Habitat, Food Resource Utilization of Himalayan Brown Bear (*Ursus arctos isabellinus*, Horsfield 1826) and Conflict with Humans in Lahaul Valley, Himachal Pradesh

Thesis submitted to the

Saurashtra University
Rajkot (Gujarat)

For the award of the Degree of

DOCTOR OF PHILOSOPHY
IN
WILDLIFE SCIENCE

Submitted by

Vineet Kumar

Under the Guidance of

Dr. B. S. Adhikari
and
Dr. Lalit Kumar Sharma

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

December, 2023

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Date:२०December, 2023

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This is to certify that the thesis entitled "**Habitat, Food Resource Utilization of Himalayan Brown Bear (*Ursus arctos isabellinus*, Horsfield 1826) and Conflict with Humans in Lahaul Valley, Himachal Pradesh**" submitted by **Mr. Vineet Kumar** (Reg. no. 20160) to Saurashtra University, Gujarat for the award of the degree of **Doctor of Philosophy in Wildlife Science**, is a record of bonafide research work carried out by him under my supervision. No part of this thesis has been submitted for any other degree and it fulfills all the requirements laid down in the ordinance of Saurashtra University, Gujarat for this purpose.

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LalitK81.

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Declaration

I, Vineet Kumar, hereby declare that the thesis entitled "**Habitat, Food Resource Utilization of Himalayan Brown Bear (*Ursus arctos isabellinus*, Horsfield 1826) and Conflict with Humans in Lahaul Valley, Himachal Pradesh**" submitted for the award of the degree of Doctor of Philosophy in Wildlife Science to Saurashtra University Rajkot, (Gujarat), is my original work which has been carried out by me under the guidance of Dr. B. S. Adhikari, Scientist-G, Wildlife Institute of India and Co-supervisor Dr. Lalit Kumar Sharma, Scientist-D, Zoological Survey of India, and has not been submitted previously for any degree or examination at any other institution. I further declare that all the sources used or referred to in the thesis have been duly acknowledged and cited. I take full responsibility for the accuracy, originality, and authenticity of the research presented in this thesis.

By signing this declaration, I affirm that I have adhered to the ethical guidelines and academic standards throughout the process of conducting this research and writing the thesis.

Vineet

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Date: 20-12-2023

Habitat, Food Resource Utilization of Himalayan Brown Bear (*Ursus arctos isabellinus*, Horsfield 1826) and Conflict with Humans in Lahaul Valley, Himachal Pradesh

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Submitted by

Vineet Kumar

Under the guidance of

Dr. B. S. Adhikari
and
Dr. Lalit Kumar Sharma

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Acknowledgments

My fascination with the brown bear began in 2014 during my undergraduate years, ignited by a memorable field trip to Kugti Wildlife Sanctuary (Chamba, Himachal Pradesh) with my college professor, Dr. Bipan C. Rathore. It was there when I first encountered this charismatic mountain dweller, sparking a dream to delve into research on the brown bear. Since that transformative moment, my journey has been an adventure filled with the support and guidance of numerous individuals. As I pen down this acknowledgment for my Ph.D. thesis, I am grateful for the collective efforts that have shaped this remarkable experience.

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Vineet Rana

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Executive summary

Globally elusive carnivores are severely impacted by habitat loss, human disturbance, and climate change. Monitoring populations of such species is pivotal for their long term viability. For the effective management planning and conservation efforts, especially for species, those are under increasing threat, it is imperative to identify and map their habitats. Brown bear, being a polytypic species of several subspecies complex has wide range distribution in the Northern Hemisphere, occurring in the North America, Europe, to Northern and Central Asia. In the Central Asian landscape, brown bears mostly inhabit in the higher elevation ranges and its distribution is governed by the habitat quality and various other associating factors.

Himalayan brown bear (*Ursus arctos isabellinus*) is one of the top carnivores dominating the higher altitudes of the North and Western Himalayan landscape. In India, based on the 2005 estimate the approximate brown bear distribution range is reported to be 36,800 km^2, whereas only 10% of the total distribution area of the brown bear comes under the protected areas. There is very low density of brown bear lies in its distribution range throughout the Western Himalaya, in alpine meadows, scrub and sub-alpine forests of two Union Territories (Jammu and Kashmir; and Ladakh) and two Indian Himalayan States, Himachal Pradesh and Uttarakhand. Due to its inaccessible and high altitude habitat, the brown bear has been poorly studied in India, as well as in other parts of the Asian highlands.

In the recent decade, the widespread exponential growth of the human population, infrastructure development, and agricultural intensification has led to the alteration of

natural habitats into human-modified landscapes, bringing humans and wildlife into close proximity. In areas where brown bear and human habitation are in close proximity, brown bears feed on agricultural/horticultural crops and livestock predation leads to human-brown bear conflict and lessens local tolerance for bears. As the human settlements encroach further into remote areas, bear-human conflict escalates. Himalayan brown bear in its distribution range in India facing prevailing threats such as habitat loss, cropland expansion, anthropogenic disturbances, human-brown bear conflict and climate changes. The Himalayan brown bear is classified as endangered based on the IUCN (International Union for Conservation of Nature) red list under criteria 'D' due to its small population size (130–220), sparse distribution, and is protected under Scheduled-I species of India's Wildlife (Protection) Act, 1972.

Given the current levels of habitat loss, anthropogenic activities, and rapid changes in land use patterns, it is essential to conduct a study covering different ecological aspects of HBB in Lahaul valley for effective and meaningful conservation. Despite being a high conservation priority species in India, there are very limited studies are available on HBB, while single study from Lahaul Valley conducted by our lab. The Lahaul Valley holds a good population of HBB and is one of the prominent habitats of the species. So far, no information is available on the brown bear feeding habits and nature and extent of human-brown bear conflict in the valley, considering the high anthropogenic disturbance and conflict and how these two are influential to brown bear conservation. Therefore, the present study was proposed to understand in detail the habitat use and feeding habits of brown bear with respect to human-brown bear conflict to develop mitigation strategies. A better understanding of the ecology of the Himalayan brown bear is crucial for its long-term conservation.

The study was conducted in the Lahaul valley of Lahaul and Spiti district of Himachal Pradesh, which is an elemental part of the Indian cold desert area of Northwest Himalaya lies between coordinates 31°44'57" to 32°59'57" N latitudes and 76°46'29" to 78°41'34" E longitudes with total area 6651 km^2. The major part of the study area harbor dry temperate to dry alpine-type vegetation interspersed with human-settlements and cropland, which is a prominent habitat for brown bears in the valley. The livelihoods of the people depended mainly on agriculture, horticulture, and livestock rearing (goat, sheep, cow, etc.).

For conducting this study, the vast geographic area of Lahual valley was stratified into different habitats and then divided into 10 km × 10 km grids for extensive study. A single-time effort was made in the extensive grids to cover the entire landscape and the collected data were used identify the intensive study area. The intensive areas were further divided into 2 km × 2 km grids and the repeated field survey was conducted using various conventional methods, including sign surveys, camera trapping, and questionnaire survey across different elevation ranges.

Total of 111 camera traps (3303 trap nights) were deployed in Lahaul valley, Himachal Pradesh which resulted in 69 captures of HBB. I also walked 116 trails (596 km) in Lahual valley of 2-7 Km in length to collect non-invasive samples for feeding analysis and other habitat parameters. A total of 306 presence records (Direct and indirect) and 279 scat samples were collected during trail transects from the study area. All the putative scat samples of HBB were air-dried in field conditions and stored in 100 ml sterilized Silica containing vials for feeding analysis.

First objective of this study aimed to understand the habitat utilization pattern of the Himalayan brown bear in selected grids of Lahaul Valley across the seasons (Intensive study area). To achieve this objective sign survey and camera trapping data was used and sixty-five logistically possible grids were surveyed across the seasons (summer and pre-hibernation), in different habitats and elevation gradients. HBB presence data was collected through the primary field survey (Summer- May to August) and (Pre-hibernation period - September to November) 2018 to 2022). A total of 67 (268.4 km) trail transect of varying lengths of 2-7 km were walked. Along with the trail transects 42 camera traps (1263 trap nights) were deployed in various habitat and in and around the cropland covering different elevational gradients. A total of 242 presence locations (sign survey n=218 and camera trap n=24) were obtained. To understand the seasonal habitat utilization pattern of Himalayan brown bear, a total of 132 presence locations of HBB for summer and 110 during the pre-hibernation period were used. After the spatial filtration, 81 presence locations from summer and 70 presence locations from the pre-hibernation period were used for the final analysis. Equal number of pseudoabsence locations were randomly generated corresponding to the presence locations at a spatial distance of 2 km. For the analysis I used four major environmental covariates *e.g.,* landscape composition, topographic, bioclimatic, and anthropogenic disturbances. A generalized linear model (GLM) with a binomial logit link function was used to understand the impact of the ecogeographic variables on habitat use of HBB across the seasons. The top model suggests that habitat use of Himalayan brown bear in Lahaul Valley was positively influenced by predictors such as distance to human settlements (β = 0.002±0.000), NDVI-Summer (β = 4.999±1.182), rangeland (β = 3.057±1.225), and Shannon diversity index (β = 2.540±0.871). On the contrary, a negative correlation was observed with the distance to road (β = -0.002±0.000).

During the pre-hibernation period, the top model showed that the distance to human settlements (β = 0.001±0.001), Shannon diversity index (β = 4.328±1.521), and slope (β = 0.088±0.043), had a significant positive influence on the habitat use of Himalayan brown bear. On the contrary, barren land (β = -4.218±1.874), distance to road (β = -0.001±0.000), and elevation (β = -0.008±0.002) showed the negative association.

The findings of the present study highlight a distinct seasonal pattern in habitat use of the Himalayan brown bear. In summer, bears predominantly utilized the areas with extensive vegetation cover as evidenced by a positive association with rangeland and Shannon diversity index and NDVI-summer, particularly away from the human settlements in the elevation range of 3000m to 4500m. Conversely, in the per-hibernation phase, Himalayan brown bear tends to avoid high-altitude areas with limited vegetation, opting for areas with available vegetative materials. Notably, habitat use was concentrated in the elevation range of 2800m to 3800m closer to the human settlements in comparison to summer. Regardless of the season, the Himalayan brown bear utilizes areas near roads, emphasizing the availability of anthropogenic food resources.

The positive association with diverse habitats, as indicated by the Shannon Diversity Index (SHDI), NDVI-summer, and rangeland, underscores the importance of maintaining varied landscapes to conserve the species. The high altitudinal preference for habitat uses and seasonal changes in food availability highlight the vulnerability of HBB to climate change and anthropogenic disturbances. The significant influence of distance to human settlements on HBB habitat use led to human-brown bear conflict. In the Lahaul valley Himalayan brown bear share the habitat and resources with local communities. Establishing clear demarcation between brown bear habitat and human settlement is needed, and should be managed carefully to ensure effective coexistence. In the transitional zone, maintaining the natural diversity of seasonal food sources is crucial, as it will immensely help minimize the human-bear interactions.

Second objective focuses on understanding the feeding preferences and its seasonal variation of Himalayan brown bear in selected grids of Lahaul Valley. To analyze the HBB feeding habits and its seasonal variations, I quantified the dietary composition using the frequency of occurrence (FO) as a percentage and percent of the fecal volume (FV) of each food item. The brown bear is an omnivore in diet and feeds on a variety of food items, that vary in nutritional attributes and digestibility. To avoid bias in the dietary estimation, I used the two-correction factor (CF_1 and CF_2) to each food category. The correction factor (CF_1) was used to ascertain the estimated dietary content (EDC), and CF_2 was used the evaluate the energy available after assimilation (EDEC). I employed the chi-square test to investigate variations in the diet of HBB across different seasons. The frequency of occurrence (FO) indicates that plant matter was the dominant food item in the HBB diet during both seasons, followed by crops, and animal matter. Plant matter constituted 62.14% and 55.79 % of the diet of HBB during the summer and pre-hibernation period respectively, followed by crops (21.90% summer, 30.53% pre-hibernation period) and animal matter (10.95% summer, 6.32% pre-hibernation period). In terms of fecal volume (FV), the majority of the diet of HBB composed of plant matter during summer as well as in pre-hibernation phase with (77.85% summer, 57.82% pre-hibernation), followed by crops (20.57% summer, 41.14% pre-hibernation), and (8.57% summer, (<1% pre-hibernation) by animal matter. The results showed that the consumption of different food items varies in the diet of HBB across the seasons. During the summer based on FO, graminoids constituted the major portions of the HBB diet i.e. (79.22%), followed by forbs (55.19%), berries (35.06%), Iceberg lettuce (27.92%), peas (21.43%), insects (mostly ants) (17.53%), animal matter (12.34%), and horticultural crops (10.39%) had the lowest FO. In terms of fecal volume (FV), graminoids (57.42%) had the major portions in the scat residues, followed by berries (15.77%), peas (12.71%), forbs, horticultural crops, and iceberg lettuce had (<5%). Findings based on EDEC showed that during the summer HBB primarily obtained 66.18% dietary energy from plant matter, 25.70%, and 7.87% from crops, and animal matter respectively. Conversely, during the pre-hibernation period, anthropogenic food (crops) provided most of the energy i.e., 68.80% followed by plants (27.98%), and animal matter (3.12%). However, in summer among the main food items berries (33.53%) contributed the highest EDEC, followed by graminoids, horticultural crops, peas, animal matter, forbs, and insects with EDEC values of 29.22%, 13.86%, 9.35%, 4.98%, 3.43%, and 2.89%, respectively. Interestingly, during the pre-hibernation, horticultural crops alone with 68.03% were the main source of energy intake, followed by berries (14.81%), graminoids (12.18%), animal matter (2.50%), whereas, the forbs, iceberg lettuce, peas, and insects were the lowest contributor of energy (<1%). The chi-square results revealed that the FO of food items in the diet of HBB varied significantly between the summer and pre-hibernation period ($\chi 2$ = 61.09, df = 8, p-value = 2.85e-10).

The annual dietary analysis suggests the frequency of occurrence (FO) shows that the major food items in the annual diet of HBB were graminoids (69.57%), forbs (45.85%), berries (29.64%), horticultural crops (24.90%), iceberg lettuce (20.55%), pea (13.83%), and (10.67%) animal matter. Fecal volume (FV) indicates that the graminoids, horticultural crops, and berries had the major portion of scats residual in the diet of HBB. However, the horticultural crops (42.87%) provided the major energy intake for HBB, followed by berries (23.51%), and graminoids (20.09%), as observed in the estimated dietary energy content.

The findings showed significant variations in the diet of the Himalayan brown bear across the seasons. The anthropogenic food resources significantly influenced the dietary pattern of the Himalayan brown bear and provided highly digestible energy during the pre-hibernation period. Whereas, plants and animal matter were important food components during the summer. The results showed that in summer HBB relied mainly on protein-rich food resources. However, during the pre-hibernation period, it consumed food items rich in carbohydrates. Various studies raised the concern that the future climate change scenario could affect the distribution, abundance, and variations in the availability of bear food resources. The findings of the present study will be of immense importance for the long-term conservation and management of the species.

My last chapter focuses on understanding the Spatio-temporal pattern of human-brown bear conflict in Lahaul valley. For this I interviewed local communities using a semi-structured "designed as both close and open-ended" questionnaire to collect information on various aspects of Human–HBB conflict in the study landscape. A total of 398 respondents (male = 294 and female = 104) were interviewed, and only one representative individual from each household, mainly the head of the family, was considered. The respondents' socioeconomic status was characterized using the Kuppuswamy socioeconomic scale, which accounts for education, occupation, and income together. The human-brown bear conflict varies significantly across seasons. I observed high conflict incidences during summer season as compared to winter, occurred in areas closer to the forest (<500 m), mainly during night hours or dusk and dawn in the elevation range of 2700 m to 3000 m above sea level. The livestock depredation during summers in high-altitude areas of the study landscape could be because of unsupervised livestock grazing practices in alpine pastures by the nomadic herders. The results indicate (56.28% of respondents) that the agricultural and horticultural lands near forest areas attract bears due to the easy and high-quality food available. The most damaged crops were apple, iceberg lettuce and pea.

The dependency of locals on forest resources (70%) for their livelihood makes them vulnerable to HBC. The "upper lower" class respondents were most impacted among the various socioeconomic classes. Two of the four clusters were identified as HBC hot spots in Lahaul valley using SaTscan analysis. The results showed that the villages viz Gowshal, Rashil, Jasrath, Nalda, Jobrang and Nainghar were more vulnerable to Human-bear conflict. I found that anthropogenic food disposal, livestock grazing in bear habitats, and poor knowledge of animal behaviour among the communities were the major causes of HBC. I suggest horticulture crop waste management, controlled and supervised grazing, sustainable ecotourism, the constitution of community watch groups, and installation of electric fencing to mitigate HBC. I also recommend notifying a few HBB abundant range/areas in the valley as protected areas for the long-term viability of the HBB in the landscape.

These objectives are designed to address key issues related to the of Himalayan brown bear in Lahaul valley. Each chapter focuses on distinct research questions, providing in-depth analyses and findings to contribute valuable insights to the field of wildlife conservation. Together, these chapters offer a comprehensive and cohesive exploration of the study species, its habitat, feeding habits, Human-bear conflict, and the crucial conservation efforts required to ensure its long-term survival in the face of mounting environmental challenges.

Chapter 1: 1.1 Introduction

Bears have a diverse distribution range and are found in four continents with the exception of Antarctica, Australia, and Africa (Nowak and Paradiso 1983). Classified under the order Carnivora and the family Ursidae, these remarkable beings comprise a total of eight species worldwide (Waits et al. 1999) Which includes the spectacled bear or Andean bear (*Tremarctos ornatus*) endemic to South America, American Black bear (*Ursus americanus*) endemic to North America, polar bear (*Ursus meritmus*) confined to the Arctic circle and north pole (Russia, Alaska, Canada, Norway (Svalbard), and Greenland), the Brown bear (*Ursus arctos*) found in North America, Europe, Eastern and Central Asia (McLellan et al. 2017, Su et al. 2018, Garshelis 2022).

On the contrary, Asia has a greater number of bear species in the world *viz.* the Brown bear (*Ursus arctos*), Asiatic black bear (*Ursus thibetanus*), Sun bear (*Helarctos malayanus*), Sloth bear (*Melursus ursinus*), and Giant panda (*Ailuropoda melanoluca*), (McLellan et al. 2017). Out of the five bear species of Asia, four species are *viz.* Sloth bear, Sun bear, Asiatic black bear, and Giant Panda are listed Vulnerable as per the IUCN Red List of Threatened Species (Swaisgood et al. 2016, Scotson et al. 2017, Dharaiya et al. 2020, Garshelis and Steinmetz 2020). Globally as per the IUCN Red List, the brown bear is listed as the Least Concern species, but the sub-populations in various regions in Asia are classified as Threatened (McLellan et al. 2017).

Bears are commonly perceived as inhabitants of forested habitats, with the majority of bear species being forest dwelling or demonstrating a preference for such habitats. However, several bear species are thriving in environments that have less tree cover (Garshelis 2022). Ursidae family has diverse adaptability, found in a diverse array of habitats such as temperate forests, northern tundra, coniferous forests, mixed-deciduous forests, boreal forests, tropical and sub-tropical forests, alpine meadows, semi-arid regions, and arctic tundra. All the terrestrial bear species are omnivorous in diet and feed on plants, insects, fruits, and animal matter with the exception of the giant panda which is a true herbivore that mainly feeds on bamboo (Garshelis 2022).

Among Ursidae, the brown bear is the most distributed species found in three continents *viz.* North America, Europe, Eastern and Central Asia (McLellan et al. 2017). Throughout its geographic range, brown bear found in a different habitat spanning from Northern tundra and temperate forest in North America, desertic regions of the Gobi Desert of Mongolia to coastal rainforest, alpine meadows, and forests of Europe and Asia (Servheen 1990). Across the geographical distribution range, brown bears are frequently engaged in conflict with humans, manifesting as instances of crop depredation and livestock attack (Can and Togan 2004, Rigg et al. 2011, Karamanlidis et al. 2011, Lamb et al. 2017).

India is home to four species of bears, the Asiatic Black bear, the Himalayan Brown bear, the Sun bear or the Malayan sun bear, and the Sloth bear (Prater 1990). They occupy a variety of habitats, temperate coniferous forests, mixed-deciduous and semi-evergreen forests, dry-deciduous and Alpine-subalpine forests, and meadows (Sathyakumar 2002, Bargali et al. 2005, Rathore 2008).

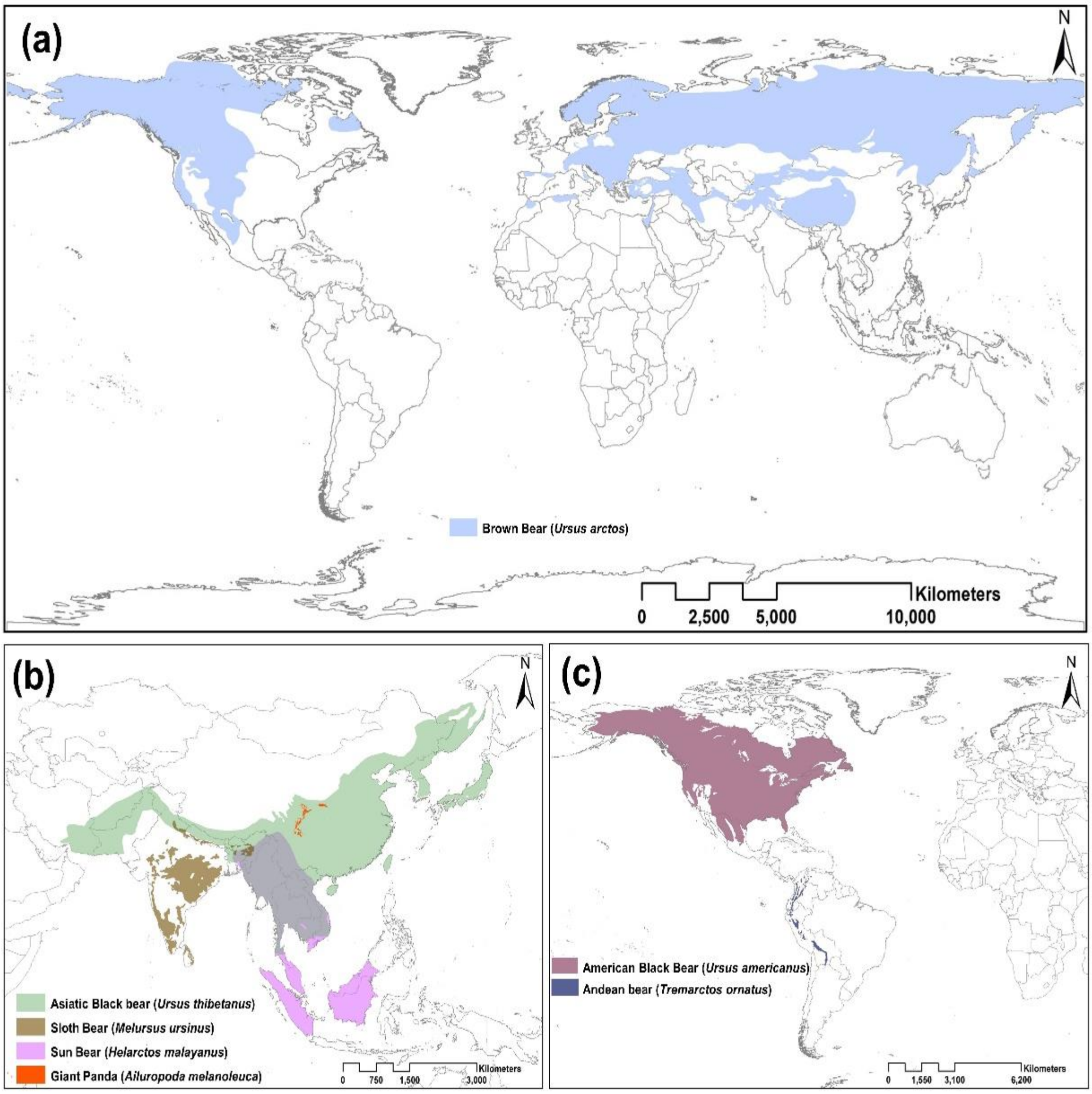

Figure 1.1. Map shows the geographic distribution of the Ursidae family; (a) depicts the brown bear distribution ranges across North America, Europe, and Asia. (b) The distribution range of Asiatic black bear, sloth bear, sun bear, and giant panda with some overlapping regions among them, all are endemic to Asia. (c) The American black bear is native to North America while the Andean bear inhabits South America. The distribution map of bear species with possible wide geographic ranges is acquired from the IUCN (International Union for Conservation of Nature) Red List.

The Himalayan brown bear (herein HBB), a polytypic species of brown bear is predominantly herbivore, mainly feeding on varieties of herbs, shrubs, fruits, ants, occasionally on small mammals (Marmots and Pikas) and livestock of nomadic shepherds (Aichun et al. 2006, Rathore and Chauhan 2007, Aryal et al. 2012, Rathore and Chauhan 2014, Swenson et al. 2020, Haroldson et al. 2021). The distribution range of HBB partially overlaps with that of black bears. In certain regions, HBB shares habitat with black bears, albeit to a limited extent. Black bears generally prefer densely forested areas, while HBB are typically found in alpine meadows (Sathyakumar 2001, Rathore 2008, Liu et al. 2009).

Contrary to HBB, Sloth bears are predominately insectivores that mainly feed on termites and ants (Joshi, Garshelis and Smith 1997). The sloth bear diet also consists of fleshy fruits, primarily depending upon the availability and the preference for plant matter is relatively low in the sloth bears diet (Ramesh et al. 2009, Baskaran and Desai 2010). The altitudinal and geographic distribution of the sloth bears is governed by the presence of termites (Steinmetz, Garshelis, and Choudhury 2020). In the Ursidae family, Sun bears are the smallest and second in position to prefer insects in its diet after Sloth bears (Garshelis 2022). Fruit plants also constitute the major proportion of its diet (Fredriksson et al. 2006).

