Ecology of Himalayan brown bear (*Ursus arctos isabellinus*) in the Trans-Himalayan region, Ladakh (Jammu & Kashmir), India

Thesis submitted for the award of the degree of

Doctor of Philosophy

In

WILDLIFE SCIENCE

By

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To

Saurashtra University
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Under the supervision of

Dr. Bivash Pandav

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This thesis is dedicated to my father, Mohammad Mussa Khan who always believed in my dreams.

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DECLARATION

I hereby declare that the work conducted under the thesis entitled "**Ecology of Himalayan brown bear (*Ursus arctos isabellinus*) in the Trans-Himalayan region, Ladakh (Jammu & Kashmir), India**", is a record of original research work, done by me and subsequently submitted for the award of the degree of doctor of Philosophy in Wildlife Science to Saurashtra University, Rajkot (***Reg. No. 19180 dated 06.02.2019***). This research work has been carried out under the guidance and supervision of **Dr. Bivash Pandav, Scientist-G, Department of Protected Area Network, Wildlife Management & Conservation Education, Wildlife Institute of India, Dehradun.** The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, observation and understanding and the particulars given in it are true to the best of my knowledge.

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This is to certify that the thesis by **Mr. Niazul Hassan Khan** entitled "**Ecology of Himalayan brown bear (*Ursus arctos isabellinus*) in the Trans-Himalayan region, Ladakh (Jammu & Kashmir), India**" is an original and independent research work submitted to the **Saurashtra University, Rajkot (Gujarat)**, for the award of the degree of **Doctor of Philosophy in Wildlife Science**.

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

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

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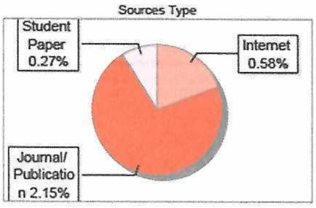

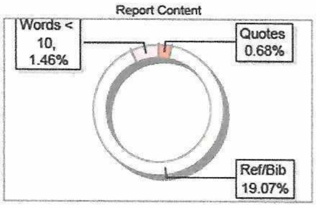

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Khan, N.H., Sadhu, A., Jain, D. *et al.* Spatial patterns and ecological determinants of Himalayan brown bear distribution in the Trans-Himalayas of India. *Sci Rep* 15, 42521 (2025). https://doi.org/10.1038/s41598-025-26632-7 (**ISSN No. 2045-2322 (online)**)

IRALE Conference 2024, held from 21-23 February 2024 at Murti, West Bengal, is organized by the Indian Regional Association for Landscape Ecology. Paper presented entitled "*Bear necessities: Navigating the Himalayan brown bear's habitat in Trans-Himalayan region of Ladakh.*"

National Conference on Ladakh Climate Change Scenario & Environmental Sustainability (LCCSES–2024) held on 12-13 September 2024 at Taru Campus, Leh was organized by University of Ladakh. The paper presented was entitled "*Bearing in High Altitude: Himalayan Brown Bear Habitat, Ecology in the Trans-Himalayan Region of Ladakh.*"

8th International Congress on Zoology and Technology (ICZAT), from 13-16 December 2024. Attended and presented oral research titled "*Bearing: Himalayan Brown Bear Habitat Ecology in the Trans-Himalayan Region of Ladakh.*"

Participated in the Indian Ecological Society International Conference 2024, IESIC-2024, on "Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions" from 12–15 November 2024 at Punjab Agricultural University (PAU), Ludhiana, with an oral presentation on "*Human-Brown Bear Interactions in Western Ladakh.*"

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"And We placed within the earth firmly set mountains, lest it should shift with them, and We made therein [mountain] passes [as] roads that they might be guided"- Verse 21:31

