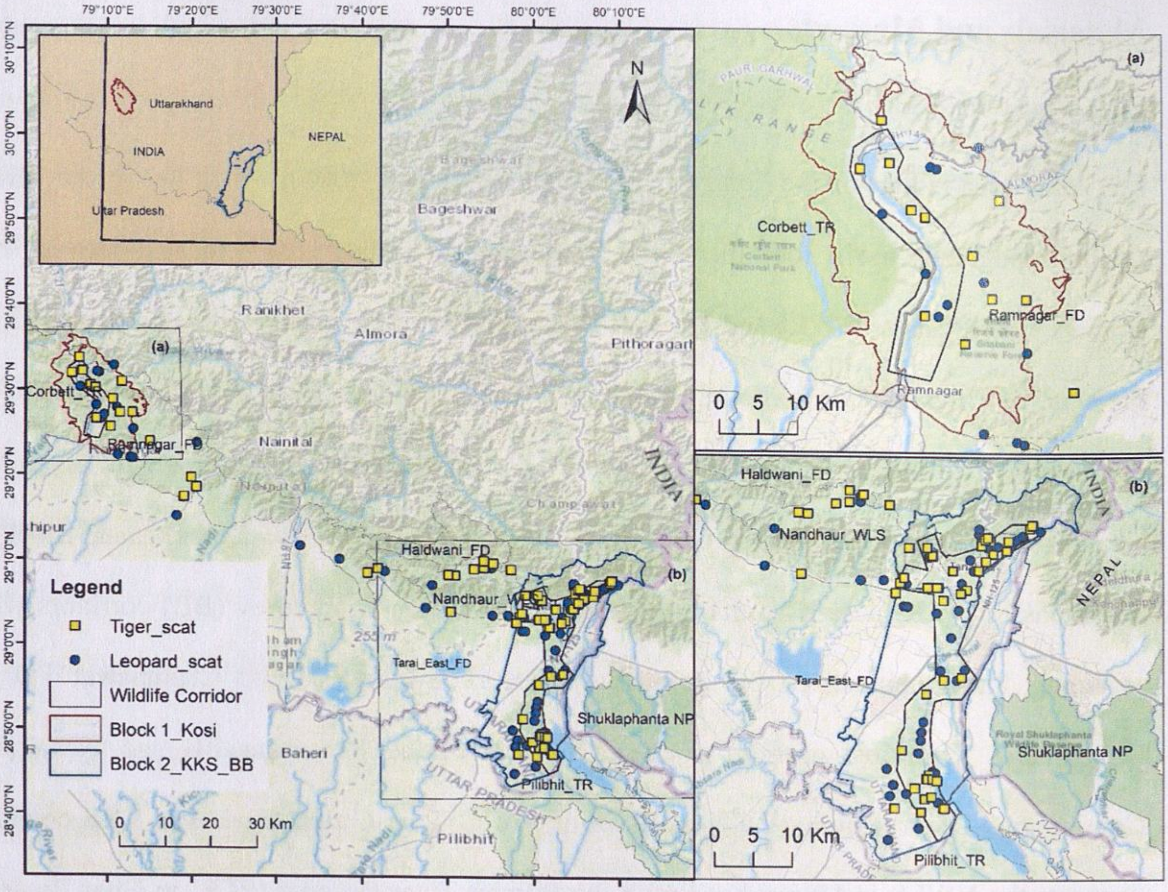


Figure 6. 1: Study area map with the two study blocks comprising of wildlife corridors (a) Block 1 with Kosi corridor connecting Corbett Tiger Reserve to Ramnagar forest division (b) Block 2 with Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridor in Indo-Nepal transboundary landscape.

The study area lies in Tiger Habitat Block (THB) II and III (Johnsingh et al., 2004) and TCL (Dinerstein et al., 2010; WWF & RESOLVE, 2015). The large mammalian species in the region are Asiatic Elephant (*Elephas maximus),* Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), Sloth Bear *(Melursus ursinus),* Sambar deer (*Rusa unicolor),* Spotted deer (*Axis axis),* Wild boar (*Sus scrofa*), and Northern Red Muntjac (*Muntiacus muntjac*). The study area falls in the 2B Himalaya-West Himalaya and 7A Gangetic Plain- Upper Gangetic Plain biogeographic provinces of India (Rodgers et al., 2000).

Methods

Scat Sample Collection

The scat samples of the tigers and leopards were collected opportunistically from the study area during the camera trapping and vegetation survey fieldwork from the animal trails and forest roads. Tigers, leopards and other carnivores deposit scats on forest roads and animal trails as part of the communication mechanism (Andheria et al., 2007; Karanth & Sunquist, 1995; Smith et al., 1989). The sample was collected from October 2019 to December 2021 using plastic Ziplock bags, and predator species were identified based on ancillary signs and methods described in earlier studies (Andheria et al., 2007; Basak et al., 2018; Harihar et al., 2011; Karanth & Sunquist, 1995; Lovari et al., 2015). After collection, the remaining scats were removed from the track to avoid repetitive sampling. We avoided collecting scats from village areas or metalled roads in forest habitats.

Sample Processing and Prey Species Identification

A substantial part of each sample was put in nylon stockings, and a knot was tied and then soaked in water for 24 hours (Klare et al., 2011). After soaking, it was washed in running water in a sieve of <1 mm to remove the debris and dirt (Ramesh et al., 2009; Upadhyaya et al., 2018). It was sun-dried for 72 hours (Andheria et al., 2007) before separating 20 random hairs per sample for identification of prey based on its general appearance, colour, relative length, width, cortex pigmentation, and medullary structures (Bahuguna et al., 2010; Dharaiya & Soni, 2012; Mukherjee et al., 1994).

Data Analysis

The frequency of occurrence of each prey item (denoted as A, expressed as a per cent of scats in which a particular prey item is found) in the scats of tiger and leopard was calculated (Andheria et al., 2007). We calculated the corrected frequency of occurrence based on the number of prey items per scat; if two items were present in one scat, it was calculated as 1/2; if three items were present, then 1/3, and so on (Karanth & Sunquist, 1995). However, when the body size of prey varies significantly, the frequency of occurrence can be misleading, as highlighted by Floyd et al. 1978, and Ackerman et al. 1984. These studies developed a linear regression model to correct the overestimation of smaller prey in wolves (*Canis lupus*; Floyd et al. 1978) and cougars (*Puma concolor*; Ackerman et al. 1984). Many studies used this model to estimate biomass consumed by predators; regression for cougars was used for tigers and leopards, and a regression model for wolves was used for dholes (Bagchi et al., 2003; Biswas & Sankar, 2002; Harihar et al., 2011; Karanth & Sunquist, 1995; Ramesh et al., 2009).

This linear model is biased for tropical large carnivores and significantly underestimates the consumption of medium-sized prey, as highlighted by Chakrabarti et al. 2016. The above study developed a nonlinear asymptotic generalised model:

$$Y_c = 0.033 - 0.025 exp^{-4.284(X/Z)}$$

Y_c is biomass consumed per collectable scat/predator weight, X is the live weight of prey, and Z is the average live weight of predator. Y_c is used as a correction factor for estimating the relative prey biomass consumed by multiplying Y_c by the observed frequency of occurrence (A). The generalised biomass model is better suited for our study, where we want to assess the contribution of livestock to the food habits of tigers and leopards since this model does not overestimate the large prey (Chakrabarti et al., 2016; Upadhyaya et al., 2018). The values for the average body weight of prey and predator species were taken from similar published studies (Ahmed & Khan, 2022; Harihar et al., 2011) and animal husbandry department. The relative prey biomass (D) and relative numbers of prey consumed (E) were calculated as per the equation below (expressed in percentage) described by Andheria et al. 2007.

$$D = \frac{A * Y}{\Sigma(A * Y)} * 100$$

$$E = \frac{D/X}{\Sigma(D/X)} * 100$$

To assess the dietary overlap between the tigers and leopards, we used the Pianka index (Pianka, 1973) based on the frequency of occurrence, which ranges from 0 (no overlap) to 1 (complete overlap).

$$Pianka\ index = \frac{\sum P_{ij} * P_{ik}}{\sqrt{\sum(P_{ij}^2 * \sum P_{ik}^2)}}$$

P_{ij} is the percentage of prey items i of predator j; P_{ik} is the percentage of prey items i of predator k

D_c and E_c denote the relative prey biomass and relative number of preys consumed using the Y_c correction factor based on the generalised biomass model, respectively. The D_c and E_c of tigers and leopards were statistically compared using the Kruskal-Wallis test statistic to understand the difference in diet profiles of the two large sympatric carnivores. We categorised the prey size into three classes based on their body weight: (i) large (above 50 kg; Sambar deer, Bluebull, cattle, domestic buffalo); (ii) medium (20–50 kg; spotted deer, Northern Red Muntjac, Wild boar, hog deer, domestic sheep); and (iii) small (below 20 kg; domestic goat, porcupine, langur, hare) to understand the food habits and diet profiles of the two sympatric large carnivores. The diet niche breadth of tigers and leopards was estimated using the Levins index (Levins, 1968), standardised to a scale of 0–1 (Hurlbert, 1978) based on the frequency of occurrence of different prey species.