In most of the part of Southeast Asia, the Sun bears overlap with Asiatic black bears, and the coexistence is possible because of some extent of preference for same dietary component in their diet. As insects are a major part of sun bears diet along with fruits, while, the latter feeds largely on fruits, nuts, herbs, grasses, small prey species, and to some extent on insects (Shaller 1969, Manjraker 1989, Koike 2010, Steinmetz et al. 2011, Steinmetz et al. 2013, Kozakai et al. 2021).

1.2. Himalayan Brown bear in Asia: An overview

The Himalayan brown bear (HBB), is the sub-species of brown bear, characterized by its exceptional adaptability to survive in the highland ecosystems spanning Iran, Afghanistan, Pakistan, and India. In this range of geographic distribution, HBB is considered Endangered under criterion-D of IUCN's Red List, occupying an estimated area of about 35,000 Km^2, with a population estimate ranging from 130-220 Individuals (McLellan et al. 2017). The ecological versatility of brown bears is evident as they inhabit diverse habitats including boreal forests, alpine, and subalpine mountain areas (Servheen 1990). Recent studies conducted on the impact of climate change on brown bears have raised apprehensions about the potential loss of suitable habitats for brown bears in the future (Su et al. 2018, Mukherjee et al. 2021, Dar et al. 2021).

In the Central Asian landscape, brown bears predominantly occupy high altitude areas (Abbas et al. 2014, Aryal et al. 2012, Shrestha et al. 2012), contributing to the challenges of studying the charismatic species in the inaccessible and high-altitude terrains of the Asian landscape (Galbreath et al. 2007). While comprehensive studies on the HBB remain limited, however, number of studies are conducted on landscape genetics, species distribution and dietary patterns within the Asian geographic range (Lan et al. 2017, Nawaz 2007, Rathore 2008, Abbas et al. 2015, Su et al. 2018, Habibzadeh and Ashrafzadeh 2018, Nawaz et al. 2019, Sharief et al. 2020, Dar et al.

2021, Ashrafzadeh et al. 2022). In most of its distribution range in Asia, brown bear faces an array of threats primarily driven by anthropogenic pressures, habitat loss, and the intensification of human-wildlife conflicts.

1.3. Himalayan Brown Bear Status in India

In India, HBB occupies the highlands of the Western Himalayan states of Himachal Pradesh, Uttarakhand, and two Union Territory *viz.* Jammu and Kashmir Union Territory (JKUT), Ladakh Union Territory (LUT) (Sathyakumar 2006). In this part of the range, bears exist in several fragmented regions (McLellan et al. 2017). In India, HBB is a conservation priority species and listed as a Schedule-I species, under Indian Wildlife (Protection) Act, 1972, and Appendix I of CITES. Based on a questionnaire survey conducted in India, brown bear occurrence was reported from 41 locations, including 23 Protected Areas (PAs) and 18 locations outside PAs (Sathyakumar, 2001). The potential distribution range of HBB in India is estimated to be 36800 km^2, of which the north-western and western Himalayan region has 28000 km^2 while the trans-Himalayan region of Ladakh has 8800 km^2 (Sathyakumar and Qureshi 2003).

The HBB population in its distribution range in Western Himalayas found in a low density and thrive in various habitats between the sub-alpine and alpine regions in the elevation gradients of 2300-5000m in the Northwest Himalaya-2A, West Himalaya-2B, and in a few regions of the Trans-Himalaya-1A and 1B. In Himachal Pradesh, brown bear population thrive in various protected areas, located in the Great

Himalayan and Trans-Himalayan regions (Green 1993, Sathyakumar 2002, Singh et al. 1990) and some regions outside the protected area.

In the Lahaul and Spiti district of Himachal Pradesh, which has two valleys *viz,* Lahaul Valley and Spiti Valley. In Spiti Valley HBB population confined only in the Pin Valley National Park. Simultaneously, in the Lahaul region in which the present study was conducted, HBB occurs in a very narrow range mainly in the areas along the left bank of Chandrabhaga River (Joshi et al. 2020). The limited studies are conducted on brown bear in India and other regions of its geographic range in Asia, primarily because of the remote and high-altitude habitats (Galbreath et al. 2007, Lan et al. 2017).

Figure 1. 2. Direct sighting of Himalayan brown bear in the study landscape (PC-Dipender Othangba).

Brown bears are facing various threats throughout their distribution range in the form of anthropogenic disturbances, habitat degradations, illegal trade, hunting, retaliatory killing, and climate change that collectively jeopardize their survival (Yokoyama et al. 2002, Ciucci and Boitani 2008, Garshelis and Steinmetz 2008, Kaczensky et al. 2011, Liu et al. 2011, Aryal et al. 2012, McLellan et al. 2017, Dai et al. 2021, Dar et al. 2023). The exponential increase in the human population over the last few decades has led to numerous infrastructural developments and agricultural expansions which in turn provide access to remote areas bringing human and wildlife nearby leading to human-bear conflict, habitat degradation, and fragmentation (Rathore 2008, Sergio et al. 2008, McLellan et al. 2017, Hartel et al. 2019, Sharief et al. 2020, Chavan et al. 2021, Kumar et al. 2022). Unsupervised grazing practices in bear habitats also pose a significant threat and can lead to overgrazing of natural vegetation, which is a crucial food source for brown bear, and consequently lead to the depredation of livestock (sheep and goat). Often in the Indian Himalayan region, livestock depredation by brown bear leads to retaliatory killing by nomadic shepherds (Rathore 2008). The recent studies of climate change impact on brown bear in the Indian Himalayan region showed that the majority of the brown bear suitable habitat will be lost in the future climate change scenario (Dar et al. 2021, Mukherjee et al. 2021).

1.4. Literature Synthesis: Brown Bear Ecology

Brown bear scientifically known as *Ursus arctos*, is a highly adaptable terrestrial carnivore. Brown bear is polytypic species having several subspecies, has a vast geographic distribution (Nowak 1999, Schwartz et al. 2003, Bellemain et al. 2006, McLellan et al. 2017). The fossil records show the genesis of the brown bear in Asia and historically ranged over Europe, North America, and even northern Africa during the Pleistocene epoch (Kurtén 1968, McLellan and Reiner 1994). Brown bear act as an umbrella species owing to its wide habitat needs and high mobility (Steenweg et al. 2023). Additionally, it serves as a keystone species playing a vital role in supporting the ecosystem (Helfield and Naiman 2006, Steenweg et al. 2023). Conserving the habitat of brown bear, significantly conserve the habitats of a wide array of co-occurring species within the same ecosystem.

The brown bear has a wide distribution range at a broader scale, it inhabits diverse habitats such as dense forests, alpine meadows, and coastal regions, but in India brown bear habitats range from alpine, sub-alpine meadows, shrublands to, temperate forest, mix-conifer forest and agricultural land (Rathore 2008, Sharief et al. 2020). Due to high adaptability, brown bears thrive in a wide array of environments, from remote wilderness to human-modified landscapes. There are numerous studies conducted across the brown bear distribution range, demonstrated that the ranging patterns and habitat utilization of brown bears are mainly governed by food resource availability, their distribution, shelter, and opportunities for reproduction (Herrero et al. 2000, Schlaepfer et al. 2002, Kristan 2003, Almpanidou et al. 2014).

During spring and summer brown bear use low elevation areas to feed on available vegetative materials and to exploit habitats with early-ripening berries, and subsequently, ascend to higher elevations to feed on ripening fruits during early fall (Darling 1987, Mace and Waller 1997, Herrero et al. 2000). Studies suggest male bears exhibit a larger home range size compared to females and transects with a home range of several females (Dahle and Swenson 2003a, Støen et al. 2005).

The larger home range of male bears is influenced by polygamous mating and food availability (Sandell 1989). The home range of female brown bears varies significantly depending on their reproductive stage. During the breeding or oestrus period female brown bear seek suitable mate, hence maximizing their home range. On the contrary, the home range of females with cubs is smaller (Hirsch et al. 1999, Bellemain et al. 2006), and avoid encounters with males to reduce the risk of infanticide by the males (Dahle and Swenson 2003b, Bellemain et al. 2006).

Previous studies suggested that bears moved to higher elevations during the denning period and preferred steep slope areas for the den site (Aune 1994, Collins et al. 2005). Hibernation is a crucial aspect of the lifecycle, this adaptation allows the animals to cope with harsh environmental conditions and scarcity of food resources (Geiser 2013, Ruf and Geiser 2015). The various studies throughout the brown bear geographic range emphasize the significance of hibernation (Friebe et al. 2001, Geiser 2004, Haroldson et al. 2002). Hibernation is critical for pregnant female brown bears, facilitating birth and lactation in dens (López-Alfaro et al. 2013). Hibernation offers substantial energy savings through unique metabolic adaptations. Premature emergence from hibernation, as indicated by (Linnell et al. 2000, Pigeon et al. 2016), adversely affects energy conservation and cub survival.

Furthermore, prior to hibernation brown bear goes through a phase called hyperphagia, characterized by an intensive quest for food to store energy. Bears begin hibernation primarily when the environmental conditions become harsh (Winter-Snowfall), and reduced food availability (Evans et al. 2016, Krofel et al. 2017), mainly in the month of late November to early December. Female bears give birth to a litter in months late January and early February (Feldhamer et al. 2003). During hibernation, the body temperature of brown bear drastically declines to 4 - 5º C, before that the body temperature during the active period ranges from 36. 5º - 38. 5º C (Follman et al. 1979).

Brown bears emerge from hibernation between March and May month. Usually, the cubs remain with their mother for a duration spanning from 1.5 to 2.5 years (Van de Walle et al. 2018) and become sexually mature at an age ranging from 4-6 years (Dahle and Swenson 2003a). The natal dispersal in brown bear is sex-biased, females tend to show strong philopatry by establishing their home ranges within or near to natal places, while males disperse to longer distances from their maternal home range (McLellan and Hovey 2001, Støen et al. 2006).

Brown bears are typical opportunistic omnivores that are capable of thriving in a range of habitats and feed on diverse available food resources (Krechmar 1995, Van Daele et al. 2012, Kavcic et al. 2015, Swenson et al. 2020), including anthropogenic foods (Bojarska and Selva 2012). Even though taxonomically brown bear is classified as carnivores, numerous studies worldwide revealed that brown bear diet is predominantly comprised of plant matter (Robbins et al. 2004, Sacco and Van Valkenburgh 2004, Rathore 2008, Nawaz et al. 2019). Their food items also include insects the phenomena of myrmecophagy (Große et al. 2003, Swenson et al. 1999). In a broader context, brown bear diet can be categorized into major food items, such as Plant matter; graminoids, forbs, shrubs (Mattson et al. 1997, Rode et al. 2001, Nawaz et al. 2019), fruits/berries (Aoi 1985, Rathore and Chauhan 2014, Nawaz et al. 2019), insects (Makarov 1987, Swenson et al. 1999, Grosse et al. 2003), and animal matter (mammals, birds, fish, rodents), (Mattson 1997, Reynolds et al. 2002, Aichun et al. 2006).

Besides the naturally available food resources, brown bears also feed on anthropogenic food such as agricultural crops, livestock, and garbage in human-modified areas (Gunther et al. 2004, Rathore 2008, Murray et al. 2017). Brown bears have exceptional adaptability in altering their diet based on the temporal and spatial availability of food resources (Mowat and Heard 2006, Bojarska and Selva 2012). The various studies across its distribution range show the seasonal changes in the brown bear diet (Herrero 1972, Servheen 1983, Hechtel 1985, Mclellan and Hovey 1995). The availability of food resources can influence their reproductive success and habitat utilization (Hilderbrand et al. 2000, Van Daele et al. 2012, Zedrosser et al. 2006), which in turn, impact Brown bear movement patterns (Barnes 1990, Ciucci et al. 2014, Kavcic et al. 2015, Nielsen et al. 2006, Stofik et al. 2013) and, leads to human-bear conflict (Mattson et al.1992). Hence, an in-depth study of feeding habits is crucial in understanding the ecology and effective management and conservation of brown bear (Balestrieri et al. 2011, Kavcic et al. 2015).

In the recent decade, the widespread exponential growth of the human population, infrastructure development, and agricultural intensification has led to the alteration of natural habitats into human-modified landscapes, bringing humans and wildlife in close proximity (Watson et al. 2015, Venter et al. 2016). The areas where brown bear and human habitation are in close vicinity brown bears feed on agricultural/horticultural crops and livestock predation leads to human-brown bear conflict and lessens local tolerance for bears (Can and Togan 2004, Karamanlidiset et al. 2011, Rigget et al. 2011, Rathore and Chauhan 2007). As the human settlements encroach further into remote areas, bear-human conflict escalates (Baruch-Mordo et al. 2011, Charoo et al. 2011, Gore et al. 2006, Worthy and Foggin 2008).

Brown bear faces conflict with humans over shared resources leading to the contraction of habitat and requires urgent conservation consideration (McLellan et al. 2017). Anthropogenic food sources (garbage, livestock feed, honey, agricultural and horticultural crops) are frequently exploited by brown bears wherever humans and bears coexist (Fedriani et al. 2001, Rathore 2008, Bojarska and Selva 2012). Instances of bears causing damage to agricultural/horticultural crops, bee hives, livestock attack and posing risk to human safety have been well documented throughout its geographic distribution range (Tsutomu and Joseph 1999, Bargali et al. 2005, Rathore 2008, Kumar et al. 2022). The various studies across brown bear distribution reveal the spatiotemporal variations in crop damage and livestock depredation (Karamanlidis et al. 2005, Kumar et al. 2022). In Himachal Pradesh, nomadic shepherd kills bear as retaliatory killing for livestock predation (Rathore 2008). Hence, in depth understanding of the ecology of the Himalayan brown bear is crucial for long-term conservation.

1.5. Rationale of the study

Extensive research has been conducted on various aspects of brown bear ecology throughout its geographic distribution range in Northern and Central Asia, Europe to North America (Dahle et al. 1998, Herrero et al. 2000, Nawaz 2008, Abbas et al. 2015, Kavcic et al. 2015, Stenset et al. 2016, Mclellan et al. 2017, Su et al. 2018, Bombieri et al. 2019, Nawaz et al. 2019, Berezowska-Cnota et al. 2023). However, limited studies are available in India on habitat ecology, species distribution modelling and feeding analysis (Sathyakumar 2002, Sathyakumar 2006, Rathore 2008, Rathore and Chauhan 2014, Maheshwari et al. 2021, Mukherjee et al. 2021, Dar et al. 2021), while the Lahaul Valley is completely lacking, only one study on HBB by (Sharief et al. 2020). Although, the Lahaul Valley holds a good population of HBB and is one of the prominent habitats of the species. However, the human-brown bear conflict is a challenging issue in the Valley. Lahaul Valley recently expanded with human settlement and agricultural expansion along with a wider influx of tourism and infrastructure development in the valley led to various conservation threats for the brown bear. So far, no information is available on the brown bear habitat use and conflict in the valley, considering the high disturbance and conflict and how these two are influential to brown bear conservation. Therefore, the present study was proposed to understand in detail the habitat use and feeding habits of brown bear with respect to human-brown bear conflict in Lahual Valley for effective conservation and management of this species.

1.6. Objectives

1. To study the habitat utilization pattern of the Himalayan brown bear in selected grids of Lahaul Valley across the seasons.
2. To understand the feeding preferences and its seasonal variation of Himalayan brown bear in selected grids of Lahaul Valley.
3. To understand the Spatio-temporal pattern of human-brown bear conflict in Lahaul Valley for developing mitigation strategies.

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Chapter 2: Study Area

2.1. Background

Himachal Pradesh the land known for its serene beauty, shadowy valleys snowcapped mountains, high altitude passes, and roaring rivers falls under the North-West Himalaya (2A) of the Great Himalayan Mountain chain. The state is known as the abode of Gods and Goddesses so called "Dev Bhumi". Himachal Pradesh is well known for its rich culture and traditions and has diverse floral and faunal diversity. The main mountain ranges are Pir Panjal Range (Jammu and Kashmir and Himachal Pradesh), and Dhauladhar Range (Himachal Pradesh). The present study was conducted in the Lahaul valley of Lahaul and Spiti district of Himachal Pradesh, which is an elemental part of the Indian cold desert area (Biogeographic Zone (1)) of North West Himalaya.

2.2. Indian Trans-Himalaya: An Introduction

The Trans-Himalaya is one of the ten Biogeographic Zone of India and is situated in the Northern part of the Great Himalaya (Mani 1974). It has harsh environmental conditions, scarce vegetation and low productivity, low oxygen and atmospheric pressure. Trans-Himalaya has a total area of 1,84.823 sq. km. and has a length of about 1000 km, with an average width of about 225 km in the central part and 40 km in the extremities (Rodgers et al. 2002) and divided into three biotic provinces *viz.* Ladakh Mountains (1A), Tibetan Plateau (1B), and Sikkim (1C). It has high altitude mountain ranges viz. Zaskar, Ladakh (5,800 m) and Karakoram ranges (5,500-6,000 m) lie on the Northern crest of the Himalayas (Mani 1974). The Northern part of the

Trans-Himalaya defines as High altitude cold desert comprised of arid mountains and sparsely vegetated dry valleys with extreme environmental conditions and rough terrain comprising the areas of Ladakh and Kargil (Union territory of Ladakh) and Lingti plains (Lahaul Valley), Spiti Valley of district Lahaul and Spiti (Himachal Pradesh), **(Figure 2.1)**. In Himachal Pradesh, it has a total area of about 11,000 sq. km, of which 7,600 sq. km is in Lahaul and Spiti and 3,400 sq. km areas are in Kinnaur district (Verma and Kapoor 2010).

Figure 2.1. Landscape view of Trans-Himalaya.

2.3. Lahaul Valley

The study was conducted in the Lahaul valley of Lahaul and Spiti district of Himachal Pradesh **(Figure 2.2)**. This region constitutes an integral part of the Indian cold desert area in the Northwest Himalaya in the coordinates between 31°44'57" to 32°59'57" N latitudes and 76°46'29" to 78°41'34" E longitudes with total area 13841 km^2 (Aswal and Mehrotra 1994). Lahaul Spiti district is located in the northeastern part of the state and has two subdivisions and two Valleys, Lahaul Valley and Spiti Valley. The terrain of the valley is mountainous with elevation ranging from 2300-6500 meters. Lahaul Valley has two seasons winter (October-March) and summer (April-September). A major part of the study area harbors dry temperate to dry alpine-type vegetation, which is a prominent habitat for brown bears in the valley (Joshi et al. 2020, Sharief et al. 2020). The livelihoods of the people predominantly rely on agriculture, horticulture, and livestock rearing (goat, sheep, cow, etc.). The highly productive cropland in the valley supports the cultivation of both local and exotic vegetables, contributing significantly to the income of the local communities. Commonly cultivated agricultural crops include peas, iceberg lettuce, cabbage, cauliflower, broccoli, and potatoes, while horticultural crops comprise apples, apricots, plums, etc. Furthermore, animal husbandry is practiced by remote communities and nomadic grazers visiting the highland grazing grounds from other regions of Himachal Pradesh. In the Lahaul Valley, there are 4 forest ranges viz. Keylong, Pattan, Udaipur, and Tindi, but there is no protected area in the landscape even though the high conservation priorities species occurred in this area such as Brown bear, Snow leopard, Kashmir musk deer, Himalayan tahr, Tibetan wolf, Himalayan goral, and Himalayan ibex etc.

Figure 2.2. The landscape view of different habitats in Lahaul Valley, with human-settlement and cropland.

In the valley human and wildlife lives in very close proximity and are often involved in human-wildlife interactions which leads to negative consequence for both wildlife and humans (Kumar et al. 2022). Despite having the diverse faunal diversity of conservation priority species, infrastructure development, agriculture expansion, unsupervised grazing practices, climate change, and other anthropogenic disturbances are threatening the long-term viability of the endangered flora and fauna of the study landscape.

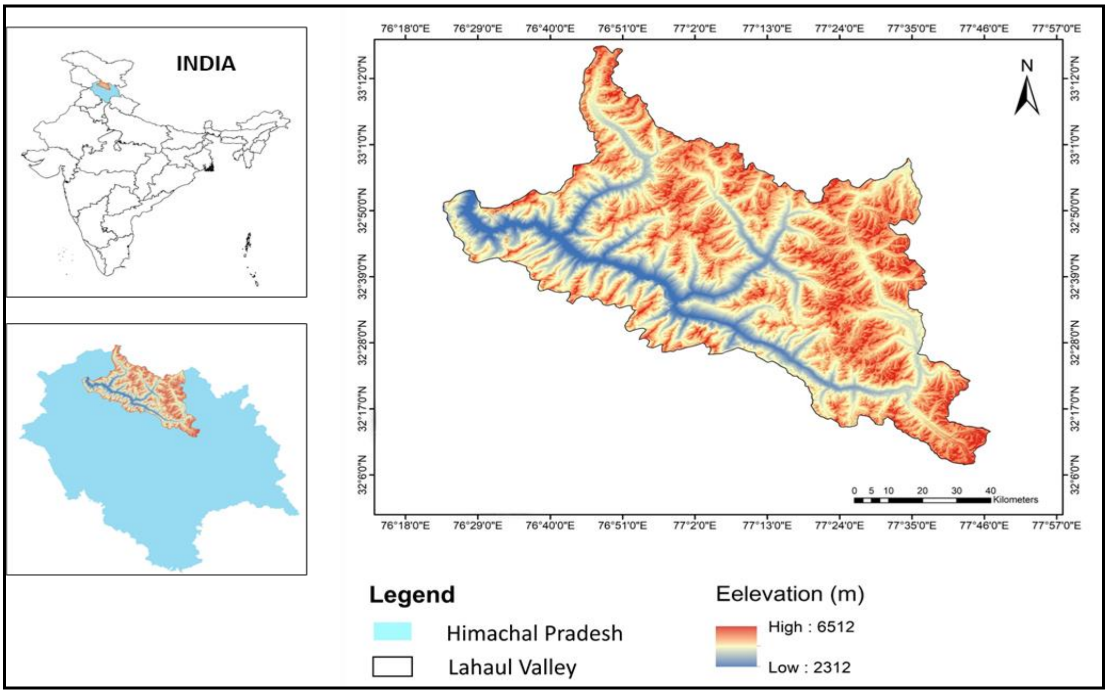

Figure 2.3. Depicts the map of the study area showing the elevation range and state boundary.

2.4. Biophysical features

The Lahaul Valley with a geographical area of 6651 sq. km lies between 32.78 to 32.178 N latitude and 76.36 to 77.80 E longitude with an elevational gradient range from 2300-6500m (**Figure 2.3; 2.4**). The valley lies between the Pir Panjal in the south and Zanskar in the north, part of the Great Himalayan range. Lahaul Valley has two rivers, Chandra and Bhaga, which arise on either side of the Baralacha La pass in the north of Darcha on the way to the Leh region. These rivers flow through the narrow Chandra and Bhaga valleys and ultimately unite at Tandi, forming the river 'Chandra-bhaga' or Chenab. The area's climate is extremely harsh and typically comes under a cold, arid zone with heavy winter snowfall and low rainfall in July and August.

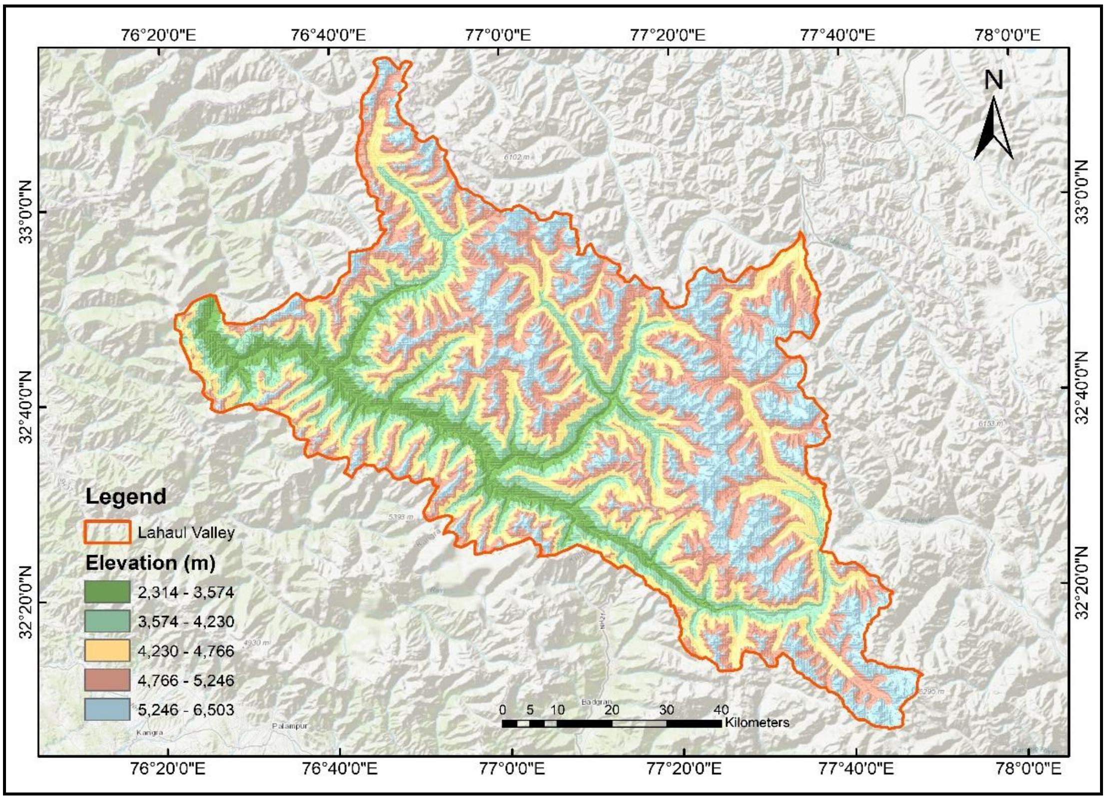

Figure 2.4. Map of study area showing different elevation ranges of Lahaul valley.