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Executive Summary

The Himalayan brown bear (*Ursus arctos isabellinus*) is among the rarest and most threatened large carnivores in South Asia, restricted to some of the most remote, rugged, and environmentally extreme high-altitude landscapes of the Indian Himalaya. Despite its status as a Schedule I species under the Wildlife Protection Act, 1972, and its ecological significance as a flagship carnivore, it remains one of the least studied mammals in India, owing to exceptionally low population densities, secretive behaviour, harsh climatic conditions, and the logistical challenges inherent to research in remote alpine and trans-Himalayan zones. Against this backdrop, the present thesis provides the first integrated, landscape-level scientific assessment of the species' habitat ecology, dietary patterns, human-bear conflict dynamics, and management requirements across the Union Territory of Ladakh, with an intensive focus on the Kargil District. Synthesising extensive multi-year fieldwork, including more than 30,000 man-days of data collection, systematic occupancy surveys, remote sensing and species distribution modelling, molecular scat analysis, socioeconomic surveys, and spatial conflict mapping, this work fills critical knowledge gaps and establishes a comprehensive baseline essential for long-term conservation planning for the Himalayan brown bear in India. Ladakh, which constitutes the westernmost extension of the Tibetan Plateau, is characterised by cold-arid, high-elevation ecosystems where environmental conditions are severe and biological productivity is naturally low. The region exhibits dramatic elevational gradients, with valley floors starting around 2,500 m and peaks exceeding 7,700 m, generating a mosaic of ecological zones ranging from desert scrublands to alpine pastures. Human settlements are sparse but highly concentrated in narrow, fertile valleys sustained by glacial meltwater. Traditional agro-pastoralism is the dominant livelihood system, and extensive seasonal grazing across alpine rangelands creates strong spatial overlap between livestock, wild herbivores, and carnivores. In this socio-ecological setting, the Himalayan brown bear occupies some of the most productive pockets of western Ladakh, particularly in Kargil's Suru, Drass, Shargole, and Zanskar valleys. These landscapes, however, are undergoing rapid change due to expanding road networks, military infrastructure, tourism growth, and energy installations, which are reshaping ecological processes and wildlife movement patterns. Within this complex backdrop, the thesis first examines, on an unprecedented landscape scale, the habitat ecology and spatial distribution of the Himalayan brown bear. Using MSTrIPES

digital data collection tools, the study systematically surveyed 10 × 10 km grid cells, which were further subdivided into 5 × 5 km sub-grid units, over a large geographic area and amassed 2,530 confirmed bear signs. Occupancy modelling pointed out that elevation, terrain ruggedness, distance to water, and the extent of alpine ranges are strong determinants of bear presence. Bears preferred rugged and moderately sloped areas between 3,300 m and 5,000 m, which also provided quick access to high-quality foraging grounds while also offering denning security. These findings are indicative of the habitat dependence of this species on very niche ecological conditions within an otherwise hostile landscape. Parallel habitat suitability modelling undertaken using MaxEnt showed that the core habitats of Himalayan brown bears in Ladakh are restricted to western districts and, more particularly, to the Suru-Drass-Zanskar belt. The highest suitability zones correspond to areas with productive alpine meadows, perennial water availability, and moderate temperatures, while marginal suitability is observed in the harsher eastern parts of Ladakh. Importantly, the modelling revealed that many such core habitats fall outside formal protected areas; hence, there is a need for community-based and landscape-level conservation measures. This thesis component was published in Scientific Reports (2025) with first detailed study on the habitat ecology of the Himalayan brown bear in the high-altitude region providing necessary information for future management and policy decisions.

A second major component of the thesis relates to the dietary ecology of the species. Given the paucity of ecological studies in the Trans-Himalaya and the challenge of distinguishing carnivore scats in multi-carnivore landscapes, the study used non-invasive molecular techniques to confirm species identity prior to micro-histological diet analysis. Of 1,380 carnivore scats collected, 408 were identified as putative brown bear scats in the field, which was confirmed by DNA sequencing. This approach greatly enhances accuracy and secures the first molecularly verified dietary profile for the species in India. Results showed that, in the summer, Himalayan brown bears in Ladakh are predominantly herbivorous, with significant consumption of graminoids, forbs, roots, and a variety of alpine herbs, a feature of the short window of plant productivity during the brief growing season. With the approach of autumn and the senescence of natural vegetation, the proportion of animal matter increases in the diet, including marmots, small mammals, and carrion. Significantly, scats in areas with close proximity to settlements, army establishments, and tourist sites contained remains of livestock and anthropogenic garbage, notably plastic. Such dependence on human-derived food sources is a cause for concern, as this may lead to altered behaviour and increasingly conflictive situations. There was spatial variation in diets, where bears inhabiting high-quality rangelands predominantly depended on natural vegetation, whereas bears inhabiting human-dominated landscapes supplemented their diet with garbage, livestock, and stored items of food. These findings not only bring out the ecological constraints for the species but also indicate the importance of proper waste disposal and livestock management in mitigation of negative human-brown bear interactions.