Result

We analysed 116 tiger (Very Old=33, Old=59, Fresh=24) and 89 leopard (Very Old=20, Old=43, Fresh=26) scats from our study area for food habits. Tiger scats contained 12 prey items, and leopard scats had 14 prey items, excluding vegetation, which was sometimes found in scats of both species (excluded from analysis). Tiger scats collected during the study had a single prey item in 64.7% of scats, 31.9% had two items, and 3.4% had three prey items. The leopard scats have one (73%) and two (27%) prey items. We observed that tigers preyed most frequently upon Wild boars (24%), followed by spotted deer (20.4%) (Table 6. 1). Cattle (7.8%) constituted the most frequent prey amongst all livestock and domesticated species for tigers. Three livestock species were observed from tiger scats, i.e., cattle, domestic buffalo (3%), and domestic goat (1.9%). Leopards most frequently preyed upon spotted deer (17.4%), followed by Wild boars (16.3%). We observed four livestock species from leopard scats, i.e., cattle (6.2%), domestic buffalo (1%), domestic goats (7.9%), and domestic sheep (1%), with the highest contribution from goats. Unidentified remains (feather and beak) of birds (3.4%) were also found in the leopard scats.

Table 6. 1 Frequency of occurrence (A) of different prey items, percent occurrence of each prey species (Po), live weight of prey (X), the number of scats with each type of prey, Relative biomass consumed (D_c) and Relative number of prey consumed (E_c) estimated using correction factor Y_c developed by Chakrabarti et al. 2016. (Average body weight of tiger =140 kg and leopard =65 kg) (X -weight of prey species is based on Harihar et al., 2011 and Ahmed & Khan, 2022)

Prey Species	X (kg)	Tiger						Leopard					
		No.	A (%)	Po	Y_c	D_c (%)	E_c (%)	No.	A (%)	Po	Y_c	D_c (%)	E_c (%)
Sambar Deer	185	23	15.9	14.29	4.61	19.54	4.91	8	9.0	7.08	2.14	10.83	1.60
Bluebull	184	12	8.5	7.45	4.61	10.38	2.62	5	5.6	4.42	2.14	6.77	1.01
Spotted Deer	50	32	20.4	19.88	3.86	20.95	19.49	17	17.4	15.04	2.08	20.39	11.18
Northern Red Muntjac	25	18	11.4	11.18	2.99	9.03	16.79	17	15.2	15.04	1.83	15.61	17.12
Wild Boar	35	36	24.0	22.36	3.42	21.82	29.00	18	16.3	15.93	1.98	18.14	14.21
Hog Deer	25	4	1.6	2.48	2.99	1.26	2.34	5	4.5	4.42	1.83	4.62	5.07
Porcupine	8	8	3.2	4.97	1.88	1.58	9.18	5	3.4	4.42	1.19	2.24	7.69
Langur	10	4	1.7	2.48	2.04	0.94	4.35	8	5.1	7.08	1.30	3.70	10.15
Hare	4	2	0.7	1.24	1.52	0.29	3.38	7	3.9	6.19	0.90	1.98	13.57
Cattle	175	14	7.8	8.70	4.60	9.50	2.52	6	6.2	5.31	2.14	7.44	1.17
Domestic Buffalo	250	4	3.0	2.48	4.62	3.70	0.69	2	1.1	1.77	2.14	1.35	0.15
Domestic Goat	10	4	1.9	2.48	2.04	1.01	4.72	8	7.9	7.08	1.30	5.76	15.80
Domestic Sheep	25	0	0	0	2.99	0	0	1	1.1	0.88	1.83	1.16	1.27
Bird (Unknown)	0	0	0	0	0	0	0	6	3.4	5.31	0	0	0

We estimated the relative prey biomass and the relative number of prey consumed by the tigers and leopards (Table 6. 1) using correction factor Y_c (Chakrabarti et al., 2016). The Wild boar (21.82%) had the highest prey biomass contribution to the tiger's diet and spotted deer (20.39%) had the highest prey biomass contribution to the leopard's diet. The cattle relative biomass contribution is the maximum among livestock species for both tigers and leopards.

Overall, for all prey items, the diet composition showed no significant difference between relative prey biomass consumption (p= 0.53, χ^2 = 0.378) and relative number of preys consumed (p= 0.85, χ^2 = 0.032) by tiger and leopard.

Tiger and leopard diets consist predominantly of medium-sized prey (Figure 6. 2). Large prey constitutes 43.1%, medium prey ~53%, and small prey ~3.8% of biomass consumption in the tiger diet profile. The leopard relative prey biomass consumption is highest for medium-sized prey (~60%), followed by large (26.4%) and small (13.7%) prey. The contribution of smaller prey is considerably higher in leopards than in tigers. Tiger relative prey biomass consumption primarily depends on wild prey (~85.8%), and around 14.2% on livestock. Relative prey biomass consumption for leopards has a slightly higher share of livestock (domestic ~15.7%; wild ~84.3%) than tigers. The relative number of medium-sized (67.6%) prey consumed by tigers is substantially higher than that of large (10.8%) and small (21.6%) prey (Figure 6. 2). However, the relative number of medium (48.9%) and small (47.2%) sized prey consumed by leopards is equivalent but, considerably higher than large prey (~3.9%) (Figure 6. 2).

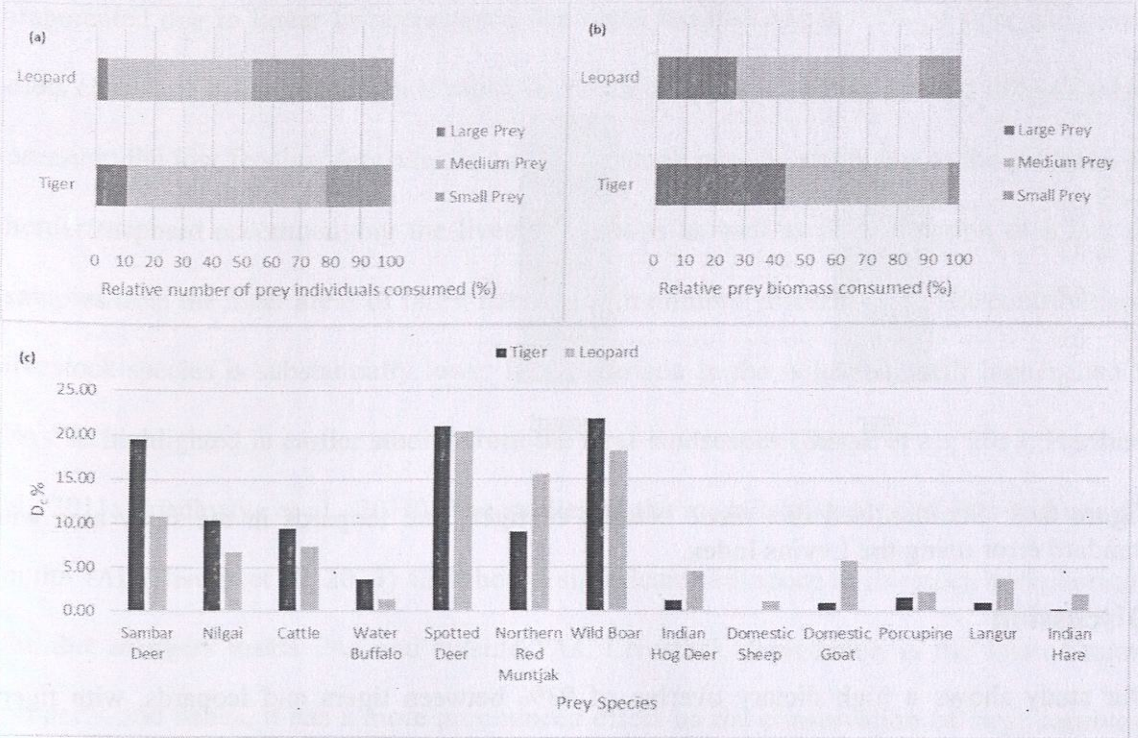


Figure 6. 2: Diet profile of tiger and leopard in the study area (a) Relative prey biomass consumed (D_c) by the two sympatric large carnivores using a generalised biomass model for three categories of prey based on body size (b) Relative number of prey consumed (E_c) by two large carnivore species using a generalised biomass model (c) Contribution of different prey species in the prey biomass consumed by two sympatric carnivores. (Large prey > 50 kg, Medium prey 20 –50 kg, Small prey < 20 kg)

The relative prey biomass contribution of Wild boars, spotted deer, and sambar deer is significant in the tiger's diet. At the same time, leopard food habits show a significant dependence on spotted deer, Wild boars, and Northern Red Muntjac for biomass consumption (Figure 6. 2). The dietary overlap between tiger and leopard in the study area is approximately 93% (Pianka Index= 0.928). The dietary niche breadth of tiger and leopard using the Levins Index is 6.51 and 9.11, respectively, and the standardised diet niche breadth is 0.5 and 0.62 for tiger and leopard, respectively (Figure 6. 3).