Annual rainfall and snowfall of the Lahaul Valley range from 241.5 to 272.4 mm and 466.2 to 693.2 mm respectively (Rawat and Everson 2012). The annual precipitation rates in the valley are 100 to 700 mm (Thakur et al. 2020). In winter the temperature remains less than 10º C and comes down to –10° C to -15° C because of heavy snowfall. In the summer, the temperature goes up from 25° C to 28° C. The topography of the area is mountainous, comprising rugged deep gorges and steep slopes. The mountainous and trans-Himalayan terrain of the landscape has rugged topography **(Figure 2.7)** presenting varying slopes **(Figure 2.6)**, and aspects **(Figure 2.5)** with an altitude ranging from 2300-6500m **(Figure 2.4)**. The land cover classes in the Lahaul Valley are predominantly categorized into seven classes such as water, forest, cropland, built-up area, barren land, rangeland, and snow **(Figure 2.8)**. The data of landcover classes were acquired from Esri land Cover dataset (https://www.esri.com).

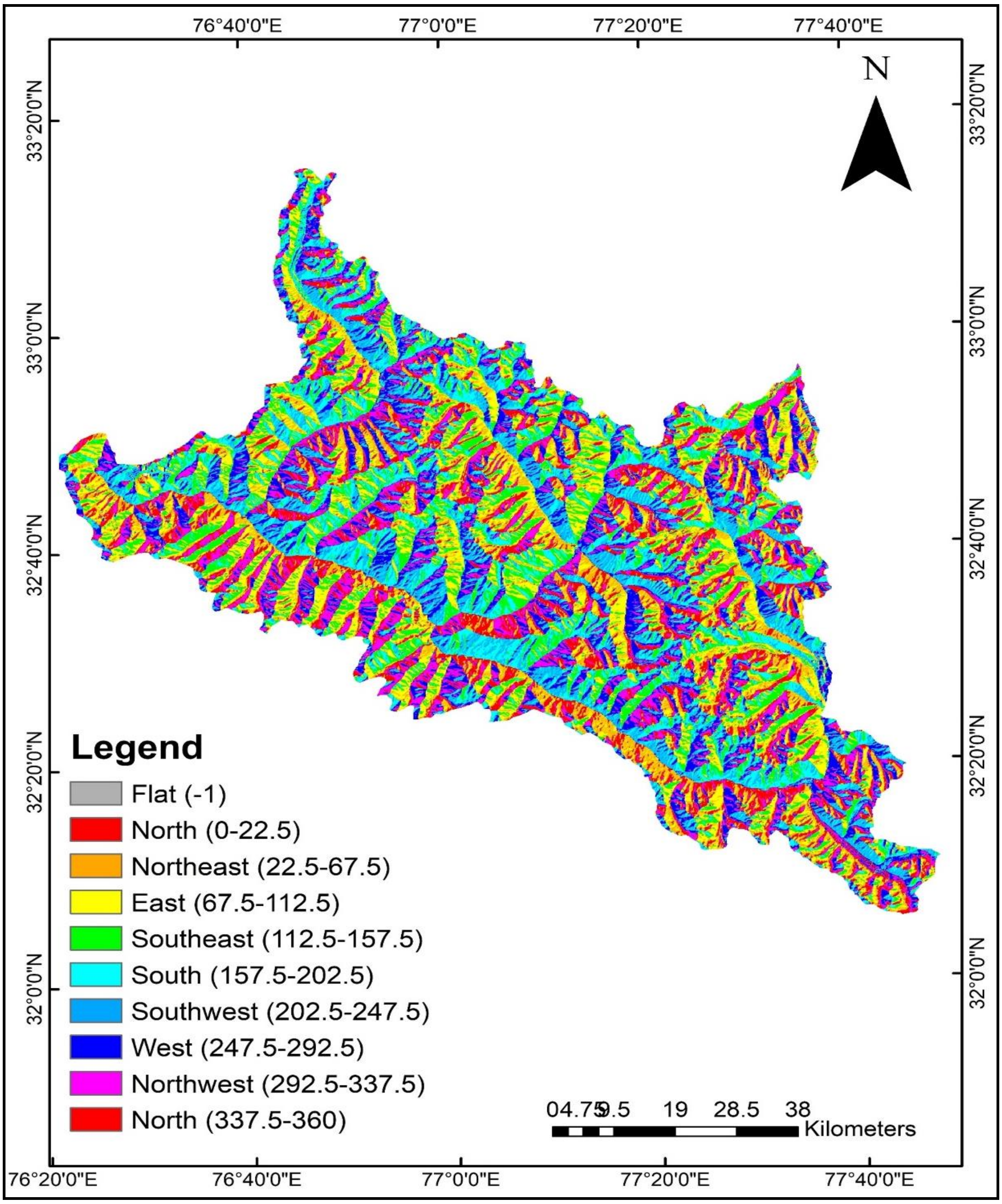

Figure 2.5. Map showing the different aspect categories of study landscape.

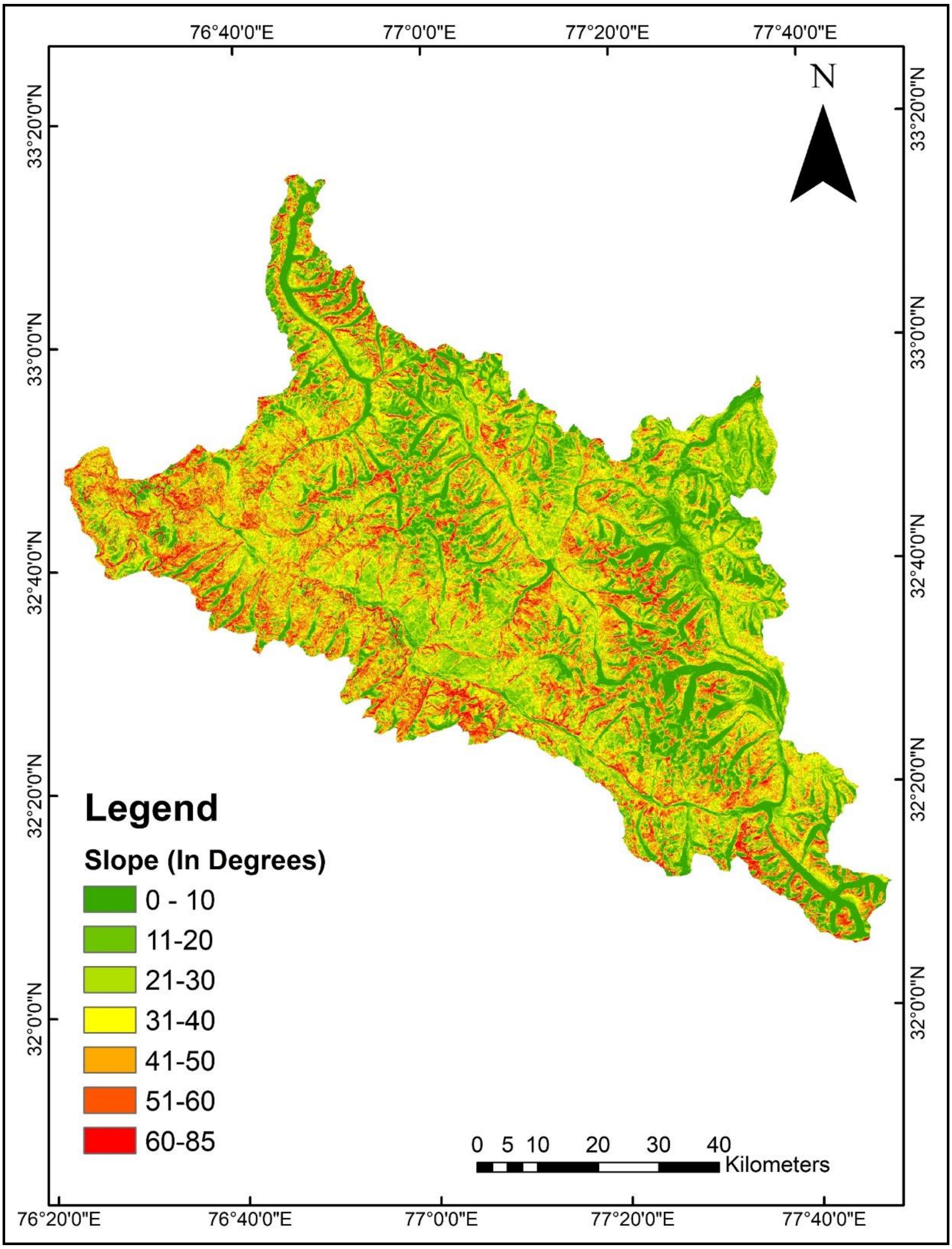

Figure 2.6. Map showing different slope categories of the study landscape.

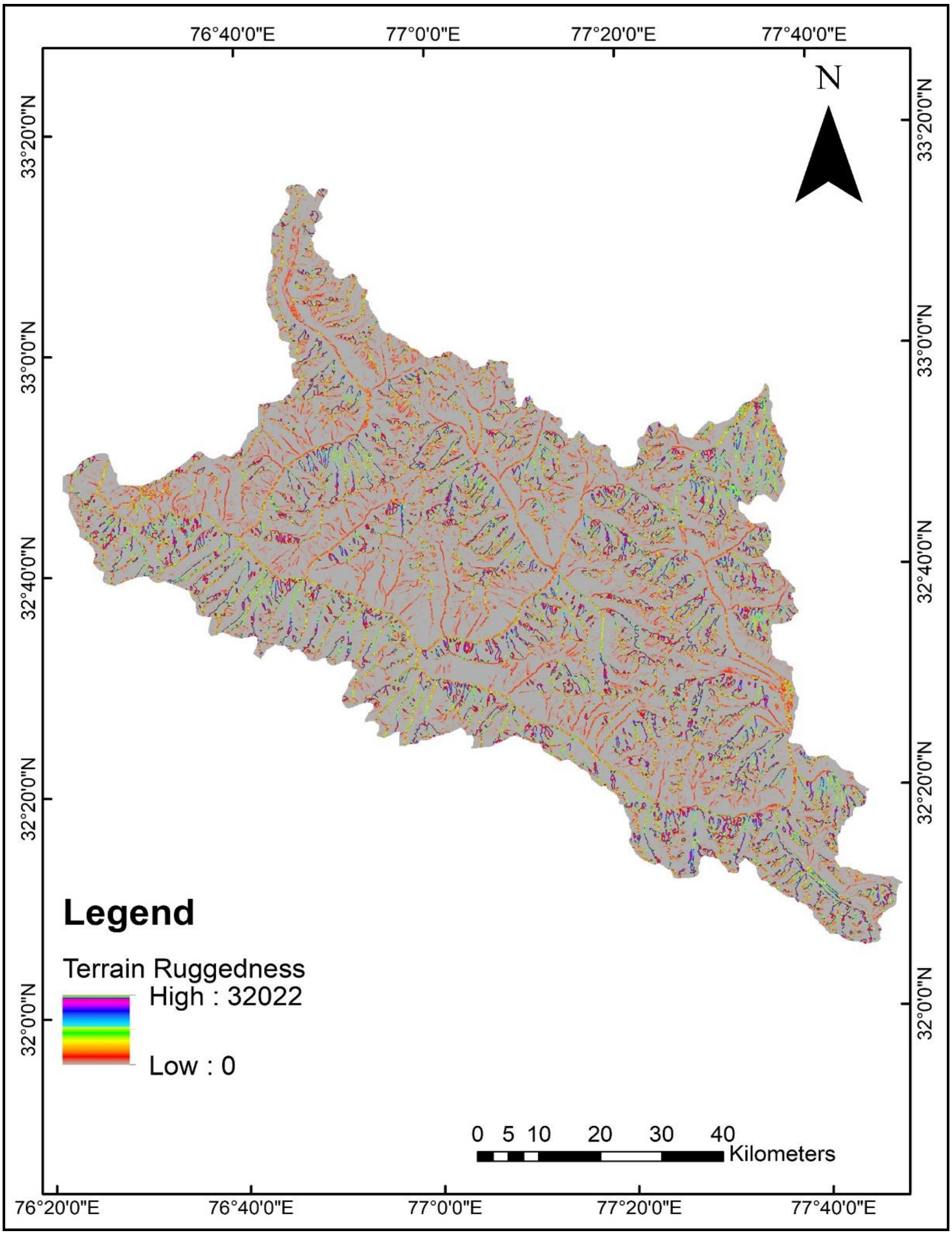

Figure 2.7. Map showing the terrain ruggedness of the study landscape.

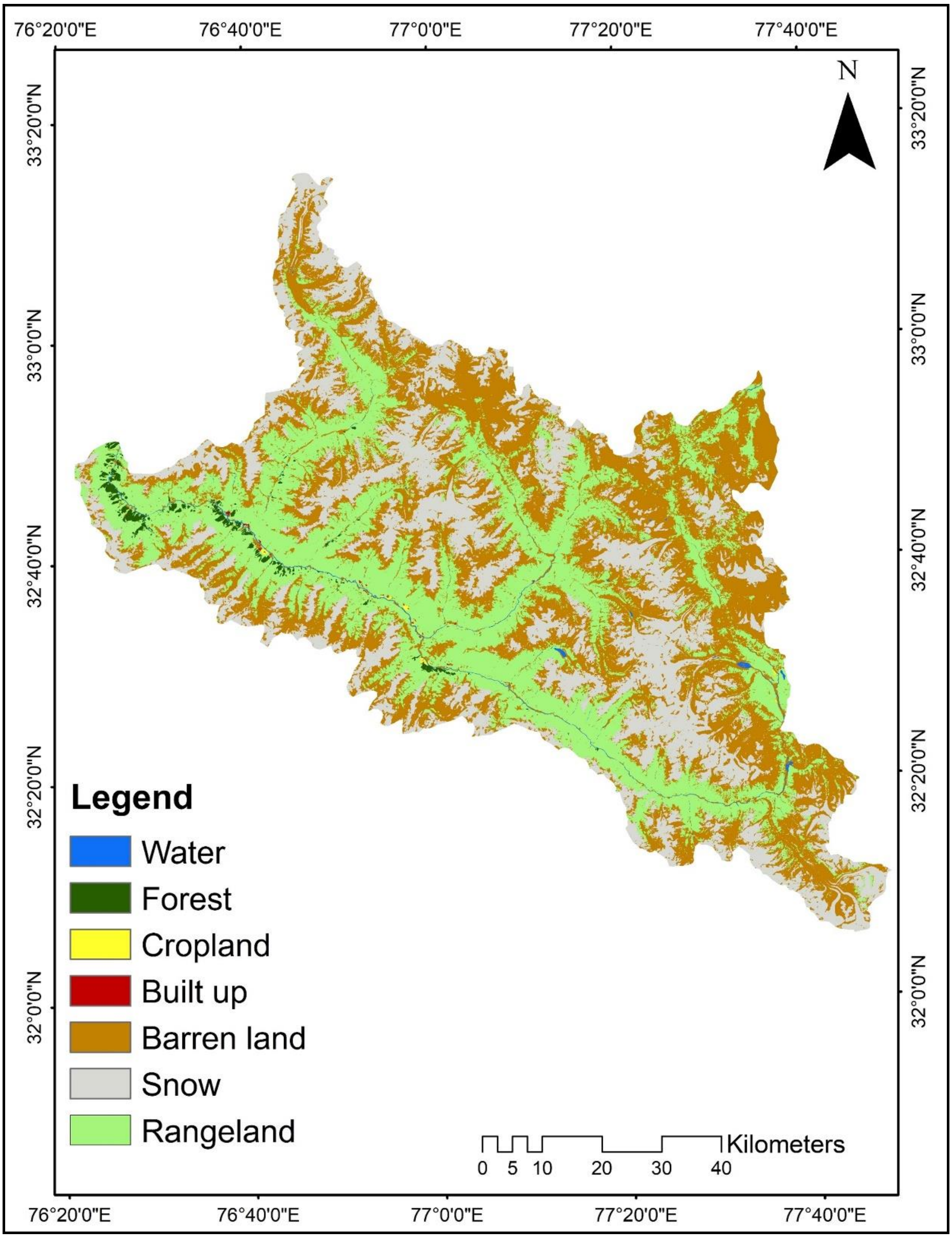

Figure 2.8. The Land Cover classes of the study landscape.

2.5. Floral Composition of the Lahaul Valley

The floral composition of the regions is mainly divided into two types 1) sub-alpine and 2) alpine region.

Sub-alpine zone: this region is confined in the elevation range of 2,350m to 3,500m distinguished by the presence of forest and shrubland. The dominant trees in the forest includes *Pinus wallichiana*, *Betula utilis*, *Cedrus deodara*, *Juniperus polycarpos*, *Juniperus communis*, *Juniperus recurva*, *Junperus macropda*, *Picea smithiana*. The local communities depend on this sub-alpine zone for the collection of fodder and fuel wood as well as grazing their livestock (mainly goat and sheep). Additionally, various herbs and shrubs thrive in this zone.

Alpine Zone: Starting above the tree lines (primarily above 3500m). This region experiences heavy snowfall during the winter and remains covered with snow, until the month of mid-March to early April. The various herbs and shrubs start flourishing after the onset of summer. The zone is categorized by the presence of alpine meadows, forest patches, pastures, and mainly the moraine area above 5000m (the vegetation above this elevation is scarce). The vegetation is most abundant between the months of May to August and decreases from September onwards.

The dominant trees in this region (primarily up to 3800m) if available are *Betula utilis*, and *Rhododendron campanulatum* forming the scattered alpine forest. The shrubs of the genus Berberis, Cotoneaster, Cassiope, and Rosa, Juniper, and *Rhododendron anthopogon* are prominent in the valley.

This region predominantly comprised of herbaceous plants which are mostly perennials, and primarily of the genus Anaphalis, Anemone, Artemisia, Aster, Astragalus, Epilobium, Delphinium, Geranium, Gentiana, Aconitum, Jurinea, Potentilla, Picorhiza, Primula, Ranunculus, Saxifraga, Thymus, and several members of Brassicaceae and Poaceae.

2.6. Faunal diversity of Lahaul Valley

Lahaul Valley harbors a good number of Mammalian and avian species diversity. A total of 20 species of mammals (Joshi et al. 2020) and 178 species of birds (Dutta et al. 2022) were found in the study landscape. Among the mammals, 11 species were reported from the order Carnivora i.e Snow Leopard (*Panthera uncia*), Himalayan Brown Bear (*Ursus arctos isabellinus*), Asiatic black bear (*Ursus thibetanus*), Tibetan Wolf (*Canis lupus*), Himalayan Red Fox (*Vulpes vulpes*), Leopard Cat (*Prionailurus bengalensis*), Jungle cat (*Felis chaus*), Himalayan Palm Civet (*Paguma larvata*), Mountain Weasel (*Mustela altaica*), Yellow Throated Marten (*Martes flavigula*), Stoat (*Mustela ermine ferghanae*), 5 from order Artiodactyla i.e Himalayan Ibex (*Capra sibrica*), Himalayan Tahr (*Hemitragus jamlahicus*), Kashmir Musk Deer (*Moschus cupreus*), Himalayan Goral (*Naemorhedus goral*), Blue Sheep (*Pseudois nayaur*), two species of order Rodentia i.e Kashmir Flying Squirrel (*Eoglaucomys fimbriatus*), Himalayan Marmot (*Marmota himalayana*), two species of order Primates, Rhesus macaque (*Macaca mulata*), Grey Langur (*Semnopithecus ajex*), one species of order Lagomorpha, Pika (*Ochotona ladacensis*). Among these species, the Snow leopard, Asiatic Black bear, Himalayan Brown bear, Kashmir Musk deer, Himalayan Tahr, Himalayan ibex, and Tibetan wolf, **(Figure 2.9)** are high-priority conservation species in India, listed as Schedule-I species of the Indian Wildlife Protection Act (IWPA 1972).

Figure 2.9. Few images of mammals present in the study area other than Himalayan brown bear, a) Tibetan wolf, b) Himalayan tahr, c) Himalayan ibex, d) Snow leopard, e) Himalayan red fox, and f) Kashmir musk deer.

2.7. Anthropogenic pressure

Lahaul Valley is a remote and ecologically fragile region located in the rain shadow area of Himachal Pradesh. During the past few years, the valley has been experiencing Anthropocene pressure in terms of agricultural expansion, unsupervised grazing practices, unsustainable tourism, infrastructure development, and inadequate waste management system (**Figure 2.10**). The livelihood for much of the local communities is agrarian, growing both traditional and high-market agricultural and horticultural cash crops.

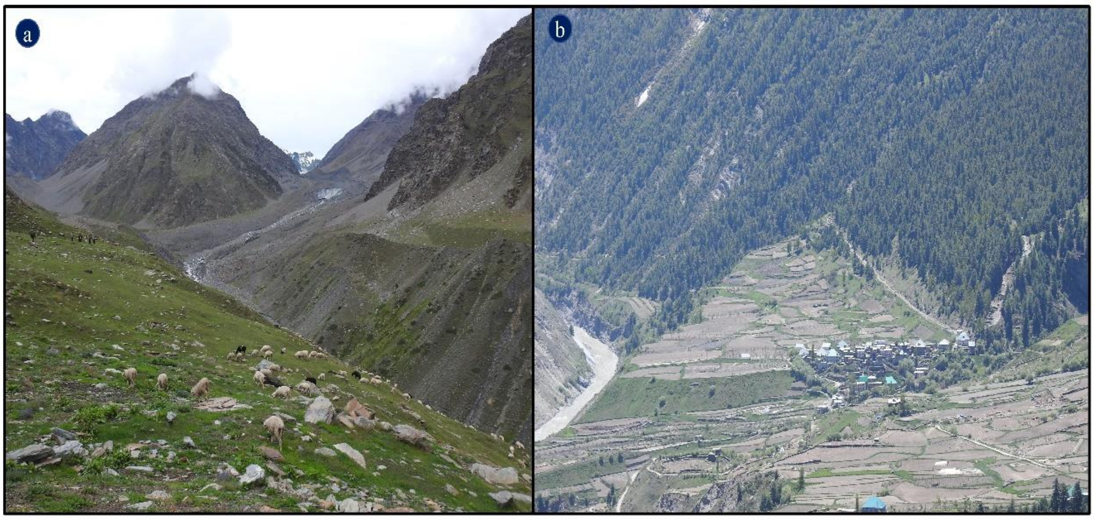

Figure 2.10. Anthropogenic pressure: a) livestock grazing in alpine pasture and b) agricultural expansion into natural areas.

The agricultural expansion led to habitat degradation and consequently brought humans and wildlife in close proximity, leading to human-wildlife conflict in the valley (Kumar et al. 2022). Also, the area is facing high grazing pressure as in summer (Mid-May to Mid-September) the nomadic shepherd with hundreds of their livestock (goat and sheep) from neighboring areas of the Chamba, Kullu, Mandi, and Kangra comes to the alpine and sub-alpine areas of the valley. Livestock shares the habitat with wildlife mainly the Himalayan Brown bear, Kashmir Musk deer, and Ibex, which exert resource partitioning pressure on the wildlife and also lead to the degradation of the habitats.

The recent opening of the Atal Tunnel (Rohtang tunnel) 9.02 km in length, connects the Kullu Valley with Lahaul Valley, as it plays a vital role in the connectivity and development of the area, but the unregulated influx of tourists in the valley is a serious concern for the wildlife. This led to the development of unsustainable infrastructure, tourist hiking trails, and camping sites, which have various negative impacts such as habitat degradation, littering, and pollution. In the Lahaul Valley, there are various Hydro-Power Projects site are identified such as Seli (400 MW), Jispa (300 MW), Bardang (124 MW), Tandi (104 MW), Rashil (102 MW), Miyar (90 MW), these hydropower projects will have negative consequences on wildlife and environment of the area. The combined effects of agricultural intensification, unregulated development, tourism activities, habitat degradation, and climate change are anticipated to adversely impact regional wildlife and consequently will affect the livelihood of the local communities as human-wildlife conflict may increase.

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Chapter 3: General Methodology

3.1. Study design

The Lahaul Valley spans an extensive geographical area of approximately 6651 km² (**Figure 3.1**). In determining suitable sites for both intensive and extensive study areas, I excluded regions inaccessible to humans and those characterized as permafrost areas.