The third important element is the dynamics and drivers of human-brown bear conflict in Ladakh, particularly in Kargil, where the species' range overlaps considerably with human-use areas. Analysis of 22 years of official conflict records, from 2001 to 2022, indicates a sharp and sustained rise in conflict incidents: only two to four incidents were reported annually during the early 2000s, suggesting negligible interactions between humans and bears. However, incidents showed a gradual rise after 2008, increasing to 11-60 cases annually between 2010 and 2014, and crossing 90 cases annually after 2015. The number of incidents reached its peak of 112 in 2021. Livestock depredation has followed an equally disturbing upward trend, with negligible losses before 2005 but rising thereafter sharply to unprecedented levels in the years 2016-2018, when annual livestock losses reached between 447 and 737 animals. Cattle were the most frequently affected livestock species, followed by horses, goats, and sheep. Overall, estimated economic losses have ranged at over INR 9.3 lakh annually, affecting vulnerable agro-pastoral households disproportionately. Spatial analysis of incidents suggested a high clustering of hotspots, especially in Drass, Suru, and parts of Zanskar, with concentrated settlements, extensive livestock grazing, waste availability, and proximity to bear habitats. Most incidents occurred in summer and autumn months, coinciding with the peak activity season of bears and reduced availability of natural forage. Household surveys across multiple valleys revealed that while fear of bears is widespread, general attitudes toward the species are positive, with a large proportion of respondents supportive of its conservation. However, rising economic losses and property damage threaten to erode tolerance, and timely and focused interventions are critical for preserving coexistence.

Guided by these ecological, dietary, and social insights, this thesis proposes an integrated set of evidence-based conservation and management recommendations tailored to the unique socio-ecological context of Ladakh. The conservation of the habitat needs to prioritise the core bear habitats in Drass, Suru, Rangdum, Shargole, and Zanskar, including their designation as Community Reserves, besides implementing effective ecological impact assessments for new infrastructure projects. Degraded alpine pastures and riparian zones need restoration.

Connectivity needs to be maintained through landscape-level planning. Management of food resources should include strict protocols for carcass disposal, installation of bear-proof waste bins, and improved storage facilities for crops and fodder to reduce attractants. Mitigation of conflicts needs to include predator-proof corrals, solar deterrent systems, early-warning networks, rapid response teams, and streamlined compensation schemes that incentivise preventive measures. Besides all the above, there is a very high potential for community-based ecotourism to serve as an alternative livelihood and conservation incentive based on successful models from other Himalayan regions. Ultimately, the development of collaborative governance among wildlife authorities, local communities, panchayats, pastoral groups, and tourism stakeholders must strike a balance between the demands of development and ecological sustainability. Overall, the present thesis undertakes the most comprehensive and integrated ecological assessment of the Himalayan brown bear in India and provides a science-based platform for conserving this threatened species in one of the world's most challenging and changing high-altitude landscape.

Chapter-1

Introduction

1. Introduction

The history of rapid development has brought human habitation near to habitats favoured by wild animals (Mano, 1994; Manferdo, 2015), and with humans moving towards the Anthropocene era, their dependency on the natural resource subsequently expanded. People seek new places for habitation, which encroaches upon wildlife habitats and leads to the fragmentation and degradation of valuable resources, as well as the dispersion of wildlife due to the unregulated use of natural habitats and resources (Kala & Rawat, 1999; Sathyakumar, 2006). Understanding habitat use and selection is crucial for the conservation of the wildlife and the enforcement of management policy. Humans have a long history with large carnivores (Zedrosser et al., 2011; Elfstrom et al., 2012). However, widespread extirpation of large carnivore populations has occurred in association with increasing human population and anthropogenic activities (Woodroffe, 2000).