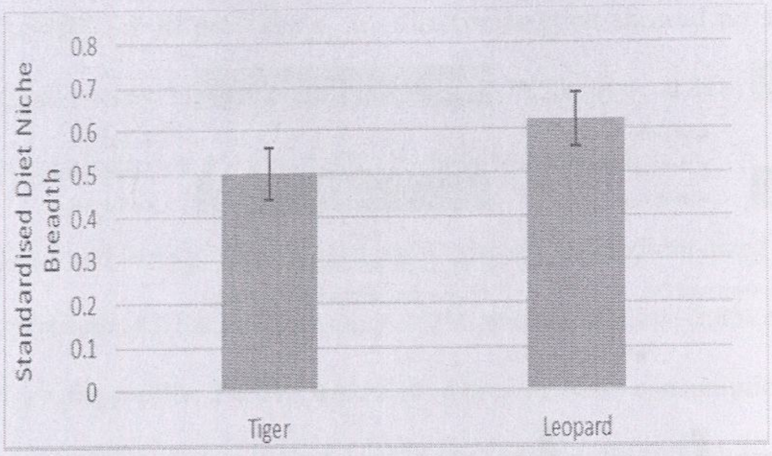


Figure 6. 3: Standardised diet niche breadth of tigers and leopards in the study area with standard error using the Levins Index.

Discussion

Our study shows a high dietary overlap of 93% between tigers and leopards, with tigers having a narrower dietary niche breadth (standardised diet niche breadth =0.5) than leopards (standardised diet niche breadth =0.62), indicating sharing of food resources by both the species (Figure 6. 3). The dietary specialisation of these two sympatric species is broad and suggests better adaptability to the existing environment and food availability. Both the species have maximum dependence on medium body-size prey, i.e., Wild boars and spotted deer, which could be attributed to the abundant distribution and population of these prey species in the study area. Similar trends and prey preferences have also been observed in many earlier studies in the Terai landscape of India and Nepal (Ahmed & Khan, 2022; Basak et al., 2018; Upadhyaya et al., 2018). The broader dietary niche of leopards observed in the study indicates the generalist nature of prey selection and opportunistic feeding behaviour of leopards. Camera trap images from our study sites have also shown evidence of poultry depredation by leopards.

Livestock grazing is common in the study area because it lies outside the PAs in a multi-use mosaic landscape where reserved forests are interspersed with human settlements and fragmented due to linear infrastructures. We observed that nearly 15% of tiger and leopard diets consist of livestock, which is much less than wild prey (~85%). Instead of high grazing pressure, the low feeding dependence on the livestock may be attributed to the presence of a herder/shepherd accompanying the livestock groups as well as the collection of a few scat samples from the inner areas of forest habitats with minimal disturbances. The contribution of livestock species is substantially lower in comparison to the wild prey, still higher than the PAs, as highlighted in earlier studies from the terai landscapes (Basak et al., 2018; Harihar et al., 2011; Upadhyaya et al., 2018). The studies in the mosaic landscape of PAs and non-PAs in the TAL (Biswas et al., 2023) also show a significant difference in livestock contribution in the diet of tigers inside PAs and outside PAs. Livestock depredation is the loss of human property, and hence, it has a more pronounced effect on the conservation of large carnivores and human-wildlife conflict (HWC).

The number of stray cattle in forest habitats has increased in recent years due to government policies, which have an aggravated negative effect on large carnivore prey availability and feeding habits. Our findings show that the relative prey biomass of cattle consumed by tiger and leopard is the maximum out of all the livestock species (Table 1), and it is also the most frequently depredated livestock species by tiger. The domestic buffalo has also been observed in two leopard scats from study block 2, which may be attributed to the buffalo calf depredation or the buffalo carcass. The carcass dumping is not observed in the Kosi corridor area; however, infrequent carcass dumping is observed in study block 2 areas. The presence of cattle and large livestock species in the forest habitats significantly affects the distribution of wild prey, especially large wild prey which are more sensitive to disturbances like sambar deer (Gaynor et al., 2018; Habib et al., 2021; Upadhyaya et al., 2018). This also explains the higher dependence on medium prey in our study area.

The notions of optimal foraging theory preferring larger prey are invalid when the availability of prey is an important limiting factor other than ecological energetics, which supports hunting of prey with equivalent body size/weight and convenience of hunting, which optimises energy use (Basak et al., 2018; Chakrabarti et al., 2016; Gittleman, 1985; Upadhyaya et al., 2018). Our study reveals that sambar deer is the most important large prey for tigers and leopards, contributing 16% and 9% of the diet, respectively. The relative number of prey consumed by leopards is almost equal for medium (48.9%) and small (47.2%) prey classes, as they are more agile and can climb trees easily to hunt smaller prey such as porcupines, hares, and langurs. The tiger is a top predator, and its increasing population density affects the food habits of its co-predators inhabiting the same habitat by shifting their prey preference, selection of prey (sex and age class), and hunting time (Andheria et al., 2007; Harihar et al., 2011; Mondal et al., 2012). It also explains the considerable difference in relative biomass and number of large prey consumption between tiger (Cumulative $D_c = 43.1\%$ and $E_c = 10.8\%$) and leopard (Cumulative $D_c = 26.4\%$ and $E_c = 3.9\%$) in our study. This substantial difference in large prey relative consumption between tiger and leopard and the higher relative number of small prey in the leopard diet indicates prey selection partitioning between the two sympatric species. The terrain of the habitat and prey behaviour also affect prey selection, causing spatiotemporal partitioning. (Wang & Macdonald, 2009).

The absence of a wider variety of wild prey, high anthropogenic disturbance, and grazing pressure increase livestock depredation by large carnivores (Basak et al., 2018; Sankar et al., 2010). Our results show a higher livestock share in the leopard diet with four types of livestock compared to the tiger diet with three, which can be attributed to the varied habitat use patterns of these two sympatric species. As the density of tigers increases in the core forest habitats, the leopards respond by spatially and temporally partitioning their habitat use, adapting to fringe habitats on the forest boundary, thereby increasing the chances of more frequent livestock depredation (Harihar et al., 2011; Naha et al., 2020; Puri et al., 2022). CTR, part of our study area, has the highest tiger density among all the PAs in India (Bisht et al., 2019; Qureshi et al., 2023) and acts as a source population for landscape metapopulation (Chanchani et al., 2014). The dispersing tigers from the core habitats of CTR face a high risk of negative human-wildlife interaction outside PAs, mainly in the form of livestock depredation and human casualty in a few incidents, as evident from compensation records of the Uttarakhand Forest Department (UKFD).

The nomadic community of *Bakarwal,* which migrates from the high-altitude Himalayas to lower elevations of Terai-Bhabar during winters with their large herds of sheep and goats camping for several days and months in the forest areas of the Himalayan foothills, disturbs the wild prey population inhabiting those habitats. It increases the probability of depredation by carnivores, which is highlighted by the fact that all the scat samples of both the species with sheep hairs and all tiger scats with goat hairs were collected during winter. The *Van Gujjars* are a pastoralist community residing in the study area's forests with large herds of buffalos and cattle, which negatively affects the wild prey population and disturbs the availability of pastures and foraging activity of the wild prey. The livestock depredation of these pastoralist communities is also observed in the compensation records of the UKFD from the study area.