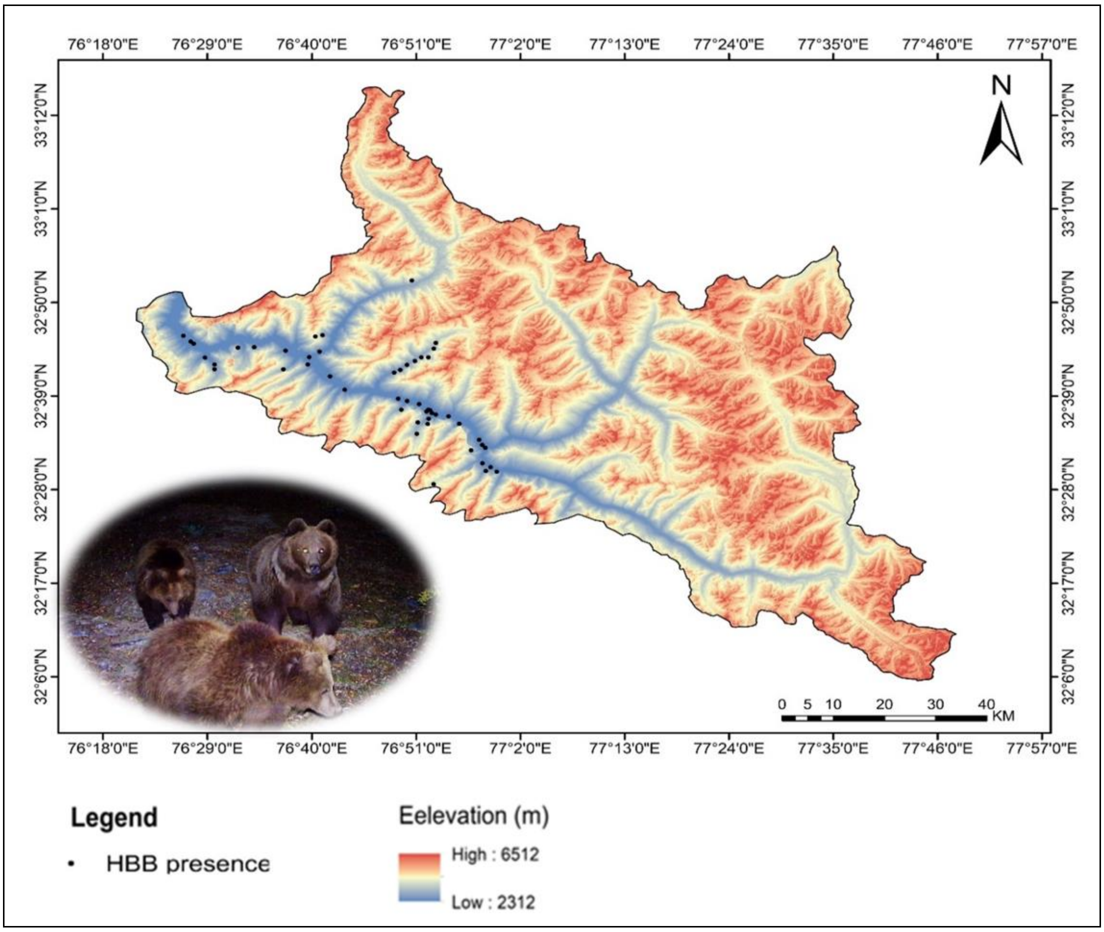

Figure 3.1. Himalayan brown bear sampling locations in the study landscape.

Following a reconnaissance survey, I divided the area into 10×10 km grids. Subsequently, camera trapping and trail sampling were done in the landscape. The collected data on brown bear presence were used to model the occupancy of the Himalayan brown bear (Sharief et al. 2020). Utilizing the occupancy results, I strategically identified grids that were further subdivided into 2×2 km grids for an intensive study area. After the selection of the intensive study area, the field survey was conducted using various conventional methods, including sign surveys, and camera trapping across different elevation ranges, to understand in depth the habitat use pattern, and feeding habits of Himalayan brown bear in the Lahaul Valley.

3.2. Sign survey

Both direct and indirect evidence of Himalayan brown bear presence were recorded through trail transects **(Figure 3.2).** The routes were closely observed for any indications of the Himalayan brown bear, including scat samples and direct observations. Along with a variety of environmental characteristics, including forest type, species of trees and shrubs, herb species, types of signs, and topographic variables, the spatial GPS coordinates were recorded for every sampling location. The utilization of GPS technology guaranteed precise spatial data gathering, and the examination of habitat factors yielded a significant understanding of the ecological needs of Himalayan brown bears in their high-altitude surroundings.

Figure 3.2. Himalayan brown bear, signs recorded during trail transect survey a) brown bear pugmark, b) scat sample, c) digging sign, d) Scat collection.

3.3. Vegetation sampling

Vegetation sampling was conducted using nested circular plots with varying sizes: Trees were sampled in 10 m radius circular plot, shrubs in 5 m radius circular plots, and herbs/grasses in 1m×1m plots **(Figure 3.3)**. These sampling plots were laid along the trail transects in all available grids. Shrub species and their individual counts were recorded within 5m radius circular plots, while for herbs and grasses, four quadrates of 1m×1m were laid within each circular plot. This meticulous method of plant sampling made it possible to evaluate the vegetation composition of the study landscape.

The use of nested circular plots helped capture information on vegetation composition at different spatial scales, providing valuable insights into the habitat utilization patterns of HBB and their interaction with the vegetation in the high-altitude environment.

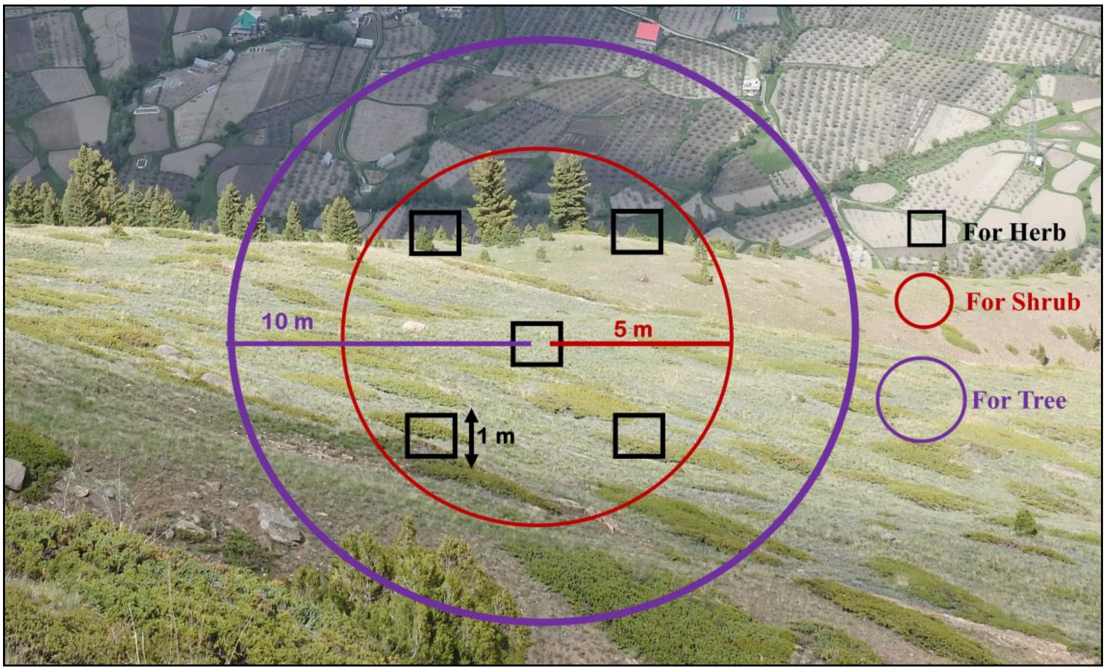

Figure 3.3. Nested circular plots used for sampling vegetation data during field survey.

3.4. Camera trapping

Since camera traps offer a non-invasive and effective way to monitor elusive and nocturnal animals in their natural habitats, thus making their application very imperative in wildlife research (Tobler et al. 2008, Joshi et al. 2019). The present study strategically deployed camera traps along the grids used for the sign survey, targeting active natural trails, areas near forests, and water sources across various elevation ranges (**Figure 3.4**). The best way to capture wildlife activity was to set up camera traps at 1.5-2 feet height, and around 2-3 meters from the natural trails.

Figure 3. 4. Deployment of camera traps for Himalayan brown bear monitoring.

Comprehensive data, including camera and SD card numbers, location names, GPS coordinates, altitude, and habitat characteristics, were noted for every camera trap. In conjunction with the sign survey and vegetation sampling, the camera trap method significantly contributed to our understanding of HBB habitat utilization patterns. Through the use of camera trap data, we were able to gather important information about the activity patterns, interactions with the surrounding environment, and temporal and geographical distribution of HBB. We conducted a thorough assessment of the HBB population and its ecological requirements in the high-altitude districts of Lahaul by integrating data from several survey methodologies.

3.5. Questionnaire Survey

A semi-structured, close and open-ended questionnaire survey was conducted following a standard procedure by (Cochran 1997, Temesgen et al. 2022). We used a random sampling approach to selcet the vaillages and sampled a minimum of thirty percent of the total number of households in each village falling under the species range (Cochran, 1997, NSSO, 2011, Taherdoost 2016).

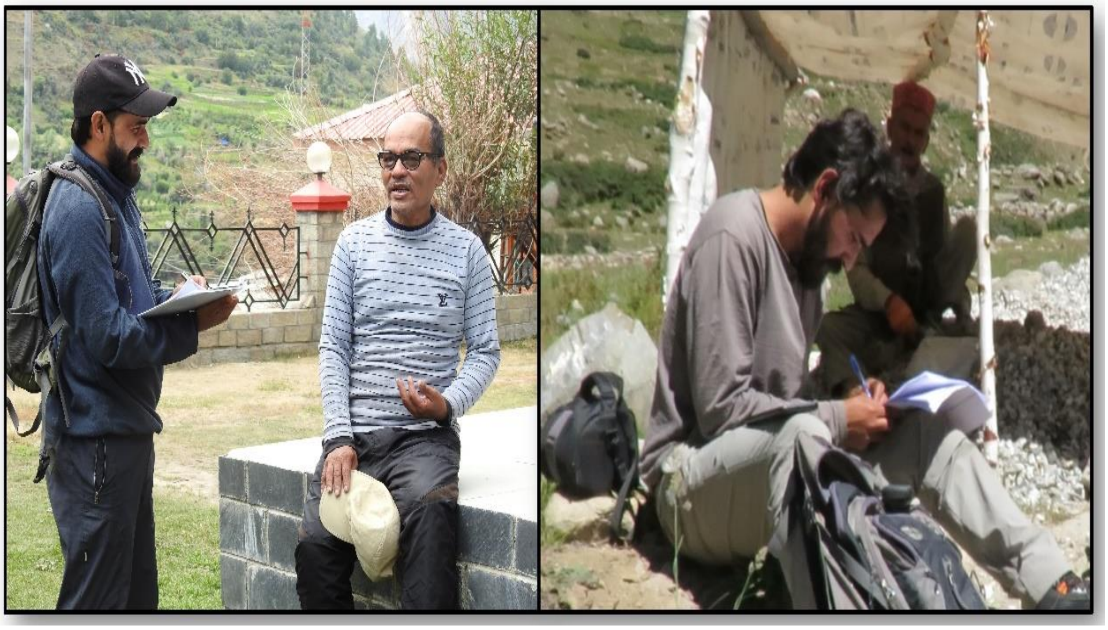

Figure 3. 5. Conducting questionnaire surveys to collect the information on Human-Brown Bear Conflict.

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Chapter 4: Objective 1: Habitat utilization pattern of the Himalayan brown bear in selected grids of Lahaul Valley across the seasons.

4.1. Introduction

In human-modified landscapes, the persistence of large carnivores is intricately tied to the delicate balance of ecological dynamics. Being a flagship species in many ecosystems, large carnivores are vulnerable to the consequences of anthropogenic disturbances, which can potentially have detrimental effects on the intricate ecological equilibrium (Linnell et al. 2000, Arim et al. 2010, Palazon 2017, Hoeks et al. 2020). In recent decades, the exponential growth of the human population led to the expansion of infrastructure development, road networks, hydropower projects, and agricultural lands to more remote areas, attributed to the alternation and loss of wildlife habitats (Bennett 2003, Berger et al. 2008, Cimatti et al. 2021). Consequently, in the human-altered landscape wild animals especially large carnivores come in close vicinity to human areas and share habitats and resources, leading to an escalation of human-wildlife conflict in the form of livestock depredation, crop damage, and human attack (Venter et al. 2016, Skuban et al. 2016, Bombieri et al. 2019, Kumar et al. 2022, Bombieri et al. 2023). The landscape-sharing pressure can have a potential negative impact on species' behavior, habitat use, and distribution (Geffroy et al. 2015, Gaynor et al. 2018, Zarzo-Arias et al. 2018, Gantchoff et al. 2020).

In the Himalayas, human encroachment and the alteration of natural habitats pose substantial peril to wildlife, especially for the long-ranging mammals, with the huge requirement for space and diverse habitats (Ripple et al. 2014). Despite the harsh climate, challenging terrain, and high anthropogenic disturbance, the Himalayas are rich in terms of biodiversity (Myers 2000). Therefore, in the present scenario of human-modified landscape, it is imperative to understand the dynamics of species interactions with the habitats and environment. The study of habitat utilization patterns and the influence of environmental covariates on species distribution is important in understanding the ecology of the species (Guisan and Zimmerman 2000, Nielsen et al. 2010, McClure et al. 2017) and for planning conservation strategies (Pearce and Boyce 2006, Shahnaseri et al. 2019, Mohammadi et al. 2021). Numerous environmental factors are decisive in the habitat preference of the species (Peterson 2011).

The brown bear (*Ursus arctos*) is one of the largest terrestrial carnivores, widely distributed in the Northern Hemisphere in Asia, Europe, and North America (McLellan et al. 2017) and is vulnerable to habitat degradation, natural resource exploitation, and climate change across the geographic range (Noss et al. 1996, Segan et al. 2016, Carter et al. 2017, Fletcher et al. 2018, Hartel et al. 2019, Mukherjee et al. 2021, Dar et al. 2023). Other than habitat degradation and climate change, anthropogenic disturbances force the different sub-species to change their behavior and foraging ecology leading to range contraction (Ripple et al. 2014, Fleschutz et al. 2016). The distribution and habitat use of brown bear is primarily governed by ecological needs such as food, shelter, and opportunity to mate

(Schlaepfer et al. 2002, Kristan 2003, Almpanidou et al. 2014). Brown bear are omnivores in feeding habits and thrive in different array of habitats with diverse food resources (Bojarska and Selva, 2012, Swenson et al. 2020).

Figure 4.1. Camera trap image of a female Himalayan brown bear with cubs.

The Himalayan brown bear (HBB) is one of the sub-species and is considered an ancient lineage due to its unique adaptability to survive in the highlands of India, Pakistan, and Afghanistan (McLellan et al. 2017), **(Figure 4.1)**. The HBB population is classified as endangered based on the IUCN red list under criteria 'D' due to its small population size (130–220), sparse distribution, prevailing threats of climate change, human population expansion, and habitat loss (Sergio et al. 2008, Sathyakumar et al. 2012, McLellan et al. 2017).

In India, HBB is a high conservation priority species, and is listed under Scheduled-I species in India's Wildlife (Protection) Act, 1972, occupies the highlands of the Western Himalaya, in Jammu and Kashmir Union Territory (JKUT), Ladakh Union Territory (LUT), Himachal Pradesh, and Uttarakhand (Sathyakumar 2006). It prefers alpine meadows and sub-alpine regions between 2500–5000m elevation in the Greater Himalayas in India (Sathyakumar 2001, Rathore 2008, Sharief et al. 2020).

Throughout the HBB distribution range in India, the species is threatened by habitat loss, climate change, unsupervised grazing practice in the alpine pasture, retaliatory killing by locals and nomadic shepherds, and other anthropogenic disturbances (Sathyakumar, 2006, Rathore 2008, Rathore and Chauhan 2007, Sharief at al. 2020, Mukherjee et al. 2021, Dar et al. 2021). Comprehending the habitat utilization of species, particularly for bears is essential since they inhabit areas of multi-use land and have varying reactions to human-caused disruptions. Additionally, croplands serve as ecological traps for Brown bears (Northrup et al. 2012), which results in bear-human conflict (Kumar et al. 2022).

There are studies available on species distribution modelling and climate change impact (Mukherjee et al. 2021, Dar et al. 2023), and dietary profile (Rathore and Chauhan 2014) but limited studies are conducted on fine-scale habitat ecology of HBB in the Himalayas (Sharief et al. 2020). The habitat use and movement of brown bear are primarily governed by the availability of food resources, which may vary across the seasons. Therefore, it is crucial to identify the eco-geographic covariates that influence the habitat use pattern of the species.

The present study was conducted to fill the prevailing knowledge gap pertaining to the habitat utilization patterns of HBB within the multi-use landscape of Lahaul Valley, Himachal Pradesh. I used the Generalized Linear Model (GLM) approach to examine the influence of ecogeographic variables and anthropogenic perturbations on habitat use of the HBB across the seasons. The GLM, a linear regression that fits binary data, is reliable and globally used to address the different ecological questions in a wide range of species (Austin 1987, Thuiller 2003, Guisan et al. 2006, Ghoddousi 2010, Salas et al. 2017). The key advantage of GLM is its adaptability to various response covariates. In this study, I hypothesized that the food resources availability (natural vegetation), topographic variables (elevation, slope), and distance to human settlement will be the key factors governing the seasonal habitat use of Himalayan brown bear in the Lahaul Valley. The study will enhance our understanding of HBB's habitat utilization patterns, identify key ecogeographic factors influencing the habitat use of HBB, and assist in designing effective management strategies to conserve this species.

4.2. Materials and Methods

4.2.1. Study Design and Data Collection

Lahaul Valley has vast geographical areas around 6651 km². To identify the intensive and extensive study site. I excluded the human-inaccessible areas and permafrost areas. Based on the reconnaissance survey, I extensively divided the area into 10×10 km Grids. Further, camera trapping and trail sampling were done in the area. The generated data was used to model the occupancy of Himalayan brown bear

(Sharief et al. 2020). Therefore, based on occupancy results, I systematically selected the high, medium, and low detection probability grids, which were further divided into 2×2 km grids to intensively study the habitat use of Himalayan brown bear. Total of 111 camera traps (3303trap nights) were deployed which resulted in 69 captures of HBB, and 116 trails (596 km) of 2-7 Km in length were walked to collect the data on HBB.

The intensive study area had 120, 2 × 2 km grids (**Figure 4.2**). All logistically possible grids were surveyed across the seasons (summer and pre-hibernation), in different habitats and elevation gradients. HBB presence data was collected through the primary field survey (Summer- May to August) and (Pre-hibernation period - September to November) from 2018 to 2022). The data on HBB presence were gathered using two methods; sign survey (direct observation and indirect signs such as scats and pugmarks, and camera trapping.

A total of 65 logistically possible girds were surveyed. However, 23 girds were excluded due to inaccessibility of the area having rugged steep terrain mainly above the elevation of 5000 meters. In the Himalayas, systematic sampling is not always possible, therefore the sign survey was done on natural/animal trails, in the alpine pasture, sub-alpine forested area, and in and around cropland, Total of 116 trails in walked in Lahaul Valley, 67 (268.4 km) trails transect of varying lengths of 2-6 km were walked in intensive study area. During the field survey, the observed signs of HBB such as scat samples, and direct sightings were noted down along with GPS locations and habitat variables. Additionally, all scat and hair samples of HBB were validated using DNA-based identification methods (Joshi et al. 2019).

In human-dominated areas, the brown bear temporally avoids the encounter with humans. To capture the presence of brown bear in the study landscape, out of total 111 camera traps deployed in Lahaul Valley, 42 camera traps (1263 trap nights) were deployed in intensive areas grids. Camera traps were deployed along the natural trails, river beds, near agricultural lands, and locations other than trails in various habitats at the elevation gradient of 2455m to 5648m. Camera traps were installed at the heights of 40-60 cm above the ground and 2-3 m away from the trails.

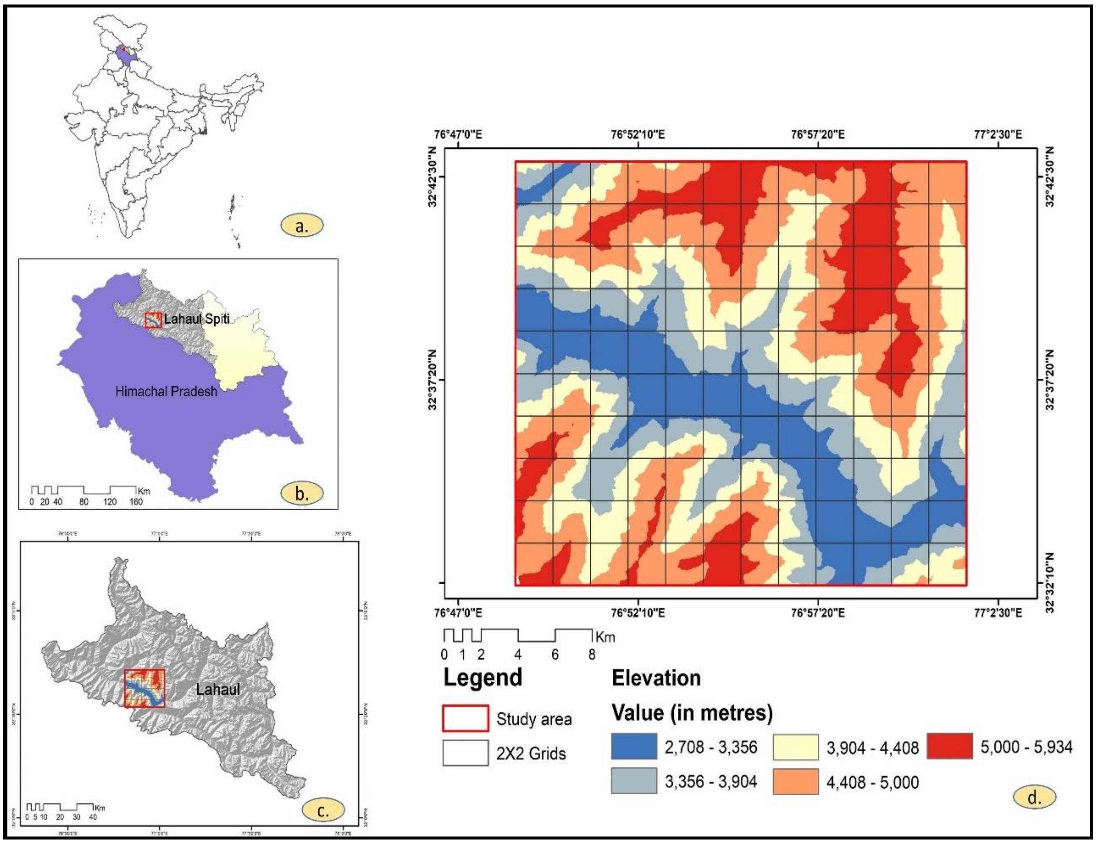

Figure 4.2. Map of the intensive study area. A. Showing the country boundary of India B. Showing the position of Lahaul and Spiti district within the state boundary of Himachal Pradesh C. Showing selected study area within Lahaul Valley. D. Showing the present study area (Lahaul Valley) with the elevation ranges depicted by colour scale.

The camera traps used for the study were, namely ultra-compact SPYPOINT FORCE-11D trail camera captures (SPYPOINT, GG Telecom, Canada, QC), Stealth Cam (SKU: STC-DS4K), and Boly trail white flash camera Scout Guard (SG562-D), (Boly Media Communication.

A total of 242 presence locations (sign survey n=218 and camera trap n=24) were obtained. The collected data for understanding the seasonal habitat use pattern of the Himalayan brown bear were categorized into two seasons: Summer (May to August) and the Pre-hibernation period (September to November). A total of 132 presence locations of HBB for summer and 110 during the pre-hibernation period. Prior to analysis, I used a spatial filtration framework to reduce spatial auto-correlation in presence points (Atzeni et al. 2020), using Spatially Rarify Occurrence Data tools in SDMtoolbox (Brown 2014). After the spatial filtration, 81 presence locations from summer and 70 presence locations from the pre-hibernation period were used for the final analysis. In the mountainous landscape acquiring real data on the absence of species is often not possible, especially for large-ranging animals such as brown bear. Therefore, pseudoabsence locations can be used in place of true absence (Brotons et al. 2004, Pearce and Boyce, 2006). Hence, an equal number of pseudoabsence locations were randomly generated corresponding to the presence locations at a spatial distance of 2 km. Additionally, absences within a buffer around the presence of data were excluded (Hirzel et al, 2001, Sahlsten et al, 2010).

Predictor variables

Brown bears' distribution and habitat use are mostly governed by the topography, vegetation, and environmental condition; therefore, I used four major covariates i.e. topographic, bioclimatic, landscape composition, and anthropogenic disturbances (McGarigal et al. 2012, Habibzadeh and Ashrafzadeh 2018, Dar et al. 2023). I acquired the Land cover or habitats variables from the ESRI Inc 2022 Esri land Cover dataset (https://www.esri.com). NDVI (normalized difference vegetation index) data were acquired from MODIS. Using Earth Explorer, I acquired a digital elevational model (DEM) with 30m resolution from Shuttle Radar Topographic Mission (SRTM) data (https://earthexplorer.usgs.gov/), then DEM was used to generate the raster layers of slope and aspect (utilizing the surface Tool in the Spatial Analyst Tools). Furthermore, the toolbox for gradient metrics and geomorphometry was used to acquire a raster layer of roughness index (Evans et al. 2014). Bioclimatic variables were acquired from the WorldClim dataset version 2 (http://www.worldclim.org/). The raster of landscape composition variables was derived from FRAGSTATS, for categorical variables (habitat), I computed the proportion of each class within the moving window utilizing FRAGSTATS (McGarigal et al. 2012). Furthermore, recognizing the significant influence of anthropogenic disturbance on HBB habitat use and movement, I used distance to the road (diva-gis.org/gdata), distance to human settlement, and the Human Influence Index (HII: acquired from https://sedac.ciesin.columbia.edu/) as an anthropogenic disturbance variable, that affects animal habitat use and movement (Sanderson et al. 2002). All covariates were relevant and accounted for as they were key in governing the movement, distribution, and habitat use of the species (Wong et al. 2013, Piedallu et al. 2017, Ashrafzadeh et al. 2022, Mukherjee et al. 2021, Dar et al. 2021). Prior to the extraction of the raster values for analysis, all covariate raster were resampled to a uniform 100m resolution. The nearest neighborhood and bilinear interpolation approaches used resample categorical and continuous variables respectively. Bioclimatic variables were downscaled to 100 × 100 m spatial resolution in R-software using spatialEco package. Geospatial analyses were exclusively performed using the GIS (ArcGIS 10.6). Initially, I selected a total of 25 variables (**Table 4.1.**) with the potential to influence the habitat use of Brown bears (Clevenger et al.1997, Su et al. 2018, Almasieh et al. 2019, Sharief et al. 2020, Dar et al. 2021, Mukherjee et al. 2021). After the correlation, I excluded highly correlated variables having a correlation (Pearson coefficient >0.7), (Brun et al. 2020). In the highly mutually correlated variables, I retained the one most pertinent to the species ecological context. Consequently, 14 variables were retained for further analysis.