1.1 Brown Bear Global Distribution and Status

Brown bears (*Ursus arctos*) are distributed across multiple countries in Europe, Asia, and North America, representing one of the most widely distributed bear species globally. Russia hosts the world's largest population of approximately 130,000 individuals, with the eastern part of their range remaining relatively stable while the western European portion has experienced dramatic reduction compared to previous centuries due to progressive deforestation (Chestin, 1997).European populations total about 50,000 bears distributed across more than 2.5 million km², with approximately 14,000 bears outside Russia occupying around 800,000 km² (Zedrosser, 2002; Swenson et al., 2000). Specific European populations include 37,500 bears in northeastern Europe, 8,100 in the Carpathian Mountains, 2,800 in the Alps-Dinaric-Pindos region, 1,000 in Scandinavia, 520 in the Rila-Rhodope Mountains, and smaller populations ranging from 4 to 200 individuals in countries including Spain, Italy, and France (Zedrosser, 2002). In Greece, brown bears occupy two distinct nuclei covering approximately 11,000 km², representing the southernmost range of the species in Europe (Mertzanis, 1994).North American brown bear distribution historically included Alaska, western Canada, the western and midwestern United States, and northern Mexico but is now limited to Alaska, Canadian provinces (Yukon, Northwest Territories, British Columbia, and Alberta), and six threatened subpopulations in the lower 48 states (Waits et al., 1998). The southern fringe of distribution spans approximately 3,050 km in British Columbia, 1,570 km in Alberta, and 1,700 km in the lower 48 states, with Canadian populations being critical to U.S. recovery efforts (McLellan, 2007).

Asian populations face significant conservation challenges, with brown bears historically occupying approximately 150,000 km² but now experiencing population declines and local extinctions, leading to their designation as critically endangered in the IUCN Red List (Nawaz, 2007).