Conclusion

In the present conservation paradigm of large carnivores, it is essential to understand the feeding habits and prey-predator dynamics outside protected areas. Our study fills this gap in the understanding of the dietary habits of sympatric large carnivore species outside PAs in the wildlife corridor habitats of the terai landscape of India. It is of paramount importance to know the true picture of feeding dependence on livestock, resource sharing, and diversity of food resources of sympatric large carnivores, which are priority animals related to Human-Wildlife Conflict in the landscape. Our results highlight that tigers and leopards still have a major dependence on wild prey, but they also indicate the increasing contribution of livestock species to the diet of these large carnivores. The decreasing abundance and diversity of wild prey, especially large-sized prey, will be suffixed by cattle and other livestock species for food by tigers and leopards, depending on their body size and hunting abilities.

Thus, augmenting the wild prey population outside the PAs in wildlife corridor habitats is vital to limit and reduce livestock depredation and improve habitat quality to accommodate the wild prey population in forest habitats. The dietary profile of large carnivores of the study area provides information about the contribution of different prey species as food, which is crucial for understanding prey-predator dynamics in the landscape outside PAs. It will help develop a scientific management and mitigation plan for HWC and long-term conservation. However, our study is based on a small sample size, but it highlights the importance of wild prey availability to contain human-large carnivore conflict. More such studies with extensive sampling outside the PAs are needed to formulate long-term landscape conservation plans.

Recommendations

- The habitat quality needs special focus in the corridor areas, since they are under immense anthropogenic pressure for fuelwood, fodder, timber and NTFPs. The vegetation of any habitat is the most basic and significant entity for quality improvement of the habitat. In recent times, the monoculture plantation trend has shifted towards mix and miscellaneous plantation by forest department which should be encouraged and more emphasis should be on wildlife friendly and fruiting species of trees and plants.
- Grassland management is an important aspect of habitat quality improvement and habitat enrichment especially in Terai landscape. The terai region is known for its grasslands which is locally called as *Chaur* or *Khalla* or *Khatta.* These are lowlands with ground seepage and highly fertile tracts. In bhabar areas, riverine grasslands are quite abundant which is located along seasonal streams in the boulder topography or perennial streams in the flat areas. These grasslands need management intervention to control the speed of natural conversion of grasslands into woodlands, and also to neutralise the impacts of anthropogenic activities and interferences. The grasslands require removal of invasive species and sowing of various palatable grasses like *Heteropogan contortius, Eragrastis tenella, and Apluda mutica* which are annual grasses; *Desmostachya bipinnata, Cynadon dactylon, Eulaliopsis binata, Vetiveria zizanoides* (preferred by Hog deers), *Chrysopogon fulvus* (preferred by Gorals), *Saccharums* and *Neyrandia arundinacea* (preferred by elephant) species are perennials. The grassland in Surai forest range (*malla-khalla*) of KKS corridor is adjacent and in continuation with the grasslands of PTR where Hog deer population is good, and Bengal Florican have also been recorded. The grasslands of Surai are

critical for endangered species, and its proper management may attract and provide foraging ground for ungulates especially Hog deer which is very less in Surai.

- Construction of water holes in the forest and grasslands as well as forest fringe areas of corridors at strategic location to restrict and control grazing livestock at fringes from entering to core areas for water may prove favourable in regulation of grazing pressure. At the same time, requirements of water for wildlife species in dry season and water deficient areas of corridor habitat can also be catered from the water holes in the less disturbed core habitats.
- Erosion control and soil moisture conservation through vegetation and mechanical measures.
- Promotion of green infrastructure development in corridor areas at policy level like under passes, wildlife bridges, culverts, canopy bridges for arboreal species, and signages etc to mitigate impacts of linear infrastructures.
- Construction of flyovers for roads or animal underpasses of standard size as per the species presence in the area to avoid collision or accidents and safe passage for wildlife through the corridors. Some of the identified stretches which need immediate focus and intervention in the landscape to keep the corridors functional are: Chakkarpur-Jagpudda (on NH-9 in SKK corridor), and near medicinal plant park on Tanakpur-Champawat road (NH-125) in BB corridor.
- New Tanakpur-Jauljibi road is under construction which opens new prospect for tourism and also bisects the corridor patch. Animal underpass or flyover at two locations one between Boom FRH and Thuligadh, and other one in Khaldunga plateau will be significant for functionality of BB corridor.

- Garbage disposal and carcass dumping in the forest should be banned.
- Physical barrier should be at entry points of wildlife in village areas like solar fencing, aniders, walls, and any other latest mechanical barriers available at the time of implementation.
- Lantana and other invasive species removal from core forest, and forest fringes with public participation and local stakeholders to reduce chances of negative Human-wildlife interaction. The lantana eradication will provide more space for native species to grow and proliferate in the core habitats leading to better foraging space for prey and better visibility in the forest-village boundaries to avoid sudden confrontation with wildlife.
- Sensitisation and confidence building in public and local communities through frontline forest staff to mitigate HWC and public management during rescue operations.
- Formation of Anti-depredation wildlife squad in zone wise manner for the landscape (Ramnagar Zone, Pawalgarh Zone, Khatima Zone, Tanakpur Zone) well equipped and trained staffs with minimum response time.
- Awareness in local communities for HWC.
- HWC and compensation data should be documented in a common format at all range levels (ground level data). This data should be updated regularly to the division office. The data documentation needs to be done digitally though mobile applications to cut down the information dissemination time and real-time management interventions can be planned.

- Communication line for all weather accessibility to remote and core areas should be available which will enhance monitoring and patrolling.
- Patrolling infrastructures like watch towers, anti-poaching chowkis with lighting and basic facilities, and patrolling roads should be constructed in the corridor forest areas of the landscape. The staffs should be well equipped and trained with patrolling equipment.
- Framework for prey base monitoring outside PAs and enhancing the patrolling intensity for protection and safeguard of wildlife. The patrolling data collected should be validated regularly (trimester) at intermediary higher level to check the gaps and strategize the patrolling accordingly.
- The eco-tourism policy should be updated as per the need of the hour in consultation with the institutions, experts, and local stakeholders. As in our study area, the eco-tourism pressure should be regulated in the CTR by alternately closing few zones seasonally or monthly for providing disturbance free refuge during peak tourist season. This will also enable diverting tourism to other potential areas of wildlife which are under the shadows, and communities in those areas can also benefit from regularization of the eco-tourism policy. The wildlife eco-tourism policy should also be prepared for PAs as well as landscape level. In any case, the tourism should not be promoted above the carrying capacity of the area, as it might affect the animal behaviour adversely as indicated during our study as well from block 1, where local communities think excessive tourism and intrusion in animal habitat have influenced the animal behaviour of large carnivores.
- Mineral exploitation under rights and concession should be restricted to minimum period of time to ensure minimal disturbance and displacement of wildlife from affected sites.

- Legitimate quantity of timber etc. or monetary incentives for the same under rights and concession may be provided to right holders regularly for confidence building in local communities and public participation with UKFD activities.
- Clean fuel schemes should be promoted and incentivised to minimise forest visit of community members for fuelwood collection.

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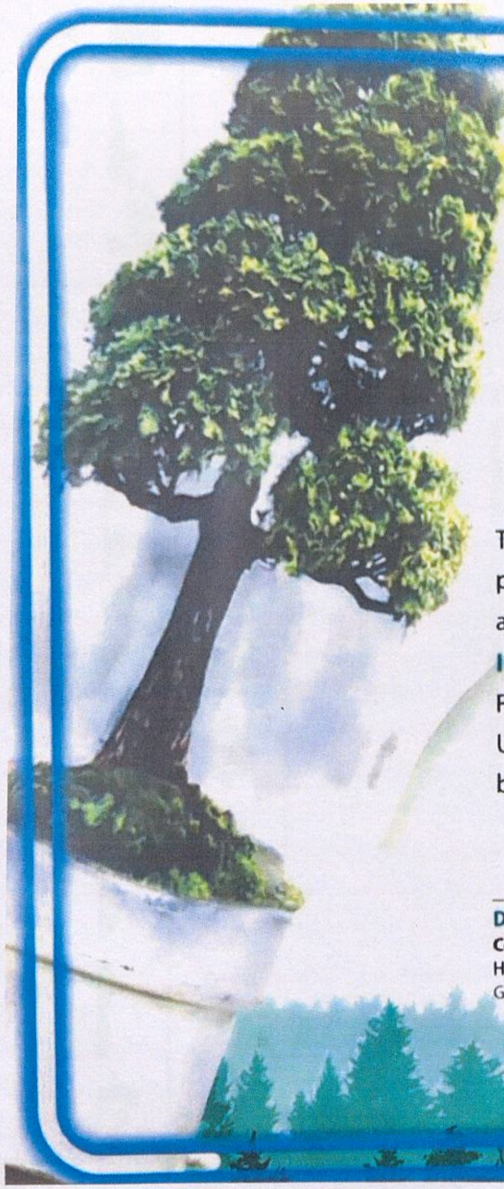