Table 4.1. Eco-geographic covariates selected for seasonal GLM analysis of Himalayan brown bear in Lahaul Valley, Himachal Pradesh.

Predictor Variables	**Description and Prior Prediction of Variables**	**Data Source**
Land Cover and Vegetation Indices		
Forest	Dense forest with >70-80% canopy cover. The predicted influence is positive.	ESRI
Rangeland	Alpine and sub-alpine pastures with shrubs or sparse trees. The predicted influence is positive.	

Predictor Variables	**Description and Prior Prediction of Variables**	**Data Source**
Barren land	Barren land with a scarcity of herbs to no vegetation. The predicted influence is negative.	
Cropland	Agricultural and Horticulture crops. The predicted influence is positive.	
NDVI_Summer	NDVI_Summer (May-August), predicted influence is positive	MODIS
NDVI_Pre-hibernation period	NDVI_Pre-hibernation (September-November) predicted influence is positive	
Topographic		
Slope	The predicted influence is positive	SRTM-USGS
Aspect	The predicted influence is negative	
Elevation	The predicted influence is negative	
Topographic roughness index	The predicted influence is negative	
Distance to Water	Calculated using Euclidean distance. The predicted influence is positive	
Bioclimatic		
Annual mean temperature	The predicted influence is negative	WorldClim
Temperature Annual range	The predicted influence is positive	
Annual Precipitation	The predicted influence is positive	

Predictor Variables	Description and Prior Prediction of Variables	Data Source
Precipitation Seasonality	The predicted influence is positive	
Precipitation of Driest Month	The predicted influence is positive	
Precipitation of Warmest Quarter	The predicted influence is positive	
Landscape composition		
Edge Density	The predicted influence is positive	FRAGSTATs software 4.2
Interspersion Juxtaposition Index	The predicted influence is positive	
Aggregation Index	The predicted influence is positive	
Largest patch index	The predicted influence is positive	
Shannon Diversity Index	The predicted influence is positive	
Disturbance		
Human influence index	The predicted influence is negative	SEDAC
Distance to road	The predicted influence is negative	Calculated using the Euclidean distance
Distance to human settlements	The predicted influence is positive	

4.2.2. Data analysis

Influence of habitat variables on habitat use of HBB.

A generalized linear model (GLM) with a binomial logit link function was used to understand the impact of the ecogeographic variables on habitat use of HBB across the seasons. The presence and pseudo-absence locations were used as the response variable and the analysis was done in R 4.2.3 (R Development Core Team 2019) using the "glm" function. For the model selection and averaging, I used the "MuMIn" package from R software libraries (Barton, 2015), The "MuMIn" package contains the 'dredge' function used for automated model selection with all possible combinations of covariates. The models were assessed and ranked using Akaike" 's Information Criterion (AIC) (Akaike, 1973, Burnham and Anderson 2002). The lowest Akaike information criterion (AIC) was used to weight the models that predict the effect of habitat variables on the habitat use of HBB in the landscape.

4.3. Results

To perceive the impact of eco-geographic variables on Himalayan brown bear habitat utilization across the seasons. I used the Generalized linear model approach.

In the summer, the top three models were selected based on the lowest AIC values from different models that were taken into consideration (**Table 4.2**.). The model having the lowest AIC value of 147.62 and the highest *w*AIC values (*wi*=0.499) was selected as the top model (**Table 4.2**.). The outcomes of the top model indicate that habitat use of Himalayan brown bear in Lahaul Valley was positively influenced by predictors such as distance to human settlements ($\beta = 0.002 \pm 0.000$), NDVI-Summer (β = 4.999±1.182), rangeland (β = 3.057±1.225), and Shannon diversity index (β = 2.540±0.871) (**Table 4.2, 4.3 and Figure 4.3, 4.5**.).

Table 4.2. β-coefficient values of the top three models influencing the habitat use of Himalayan brown bear during the Summer.

Covariates	**Model 1**	**Model 2**	**Model 3**
Aspect	0.004**.**	0.005*	0.004**.**
SE	(0.002)	(0.002)	(0.002)
Barren land	1.707		
SE	(1.389)		
Distance to Human Settlement	0.002***	0.002***	0.002***
SE	(0.000)	(0.000)	(0.000)
Distance to road	-0.002***	-0.002***	-0.002***
SE	(0.000)	(0.000)	(0.000)
NDVI Summer	4.999***		3.261*
SE	(1.182)		(1.315)
Rangeland	3.057 *	2.245 **	
SE	(1.225)	(0.839)	
Shannon Diversity Index	2.540**	1.648**.**	
SE	(0.871)	(0.855)	
Elevation		-0.003 ***	-0.002*
SE		(0.001)	(0.001)
AIC	**147.62**	**148.9**	**149.11**
ΔAIC	**0**	**1.28**	**1.49**
wAIC	**0.499**	**0.263**	**0.237**

On the contrary, a negative correlation was observed with the distance to road (β = -0.002±0.000). Additionally, the supporting model suggests that elevation (β= -0.003±0.001) was negatively correlated with the habitat use of the Himalayan brown bear (**Table 4.2., Figure 4.3**.).

Table 4.3. β-coefficient values of the top model influencing the habitat use of Himalayan brown bear during the summer.

Variable	**β-estimate**	**Std. Error**	**Z-value**	**Significance (p-value)**	
(Intercept)	-4.657	1.510	-3.085	0.002	**
Aspect	0.004	0.002	1.876	0.061	.
Barren land	1.707	1.389	1.229	0.219	
Distance to Human Settlement	0.002	0.000	5.015	0.000	***
Distance to road	-0.002	0.000	-5.481	0.000	***
NDVI Summer	4.999	1.182	4.230	0.000	***
Rangeland	3.057	1.225	2.496	0.013	*
Shannon Diversity Index	2.540	0.871	2.916	0.004	**
AIC	**147.62**				

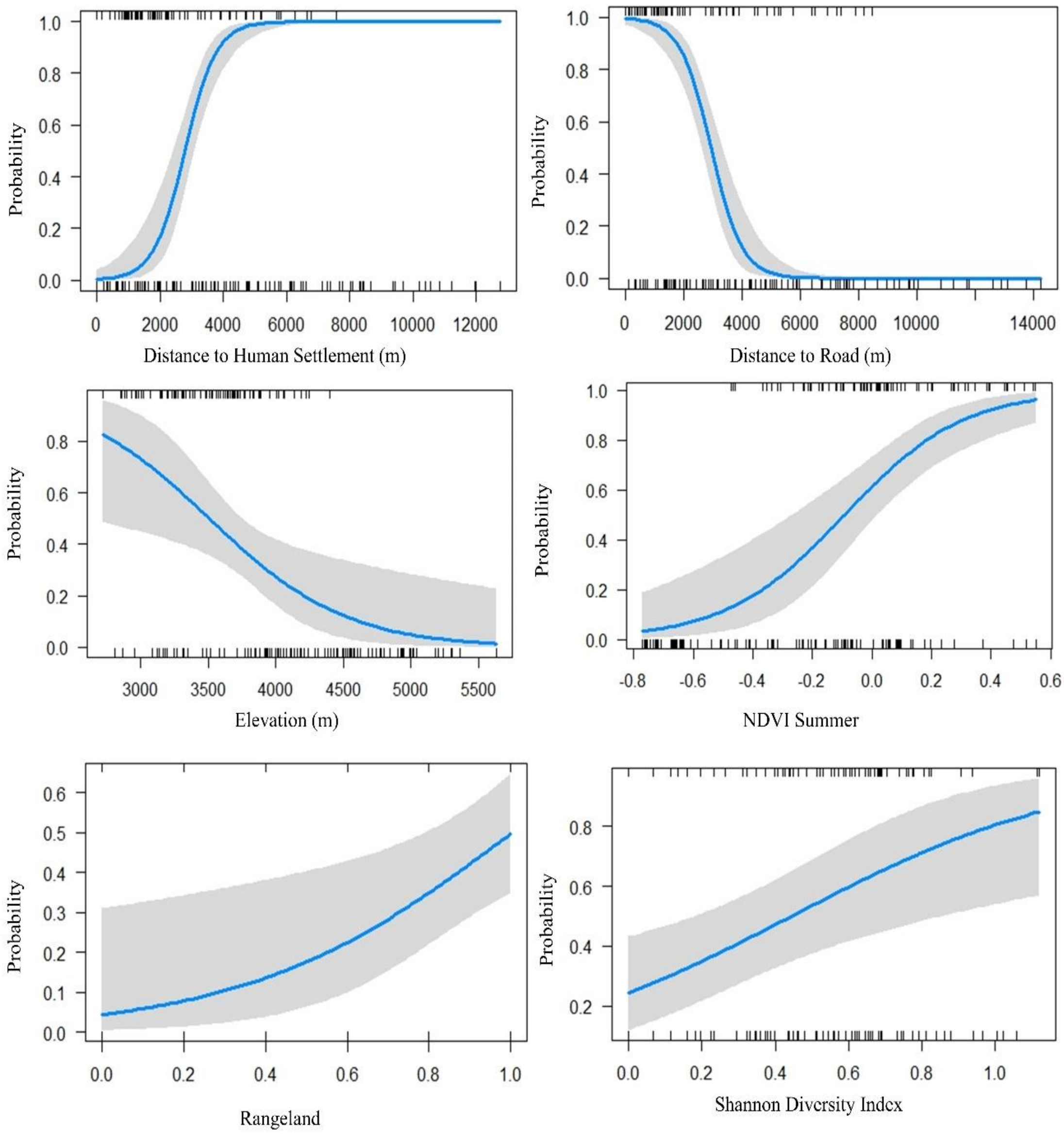

Figure 4.3. The predicted plots depicting the influence of different covariates on the habitat use of Himalayan brown bear during summer.

The pre-hibernation period, known as the hyperphagia phase, was crucial for understanding the habitat use dynamics, as during this phase the Himalayan brown bear predominantly consumes carbohydrate-rich food items. The change in the requirement and the availability of food resources has been the governing factor in habitat use by brown bear. The various GLM models were evaluated and the top three models were selected based on the AIC criteria, aligning with the approach employed in the summer season. During the pre-hibernation period, the top model with an AIC value of 67.44 and the highest *w*AIC values (*wi*=0.737) (**Table 4.4**).

Table 4.4. β-coefficient values of the top three models influencing the habitat use of Himalayan brown bear during the Pre-hibernation period.

Covariates	Model 1	Model 2	Model 3
Barren land	-4.218*	-3.819*	-3.193**.**
SE	(1.874)	(1.911)	(1.706)
Distance to Road	-0.001*	-0.001*	
SE	(0.000)	(0.000)	
Distance to Human Settlement	0.001*	0.001*	
SE	(0.001)	(0.001)	
Elevation	-0.008***	-0.006***	-0.006***
SE	(0.002)	(0.001)	(0.001)
Shannon Diversity Index	4.328**	3.765**	4.283**
SE	(1.521)	(1.430)	(1.381)
Slope	0.088*		0.078*
SE	(0.043)		(0.039)
NDVI Pre-hibernation			-0.000
SE			(0.001)
AIC	**67.44**	**70.22**	**71.88**
ΔAIC	**0**	**2.788**	**4.44**
wAIC	**0.737**	**0.183**	**0.080**

The results showed that the distance to human settlements (β = 0.001±0.001), Shannon diversity index (β = 4.328±1.521), and slope (β = 0.088±0.043), had a significant positive influence on the habitat use of Himalayan brown bear (**Table 4.4, 4.5 and Figure 4.4, 4.6**). On the contrary, barren land (β = -4.218±1.874), distance to road (β = -0.001±0.000), and elevation (β = -0.008±0.002) showed the negative association (**Table 4.5. and Figure 4.4**). The findings of the present study highlight a distinct seasonal pattern in habitat use of the Himalayan brown bear.

Table 4.5. β-coefficient values of the top model influencing the habitat use of Himalayan brown bear during the Pre-hibernation period.

Variable	β-estimate	Std. Error	Z-value	Significance (p-value)	
Barren land	-4.218	1.874	-2.251	0.024	*
Distance to Road	-0.001	0.000	-2.205	0.027	*
Distance to Human Settlements	0.001	0.001	2.047	0.041	*
Elevation	-0.008	0.002	-4.207	0.000	***
Shannon Diversity Index	4.328	1.521	2.845	0.004	**
Slope	0.088	0.043	2.021	0.043	*
AIC	**67.44**				

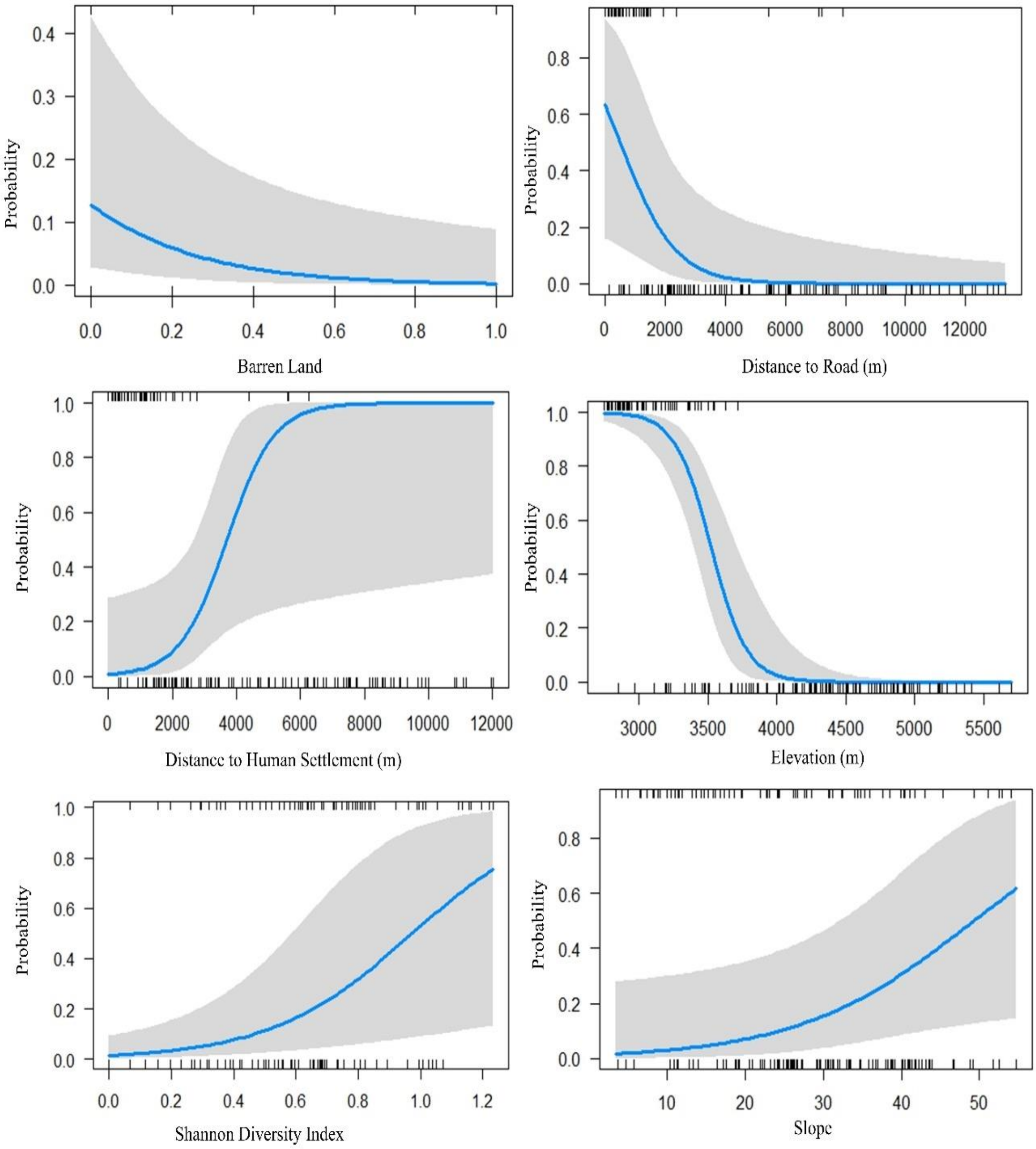

Figure 4.4. The predicted plots depicting the influence of different covariates on the habitat use of Himalayan brown bear during the Pre-hibernation period.

In summer, HBB predominantly utilized the areas with extensive vegetation cover as evidenced by a positive association with rangeland and Shannon diversity index and NDVI-summer, and particularly away from the human settlements in the elevation range of 3000m to 4500m.

Conversely, in the per-hibernation phase, Himalayan brown bear tends to avoid high-altitude areas with limited vegetation, opting for areas with available vegetative materials. Notably, habitat use was concentrated in the elevation range of 2800m to 3800m closer to the human settlements in comparison to summer. Regardless of the season, the Himalayan brown bear consistently utilize the areas near roads emphasizing on the availability of anthropogenic food attractant.

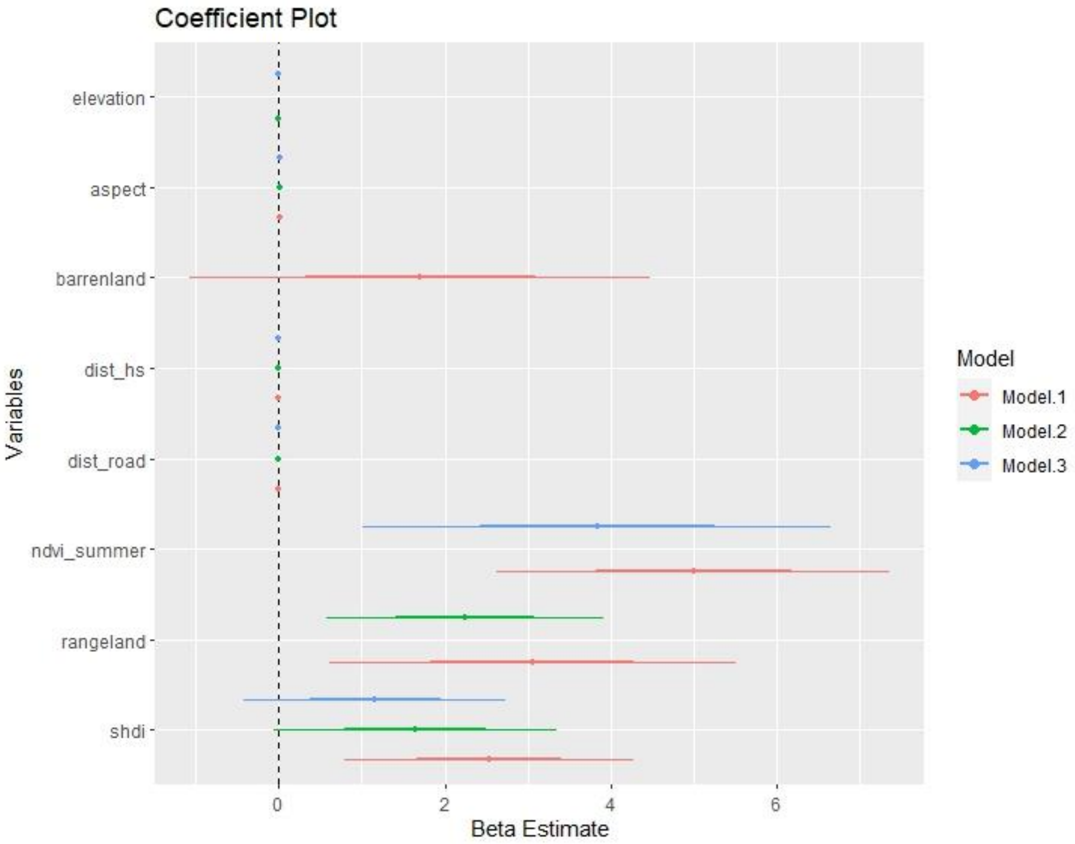

Figure 4.5. Coefficient plot of predictor use in Generalized Linear Model for the summer.

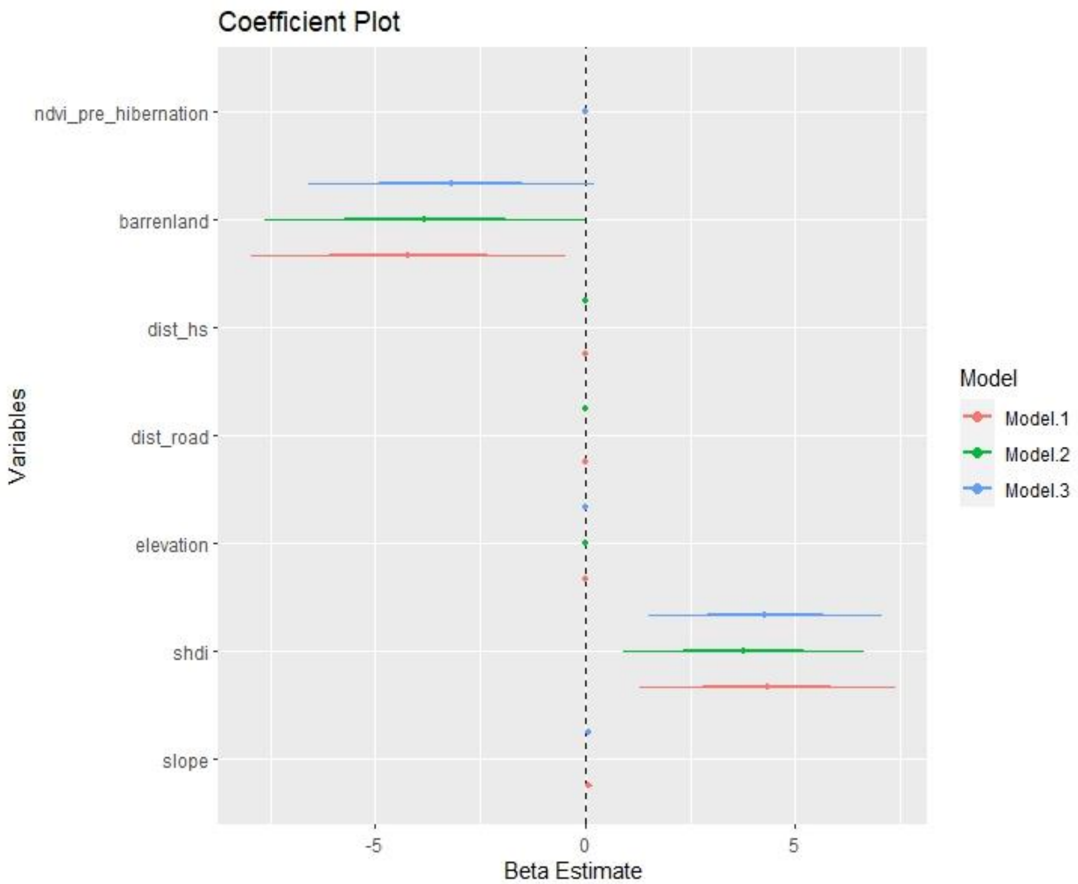

Figure 4.6. Coefficient plot of predictor used in Generalized Linear Model for the pre-hibernation period

4.4. Discussion

In the Western Himalayas, the Himalayan brown bear (HBB) population exists in several fragmented habitats and is at high risk because of human-wildlife conflict and resource competition (Rathore 2008, Aryal et al. 2012, McLellan et al. 2017, Kumar et al. 2022). In this study, I, employed the Generalized linear model to understand the impact of eco-geographic variables on the seasonal habitat utilization of HBB in Lahaul Valley, an area characterized by both favorable habitat conditions and a significant level of human-bear conflict (Sharief et al. 2020, Kumar et al. 2022).

The present findings shed light on the significance of various key factors in shaping the habitat use of HBB. During the summer habitat utilization of HBB was positively influenced by distance to human settlements, HBB mainly utilized the areas far away from human settlements, concordant with the findings of (Almasieh, Rouhi and Kaboodvandpour 2019). NDVI is widely established as the indicator of both quality and quantity of vegetation and correlates with net primary production and availability of seasonal energy (Goward et al. 1994, Hobbs 1995, Paruelo et al. 1997). The significant positive association between NDVI-summer and HBB habitat use indicates that Himalayan Brown Bears prefer areas with higher NDVI values (**Figure 4.3**), signifying a more favorable habitat with abundant availability of food resources, corroborated with the previous findings (Mace et al. 1999, Nielsen et al. 2002, Wiegand et al. 2008, Ziolkowska et al. 2016). The rangeland positively correlated with the habitat use of HBB in the study landscape, comparable with the findings of (Mohorovic et al. 2017, Ahmadipari et al. 2021). On the contrary, distance to roads negatively correlated with habitat utilization of HBB (**Table 4.3 and Figure 4.3**).