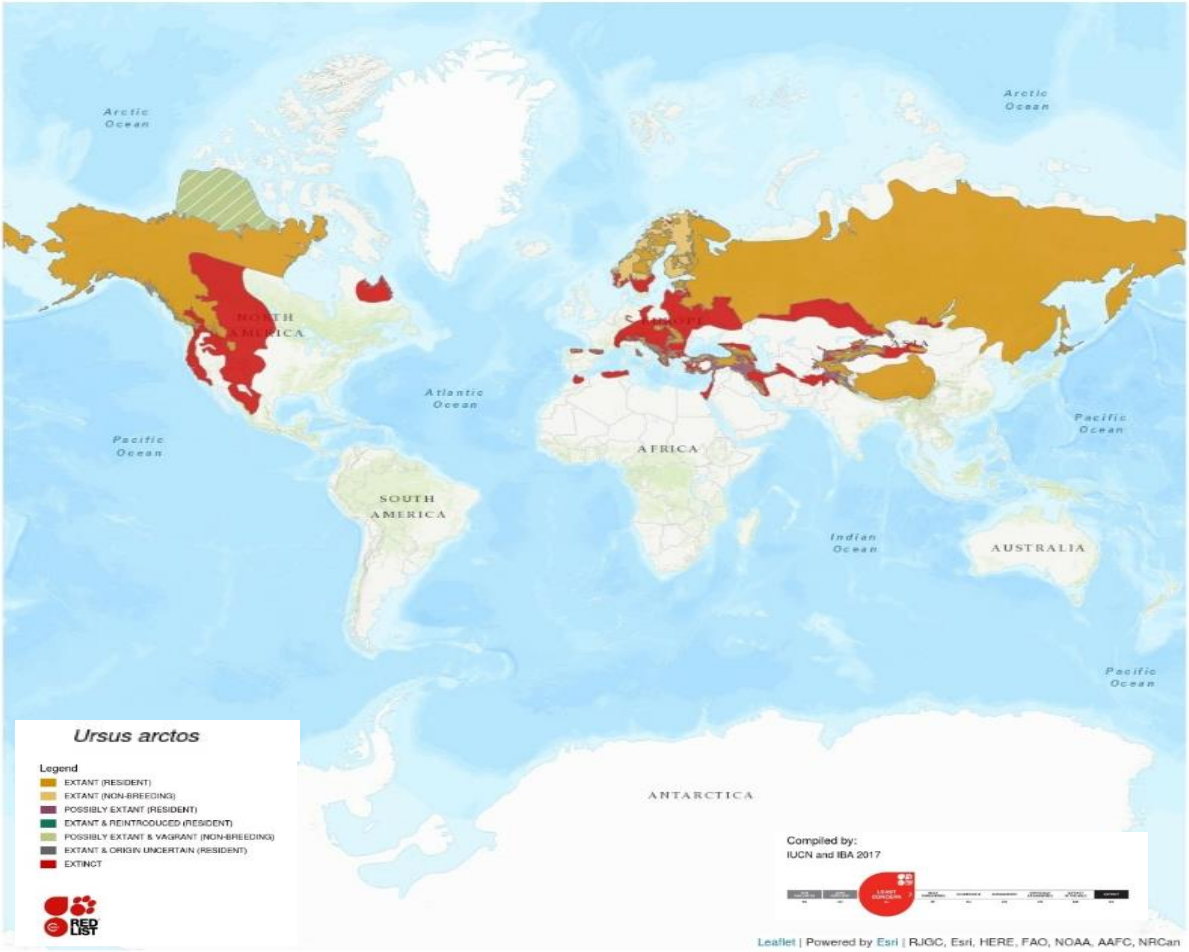


Figure 1.1: The map shows the geographical range of Brown bear *Ursus arctos* (https://iucnredlist.org/species)

1.2 Species Characteristics and Biology

Brown bears are large carnivores with thick fur, which is often reddish-brown or sandy in colour. Males are larger than females, ranging from 150 to 230 cm in length compared to 137 to 183 cm in the case of female bears, and tail length is around 10 cm. The average lifespan of brown bears is 25 years in the wild, but they can live longer in captivity. Bears have an excellent sense of smell and can run much faster than humans. Bears are mostly omnivorous except for the giant panda, which feeds entirely on bamboo. Male brown bears weigh 130-400 kg, and the females weigh between 80 and 230 kg (Prater, 1980; Roberts, 1997; Shawl et al., 2008). Brown bears are solitary except for courting individuals or mothers with their cubs.

Brown bears exhibit continuous dormancy for up to seven months without eating, drinking, defecating, or urinating (Folk et al., 1976) and are generally considered less of a 'true' hibernator than the ground squirrel of the family Sciuridae (Lyman et al., 1982). Many bears of the northern region go into a period of dormancy during the winter period called 'torpor' (Lyman & Dawe, 1960). During the winter sleep bears are in a torpor state because they can be easily aroused when disturbed, featuring enhanced survival of a group of the species (Craighead and Craighead, 1972). For many species, hibernation is an important life-history strategy that is likely to be impacted by changing patterns of land use and climate (Johnson et al., 2017). Animals hibernate in response to scarce resource availability (Nelson, 1980; Ruf & Geiser, 2015), so obtaining food from subsidies that are available could alter patterns of hibernation with subsequent effects on physiology, demography, and even human-bear conflicts (Lane et al., 2012). Nevertheless, the long-term trend of warmer winter weather (Williams et al., 2015) has been associated with late hibernation and earlier emergence from hibernation for some animals (Inouye et al., 2000).

Usually, their body temperature ranges from 36.5°C to 38.5°C when active. However, it declines to 4°C to 5°C during hibernation (Irving & Krog 1954; Flock et al., 1972; Hilderbrand et al., 2000). Males reach sexual maturity between the ages of 3.5 and 7 years, and mating begins from early May to the middle of July, but implantation does not occur until October-November, while young are born between January and March after the gestation period of 180-270 days. Cubs weigh only about half a kilo and stay with their mother usually for at least two and a half years; thus, most females breed after every three years (Schwartz et al., 2003; http://www.bearbiology.com).

1.3 Brown Bear Ecology

Brown bears require large territories with access to diverse natural food resources and water for habitat suitability globally. Studies highlight the importance of water availability, forested landscapes, and vegetative cover in brown bear habitat selection (Steyaert et al., 2020), particularly near the southern range margins such as in southwestern Asia. Habitat fragmentation and human activities, including infrastructure development, reduce habitat quality, pushing bears into human-dominated landscapes and increasing conflict risk. In Türkiye, proximity to villages, protected areas, farmland, and human footprints are key drivers of human-brown bear conflicts (HBC), often related to bear foraging near settlements due to limited natural food and habitat. Similarly, in Iran, landscape fragmentation and forest patchiness are strongly correlated with bear damage and conflict risk areas, emphasising corridors and habitat connectivity for conservation and conflict mitigation (Sıkdokur et al., 2024; Khosravi et al., 2022).