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ARTICLE

Feeding dynamics of sympatric large carnivores in an anthropogenic landscape of the Indian Terai

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Abstract: An important challenge for large carnivore conservation is negative human-wildlife interaction. Livestock depredation by carnivores is one important aspect of this negative interaction. Hence, it is critical to understand the extent of livestock depredation by large carnivores through their diet profiles and feeding habits for managing and strategizing conservation measures. We investigated the food habits and dietary patterns of two large sympatric carnivores, the Tiger *Panthera tigris* and the Leopard *Panthera pardus* based on scat samples collected in wildlife corridors outside protected areas (PAs) in the Indo-Nepal transboundary and Corbett landscape in Uttarakhand, India. The frequency of occurrence of prey items in the scat samples was used to estimate the relative prey biomass and number of preys consumed by the Tigers and Leopards using a generalised biomass model. Scat analysis revealed the presence of mainly wild prey species, encompassing 12 species in tiger scat and 14 species in Leopard scat. The results show that Tigers and Leopards primarily depend on medium-sized prey, with relative prey biomass consumption of 53% and 60%, respectively. Tigers preyed most frequently on Wild Boar *Sus scrofa*, followed by Spotted Deer *Axis axis*, and Leopards preyed mostly on Spotted Deer, followed by Wild Boar. The relative biomass of livestock species in Tiger and Leopard diets is 14.2% and 15.7%, respectively. Dietary overlap between Tiger and Leopard was high, with the Leopard exhibiting a broader dietary niche breadth than the Tiger. Augmenting wild prey population through habitat improvement and protection outside PAs can significantly limit human-large carnivore conflict by decreasing livestock contribution in their diet. Studies on dietary habits need to expand to wildlife corridors and outside PAs in human-dominated landscapes to understand the ecological dynamics of human-wildlife negative interaction for future conservation strategies.

Keywords: Dietary profile, human-wildlife interaction, leopard, tiger, wildlife corridor.

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भारतीय वन्यजीव संस्थान
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INTRODUCTION

Large carnivores are wide-ranging species inhabiting variable habitats and serving as flagship species for biodiversity conservation (Harihar et al. 2011). Although energy restrictions limit their population sizes in the wild, large predators significantly influence the organisation of communities through trophic cascades (Lamichhane et al. 2019). Predation is a phenomenon that connects trophic levels and is essential to many ecological and evolutionary processes (Fryxell et al. 2007). When sympatric species share a trophic level, niche differentiation and resource partitioning are evident (Schoener 1986). Differential use of food resources is an essential mode of resource partitioning in ecological communities (Karanth & Sunquist 2000) in addition to prey size (Gittleman 1985), activity patterns (Fedriani et al. 1999), space use patterns, and habitat use preference (Palomares et al. 1996; Shameer et al. 2021). Understanding the patterns of dietary niche overlap of sympatric carnivores is crucial for devising adequate conservation measures.

India harbours more than 75% of the world's wild Tiger population, with a population growth of 6.1% from 2006 to 2022 (Qureshi et al. 2023). The Tiger is distributed across India along with its co-predators Leopard and Dhole *Cuon alpinus* (Ramesh et al. 2012; Qureshi et al. 2023). These three large carnivores inhabit forests and coexist across various landscapes through spatio-temporal & dietary partitioning (Karanth & Sunquist 1995; Andheria et al. 2007; Ramesh et al. 2012; Selvan et al. 2013; Lamichhane et al. 2019; Mohan et al. 2021; Shameer et al. 2021). The distribution of the Dhole in the Indian Terai has declined extensively due to persecution in the past and is now restricted to a few protected areas (PAs) (Qureshi et al. 2023), including Nandhaur Wildlife Sanctuary, and adjoining wildlife corridors in the Terai of Uttarakhand (Ranjan & Dhakate 2021).

The dietary profile of animals can be studied easily with the most widely used non-invasive method of scat or faecal analysis (Ackerman et al. 1984; Karanth & Sunquist 1995; Klare et al. 2011). This method is very effective for large carnivores (Karanth & Sunquist 1995; Chakrabarti et al. 2016; Biswas et al. 2023). The dietary habits of the tiger and leopard have been studied extensively in India mainly in PAs (Andheria et al. 2007; Majumder 2011; Athreya et al. 2013; Basak et al. 2018; Biswas et al. 2023). Limited studies are available on the diet of the two species outside PAs in India, such as food habits and characteristics of livestock predation in human-dominated landscapes (Puri et al. 2020; Mohan et al. 2021; Dahya et al. 2023).

In tropical forests, the relative densities of various size classes of prey can vary naturally and due to human activity, affecting or influencing the community structures of large carnivores (Karanth & Sunquist 1995). The abundance and availability of prey species are critical to the sympatry of large carnivores (Andheria et al. 2007). Prey abundance does not necessarily affect prey selection (Bagchi et al. 2003; Lovari et al. 2015). The high density of wild prey limits or reduces livestock depredation and negative human-wildlife interactions (Basak et al. 2018; Upadhyaya et al. 2018; Puri et al. 2020). Sometimes, the human-large carnivore conflict scenarios are exaggerated due to political and social attributes of a specific region (Dickman 2010; Dickman et al. 2013; Nyhus 2016). Thus, the diet profile of large carnivores will also reveal the nature of conflict situations.

Our study focused on the feeding habits and dietary overlap of Tigers and Leopards in a multi-use landscape outside the PAs encompassing the critical wildlife corridors in the Terai-Bhabar region of northern India at the foothills of the Himalaya, a critical Tiger conservation landscape (Sanderson et al. 2006). We also explored the dependence of the large carnivores on livestock for food in areas outside PAs, where wild prey population is low and anthropogenic disturbances are high.

Study Area

Our study area is part of the Terai Arc Landscape, which lies in the Terai-Bhabar topography at the foothills of the Himalaya (Semwal 2005). The study area is located between Corbett Tiger Reserve (CTR) and the Indo-Nepal border in the eastern and southern parts of the state of Uttarakhand, bordering the Indian state of Uttar Pradesh. The study area is divided into two blocks (Image 1). Block 1 constitutes the Kosi corridor with adjoining areas of CTR, Ramnagar Forest Division (FD), and Almora FD of Uttarakhand. Block 2 encompasses the Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridors with adjoining forest habitats of the Terai East FD, Haldwani FD, and Champawat FD of Uttarakhand. The Kosi corridor connects CTR with the Ramnagar FD and Pawalgarh Conservation Reserve along the Kosi River east of CTR in Uttarakhand (Johnsingh 2006; Anwar et al. 2014). The KKS corridor connects Nandhaur Wildlife Sanctuary (NWS) in Uttarakhand with Pilibhit Tiger Reserve (PTR) in Uttar Pradesh and the Indo-Nepal border in the Khatima forest range of the Terai East FD. The BB corridor connects NWS to the Kanchanpur

FD in Nepal, a transboundary landscape that expands to Shuklaphanta National Park in Nepal (Semwal 2005; Qureshi et al. 2014).

The study area lies in Tiger Habitat Block (THB) II and III (Johnsingh et al. 2004) and tiger conservation landscape (Sanderson et al. 2006; WWF & RESOLVE 2015). The large mammalian species in the region are Asiatic Elephant *Elephas maximus*, Tiger, Leopard, Sloth Bear *Melursus ursinus*, Sambar Deer *Rusa unicolor*, Spotted Deer *Axis axis*, Wild Boar *Sus scrofa*, and Northern Red Muntjac *Muntiacus vaginalis*. The study area falls in the 2B Himalaya – western Himalaya and 7A Gangetic Plain – upper Gangetic Plain biogeographic provinces of India (Rodgers et al. 2000).

Livestock grazing is common in the study area because it lies outside the PAs in a multi-use mosaic landscape where reserved forests are interspersed with human settlements and fragmented due to linear infrastructures (Johnsingh et al. 2004; Chanchani et al. 2014). Two important pastoralist community in the study area are 'Bakarwal' and 'Van Gujjars'. The nomadic community of 'Bakarwal' migrates from the high-elevation Himalaya to lower elevations of the Terai-Bhabar during November to January with their large herds of sheep and goats camping for several days and months in the forest areas of the Himalayan foothills (Dangwal 2024). The 'Van Gujjars' is a pastoralist community residing in the study area's forests with large herds of Water Buffalos *Bubalus bubalis* and Cattle *Bos taurus* (Sharma et al. 2012; Dangwal 2024).