These results suggest the HBB actively utilized the alpine, and sub-alpine areas and available natural food resources. However, HBB opportunistically roamed in and around human settlements for easily accessible anthropogenic foods (agricultural and horticultural crops). My findings align with the earlier studies indicating that during the summer brown bear forage on the natural food resources available in the alpine, and sub-alpine habitats, and occasionally descend to lower areas to consume anthropogenic foods if available (Lefranc et al. 1987, Schoen et al. 1994, Rathore 2008, Bojarska and Selva 2012, Kavcic et al. 2015). In the study landscape, HBB uses the areas near human settlements primarily due to the availability of anthropogenic foods in the form of agricultural/horticultural crops. Specifically, during the summer when both the natural foods resources and anthropogenic foods were available simultaneously, HBB mainly utilized the areas with the availability of nutrient-rich natural foods than those near the human settlements. Present findings corroborated with the previous studies that showed during summer brown bear prefer areas with natural food availability over anthropogenic foods (Kavcic et al. 2015). Interestingly, a similar pattern was observed in the diet of HBB in the study landscape, and during the summer HBB opportunistically feeds on anthropogenic foods such as iceberg lettuce, peas, and apricots.

The supporting model showed the negative influence of elevation on HBB habitat use (**Table 4.2**). HBB mostly utilized the areas in the elevation range of 3000m to 4500m. Further increase in elevation beyond 4500m, there was a decrease in habitat utilization. I infer that this altitudinal range provides abundant food and shelter, while above 4500m are currently not found suitable areas for HBB due to the scarcity of food resources in these areas and corroborated with previous research studies (Nawaz 2008, Selva et al. 2017, Su et al. 2018, Collalti et al. 2020).

During pre-hibernation or hyperphagia brown bear must store needed fats for the hibernation period, which leads to an intensive increase in foraging activity, which is pivotal for the litter birth and hibernation (Lopez-Alfaro et al. 2013, Swenson et al.

2020). During hyperphagia, HBB mainly does nocturnal and crepuscular foraging to avoid the chances of encounter with humans.

The results of hyperphagia showed that factors such as distance to human settlements, Shannon diversity index, and slope positively influenced the habitat use of Himalayan brown bear (**Table 4.4. and Figure 4.4**.). On the contrary, barren land, elevation, and distance to the road showed a negative association (**Table 4.4 and Figure 4.4**.). The Lahaul Valley comes under the rain shadow area of Himachal Pradesh, with minimal rainfall. The vegetation in this region is characterized as dry-temperate to dry-alpine type vegetation. During the pre-hibernation period, the food availability was reduced in the alpine areas as evidenced by the negative association of barren land with HBB habitat use. Instead, brown bear utilized the areas having available diverse food resources in the elevation range of 2600m to 3500m, also this mid-elevation range could be ideal for the den site selection for hibernation (**Table 4.5. and Figure 4.4).** The studies conducted on den site selection by brown bear showed that brown bear prefer moderate elevation for den sites in the alpine habitat (Crupi et al. 2020).

Results suggests during this phase HBB utilized the areas near human settlements more intensively than in the summer. These findings align interestingly with observations of feeding habits during the pre-hibernation period, suggesting that HBB primarily fulfilled its energy requirements by consuming anthropogenic food resources. This inclination of HBB towards the human settlements was because of the availability of energy-rich anthropogenic foods such as apples. Apples are a rich source of carbohydrates, and they provide more energy in less time than the limited available natural food resources (Naves et al. 2006, Štofik et al. 2013). Earlier studies observed that brown bear feeding pattern of carbohydrates-rich food items during hyperphagia (Welch et al. 1997, Naves et al. 2006). HBB shows a strong affinity towards the slope during the pre-hibernation period (**Table 4.5 and Figure 4.4**). Slope governs the availability of many herbaceous plants, shrubs, and berries which play a significant role in providing energy during hyperphagia. Slope also acts as a protective cover for the brown bear (Almasieh et al. 2019). Rugged and steep areas are preferred by brown bears, especially females accompanied by their cubs (Ziołkowska et al. 2016, Zarzo-Arias et al. 2019). A positive association between slope and HBB habitat utilization during the hyperphagia phase showed the significance of alpine habitats with a moderate slope range for den site selection (**Figure 4.6**). Previous studies have indicated that brown bears tend to prefer areas with slopes between 20˚ and 50˚ for den site selection (Crupi et al. 2020).

Regardless of the seasons, present findings indicate a positive correlation with the Shannon diversity index (SHDI) corroborated by the findings of (Cimatti et al. 2021). This index pertains to the heterogeneity and relative occurrence of the diverse land cover types (Shannon, 1948, McGarigal et al. 2012). SHDI value ranges from 0 to 1 to represent landscapes with varying degrees of uniformity and diversity in habitat types. Brown bears being opportunistic omnivores with a significant portion of their diet comprising plant matter (Herrero, 1972, Rathore and Chauhan 2014). I infer the connection between the SHDI and the richness and diversity of habitats and plant communities, which is a major portion of the Brown bear diet. This inference highlights the importance of habitat diversity in sustaining the species.

This inclination towards the higher value of SHDI during summer and pre-hibernation arises from the advantages associated with diverse food resource availability, and suitable habitats as they offer greater resources, cover, and facilitate connectivity in the landscape, thereby enhancing the movement and dispersal of the species (Servheen et al, 1998).

The forest in the Lahaul Valley was interspersed with alpine meadows and human settlements, serving as ideal habitat and escape cover for HBB and are consistent with the previous finding across the brown bear distribution range (Clevenger et al. 1992, Kobler and Adamic 2000, Swenson et al. 2000, May et al. 2008, Ziołkowska et al. 2016, Pop et al. 2018, Cimatti et al. 2021, Mohammadi et al. 2021, Bogdanovic et al. 2023). The forest patches in the study landscape were characterized by dominant tree species such as blue pine (*Pinus wallichiana*), Birch (*Betula utilis*), Deodar (*Cedrus deodara*), Juniperus (*Juniperus polycarpos*), Spruce (*Picea smithiana*).

In the Lahaul Valley regardless of the seasons, Himalayan brown bear utilized the areas near the roads. However, there is slight difference during hyperphagia, HBB approached human settlements and occasionally used the areas near roads more frequently than in summer and foraging on high-quality anthropogenic foods, which act as ecological trap. In this landscape the brown bear association with roads is mainly govern by the habitat types interspersed with road and the spatio-temporal availability of food resources, as during hyperphagia (pre-hibernation) brown bear need to consume large amount of food for the successful hibernation period. Findings of the present study is consistent with the previous studies conducted globally within the brown bear distribution range (Roever et al. 2010, Northrup et al. 2012, Stewart et al. 2013, Lyonset al. 2018, Find’o et al. 2019). Studies suggests that female with cub sometime uses the area near road to avoid the encounter with male bear (Graham et al. 2010, Penteriani et al. 2018). However, near human settlements, to minimize interactions with humans, HBB temporally avoided humans and became more nocturnal and crepuscular in their foraging patterns.

Brown bear in the Lahaul Valley has a very narrow range of habitats and share the habitats and resources with local communities. The average elevation of the human settlement is around 3000 m. As observed during the field studies the Himalayan brown bear faces severe threats in the Lahaul Valley due the various anthropogenic disturbances such as unsupervised grazing practice, expansion of cultivation lands to natural habitats, unsustainable tourism, proposed hydro power projects.

Unsupervised grazing practices in the alpine, and sub-alpine regions, especially during the summer were evident in the valley. Nomadic shepherds with hundreds and thousands of their livestock (sheep and goat) from the adjoining areas of Chamba, Bharmour, Kangra, Kullu, and Mandi comes to the alpine pasture of the valley, locally called “Dhar”. Livestock presence in the alpine pastures exerts resource-sharing pressure on the HBB as vegetative materials contribute significantly to their diet.

Brown bear is an opportunistic omnivore that feeds on various food sources (Krechmar 1995, Van Daele et al. 2012, Kavcic et al. 2015), thus resource competition can potentially lead brown bear to attack livestock and damage crops in the area, as evident in the present findings that HBB utilized the areas in and around human settlements, and cause human-bear conflict (Rathore 2008, Kumar et al. 2022). The habitat loss due to other anthropogenic activities such as hydropower projects, linear development, unsustainable tourism, and expansion of human settlement and agricultural lands to bear natural habitat and human-brown bear conflict are posing the main threats along with climate change to the viability of the HBB (Sue et al. 2018, Dar et al. 2021, Dar et al. 2023, Kumar et al. 2022). Recent studies suggest that prudent habitat for the species in future climate scenarios will be lost in most of the distribution range (Mukherjee et al. 2021, Dar et al. 2021). Being a keystone species and a high conservation priority species in India, fine-scale habitat management is required for effective conservation and long-term survivability of HBB along with other co-occurring species (Roberge and Angelstam, 2004, Minor and Lookingbill 2010).

4.5. Conclusion

In the Western Himalayas, the Himalayan brown bear faces significant challenges within its fragmented habitats, such as high risks associated with human-wildlife conflict and resource competition. The present findings highlight a positive association between habitat quality and food resource availability with HBB habitat utilization in the study landscape. The present study confirms that the habitat utilization pattern of brown bears is governed by the food resource availability and changes with its seasonal availability (Bojarska and Selva, 2012, Swenson et al. 2020). Understanding the seasonal habitat utilization patterns of HBB is crucial for effective conservation. The positive association with diverse habitats, as indicated by the Shannon Diversity Index (SHDI), NDVI-summer, and rangeland, underscores the importance of maintaining varied landscapes to conserve the species. The high altitudinal preference for habitat uses and seasonal changes in food availability highlight the vulnerability of HBB to climate change (Su et al. 2018)

The significant influence of distance to human settlements on HBB habitat use led to human-brown bear conflict (Kumar et al. 2022). There is a need to manage the landscape effectively, considering the intensive habitat use near human settlements during the hyperphagia. The previous studies indicated a high correlation between HBB and cropland which escalates the human-brown bear conflict in the valley (Sharief et al. 2020, Kumar et al. 2022). Which can have negative consequences in the form of economic loss to humans and threats to the long-term survival of the species. To minimize such conflict, it is imperative to identify and delineate the ideal habitat patches within the landscape. Effective management of these areas, including the facilitation of connectivity between different suitable habitats for the movement of the species in the landscape with the least chances of interaction with humans, is crucial.

In the Lahaul valley Himalayan brown bear share the habitat and resources with local communities. Establishing clear demarcation between brown bear habitat and human settlement is needed, which will immensely help to minimize the human-bear interaction (Takahata et al. 2017). Furthermore, the area between the forest/bear habitat and human settlement which acts as an ecotone zone should be managed anxiously, in this transitional zone, maintaining the natural diversity of seasonal food sources is crucial. It is crucial to adopt a collaborative approach that includes local stakeholders, nomadic shepherds, wildlife authorities, and conservation organizations. Public awareness, community engagement, and implementing sustainable land-use practices can be key components for the conservation of the HBB. This holistic approach will significantly minimize the conflict and contribute to the long-term conservation and management of the Himalayan brown bear in the Lahaul valley.

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Chapter 5: Objective 2. To understand the feeding preferences and its seasonal variation of Himalayan brown bear in selected grids of Lahaul Valley.

5.1 Introduction

Brown bear, throughout their geographic distribution, has a polyphagous diet and feeds on diverse food sources that vary in their physical, ecological, and nutritional attributes. The variability in the diet is contingent upon the temporal and geographic availability of the food resources (Bojarska and Selva 2012, Coogan et al. 2014). Because of the variability in the feeding habits of brown bears, it is categorized as a generalist, in both dietary behaviour and food composition (Coogan et al. 2018), and change their diet based on the availability of food resources.

Brown bears are opportunistic omnivores, and their diets are predominantly constituted of plant matters such as graminoids, forbs, berries, roots, and corms (Robbins et al. 2004, Hamer and Herrero 1987, Rathore and Chauhan 2014, Stenset et al. 2016, Nawaz et al. 2019). Across the distribution range, brown bears act as apex predators and consume various prey species, small mammals such as pikas, marmots and sometimes large mammals such as ungulates along with insects, fish, and birds (Swenson et al. 1999, Rigg and Gorman 2005, Aichun et al. 2006, Ciucci et al. 2014).

The recent increase in the human population, agricultural expansion, and other anthropogenic activities have led to the encroachment of remote areas, which in turn brings humans and wildlife into close vicinity. In this human-modified landscape, brown bears opportunistically feed on anthropogenic food resources such as agricultural and horticultural crops, livestock, and human waste food (Gunther et al. 2004, Rathore 2008, Murray et al. 2017, Bautista et al. 2017, Coogan et al. 2018, Kumar et al. 2022). Despite the easy availability of anthropogenic food resources, it poses a potential effect on bear ecology, movement patterns, reproductive success, population structure, infection risk, and change in denning temporal patterns, leading to human-bear conflict and threatening the long-term viability of the population (Rogers 1976, Boutin 1990, Mattson et al. 1992, Hilderbrand et al. 1999, Fedriani et al. 2001, Beckmann and Berger 2003, Sato, 2017, Penteriani et al. 2018).

The majority of foraging ecological studies have been concentrated on energy acquisition (MacArthur and Pianka 1966). However, the foraging pattern and diet preference are not purely determined by energy acquisition (Simpson and Raubenheimer 2012), species such as brown bear are observed to select the resources that complete their overall nutritional requirement and consume a diverse diet that provides protein, carbohydrates, and lipids (Erlenbach et al. 2014). Which plays a crucial role in reproductive success, longevity, and overall fitness (Simpson et al. 2004, Robbins et al. 2007, Cotter et al. 2011). Due to the wide dietary spectrum and vast geographic distribution, the feeding habits of brown bears show significant regional disparities and, notable seasonal variations in the diet (Welch et al. 1997, MacHutchon and Wellwood, 2003). There are various factors such as weather, snow depth, human-influenced habitat use, and climate change that influence the seasonal or annual variations in the diet selection of the bears (Bojarska and Selva 2012, Stenset et al. 2016). Studies in the past have shown that during the spring and early summer, graminoids and forbs constitute the major diet portion (Lefranc et al. 1987, Swenson et al. 2000), while in the late summer and autumn, fruits, berries, hard mast, domestic apples are the main dietary preference of brown bears (Dahle et al. 1998, Swenson et al. 1999, Stenset et al. 2016, Nawaz et al. 2019). Food nutritional qualities and availabilities in the habitats have potential effects on the brown bear reproductive success, body mass, and movement patterns (Roger 1976, Noyce and Garshelis 1997, Zedrosser et al. 2006, Van Daele et al. 2011). The hyperphagia phase prior to hibernation is pivotal for the brown bear. During this phase, the time for foraging activity increases because the bear needs to accumulate fat reserves for the hibernation periods, which directly influences its survival and litter birth (Elowe and Dodge 1989, Swenson et al. 2007). To meet the dietary requirement or to maintain the dietary balance, during the pre-hibernation period, the brown bear forage on food resources which has high carbohydrates and lipid content.

Comprehensive documentation and analysis of feeding habits, and seasonal variation in food consumption are crucial in elucidating the ecological dynamics and long-term conservation and management of the bear. Particularly, for the small isolated population (Naves et al. 2006). Adequate knowledge of feeding habits and the movement pattern of the bear can have significant importance in minimizing and mitigating the human-bear conflict (Bojarska and Selva, 2012, Stenset et al. 2016).

Lahaul Valley holds a good population of HBB, and human-brown bear conflict is a challenging issue in the valley. In the Western Himalayas, the distribution of HBB occurs in the elevation range of 2400m-5000m. The elevation at which the human settlement and croplands were mainly distributed in the Lahaul Valley was 2500m to

3300m. In this landscape, the HBB and locals share the lands and natural resources. Often, depending upon the seasonal availability of anthropogenic food, HBB raids the agricultural/horticultural crops which leads to the development of an antagonistic perception of locals to the conservation of the species. Therefore, the present chapter aims to understand the feeding habits of HBB and its seasonal variations.

5.2. Materials and Methods

The dietary patterns of HBB were quantified using the scat analysis.

5.2.1. Scat collection

During the field survey (2018-2022), Himalayan brown bear scats were collected from different parts of the Lahaul Valley from May to November. The landscape of the valley is mountainous with rugged terrain, it is not always possible to systematically collect the scat samples. Therefore, the scats were collected systematically (where possible) while walking on trails/transects and opportunistically from areas such as agricultural/horticultural land. A total of 116 trails were trans-versed in the study area of varying lengths of 3-6 km. The scats were collected at different elevational gradients in different habitats (sub-alpine forest, mixed-coniferous forest, alpine pasture, shrubland, river bed, and in the cropland) along the natural trails and trail walked. All the collected scats were separately placed in brown paper enclosed by plastic bags with notes of GPS coordinates, date of collection, locality, habitat type, distance from human habitation, etc. A total of 279 scat samples were collected from the study area. The scat samples were then air/sun-dried in the field and stored in 100 ml vials using silica gel for later analysis.

5.2.2. Diet analysis

The diet analysis of HBB was carried out by following the standard procedure outlined by (Hamer and Herrero 1987, Mattson et al. 1991, Dahle et al. 1998, Stenset et al. 2016). A total of 253 scat were used for the feeding analysis. To understand the seasonal variations if any in the diet of HBB, the scats were divided into two seasons i.e., summer (May-August) and Pre-hibernation period (September-November). The total number of scats analyzed for the summer is 154 and 99 for the pre-hibernation period. Scat samples were immersed in water in a beaker for 10-15 hours. After that, scat samples were washed using 0.8mm sieves and rinsed thoroughly (Dhale et al. 1998). Then the sample was homogenized and three sub-samples of 10% each were taken for further analysis. The scat samples were examined manually and also using a Leica stereo microscope, and the various food components such as seed, plant matter, insect, hairs, and bones were identified visually. I classified the food items into the following nine categories “Graminoids, forbs, berries/fruits, iceberg lettuce, peas, horticultural crops, insects, animal matters, and unidentified. The percent volume of each dietary item was visually estimated (Dahle et al. 1998). The visual estimate of percentage volume aligns closely with those derived from precise volume measurement (Mattson et al. 1991).

To analyze the HBB feeding habits and its seasonal variations, I quantified the dietary composition using the frequency of occurrence (FO) as a percentage and percent of the fecal volume (FV) of each food item:

$$\mathrm{FO} = \frac{\text{total number of scats containing food item } (i) \text{in a given season}}{\text{total number of scat in that season}}$$

$$\mathrm{FV} = \frac{\Sigma \text{ the percent volume of food item } (i) \text{ in each scat in a given season}}{\text{total number of scat in that season}}$$

Since brown bear is an omnivore in diet, feeds on a variety of food items, that vary in nutritional attributes (Mealey 1980, Pritchard and Robbins 1990). Thus, may exhibit varying digestibility of different food items which may result in the potential overestimation of certain food items that are challenging to metabolize and conversely, the underestimation of those food items that are easily digestible (Hewitt and Robbins, 1996). To avoid bias in the dietary estimation, I used the correction factor (CF_1) as introduced by (Pritchard and Robbins 1990, Hewitt and Robbins 1996, Persson et al. 2001, Lopez-Alfaro et al. 2015, Stenset et al. 2016, Nawaz et al. 2019) was applied to each food category.

The correction factor (CF_1) was used to ascertain the estimated dietary content (EDC) using the following formula:

$$EDC(\%) = \frac{CF_1 \ x\ FV}{\sum CF_1 \ x\ FV \ for\ all\ food\ items} \ x\ 100$$

The correction factor (CF_1) used for the different food items was 0.24 for graminoids, forbs 0.26, berries 0.54, insects 1.1, 2 animal matter (hair and bones), vegetables: Iceberg lettuce and peas 0.26, 0.51 for horticultural crops (apple, apricot, plum) and 0.99 for unidentified.

To ascertain the energy available for the assimilation. I used another set of correction factors (CF_2) to calculate the estimated dietary energy content (EDEC) from the EDC employing the following formula:

$$EDEC(\%) = \frac{CF_2 \, x \, EDC}{\sum CF_2 \, x \, EDC \; for \; all \; food \; items} \, x \, 100$$

I used the correction factor (CF_2) outlined by (Pritchard and Robbins 1990, Hewitt and Robbins, 1996, Persson et al. 2001, Lopez-Alfaro et al. 2015), for graminoids 6.3, forbs 8.4, berries 11.7, insects 17.7, animal matter 17.8, vegetables: Iceberg lettuce and pea 8.4, 18.1 for horticultural crops (apple, apricot, plum), and 0.99 for unidentified.

To analyze the variations in the HBB diet across the seasons, I used a non-parametric statistical method, the chi-square test, to assess the variations in the frequency of occurrence across different seasons.

5.3. Results

5.3.1. Seasonal diet of Himalayan brown bear

A total of 253 scat samples were analyzed, 154 were assigned for summer, and 99 for the pre-hibernation period. Himalayan brown bear consumes a wide variety of foods such as graminoids, forbs, berries, insects, animal matter, and crops (Iceberg lettuce, peas, apples, apricots) (**Table 5.1**). When I divided the food items into broader categories such as plant matter, crops, and animal matter (insects, hairs, bones). The frequency of occurrence (FO) indicates that plant matter was the dominant food item in the HBB diet during both seasons, followed by crops, animal matter, and unidentified or miscellaneous. Plant matter constituted 62.14% and 55.79 % of the diet of HBB during the summer and pre-hibernation period respectively, followed by crops (21.90% summer, 30.53% pre-hibernation period) and animal matter (10.95% summer, 6.32% pre-hibernation period) (**Figure. 5.1**). In terms of fecal volume (FV),

Table 5. 1. Himalayan Brown bear seasonal food intake, the food items are shown as, frequency of occurrence (FO), fecal volume (FV), Estimated dietary content (EDC), and Estimated dietary energy content (EDEC).

	Summer (n=154)				**Pre-hibernation (n=99)**			
Food item	**FO**	**FV**	**EDC**	**EDEC**	**FO**	**FV**	**EDC**	**EDEC**
Graminoids	79.22	57.42	43.06	29.22	54.55	42.91	26.01	12.18
Forbs	55.19	4.67	3.79	3.43	31.31	2.42	1.59	0.99
Berries	35.06	15.77	26.60	33.53	21.21	12.49	17.04	14.81
Iceberg lettuce	27.92	3.40	2.76	2.50	9.09	1.12	0.74	0.46
Pea	21.43	12.71	10.33	9.35	2.02	0.76	0.50	0.31
Horticultural crops	10.39	4.46	7.11	13.86	47.47	39.27	50.58	68.03
Insect	17.53	0.44	1.52	2.89	4.04	0.17	0.48	0.63
Animal Matter	12.34	0.42	2.60	4.98	8.08	0.37	1.89	2.50
Unidentified	13.64	0.72	2.23	0.24	14.14	0.47	1.19	0.09

the majority of the diet of HBB composed of plant matter during summer as well as in pre-hibernation phase with (77.85% summer, 57.82% pre-hibernation), followed by crops (20.57% summer, 41.14% pre-hibernation), and (8.57% summer, (<1% pre-hibernation) by animal matter (**Figure 5.1**). The results showed that the consumption of different food items varies in the diet of HBB across the seasons. During the summer based on FO, graminoids constituted the major portions of the HBB diet i.e. (79.22%), followed by forbs (55.19%), berries (35.06%), Iceberg lettuce (27.92%), peas (21.43%), insects (mostly ants) (17.53%), animal matter (12.34%), and horticultural crops (10.39%) had the lowest FO (**Table 5.1 and Figure 5.2**).

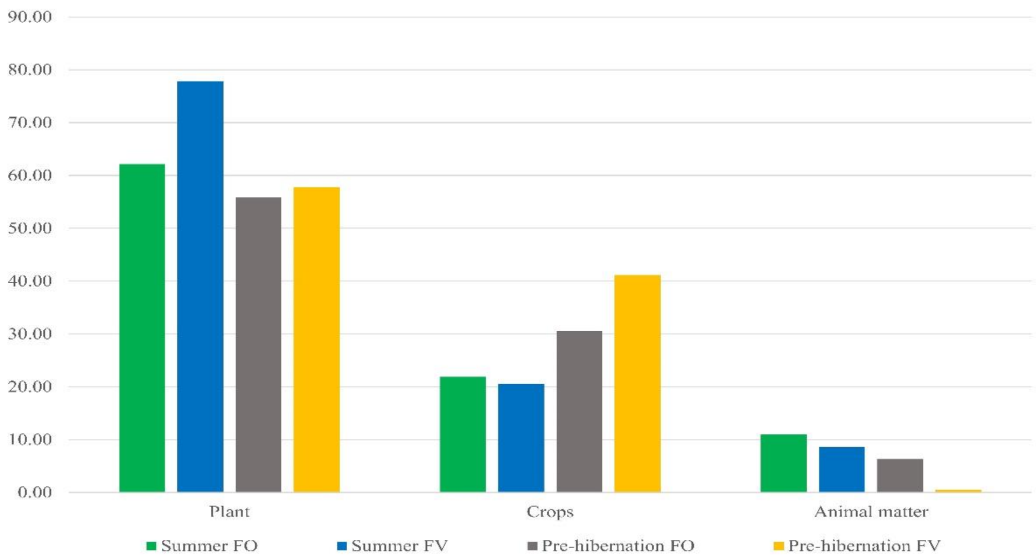

Figure 5.1. The difference in the FO and FV of broad food categories in the diet of HBB during the summer and pre-hibernation phase.

In terms of fecal volume (FV), graminoids (57.42%) had the major portions in the scat residues, followed by berries (15.77%), peas (12.71%), forbs (4.67%), horticultural crops (4.46%), and iceberg lettuce (3.40%), the insects and animal matters had (<1%) residues in the scats (**Table 5.1**).

Whereas, during the pre-hibernation period the graminoids (54.55%) had the highest FO, followed by horticultural crops (47.47%), forbs (31.31%), berries (21.21%), iceberg lettuce (9.09%), animal matter (8.08%), and pea and insects had FO (<5%). In the pre-hibernation period, with fecal volume (FV) of 42.91%, 39.27%, 12.49%, and 2.42%, respectively, the graminoids, horticultural crops, berries, and forbs constituted the scats residues of HBB (**Table 5.1**).