Only a few studies have been conducted on the habitat use and selection by large carnivores, especially bears, in the Indian Himalayan Region (Rathore, 2008; Sathyakumar et al., 2013; Mohanta, 2011). Out of eight species of bears (Waits et al., 1999), only four species of bears, viz., Himalayan brown bear (*Ursus arctos isabellinus*), Asiatic black bear (*Ursus thibetanus*), sun bear (*Helarctos malayanus*) and sloth bear (*Melursus ursinus*), are found in India. The Himalayan brown bear is found mostly in the western Himalayan region (Satyakumar, 2006). Globally, brown bears *Ursus arctos* (Linnaeus, 1758) are found in four major continents (North America, South America, Europe, and Asia), and in Asia, brown bears are distributed in Turkey, Iran, Afghanistan, Pakistan, India, Nepal, China, Mongolia, Russia, and Japan. Brown bears are possibly extinct in Bhutan. Along the Himalayan Tibetan region, a subspecies of brown bears called the Tibetan blue bear (*Ursus arctos pruinosus*) is recorded from the Damodar Hunda valley, district Mustang, Nepal (Gurung, 2004). The early reference to the occurrence of the Tibetan brown bear in India dates back to the 19th century (Donald, 1898), but recently the first camera trap record of the Tibetan brown bear has been recorded in Changthang Wildlife Sanctuary (Kungyam) by the Wildlife Protection Department of Ladakh (Kumar et al., 2024).

Research on India's four bear species reveals significant knowledge gaps, with the Malayan sun bear and Himalayan brown bear being the least studied due to their secretive nature, extremely low population densities, and the challenging habitats they occupy. Among these, the Himalayan brown bear emerges as the most understudied species for several critical reasons. Sathyakumar et al. (2005) reported that very little information exists on the relative abundance of Himalayan brown bears and noted that available data are insufficient to elucidate population trends. The species occurs in extremely low densities across subalpine and alpine regions above 3,300 m elevation, with only guestimate populations reported from 23 protected areas and 18 additional localities in India.

Research challenges are particularly acute for Himalayan brown bears. Kumar et al. (2025) emphasise that because of the secretive behaviour of the species, combined with extreme terrain and logistical difficulty, they have received limited scientific attention. The authors specifically highlight scarce information on species distribution ranges, with only a few range reports and short-term bear-human interaction studies, resulting in a lack of scientific knowledge essential for conservation and habitat management. Population estimates across the Himalaya further highlight the species' precarious status. Brown bears are restricted to the Greater and Trans-Himalayan regions of Jammu & Kashmir, Himachal Pradesh, and Uttarakhand, with an estimated potential habitat of only 4,300 km² (Sathyakumar et al., 2005). In Himachal Pradesh alone, the species is documented in only ten protected areas. In contrast, the Asiatic black bear, although also elusive, has a substantially broader distribution across nine states with nearly 14,500 km² of estimated habitat and recent genetic studies identifying 307 unique individuals in Himachal Pradesh (Kumar et al., 2025). The sun bear, despite being critically endangered, has benefited from species-specific distribution assessments in sites such as Namdapha Tiger Reserve (Sethy et al., 2016).

These research deficiencies have direct conservation implications. Bargali et al. (2012) recommend protection of critical Himalayan brown bear habitats as a national priority, while Kumar et al. (2025) caution that the absence of robust scientific data significantly hinders effective conservation and habitat management. This knowledge deficit is particularly concerning given the species' heightened vulnerability to habitat degradation, climate change, land-use intensification, and human-bear conflict across its already restricted distribution.

The The Himalayan brown bear is primarily confined to rolling uplands, alpine, subalpine, glacial moraines, barren regions of the Greater Himalayas, and some parts of the Trans-Himalayas (Schaller, 1967; Sathyakumar, 2006; Rathore, 2008). However, there are a few regions in the Himalayas where the brown bear uses the sub-alpine areas to some extent, thereby overlapping with the distribution of Asiatic black bears (Sathayakumar, 2001; Rathore, 2008).