MATERIALS AND METHODS

Scat Sample Collection

Scat samples of Tigers and Leopards were collected opportunistically in the study area during camera trapping and vegetation surveys on wildlife trails and

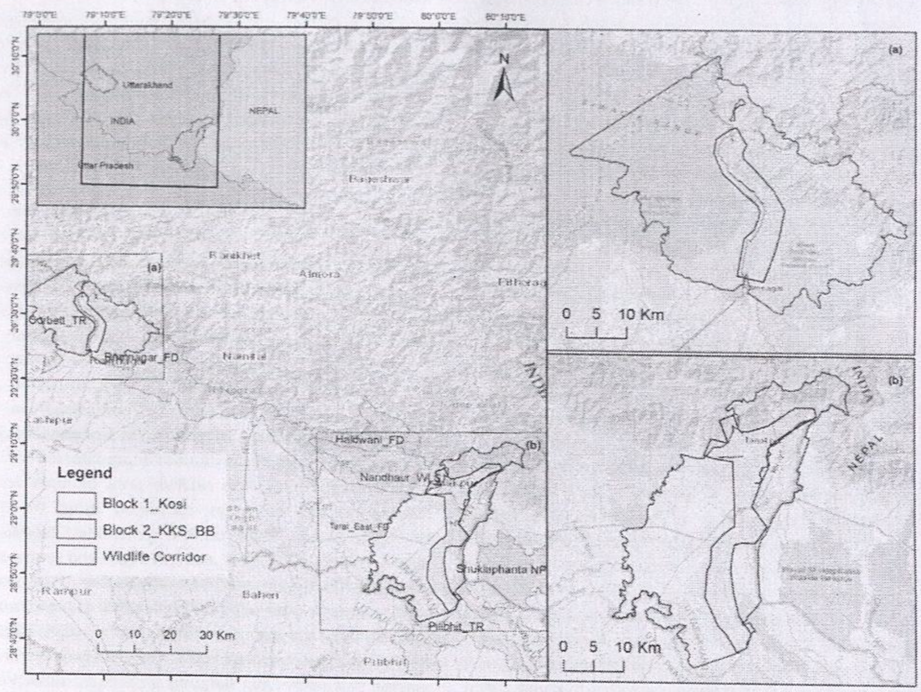

Image 1. Study area map with the two study blocks comprising of wildlife corridors: a—Block 1 with Kosi corridor connecting Corbett Tiger Reserve to Ramnagar forest division | b—Block 2 with Kilpura-Khatima-Surai (KKS) and Boom-Brahmadev (BB) corridor in Indo-Nepal transboundary landscape.

forest roads. We collected scat in the summer season from March–June and in winter season from October–February. Scat collection was not possible during the monsoon season as forest areas were not accessible.

Tigers, Leopards, and other carnivores deposit scat on forest roads and wildlife trails as part of the communication mechanism (Smith et al. 1989; Karanth & Sunquist 1995; Andheria et al. 2007). The samples were collected from October 2019 to December 2021, stored in plastic zip lock bags, and predator species were identified based on ancillary signs and methods described in earlier studies based on visual and indirect signs (Karanth & Sunquist 1995; Andheria et al. 2007; Harihar et al. 2011; Lovari et al. 2015; Basak et al. 2018). Tiger scat has been observed to be less coiled with a more considerable distance between two successive constrictions (Johnsingh 1983; Mohan et al. 2021). The scat samples which were not identified for species based on ancillary signs were not analysed. After collection, the remaining scat samples were removed from the track to avoid repetitive sampling. We avoided collecting scat in village areas or metalled roads in forest habitats to avoid misidentification of species due to lack of indirect signs of species.

Sample processing and prey species identification

A substantial part of each sample was put in nylon stockings, a knot was tied and then soaked in water for 24 hours (Klare et al. 2011). After soaking, it was washed in running water in a sieve of <1 mm to remove debris and dirt (Ramesh et al. 2009; Upadhyaya et al. 2018). Then it was sun-dried for 72 hours (Andheria et al. 2007) before separating 20 random hairs per sample for identification of prey based on its general appearance, colour, relative length, width, cortex pigmentation, and medullary structures under a microscope (Mukherjee et al. 1994; Bahuguna et al. 2010; Dharaiya & Soni 2012).

Data analysis

We did not perform an analysis of vegetation, which we found in some scat samples of both species. We calculated the frequency of occurrence of each prey item in the scat samples, denoted as A, and expressed as a per cent of scat samples in which a particular prey item was found (Andheria et al. 2007). We calculated the corrected frequency of occurrence based on the number of prey items per scat; if two items were present in one scat, it was calculated as 1/2; if three items were present, then 1/3, and so on (Karanth & Sunquist 1995). However, when the body size of prey varies significantly, the frequency of occurrence can be misleading (Floyd et al. 1978; Ackerman et al. 1984). The non-linear models developed for the leopard (Lumetsberger et al. 2017) and the Tiger (Fàbregas et al. 2017) show better accuracy than linear models in assessment of biomass and number of prey consumed. The linear model is biased for tropical large carnivores and significantly underestimates the consumption of medium-sized prey (Chakrabarti et al. 2016). We used the nonlinear asymptotic generalised model developed by Chakrabarti et al. (2016) for carnivores in India based on the following formula:

$$Y_c = 0.033 - 0.025exp^{-4.284 (X/Z)}$$

Y_c is biomass consumed per collectable scat/predator weight, X is the live weight of prey, and Z is the average live weight of predator. Y_c is used as a correction factor for estimating the relative prey biomass consumed by multiplying Y_c by the observed frequency of occurrence (A). The generalised biomass model is better suited for our study, where we want to assess the contribution of livestock to the food habits of Tigers and Leopards since this model does not overestimate large prey (Chakrabarti et al. 2016; Upadhyaya et al. 2018).

Our calculations are based on values for the average body weight of prey (Table 1), Tiger (140 kg) and Leopard (65 kg) (Harihar et al. 2011; Ahmed & Khan 2022). The relative prey biomass (D) and relative numbers of prey consumed (E) were calculated as per the equation below (expressed in percentage) described by Andheria et al. (2007).

$$D = \frac{A * Y}{\Sigma(A * Y)} * 100$$

$$E = \frac{D/X}{\Sigma(D/X)} * 100$$

To assess the dietary overlap between the Tigers and Leopards, we used the Pianka index (Pianka 1973) based on the frequency of occurrence, which ranges from 0 for no overlap to 1 for complete overlap.

$$Pianka\ index = \frac{\Sigma P_{ij} * P_{ik}}{\sqrt{\Sigma(P_{ij}^2 * \Sigma P_{ik}^2)}}$$

P_{ij} is the percentage of prey items i of predator j; P_{ik} is the percentage of prey items i of predator k

D_c and E_c denote the relative prey biomass and relative number of preys consumed using the Y_c correction factor based on the generalised biomass model, respectively. The D_c and E_c of Tigers and Leopards were statistically compared using the Kruskal-Wallis test statistic to understand the difference in diet profiles of the two large sympatric carnivores. We used Kruskal-Wallis as it is a non-parametric test, which does not assume that underlying data has a normal distribution (Xia 2020). We categorised the prey size into three classes based on their body weight: (i) large (above 50

Table 1. Frequency of occurrence (A) of different prey items, percent occurrence of each prey species (Po), live weight of prey (X), the number of scats with each type of prey (No.), Relative biomass consumed (D_c) and Relative number of prey consumed (E_c).