In the evaluation of the HBB diet, along with the FO and FV, the estimated dietary energy content (EDEC) is also an important parameter. It calculates the actual amount of energy provided by different food items to the bear after the assimilation. Findings based on EDEC showed that during the summer HBB primarily obtained 66.18% from plant matter, 25.70%, and 7.87% from crops, and animal matter respectively (**Table 5.1**, **Figure 5.2**).

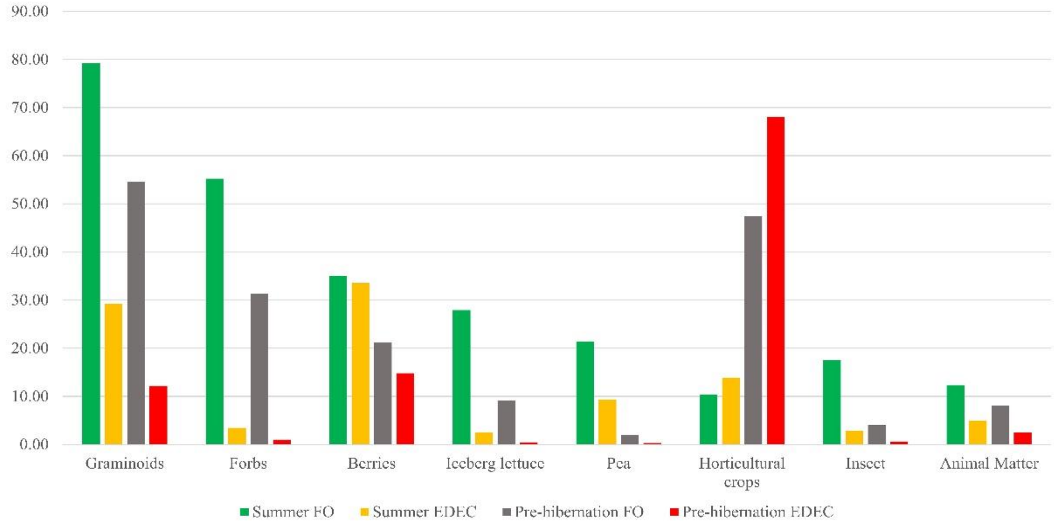

Figure 5.2. Difference in FO and EDEC of major food items in the diet of HBB during summer and pre-hibernation phase.

Conversely, during the pre-hibernation period, anthropogenic food (crops) provided most of the energy i.e., 68.80% followed by plants (27.98%), and animal matter (3.12%). However, in summer among the main food items berries (33.53%) contributed the highest EDEC, followed by graminoids, horticultural crops, peas, animal matter, forbs, and insects with EDEC values of 29.22%, 13.86%, 9.35%, 4.98%, 3.43%, and 2.89%, respectively (**Table 5.1**, **Figure 5.2**). Interestingly, during the pre-hibernation phase horticultural crops alone with 68.03% were the main source of energy intake, followed by berries (14.81%), graminoids (12.18%), animal matter (2.50%), whereas, the forbs, iceberg lettuce, peas, and insects were the lowest contributor of energy (<1%) (**Table 5.1, Figure 5.2**).

Does the HBB diet vary across the seasons?

I used the chi-square test to ensure is there any variations in the diet of HBB across the seasons. The results revealed that the FO of food items in the diet of HBB varied significantly between the summer and pre-hibernation period ($\chi 2 = 61.09$, df = 8, p-value = 2.85e-10); (**Table 5.2**). To see if there were any differences in the frequency of occurrence (FO) in the food items in the diet of HBB across the seasons. The Chi-square test was computed. The results show that there was a highly significant difference in the FO of iceberg lettuce, pea, and horticultural crops (anthropogenic food), and insects across the seasons. Whereas, graminoids, forbs, and berries (Plant matter) show a significant difference. However, no significant difference was observed in the FO of animal matter (**Table 5.2**).

Table 5. 2. Difference in the Frequency of Occurrence (FO) of main food items in the diet of HBB during the summer and pre-hibernation phase.

	Summer	**Pre-hibernation**	
Food item	**FO**	**FO**	**P-value**
Graminoids	79.22	54.55	0.033
Forbs	55.19	31.31	0.014
Berries	35.06	21.21	0.065
Iceberg lettuce	27.92	9.09	0.002
Pea	21.43	2.02	0.000
Horticultural crops	10.39	47.47	0.000
Insect	17.53	4.04	0.004
Animal Matter	12.34	8.08	0.346

5.3.2 Annual dietary composition of HBB

On the basis of 253 samples analyzed. The frequency of occurrence (FO) shows that the major food items in the annual diet of HBB were graminoids (69.57%), forbs (45.85%), berries (29.64%), horticultural crops (24.90%), iceberg lettuce (20.55%), pea (13.83%), and (10.67%) animal matter (**Table 5.3**). Fecal volume (FV) indicates that the graminoids, horticultural crops, and berries had the major portion of scats residual in the diet of HBB (**Table 5.3**). However, the horticultural crops (42.87%) provided the major energy intake for HBB, followed by berries (23.51%), and graminoids (20.09%), as observed in the estimated dietary energy content (**Table 5.3**).

Table 5. 3. HBB annual food intake; frequency of occurrence (FO), fecal volume (FV), Estimated dietary content (EDC), and Estimated dietary energy content (EDEC).

Annual (n=253)				
Food item	**FO**	**FV**	**EDC**	**EDEC**
Graminoids	69.57	51.74	35.50	20.09
Forbs	45.85	3.79	2.82	2.13
Berries	29.64	14.49	22.37	23.51
Iceberg lettuce	20.55	2.51	1.86	1.41
Pea	13.83	8.04	5.97	4.51
Horticultural crops	24.90	18.08	26.37	42.87
Insect	12.25	0.34	1.06	1.68
Animal Matter	10.67	0.40	2.28	3.65
Unidentified	13.83	0.62	1.77	0.16

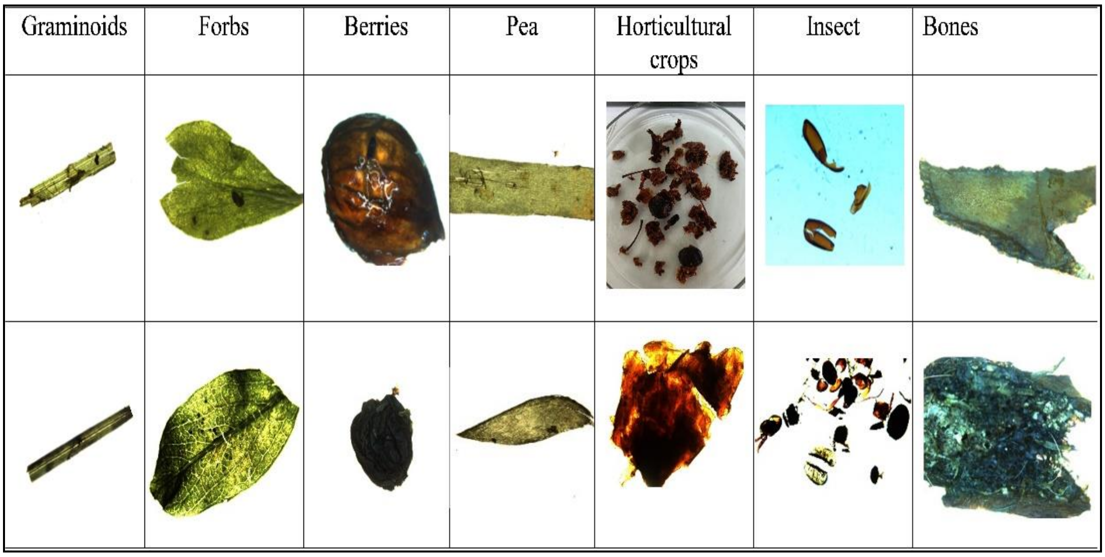

Figure 5.3. Major food items in the diet of Himalayan brown bear.

5.4. Discussion

The dietary patterns of Himalayan brown bear were analyzed using the scat samples. This method had a few limitations as it could not identify the food items at the species level. However, it remains the most cost-effective and widely employed method for providing a reliable assessment of bear diet composition (Robbins et al. 2004, Stenset et al. 2016). Due to the variability in the digestion of different food items, the correction factors were used to ensure an accurate estimate of the diet compositions (Hewitt and Robbins 1996, Bojarska and Selva 2012, Stenset et al. 2016, Nawaz et al. 2019).

In the Lahaul Valley, the HBB diet was comprised of a wide range of food items. I found that the feeding habits of HBB varied significantly across the seasons and the substantial portions of HBB diet comprised of anthropogenic food (agricultural and horticultural crops). The seasonal variations and the diverse array of food components in the brown bear diet were observed in the various studies conducted throughout its geographic distribution (McLellan and Hovey 1995, Craighead et al. 1995, Dahle et al. 1998, Persson et al. 2001, Bojarska and Selva 2012, Stenset et al. 2016, Skuban et al. 2016, Kavcic et al. 2015, Nawaz et al. 2019).

The seasonal variability in the diet of HBB was primarily due to the availability of natural and anthropogenic food resources and nutritional requirements. During both seasons, HBB pre-dominantly feeds on plants (summer 62.14%, pre-hibernation 55.79 %) and anthropogenic food (summer 21.90%, pre-hibernation period 30.53%).

However, animal matter (10.95%) was also an important part of the HBB diet during summer.

In summer, based on the frequency of occurrence (FO), graminoids (79.22%), forbs (55.19%), and berries (35.06%) were the dominant natural food items in the diet of HBB. Insects (mostly ants) (17.53%) also played a significant role in the HBB diet during summer, corroborated with the previous findings (Dahle et al. 1998, Ciucci et al. 2014, Klamárová 2019). Insects (mostly ants), being high in protein (Southwood 1973), contribute essential amino acids and aid in maintaining a crucial macronutrient balance in a bear diet (Eagle and Pelton 1983, Redford and Dorea 1984). Moreover, the protein content in insects supports muscle recovery post-hibernation, particularly significant in northern regions where bears experience prolonged hibernation and greater weight loss (Swenson et al. 2007, Bojarska and Selva 2012). I observed a decrease in the FO of insects in the HBB diet during the pre-hibernation period corroborating with the previous findings (Swenson et al. 1999). Anthropogenic food resources constituted a significant portion of the HBB diet, with iceberg lettuce (FO: 27.92%), and peas (FO: 21.43%) during summer.

Prior to hibernation, hyperphagia phase, brown bears feed on food items rich in carbohydrates to accumulate high-fat reserve, which is essential for survival during hibernation (Swenson et al. 1999). In the present study during the pre-hibernation period in the HBB diet, graminoids, (FO: 54.55%), horticultural crops (FO: 47.47%), forbs (FO: 31.31%) and berries (FO: 21.21%) were the key contributors. The diet of HBB in terms of FO of different foods was more diverse in summer than in the pre-hibernation period. This can be attributed to the seasonal availability of different foods in the study landscape.

The results of the Estimated dietary energy content (EDEC) revealed that the berries (EDEC: 33.53%) and graminoids (EDEC: 29.22%) provided the highest energy intake for HBB during the summer. However, the highest energy intake during the hyperphagia phase comes from horticultural crops (EDEC: 68.03%), followed by berries (EDEC: 14.81%).

In the Lahaul Valley during the hyperphagia phase, natural food resources were scarce. HBB travels long-distance to human settlements to meet the high energy dietary requirements, HBB raided the horticultural crops (mainly apple orchids). These findings are consistent with the outcomes of the analysis on seasonal habitat use by HBB, indicating a predominant preference for areas near human settlements during the pre-hibernation period. The apples are highly rich in carbohydrates and constitute the major portion of the brown bear diet during fall or hyperphagia (Naves et al. 2006, Štofik et al. 2013). Horticultural crops and berries, a rich source of carbohydrates contributed the most in terms of energy, and comparable with the previous studies that in hyperphagia, brown bear mostly feeds on food items that are a good source of carbohydrates (Elowe and Dodge 1989, Welch et al. 1997, Persson et al. 2001, Robbins et al. 2004, Naves et al. 2006).

Himalayan brown bear in the study landscape feeds consistently on vegetative materials such as graminoids and forbs in summer as well as during hyperphagia. However, in summer the intake of vegetative materials was notably high in comparison to hyperphagia. The seasonal variability in the consumption of brown bear diets was reported in the earlier studies conducted throughout its distribution range (Cicnjak, et al. 1987, Clevenger et al. 1992, Dahle et al. 1998, Rathore 2008, Klamárová 2019). Despite the relatively low energy intake from vegetative materials, it contributes significantly to the brown bear diet in summer. This preference might be because of the fact that the graminoids and forbs had low concentrations of undigestible components with higher levels of soluble proteins and essential nutrients crucial for bears (Hamer and Herrero 1987, Mealey 1980, Clevenger et al. 1992).

The annual diet composition of the Himalayan brown bear in the Lahaul Valley revealed that graminoids constituted the major portion of the diet (FO: 69.57%), followed by forbs (FO: 45.85%), berries (FO: 29.64%) and, horticultural crops (FO: 24.90%). However, the highest energy intake was provided by horticultural crops (EDEC: 42.87%), followed by berries (EDEC: 23.52%) and, graminoids (EDEC: 20.09%). The dietary pattern of HBB in the study landscape shows that along with natural food resources, anthropogenic foods (agricultural and horticultural crops) were the key contributors. Raids by Himalayan brown bear on the agricultural and horticultural crops in the study area were identified as one of the major causes of human-brown bear conflict (Kumar et al. 2022).

The present study indicates a dominant consumption of plant matter by the Himalayan brown bear, a pattern comparable to the study conducted in the adjoining area of Kugti Wildlife Sanctuary (Rathore and Chauhan 2014), and other ranges of its distribution (Cicnjak et al. 1987, Clevenger et al. 1992, Munro et al. 2006, Naves et al. 2006, Ciucci et al. 2014, Ogurtsov 2018, Nawaz et al. 2019). Animal matter was a significant part of the diet mainly in summer as reported in the other studies (Dahle et al. 1998, Persson et al. 2001). However, anthropogenic foods seem to act as ecological traps for the Himalayan brown bear in the Lahaul Valley.

5.5. Conclusion

The findings of the present study showed significant variations in the diet of the Himalayan brown bear across the seasons. The anthropogenic food resources significantly influenced the dietary pattern of the Himalayan brown bear and provided highly digestible energy during the pre-hibernation period. Whereas, plants and animal matter were important food components during the summer. The results showed that in summer HBB relied mainly on protein-rich food resources. However, during the hyperphagia, it consumed food items rich in carbohydrates. Various studies raised the concern that the future climate change scenario could affect the distribution, abundance, and variations in the availability of bear food resources (Bojarska and Selva 2012, Penteriani et al. 2019).

Additionally, several studies highlighted the vulnerability of the Himalayas in future climate change scenarios (Shrestha et al. 2012, Kulkarni et al. 2013, Wu et al. 2017). Which may have negative consequences on brown bear food resources, and habitat loss. Therefore, forthcoming research should prioritize identifying the major food items in the diet of brown bear at the species level and the potential effects of climate change on their distribution and abundance. The change in the availability of natural food resources could potentially shift the movement of the brown bear more towards the human settlements, where plenty of high-nutrition value anthropogenic foods are available. Which will consequently escalate the human-brown bear conflict. In Lahaul Valley, the results of the present study highlight the evident presence of anthropogenic foods in the brown bear diet, posing a challenging issue for the long-term conservation of brown bear in the study landscape.

The present study has significance in documenting and understanding the dietary patterns of Himalayan brown bear and how they change dietary patterns based on the seasonal availability of food resources. The study sheds light on the consumption of anthropogenic food, one of the key contributors to the diet of Himalayan brown bear. The findings of the present will be of immense importance for the long-term conservation and management of the species in Lahaul Valley.

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Chapter 6: Objective 3. Spatio-temporal pattern of human-brown bear conflict in Lahaul valley.

6.1 Introduction

There is a general agreement that biodiversity is under threat globally due to human population growth and the exponential use of natural resources (Whittaker et al. 2005, Blount-Hill 2021, Zarzo-Arias et al. 2021). The human population expansion into the wildlife habitat, agricultural intensification, change in the cropping pattern and dependence on natural resources, and altered habitats into so-called Human-modified landscapes, are the main causes behind the widespread human-wildlife conflicts (Treves and Karanth 2003, Dickman 2010, Zedrosser et al. 2011, Chapron et al. 2014, Miller 2015, Berihun et al. 2016, Lozano et al. 2019, Sharma et al. 2021). Habitat fragmentation and modification bring the bear and human in close proximity, and the chances of conflict tend to escalate more frequently.

The brown bear (*Ursus arctos* Linnaeus, 1758) is distributed in most of Europe, Asia, North America, the Middle East, and some parts of North Africa (Servheen et al. 1999, Swenson et al. 2000). According to the global assessment, the Brown bear is categorized as 'Least Concern' by the International Union for Conservation of Nature Red List (IUCN). However, the Himalayan brown bear (*Ursus arctos isabellinus* Horsfield, 1826) population is considered Endangered as per the Red List criterion D, it is distributed in the Northern and Southern flanks of the Himalayas in Pakistan, Afghanistan, and India (Sathyakumar 2001, Nawaz 2007, McLellan et al. 2017). Across its geographic range, in many regions, brown bear occurs in human-altered landscapes (Morales-Gonzalez et al. 2020), and co-exists with humans (Tosi et al. 2015, Zarzo-Arias et al. 2018). Besides the fact that the species is sensitive to anthropogenic disturbances (Ordiz et al. 2011), bears primarily, avoid direct encounters with humans by altering geographical and temporal patterns of landscape usage (Støen et al. 2015). Shift to being more nocturnal or crepuscular (Gibeau et al. 2002, Kaczensky et al. 2006, Martin et al. 2010, Schwartz et al. 2010, Ordiz et al. 2014, Oberosler et al. 2017). The existence of human-wildlife conflict is an undeniable challenge to wildlife conservationists.

In recent years, HBC has increased globally and has become a major challenge for long-term conservation and management (Xu et al. 2019, Dai et al. 2020). The movement and landscape utilization patterns of the bears are governed by food availability (Bojarska and Selva 2012, Sharma 2012). The anthropogenic food near bear habitats leads to bear-human interactions throughout their distribution ranges. Such movements from natural habitats to croplands result in direct attacks on humans and crop damage (Rathore 2008, Bombieri et al. 2019, Hipolito et al. 2020, Krofel et al. 2020). Moreover, several studies have suggested that livestock depredation by bears is one of the major issues leading to aggravated human-bear conflicts (Kharel 1997, Sekhar 1998, Stein 2000, Goldstein 2002, 2006). These interactions between bears and humans have detrimental psychological and economic effects, which affect the conservation and social acceptance of carnivores (Dickman 2010, Bautista et al. 2019, Redpath et al. 2017).

However, in India studies on ecological aspects and human-brown bear interaction are limited and most of them are of short terms conducted in selected landscapes

(Nawaz 2007, Rathore 2008, Sharief et al. 2020). Furthermore, human-HBB interactions are widespread across the distribution range but the negative interactions are putting the safety of humans and HBB at risk and leading to economic losses to the communities. The increasing economic loss and life threats to humans result in antagonistic behavior among the local communities toward the HBB. The retaliatory killing of the HBB by the migratory shepherd and local communities to reduce livestock depredation is a serious conservation and management challenge (Sathyakumar 2001, Rathore and Chauhan 2007, Beckmann and Lackey 2018). Previous studies from the other parts of Himachal Pradesh brought out that crop damage, livestock attack, and human casualties by HBB and black bears are prominent (Chauhan 2003) which leads to economic losses to local communities (Rathore 2008). The crop depredation by the black and HBB is more prevalent in the forest–village interface throughout the Western Himalayan region of India (Chauhan 2003, Charoo et al. 2011).

The HBB populations in the Indian Himalayan Region are mostly disjunct and are mostly restricted to Protected Areas (PA) distributed in the high-elevation zones (Sathyakumar 2001, Mukherjee et al. 2021). Lahaul Valley of Himachal Pradesh does not have designated protected areas, and HBB occupies habitats that are in close proximity to the human settlement (Sharief et al. 2020). The Lahaul Valley encompasses diverse habitats such as mixed temperate coniferous forests, Juniper, and Betula forest patches, and alpine-subalpine meadows with steep mountains, and valleys interspersed with agricultural land and human habitation that provide the ideal habitats for many wildlife species. The livelihood of the local communities primarily depends on agriculture and livestock rearing.

However, the recent expansion of agricultural land, developmental activities, and unsupervised grazing pose serious threats to brown bear conservation in the areas. During the summer seasons migratory shepherds, from the various regions of Himachal Pradesh come to the alpine-sub-alpine pasture of the areas with thousands of livestock. The livestock presence in the area exerts habitat and food resource-sharing pressure on the brown bear. Subsequently, this leads to livestock depredation. The consequences of unsupervised grazing can lead to the scarcity of natural food resources in the bear habitats, which in turn can force the bear movement to human-inhabited areas to depredate on anthropogenic food such as agricultural, horticultural crops (Iceberg, Pea, Apricot, apple), bee hives and on garbage.

Additionally, this change in movement patterns can escalate the likelihood of bear-human interactions. The increasing human interactions with the HBB are leading to HBC which is a serious threat to HBB long-term viability and significant economic loss to the local communities. Therefore, it is imperative to understand HBC in the Lahaul Valley to develop a data-driven effective conflict mitigation strategy for the valley. Hence, we designed this study with the aim to document and analyze the nature, extent, and cause of human-HBB conflict. Further, we also modelled the HBC hot spots in the region for better management of the HBC.

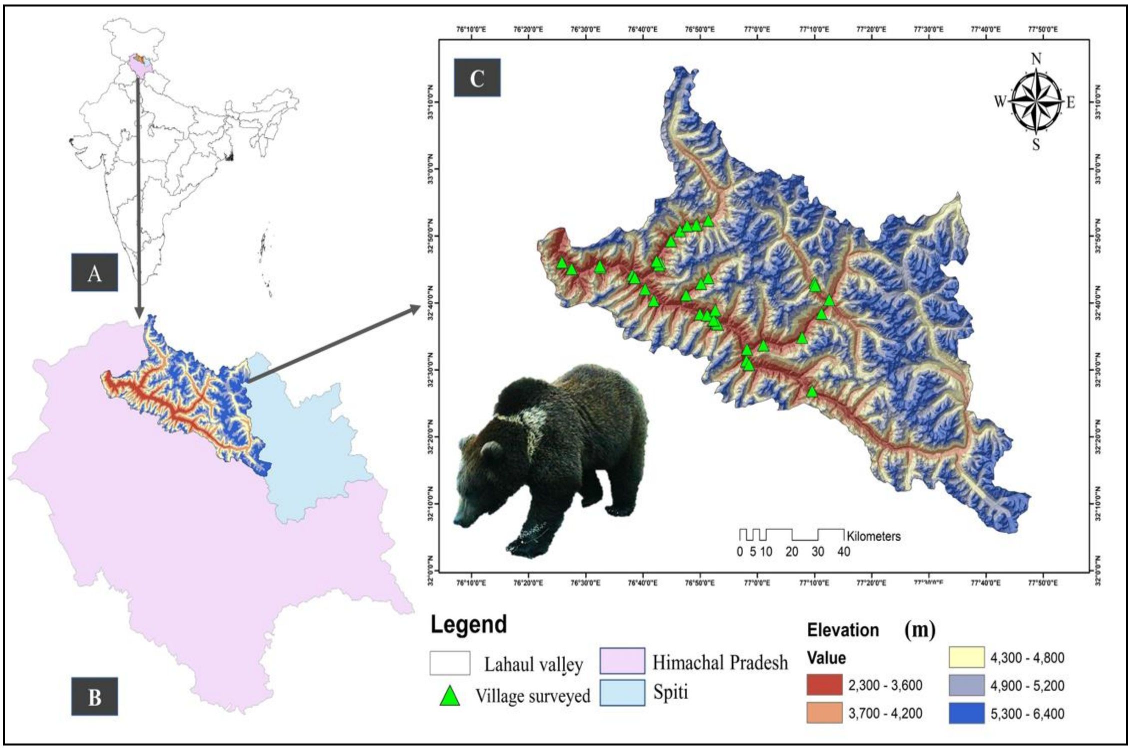

Figure 6.1. Map of the study area: A. Showing the country boundary of India B. Showing the position of Lahaul and Spiti district within the state boundary of Himachal Pradesh C. Showing the present study area (Lahaul Valley) with location of village surveyed, and the elevation ranges depicted by colour scale.

6.2. Materials and Methods

The assessment of the Human–HBB conflict was carried out in Lahaul Valley from July 2018 to December 2020. We interviewed local communities using a semi-structured "close and open-ended" questionnaire to collect information on various aspects of Human–HBB conflict in the study landscape (Temesgen et al. 2022). We also placed a total of twelve camera traps in the agriculture field and recorded the presence of HBB in the seven camera traps. We used a random sampling approach (Taherdoost 2016) to record the responses of locals from 37 villages distributed throughout the valley (**Figure 6.1**). About 30% of total households were interviewed from each village representing affluent and nonaffluent socioeconomic status following the National Sample Survey Organization guidelines, Government of India (Cochran 1977, NSSO 2011, Joshi et al. 2020, Jyrwa et al. 2020).

A total of 398 respondents (male = 294 and female = 104) were interviewed, and only one representative individual from each household, mainly the head of the family, was considered. We asked both open-and close-ended questions to gather information on types and causes of conflicts, location, timing, seasonality, and place of conflict incidence. We have considered only one record of conflict presence irrespective of the number of conflict cases to maintain consistency and mitigate correlation. We further gathered information on the attitude of locals toward wildlife. The Human–HBB conflict was categorized into three categories (a) crop damage (agricultural/horticultural), (b) livestock depredation, and (c) human attacks and casualties. The data were also gathered on mitigation measures used by the local communities to minimize conflicts with HBB. The GPS coordinates along with other covariates such as types and causes of conflict (crop damage or livestock attack), crops cultivated and the crops damaged by HBB, mitigation measures owned by local people, dependency on the forest, an approximate distance of the village from the nearest HBB habitat (habitat type we defined in our previous article, (Sharief et al. 2020), distance from the road and the water resources were also recorded during the interview.