A small isolated sub-population of the Himalayan brown bear is spread across many regions of the Asian subcontinent. It is postulated that in Pakistan there are an estimated 15-30 brown bears in the Hindu Kush range (Nawaz et al., 2014). Moreover, in the Himalayas and Trans-Himalayan mountain ranges of India and Pakistan, it is speculated that an estimated sub-population of 130-220 (Bellemain et al., 2007; Sathyakumar et al., 2012; Abbas et al., 2015) brown bears is present and is possibly linked to the population in India (Bellemain et al., 2007). The potential brown bear distribution range in India is 36,800 sq. km, and only 10% of the area is protected under the existing network of protected areas in India (Sathyakumar, 2006), of which 28,000 sq. km are in the north-western and upper western Himalayan region and 8,800 sq. km are in the Trans-Himalayan region of Ladakh (Sathyakumar, 2006; Sathyakumar & Qureshi, 2003).

In India, Himalayan brown bears are primarily found in two union territories, viz., Ladakh and Jammu & Kashmir, and two states, namely, Himachal Pradesh and Uttarakhand, and some upper parts of Sikkim. In Jammu & Kashmir, brown bears are found in eight protected areas, such as Dachigam National Park (NP), Gulmarg Wildlife Sanctuary (WS), Hirapora WS, Overa Aru WS, Limber WS, Lachipora WS, and Kishtwar NP, and in Ladakh, Himalayan brown bears are prominently found in Drass, Suru Valley, Shargole, and Zanskar Valley of Ladakh (Mallon, 1991; Sathyakumar, 2001; Sathyakumar, 2006). In Himachal Pradesh, Himalayan brown bears are found in ten Protected Areas, while in Uttarakhand, Himalayan brown bears are reported from Gangotri N.P., Govind N.P. and the Bhagirathi basin (Sathyakumar, 2006; Pal et al., 2016). In Sikkim, the brown bear is said to be present in the upper reaches of Kanchenjunga National Park (Gee, 1967; Sathyakumar, 2001).

Brown bears have a strong relationship between population density, habitat productivity and energy availability (Ferguson and Mcloughlin, 2000; Hilderbrand et al., 1999). Bears occupy a diverse array of habitats, from the arctic tundra and boreal forests of Russia to the coastal and mountain forests and grassland ecotone of the Himalayas in the subcontinent of Asia (Servheen, 1990). In India, the brown bear (*Ursus arctos isabellinus*) occurs in a very low density in the alpine and subalpine areas (between 3000m and 5000m) in the Greater Himalaya and the Trans-Himalayan region (Sathyakumar, 2006), and the population is confined to the northwestern and western Himalayan region of India (Sathyakumar, 2002). The capacity of brown bears to use different landscapes can be attributed to their omnivorous nature. In Alaska and Columbia, bears were found to use various habitats, including old-growth forests, coastal sedge meadows and south-facing slopes. During summer, most bears use alpine and subalpine meadows (Schoen et al., 1994; Sathyakumar, 2006; Rathore, 2008). In Deosai National Park, Pakistan, Nawaz et al., (2008) found that bears avoided higher elevations and steeper slopes. The marshy type of vegetation is the most preferred habitat, probably due to its highest forage production and highest density of golden marmots (*Marmota caudata*), similar to the long-tailed marmot *(Marmota caudata*) found in the Zanskar valley of Ladakh. Whereas, in Kugti Wildlife Sanctuary, H.P. (India), brown bears use different categories of habitats, viz., grasslands, agricultural fields, forest blanks, mixed forest, moist temperate forests, water bodies, dry alpine scrub distinguished by Juniperus species, exposed rock with slope pastures and sub-alpine scrub dominated by Rhododendron species (Rathore, 2008). Due to the collection of fuelwood and non-timber forest produce (NTFP) from the habitats favoured by brown bears, adverse daunting consequences result (Chauhan, 2003; Rathore, 2008).

1.4 Diet and Foraging Behavior

A 2022 landscape-connectivity analysis (Dar et al., 2022) Brown bear diets show strong seasonality and reliance on natural food sources, particularly plant matter such as berries and insects, despite access to anthropogenic food in some human-influenced landscapes. In Tatra National Park (Poland), brown bears predominantly consumed graminoids in spring and fleshy-fruited plants during summer and autumn. Despite human disturbance and tourism, bears maintain their ecological role as seed dispersers by consuming natural fleshy fruits.