Prey species	X (kg)	Tiger						Leopard					
		No.	A (%)	Po	Y_c	D_c (%)	E_c (%)	No.	A (%)	Po	Y_c	D_c (%)	E_c (%)
Sambar Deer	185	23	15.9	14.29	0.033	19.54	4.91	8	9.0	7.08	0.033	10.83	1.60
Nilgai	184	12	8.5	7.45	0.033	10.38	2.62	5	5.6	4.42	0.033	6.77	1.01
Spotted Deer	50	32	20.4	19.88	0.028	20.95	19.49	17	17.4	15.04	0.032	20.39	11.18
Northern Red Muntjac	25	18	11.4	11.18	0.021	9.03	16.79	17	15.2	15.04	0.028	15.61	17.12
Wild Boar	35	36	24.0	22.36	0.024	21.82	29.00	18	16.3	15.93	0.031	18.14	14.21
Indian Hog Deer	25	4	1.6	2.48	0.021	1.26	2.34	5	4.5	4.42	0.028	4.62	5.07
Porcupine	8	8	3.2	4.97	0.013	1.58	9.18	5	3.4	4.42	0.018	2.24	7.69
Langur	10	4	1.7	2.48	0.015	0.94	4.35	8	5.1	7.08	0.020	3.70	10.15
Indian Hare	4	2	0.7	1.24	0.011	0.29	3.38	7	3.9	6.19	0.014	1.98	13.57
Cattle	175	14	7.8	8.70	0.033	9.50	2.52	6	6.2	5.31	0.033	7.44	1.17
Water Buffalo	250	4	3.0	2.48	0.033	3.70	0.69	2	1.1	1.77	0.033	1.35	0.15
Domestic goat	10	4	1.9	2.48	0.015	1.01	4.72	8	7.9	7.08	0.020	5.76	15.80
Domestic sheep	25	0	0	0	0.021	0	0	1	1.1	0.88	0.028	1.16	1.27
Bird (Unknown)	0	0	0	0		0	0	6	3.4	5.31		0	0

kg; Sambar Deer, Nilgai *Boselaphus tragocamelus*, cattle *Bos taurus*, Water Buffalo *Bubalus bubalis*; (ii) medium (20–50 kg; Spotted Deer, Northern Red Muntjac, Wild Boar, Indian Hog Deer *Axis porcinus*, Domestic Sheep *Ovis aries*); and (iii) small (below 20 kg; domestic goat *Capra hircus*, porcupine, langur, Indian Hare *Lepus nigricollis*) to understand the food habits and diet profiles of the two sympatric large carnivores (Harihar et al. 2011). The diet niche breadth of Tigers and Leopards was estimated using the Levins index (Levins 1968), standardised to a scale of 0–1 (Hurlbert 1978) based on the frequency of occurrence of different prey species. The standardised scale considers the proportional abundance of each resource state (Hurlbert 1978). The statistical tests were performed in PAST 4.03 and other analysis related to scat were performed in Microsoft Excel application. The map was prepared in ArcGIS 10.7, and graphs were prepared in PAST 4.03 and Ms-Excel.

RESULTS

From October 2019 to December 2021, we collected and analysed 116 Tiger and 89 Leopard scat samples in our study area. Our sample size was adequate for dietary profile investigation of Tigers and Leopards as the graph reached asymptote position for the number of preys detected with increasing number of samples (Figure 1).

Scat samples of tigers contained 12 prey species, with 64.7% of all consisting of one prey species, 31.9% of two species and 3.4% of three species. Tigers preyed most frequently upon Wild Boar (24%), followed by Spotted Deer (20.4%) (Table 1), and cattle (7.8%) constituted the most frequent prey amongst all livestock species. Three livestock species were observed in tiger scat, i.e., cattle, Water Buffalo (3%), and domestic goat (1.9%). All 12 prey items were observed in scat collected during the winter season. Scat collected in the summer contained 10 species except goat and Water Buffalo, and a higher contribution of cattle remains (14%) than in the winter (8%).

Scat samples of leopards contained 14 prey species, with 73% of all samples consisting of one species and 27% of two species. Leopards preyed most frequently upon Spotted Deer (17.4%), followed by Wild Boar (16.3%). Four livestock species were observed in Leopard scat, namely domestic goat (7.9%), cattle (6.2%), Water Buffalo (1%), and domestic sheep (1%). Unidentified remains like feather and beaks of birds (3.4%) were also found in leopard scat samples (Table 1). All 14 prey items were observed in leopard scat collected during the winter season and 10 prey species in scat collected during the summer except langur, Cattle, Water Buffalo, and sheep. The contribution of Wild Boar remains was higher in summer (23%) than in winter (14%).

The Wild Boar had the highest prey biomass contribution to the Tiger's diet with 21.82%, while Spotted Deer had the highest prey biomass contribution

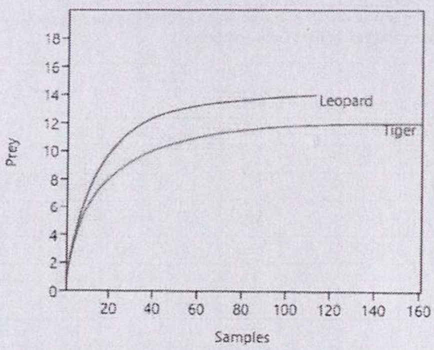

Figure 1. Graph showing number of preys in scat samples of Tiger and Leopard analysed for the study.

to the Leopard's diet with 20.39%. The cattle relative biomass contribution is the maximum among livestock species for both Tigers and Leopards. Overall, for all prey items, the diet composition showed no significant difference between relative prey biomass consumption (p = 0.53, χ^2 = 0.378) and relative number of preys consumed (p = 0.85, χ^2 = 0.032) by Tiger and Leopard.

Tiger and Leopard diets consist predominantly of medium-sized prey (Figure 2). Large prey constitutes 43.1%, medium prey ~53%, and small prey ~3.8% of biomass consumption in the Tiger diet profile. The leopard relative prey biomass consumption is highest for medium-sized prey (~60%), followed by large (26.4%) and small (13.7%) prey. The contribution of smaller prey is considerably higher in the diet of Leopards than of Tigers. Tiger relative prey biomass consumption primarily depends on wild prey (~85.8%), and around 14.2% on livestock. Relative prey biomass consumption of Leopards has a slightly higher share of livestock (~15.7%) than of Tigers (~14.2%). The relative number of medium-sized prey (67.6%) consumed by Tigers is substantially higher than that of large (10.8%) and small (21.6%) prey (Figure 2). However, the relative number of medium (48.9%) and small (47.2%) sized prey consumed by Leopards is equivalent but considerably higher than large prey (~3.9%) (Figure 2).

The relative prey biomass contribution of Wild Boar, Spotted Deer, and Sambar Deer is significant in the Tiger's diet. At the same time, Leopard food habits show a significant dependence on Spotted Deer, Wild Boar, and Northern Red Muntjak for biomass consumption (Figure 2). The dietary overlap between Tiger and Leopard in the study area is approximately 93% (Pianka Index = 0.928). The dietary niche breadth of Tiger and Leopard using the Levins index is 6.51 & 9.11, respectively, and the standardised diet niche breadth is 0.5 & 0.62 for Tiger and Leopard, respectively (Figure 3).

DISCUSSION

In the present conservation paradigm of large carnivores, it is essential to understand the feeding habits and prey-predator dynamics outside protected areas (Kshettry et al. 2018; Puri et al. 2020; Mohan et al. 2021; Dahya et al. 2023). Our study fills this gap in our understanding of the dietary habits of sympatric large carnivore species outside PAs in wildlife corridors of the Terai landscape of India. It is of paramount importance to understand the dependence on livestock, resource sharing, and diversity of food resources of sympatric large carnivores to address human-wildlife conflict in the landscape (Chakrabarti et al. 2016; Fàbregas et al. 2017; Lumetsberger et al. 2017; Puri et al. 2020; Dahya et al. 2023). Our results highlight that Tigers and Leopards prey largely on wild species, but they also indicate a substantial contribution of livestock to their diets, likely due to the lower abundance of wild species in wildlife corridors.

The higher dietary contribution of wild prey highlights that both Tiger and Leopard prefer wild prey over livestock. The lower share of livestock species in Tiger and Leopard diet even when the grazing is high can be attributed to the presence of a herder accompanying livestock herds, and the collection of a few scat samples from the inner areas of forest habitats with minimal disturbances. The contribution of livestock species is substantially lower in comparison to wild prey, still higher than inside PAs in the Terai landscape (Harihar et al. 2011; Basak et al. 2018; Upadhyaya et al. 2018). Studies in the mosaic landscape of PAs and non-PAs in the Terai Arc landscape also show a significant difference in livestock contribution in the diet of Tigers inside PAs and outside PAs (Harihar et al. 2011; Lamichhane et al. 2019; Biswas et al. 2023). Livestock depredation entails the loss of human property, and hence has a more pronounced effect on the conservation of large carnivores and human-wildlife negative interactions (Dickman et al. 2013; Nyhus 2016).

The number of stray cattle in forest habitats has increased in recent years due to government policies (Vivek Ranjan, pers. obs.; Governor of Himachal Pradesh 2014), which have an aggravated negative effect on large carnivore prey availability and feeding habits (Baker et al.