The respondents' socioeconomic status was characterized using the Kuppuswamy socioeconomic scale, which accounts for education, occupation, and income together (Saleem 2019). We used a one-way analysis of variance (ANOVA) to understand whether the crop damage and livestock depredation varied significantly at different elevations and distances from the forest.

6.2.1. Data Analysis

Spatial analysis of crop damage by the Himalayan brown bear (HBB)

Spatial analysis for crop damage by HBB in the study landscape was performed using SaTScan Ver 9.6, which is an extension of the scan statistics introduced in the 90s (Kulldorff 1997, Kulldorff et al. 1998). The spatial scan statistics method was developed to analyze the localization, early detection, and for the substantial evaluation of clusters. The combination of the searching window and the resulting circle clusters build one of the most effective circle-based scan statistics, which help to generate purely spatial, purely temporal or spatiotemporal hotspots by using the SaTScan software (Kulldorff 2018). While in this study, we used purely spatial analysis with crop damage events of HBB and a discrete Poisson-based model to run the analysis. This model helps to understand whether the reported spatial clusters are statistically significant or not and detect high or low rates cluster of damage events in the landscape. As per the null hypothesis, we assume the expected number of damages reported by interviewees in each village is in proportion to the total household in these villages. This model requires case and population counts for a given location, such as countries and zip code areas, and also needs the geographical coordinates for each of these locations (Kulldorff 2018).

We have considered the individual case counts for conflict as individual household reports and the total number of households within the village as the population count for the primary input file. Furthermore, the spatial location of the villages acquired from the primary field survey was used as the location file in the SaTScan Ver 9.6. Then, we set the year as time precision because the analysis was purely based on spatial scale. The high or low rates for the scan areas with 9999 Monte Carlo replications and at least two cases were examined to restrict the high-rate clusters with relative risk. The relative risk was defined as the estimated risk within the cluster divided by the estimated risk outside the cluster of a given area. It was calculated as the observed risk divided by the expected risk within the cluster and then divided by the observed divided by the expected risk outside the cluster. The mathematical equation to

evaluate the relative risk (RR) is as follows:

$$RR = \frac{\frac{\frac{c}{E[c]}}{(C-c)}}{(E[C]-E[c])} = \frac{\frac{\frac{c}{E[c]}}{C-c}}{C-E[c]}$$

where, c = cases observed within the cluster and C = the total number of cases in the entire area. E[C] = total no. of expected cases in the entire area, E[c] = total no. of expected cases within the cluster since the analysis is conditioned on the total number of cases observed, E[C] = C (Kulldorff 2018).

6.3. Results

A total of 398 respondents (294 males and 104 females) were interviewed to understand the human–brown bear conflict on livestock depredation, crop damage (agriculture/horticultural crops), and human casualties. The age of interviewees ranged from 15 to 88 years (average = 45.91). Among these respondents, about 71% of respondents admitted their dependency upon the forest for livestock grazing or the collection of nontimber forest products. Based on the information obtained, in the last 5 years, no human casualties were caused by a brown bear in Lahaul valley, but only two incidences where brown bear assaulted nomadic shepherds in the Lahaul valley during day hours. Whereas, two types of humans–brown bear conflict in Lahaul valley were prominent viz., (1) crop damage (58.54%) (agricultural/horticultural) and (2) livestock depredation (34.42%).

6.3.1. Himalayan Brown bear conflict across socioeconomic classes

Based on the Kuppuswamy socioeconomic scale, of the total 398 respondents, the upper–lower class (IV) constitutes about 35.7%, followed by lower (V) (30.9%), and the upper (I) socioeconomic class constitute only 8.29%. Among these five socioeconomic classes, the crop and livestock damage because of HBB was in the following order: upper–lower (IV) crop (22.61%) and livestock (14.82%) damage, followed by lower (V) (crop-17.09%, livestock-9.05%), upper–middle (II) (crop-7.29%, livestock-4.27%), lower–middle (III) (crop-6.28%, livestock-3.77%) and lowest one was of upper (I) (crop-5.28%, livestock-2.51%) (**Figure 6.2**). Furthermore, the ANOVA result suggests significant variation between the five socioeconomic groups for crop damage incidence ($p = .045$).

6.3.2. Crop damage by the Himalayan brown bear

In the Lahaul valley the human settlements are closely located to the brown bear habitat, leading to a high level of crop damage. Among the crops, 19.85% of respondents admitted iceberg lettuce was the most depredated crop, followed by apple orchard (16.58%) (**Figures 6.2**). In which 36.68% of the crop depredation incidence was recorded during summer (**Figure 6.2**) followed by winter (21.86%) in the valley. The brown bear conflict mostly took place from midnight 100 h–600 h in the morning (41.46%), followed by evening from 1800 h to late-night 2400 h (31.66%) (**Figure 6.2**).

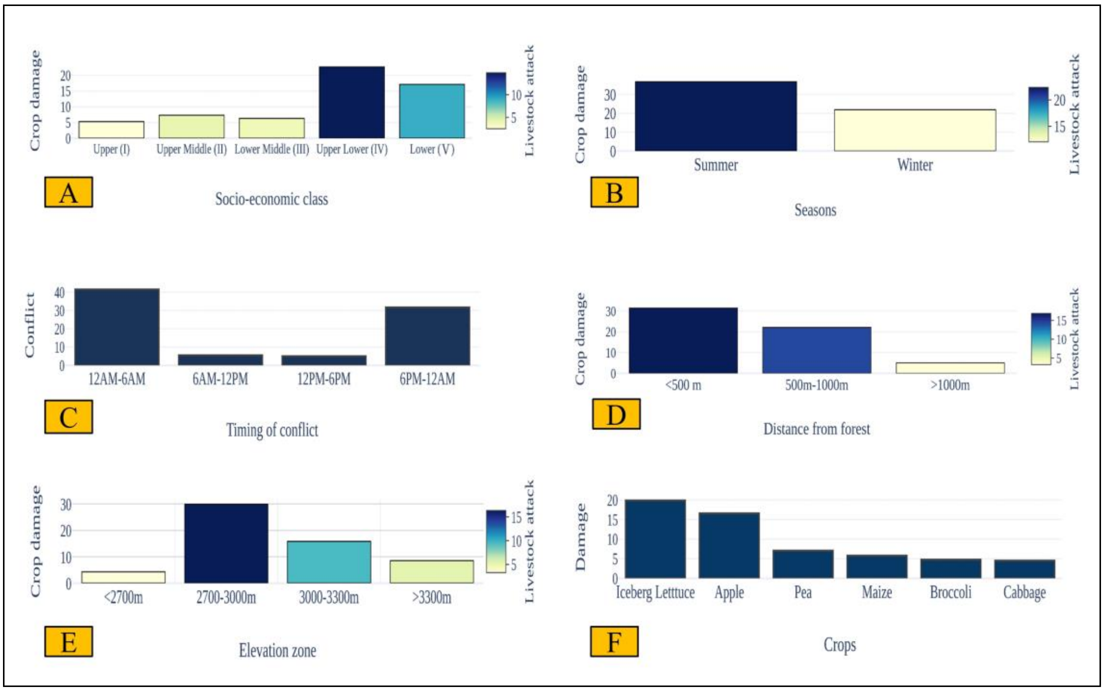

Figure 6.2. Depicts the human-brown bear conflict in the Lahaul valley. (A) showing socioeconomic class-wise crop damage (Bar graph) and livestock attack (Colour ramp), (B) showing season-wise crop damage (Bar graph) and livestock attack (Colour ramp), (C) showing the timing of conflict as per respondent (n=398), (D) showing crop damage (Bar graph) and livestock attack (Colour ramp) by HBB at different distance range from forest/brown bear habitat, (E) shows crop damage (Bar graph) and livestock attack (Colour ramp) at different altitudinal zone by HBB, (F) showing the main crop damaged by HBB.

We found that the Human–HBB conflict increases as the distance of cropland decreases from the nearest brown bear habitat. The crop damage incidences were highest (31.41%) in locations with <500 m distance from forest/brown bear habitat, followed by 500–1000 m (22.11%) and >1000 m (5.03%), respectively (**Figure 6.2**). The conflict incidences also varied by altitudinal zone. However, the crop damage did not differ significantly ($p > 1$) among the elevation zones. The highest number of incidences took place in an elevation gradient of 2700–3000 m (29.90%), and the least was at localities <2700 m (4.27%;). Moreover, the crop incidences also did not vary significantly with the distance from forested areas to the village (p > 1).

6.3.3. Livestock depredation by the Himalayan brown bear and protection measures used by locals.

The data on livestock depredation suggested that among all livestock species depredated, the sheep, goats, and cattle were the most predated domestic animals by the brown bear. Livestock depredation was reported by 34.42% of the respondents, with the highest reports during summer (22.36%) than in winter (12.06%; **Figure 6.2**). The livestock damage also varied with distance from the forest, with most of the cases taking place in areas <500 m (16.83%), followed by 500 m–1000 m (14.32%), and least in distantly located locations >1000 m distance (3.27%; **Figure 6.2**). The livestock depredation also varied significantly ($p < .05$) with altitudinal range, and the highest incidence took place in the elevation zones of 2700 m–3000 m (16.33%), followed by the 3000 m–3300 m (9.55%) (**Figure 6.2.**). Only 12.31% (49 of the total respondents 398) respondents use protective measures to protect their livestock and crops from getting depredated by HBB. These include electric or solar fences, scarecrows, and barbed wire fencing in croplands, and some local communities also use a metal container as a drum to scare the bear.

6.3.4. Spatial analysis of crop damage

The spatial analysis results depict that cropland damaged by HBB forms two clusters II and IV (**Figure 6.3**.). The radius of the high-rate clusters was 14.35 km (cluster II) and 7.97 km (cluster IV), with an observed/ expected value of 1.6 and 1.58, respectively (**Table 6.1**).

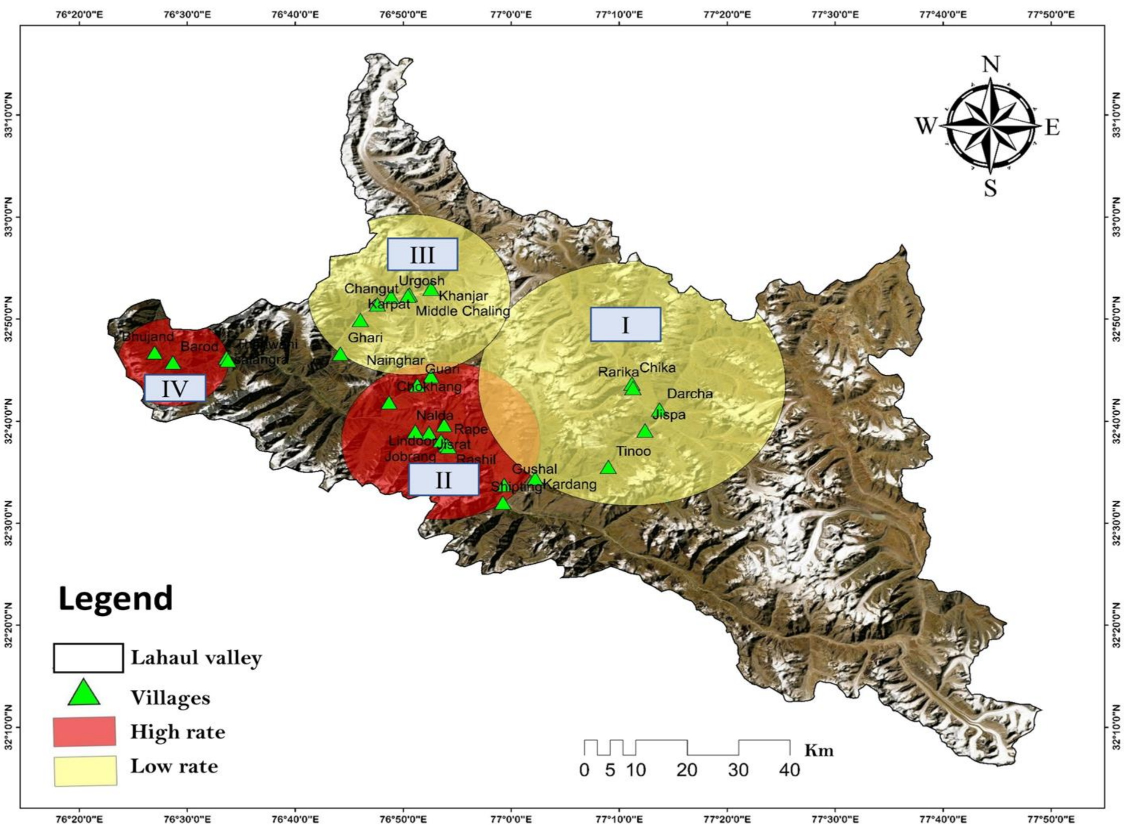

Figure 6.3. Depiction of crop damage by Himalayan brown bear in Lahaul valley. The red cluster shows the high rates of crop damage areas while the yellow cluster depicts the low rates of crop damage by Himalayan brown bear.

This suggests that the observed number of cases inside the clusters was higher than the expected number of cases. For clusters, I and III, the observed/expected values were 0.07 and 0.65, respectively, which detects fewer observed cases than expected. Furthermore, the relative risk of conflict was higher in clusters II and IV with values of 2.22 and 1.69, respectively, and was lower in clusters I and III with values of 0.06 and 0.59.

Table 6.1. Trends of crop damage by Himalayan Brown Bear in the four clusters based on a spatial model using SaTScan.

Cluster no	Locations	Coordinates	Radius (in km)	Observed/ expected	Relative risk	P-value
I	Chika, Rarika, Darcha, Jispa, Tinoo, Kardang	32.717 N, 77.167 E	22.18	0.07	0.06	0
II	Jobrang, Rape, Rashil, Jisrat, Lindoor, Nalda, Chokhang,Guari, Nainghar,Gushal, Shipting,	32.624 N, 76.872 E	14.35	1.6	2.22	0.00
III	Chaling, Middle Chaling, Urgosh, Khanjar,Changut, Karpat, Ghari	32.862 N, 76.824 E	14.60	0.65	0.59	0.80
IV	Barod, Bhujand, Salangra, Thanwani	32.752 N, 76.459 E	7.97	1.58	1.69	0.92

*****In this table, Locations refer to the name of villages in which the questionnaire survey was done, in coordinates column show their GPS location and the radius (km) depicts the radius of the high and low-risk cluster of the conflict.

Figure 6.4. Camera traps images showing the incidences of crop depredation by HBB. (a) apple orchard in which HBB damaged the apple tree, villager collecting the apple and HBB scat in yellow circle. (b) during the night at the same location HBB raiding the orchard. (c) iceberg lettuce field and owner working in it. (d) at same site HBB captured during night depredating on iceberg lettuce. (e and f) Mother with cubs raiding apricot and apple orchard.

6.3.5 Respondent’s attitude and perception on Human–brown bear conflict

About 93% (n = 370) of the respondents affirm that they are impacted by HBB conflict (agricultural/horticultural crops or livestock depredation). About 83% (n = 334) of respondents did not appreciate the existing compensation policy of the forest department for the damage caused by the HBB conflict. When asked about their perception toward HBB, most 75% (n = 302) dislike HBB in their locality because they lead to economic loss (crop damage and livestock depredation). About 56.28% of respondents reported that easy access to crops by the HBB is the main reason for the increasing HBB conflicts, followed by poor natural food availability (11.55%) in the wilderness areas. Whereas, only 10.80% of respondents said natural calamities were behind increasing HBC cases, and 5.02% reported that habitat encroachment and fragmentation as the cause of increasing HBC in the valley.

6.4. Discussion

The human-HBB conflict is identified as one of the major problems in ensuring the long-term conservation of the brown bear in the Western Himalayas (Sathyakumar 2001) and elsewhere (McLellan et al. 2017). The present study assesses the human-HBB conflicts in Lahaul Valley and the drivers of conflict in the landscape for conservation and management. Our results indicate (56.28% of respondents) that the agricultural and horticultural lands near forest areas attract bears due to the easy and high-quality food available, which corroborates with the findings of other studies (Can and Togan 2004, Bargali et al. 2005, Charoo et al. 2011, Rigg et al. 2011, Rathore and Chauhan 2014, Steyaert et al. 2016).

Furthermore, most of the crop damage by HBB was done during night hours in the absence of humans. This was also verified from our seven cameras out of 12 placed near agricultural lands (**Figure 6.4**), and similar findings of the other studies conducted elsewhere (Mace et al. 1996, Ordiz et al. 2011, Stoen et al. 2015, Lamb et al. 2020). The higher percentage of HBC (crop damage and livestock depredation) observed at elevation zone 2700–3000 m could be because the crop and grazing lands are distributed at this elevation and primarily distantly located from the human settlements. The expansion of agricultural lands and the adoption of high economic crops in place of traditional crops in the study landscape is one of the reasons for increase in conflict cases in the study area.

Nevertheless, during our field survey, we noticed that the traditional cultivation of potato (*Solanum tuberosum*) is replaced by high economic crops (Iceberg lettuce, broccoli, red leaf lettuce, etc.), which attract HBB. Hence, these shifts in the agricultural practices are playing a major role in increasing human-brown bear conflict in the landscape. The bears are attracted to the rancid smells of the rotten horticultural and agricultural crop residuals from long distances because of their extraordinary olfactory abilities (Green et al. 2012). The livestock depredation in high-altitude areas of the study landscape could be because of unsupervised livestock grazing practices in alpine pastures by the nomadic herders. The is consistent with the results of our previous study (Sharief et al. 2020), which brought out that in Pattan valley with higher elevation villages such as Jobrang, Rashil, Goushal, Shipting, Mooling, Jasrath, Nalda, etc., are more prone to brown bear conflict.

The SaTScan results showed that Cluster II, with a radius of 14.35 km, encompasses the villages mentioned by (Sharief et al. 2020), resulting in higher crop damage and more cases than expected (**Table 6. 1, Figure 6.3**). Clusters II and IV cover the areas with a higher probability of HBB occupancy (Sharief et al. 2020) and have ideal habitats for HBB in the valley. Further, HBB habitats are also in close vicinity of human settlements in these areas, and frequent migrations of the nomadic shepherd through these habitats during summers also increase the grazing pressure, degradation of habitats, and depletion of natural food resources (Elfstr¨om et al. 2014, Baruch-Mordo et al. 2014, Sharma et al. 2021).

Consequently, HBB depredates readily available crops in agricultural lands that fall under Cluster II and IV before hibernation to meet energy requirements during a hyperphagia period (Herrero 2018). These findings align with the outcomes of seasonal diet analysis of HBB in the Lahaul Valley. In the study landscape, human food is the main attractant for HBB, consistent with the other studies (Rathore 2008, Bojarska and Selva 2012, Bombieri et al. 2019). However, villages that fall under clusters I and III had few HBC instances due to less numbers of horticulture orchards, less scattered agricultural lands, and low detection probability of HBB in the areas.

In the valley, traditional protection measures were adopted to prevent damage such as metal drumming and crackers, which were effective up to some extent. However, such practices may not have worked because of differences in localities. The respondent claimed only two incidents of lethal removal of HBB, suggesting retaliatory killing of the brown bear to reduce damage. Several studies have highlighted that the retaliatory killing of bears is a major conservation and management issue for bears in the Himalayas and elsewhere (Rathore 2008, Charoo et al. 2011, Temesgen et al. 2022). The local communities have developed a negative perception of HBB due to the associated high economic loss imposed by HBC. Thus, it implicates a more significant threat to HBB conservation in the study landscape.

6.5. Management recommendations

The HBC is a growing conservation and management issue in the study landscape. The local communities are developing negative perceptions about the bear's presence in the vicinity, which is alarming for the long-term viability of HBB in the study landscape. The present study has identified a major Human–HBB conflict hot spot, facilitating local stakeholders to identify high-priority villages for conflict intervention. Furthermore, the identified hot spots will encourage mitigation efforts to focus on the vulnerable regions and provide suggestions to improve the current mitigation approaches cost-effectively (Tripathy et al. 2021).

The local communities have adopted protective measures, including barbed wire fencing, metallic doors in cattle sheds, crackers to scare away bears from human settlements, and installed scarecrows at corners of the croplands. However, many of them are less effective in controlling the increasing instances of HBB in the landscape. Thus, to mitigate HBC in the study landscape, there is a need to adopt strategies such as installing electric fencing in HBC hot spots/ cluster II and IV village boundaries with the support of the Government of Himachal Pradesh by subsidizing the cost at the community level. These electric fencings effectively control the HBC elsewhere (Ambarlı and Bilgin 2008, Huygens and Hayashi 1999, Linnell et al. 1996).

The garbage/waste management mechanism may be considered for removing the crop residuals, which act as bear attractants in cluster II, where horticulture is more intense than in the other clusters. Anthropogenic food such as livestock feed, agricultural, and horticultural crop residuals attract brown bears (Bojarska and Selva 2012, Herrero and Higgins 2003). Creating community watch groups in the landscape can significantly minimize the crop damage where the community members should opt for turn-wise guarding of agricultural crops and apple orchards (Charoo et al. 2011).

Our results suggest that the local communities are least interested in conserving HBB in the landscape because of the economic losses. Therefore, appropriate compensation schemes for crop damage, crop insurance, and other conflict mitigation strategies must be implemented to change local attitudes. Furthermore, change in cropping patterns such as cultivating crops such as potato, capsicum, and amaranths in place of maize and crops which attract bears may be adopted in croplands which are on the forest fringe. Ecotourism holds potential in changing the local's perception as reported in adjoining valley hence shall be promoted in Lahaul valley.

The Lahaul valley has some of the most charismatic species, such as snow leopard, musk deer, and also brown bear, which will attract wildlife enthusiasts. Furthermore, ecotourism has significantly changed the lives of remote communities elsewhere and provided positive dividends toward improving the population of conservation-dependent species such as snow leopard (Vannelli et al. 2019). Therefore, the involvement of locals and the nomadic shepherds in planning and implementing brown bear conservation actions in high conservation priority areas of Lahaul Valley will be of significant importance. Furthermore, there is a need to notify few areas as protected areas identified in our previous study (Sharief et al. 2020), so that effective management actions related to habitat improvement, protection, and resource extraction can be minimized.

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Publications and conferences

Peer-reviewed research paper

1. Kumar, V., Sharief, A., Dutta, R., Mukherjee, T., Joshi, B.D., Thakur, M., Chandra, K., Adhikari, B.S. and Sharma, L.K., 2022. Living with a large predator: Assessing the root causes of Human–brown bear conflict and their spatial patterns in Lahaul valley, Himachal Pradesh. Ecology and Evolution, 12(7), p.e9120. https://doi.org/10.1002/ece3.9120

Conferences

1. Kumar, V., Sharief, A., Thakur, M., Adhikari, B.S., and Sharma, L.K. Human-brown bear (*Ursus arctos isabellinus*) conflict in the Lahaul valley, Himachal Pradesh. Virtual 27th International Conference on Bear Research & Management: Conserving Bear in a Changing World held in September of 2021, organized by the International Bear Association.
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CONSERVING BEARS IN A CHANGING WORLD

Certificate of Attendance

This is to certify that

Vineet Kumar

Attended and presented the 27th International Conference on Bear Research and Management held in September of 2021.

Presented a paper entitled "Human-brown bear (*Ursus arctos isabellinus*) conflict in the Lahaul Valley, Himachal Pradesh"

Presented on **10/1/2021** by

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BEST PAPER PRESENTATION AWARD

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Zoological Survey of India, Kolkata, West Bengal, India

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Eco-geographic covariates influencing the habitat use of the Himalayan brown bear in Lahaul Valley, India

Prof. D. Thangadurai EAES President	Prof. K. Soytong AATSEA President	Dr. J. Sangeetha Convener	Dr. S. Deshpande Organizing Secretary

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RESEARCH ARTICLE

Living with a large predator: Assessing the root causes of Human–brown bear conflict and their spatial patterns in Lahaul valley, Himachal Pradesh

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Abstract

Brown bear-mediated conflicts have caused immense economic loss to the local people living across the distribution range. In India, limited knowledge is available on the Himalayan brown bear (HBB), making human–brown bear conflict (HBC) mitigation more challenging. In this study, we studied HBC in the Lahaul valley using a semi-structured questionnaire survey by interviewing 398 respondents from 37 villages. About 64.8% of respondents reported conflict in two major groups—crop damage (30.6%) and livestock depredations (6.2%), while 28% reported both. Conflict incidences were relatively high in summer and frequently occurred in areas closer to the forest (<500 m) and between the elevations range of 2700 m to 3000 m above sea level (asl). The dependency of locals on forest resources (70%) for their livelihood makes them vulnerable to HBC. The "upper lower" class respondents were most impacted among the various socioeconomic classes. Two of the four clusters were identified as HBC hot spots in Lahaul valley using SaTscan analysis. We also obtained high HBC in cluster II with a 14.35 km radius. We found that anthropogenic food provisioning for HBB, livestock grazing in bear habitats, and poor knowledge of animal behavior among the communities were the major causes of HBC. We suggest horticulture crop waste management, controlled and supervised grazing, ecotourism, the constitution of community watch groups, and others to mitigate HBC. We also recommend notifying a few HBB abundant sites in the valley as protected areas for the long-term viability of the HBB in the landscape.

KEYWORDS
conflict mitigation, human-brown bear conflict, India, SaTScan, trans–Himalaya

TAXONOMY CLASSIFICATION
Applied ecology; Conservation ecology; Human ecology; Population ecology; Zoology