2008; Harihar et al. 2011; Pimenta et al. 2017). Moreover, the depredation of these stray livestock is not reported or recorded by the Forest Department. The maximum share of cattle in the diet of Tiger and Leopard amongst the livestock species can be attributed to its higher population than other livestock species and easier to hunt than Water Buffalo which is similar in other studies (Harihar et al. 2011; Lamichhane et al. 2019; Puri et al. 2020; Biswas et al. 2023). The Water Buffalo has also been observed in two Leopard scat samples from study block 2, which may be attributed to the Water Buffalo calf depredation or buffalo carcass. Carcass dumping was not observed in the Kosi corridor area; however, infrequent carcass dumping was observed in study block 2 areas. The presence of cattle and large livestock species in the forest habitats significantly affects the distribution of wild prey, especially large wild prey like Sambar Deer, which are more sensitive to (Gaynor et al. 2018; Upadhyaya et al. 2018; Habib et al. 2021). This also explains the higher dependence on medium-sized prey in the current study area.

The high dietary overlap of 93% between Tigers and Leopards in the current study area is consistent with findings in earlier studies from the Indian subcontinent (Wang & Macdonald 2009; Harihar et al. 2011; Mondal et al. 2012; Lamichhane et al. 2019). The high dietary overlap also indicates that these sympatric species do not base their coexistence on diet partitioning based on prey type, however, apparent partitioning may occur in prey selection based on body size, age class, and sex of the species (Ramesh et al. 2012; Lovari et al. 2015). The notions of optimal foraging theory preferring larger prey are invalid when the availability of prey is an important limiting factor other than ecological energetics, which supports hunting of prey with equivalent body size/weight and convenience of hunting, which optimises energy use (Gittleman 1985; Chakrabarti et al. 2016; Basak et al. 2018; Upadhyaya et al. 2018). The equivalence of relative number of medium and small prey consumed by leopards can be attributed to their agility and ability to climb trees easily for hunting smaller prey such as porcupines, Indian Hare, and langurs. The Tiger is a top predator, and its increasing population density affects the food habits of its co-predators inhabiting the same habitat by shifting their prey preference, selection of sex, age classes of prey, and hunting time (Andheria

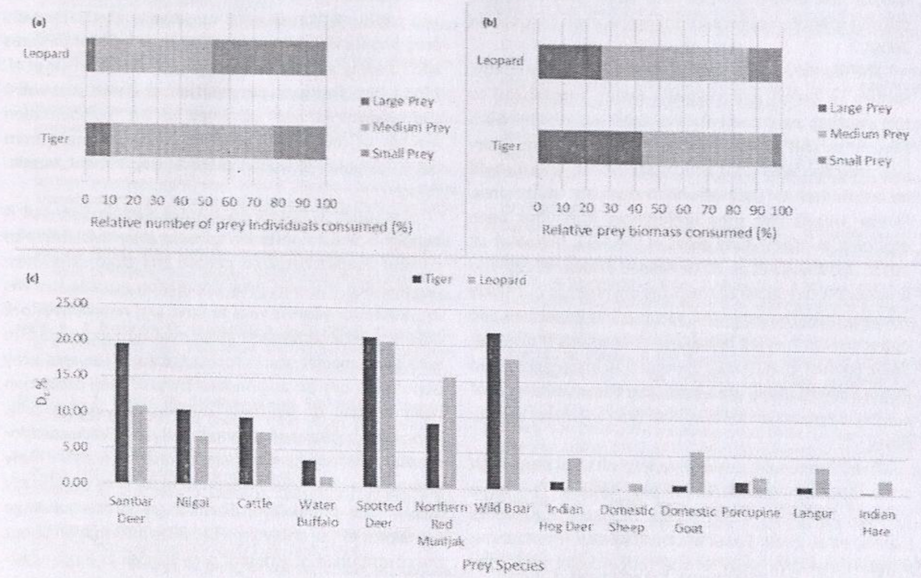

Figure 2. Diet profile of tiger and leopard in the study area: a—Relative prey biomass consumed (D_c) by the two sympatric large carnivores using a generalised biomass model for three categories of prey based on body size | b—Relative number of prey consumed (E_c) by two large carnivore species using a generalised biomass model | c—Contribution of different prey species in the prey biomass consumed by two sympatric carnivores. (Large prey >50 kg, Medium prey 20–50 kg, Small prey <20 kg)

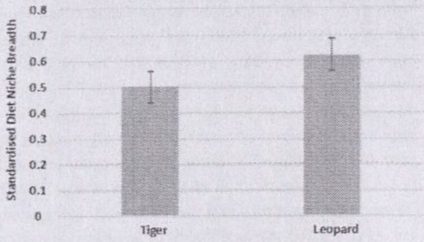

Figure 3. Standardised diet niche breadth of Tigers and Leopards in the study area with standard error using the Levins index.

et al. 2007; Harihar et al. 2011; Mondal et al. 2012; Shameer et al. 2021). It also explains the considerable difference in relative biomass and number of large prey consumption between Tiger (cumulative Dc = 43.1% and Ec = 10.8%) and leopard (cumulative Dc = 26.4% and Ec = 3.9%) in our study. This substantial difference in large prey relative consumption between Tiger and Leopard and the higher relative number of small prey in the Leopard diet indicates prey selection partitioning between the two sympatric species. The terrain of the habitat and prey behaviour also affect prey selection, causing spatiotemporal partitioning (Wang & Macdonald 2009).

The dietary specialisation of these two sympatric species is broad and suggests better adaptability to the existing environment and food availability. Both species exhibit a high dependence on medium body-size prey like Wild Boar and Spotted Deer, which could be attributed to their abundance in our study area. Similar trends and prey preferences have also been observed in other study areas of the Terai (Basak et al. 2018; Upadhyaya et al. 2018; Ahmed & Khan 2022). The broader dietary niche of Leopards observed in our study area indicates the generalist nature of prey selection and opportunistic feeding behaviour of Leopards (Puri et al. 2020; Mohan et al. 2021). Camera trap images obtained in the current study area have also shown evidence of poultry depredation by Leopards (Vivek Ranjan, unpub. data).

The absence of a wider variety of wild prey, high anthropogenic disturbance, and grazing pressure increase livestock depredation by large carnivores (Sankar et al. 2010; Basak et al. 2018). Our results show a higher livestock share in the Leopard diet with four livestock species compared to the Tiger diet with three species, which can be attributed to the varied habitat use patterns of these two sympatric predators. As the Tiger population density increases in the core forest habitats, the Leopard responds by spatially and temporally partitioning its habitat use, adapting to fringe habitats on the forest boundary, thereby increasing the chances of more frequent livestock depredation (Harihar et al. 2011; Bisht et al. 2019; Naha et al. 2020; Puri et al. 2022). Corbett Tiger Reserve (CTR), part of our study area, has the highest tiger population density among all the PAs in India (Bisht et al. 2019; Qureshi et al. 2023) and acts as a source population for the metapopulation of this landscape (Chanchani et al. 2014). The Tigers dispersing from the core habitats of CTR face a high risk of human-wildlife interactions outside PAs, mainly in the form of livestock depredation and human casualty in a few incidents (Bargali & Ahmed 2018; Bisht et al. 2019), as evident from compensation records of the Uttarakhand Forest Department (Uttarakhand Forest Department, unpub. data).

The seasonal migration of 'Bakarwal' disturbs the wild prey populations inhabiting those habitats and increases the probability of depredation by carnivores (Bisht et al. 2019; Qureshi et al. 2023), which is highlighted by the fact that all the scat samples of both the species with sheep hairs and all tiger scats with goat hairs were collected during winter. The large herds of Water Buffalo and cattle of 'Van Gujjars' negatively affects the wild prey population and disturbs the availability of pastures and foraging activity of wild prey species (Harihar et al. 2011). The livestock depredation of these pastoralist communities is also observed in the compensation records of the Uttarakhand Forest Department from the study area (Uttarakhand Forest Department, unpub. data).

Our study is based on a small sample size, but it highlights the importance of wild prey availability to contain conflict between people and large carnivores. Augmenting the wild prey population outside the PAs in wildlife corridors is vital to limit and reduce livestock depredation and improve habitat quality to accommodate wild prey populations in forest habitats. The wild prey population can be augmented by providing protection from hunting or poaching outside PAs. Additionally, improving habitat and heterogeneity in wildlife corridor areas and reducing anthropogenic disturbances are likely to provide a conducive environment for prey to naturally increase its population. The dietary profile of large carnivores of the study area provides information about the contribution of different prey species as food, which is crucial for understanding prey-predator dynamics in the landscape outside PAs. It will help develop a scientific management and mitigation plan for human-wildlife negative interaction and long-term conservation. More such studies with extensive sampling outside the PAs are needed to formulate long-term landscape conservation plans.

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