Supplemental feeding, common in some European countries, significantly influences diet composition but may not reduce human-bear conflicts. Bears still prefer high-energy natural foods when available, and supplemental feeding might alter bear behaviour and exacerbate conflicts in some cases (García-Rodríguez et al., 2021; Kavčič et al., 2015). Knowledge regarding food habits and foraging behaviour is essential for understanding the ecology and evolution of any wild animal (Sih, 1993). Brown bear food habits vary widely from roots, tubers, insects, fishes, fruits, and crops to livestock (Rathore, 2008; Paralikidis, 2010; Seryodkin, 2012). High-calorie foods were found mainly in the diet of bears (Pritchard and Robbins, 1990; Welch et al., 1997; and Hilderbrand et al., 1999). Schaller in 1989 reported that bears' resources are patchy, and their food items are small, requiring extra energy for searching and feeding, but the animals still obtain such a daily surplus of calories that they can store enough fat for hibernation. Habitat quality and changing food conditions due to density-independent environmental fluctuations have also been reported to influence life history traits and consequently population dynamics (Lindstrom and Kokko, 2002; Zedrosser et al., 2006). Smaller mammals can also potentially limit larger-sized species, as there is extensive dietary overlap for the same food resource (Zedrosser et al., 2011).

Male bears are reported to be more carnivorous than females, possibly because of larger body size, which demands higher-energy food (Nawaz et al., 2008). Meat contains the highest digestible components and is the primary source of protein content among bear food items (Felicetti et al., 2003; Robbins et al., 2007). It is speculated that the size of the litter varies with the amount of meat in the diet (Hilderbrand et al., 1999). Grasses and sedges are another major food component of the grizzly bears. Hamer and Herrero's (1987b) investigations indicated that ants (Formicidae) frequently occurred in the bears' diet. All eight species of bears, except polar bears (*Ursus maritimus*), feed on insects, especially ants. The diet of brown bears in Kugti Wildlife Sanctuary, Himachal Pradesh (Rathore, 2008), contains both plant and animal matter, and the annual frequency of occurrence of plant matter was found to be higher than animal matter in the scats. It is evident from the inference that bears were reported to cause a massive loss to crops (Azuma and Torii, 1980; Garshelis et al., 1999; Chauhan, 2003; Rathore, 2008).

Molecular diet studies in high-altitude bear habitats (Fida et al., 2024) show Himalayan brown bears consume more than 50 plant species, including graminoids (Poaceae, Cyperaceae), forbs, roots, tubers, and fruits. Animal matter, including marmots, pikas, rodents, and ungulate carrion, accounts for 20-36% of diet biomass. The Deosai study (Fida et al., 2024) reported seasonal shifts, with marmots being dominant in early summer and berries/seeds in late summer. Brown bears exhibit significant dietary plasticity. Spring and early summer diets include roots, shoots, graminoids, and small mammals such as marmots. Late summer and autumn diets shift toward berries, seeds, and carrion to accumulate fat reserves (Fida et al., 2025; Kumar, 2024). The Scat analysis indicates >70% plant matter and 20–25% animal matter.

1.5 Human-Bear Conflicts

Across millennia the most significant source of conflict between humans and carnivores comes from carnivores killing livestock (Mishra, 1997; Conover, 2002; Treves & Karanth, 2003; Namgial et al., 2007), and apart from livestock killing, carnivores like bears cause huge horticulture and crop field loss (Rathore, 2008; Peterson et al., 2010). In the Himalayan region of South Asia, rangelands and livestock are main sources of subsistence and are the primary cause of conflicts with large carnivores (Mishra, 2001). There are eleven threatened large carnivores in the Himalaya. One such large carnivore species is brown bears. In recent years the brown bear population in Asia has declined in distribution range up to 50% (Servheen, 1990). Cowan (1972) indicated that the livestock killing by bears required experience and specialised predation techniques which are introduced to a population through learning behaviour. When livestock depredation occurs, enormous loss to the owner happens, and in extreme cases, locals persecute the problem animal. As a result of human-caused mortality and disturbance, bear populations become patchy and are locally extinct from some areas (Servheen et al., 1999; Mattson & Marrill, 2002).

Human-brown bear conflicts are increasingly reported worldwide due to habitat loss, human encroachment, and bear population growth. In Turkey, 60% of conflicts arise from bears foraging near human settlements, with significant injuries to humans or bears in over half of events. Similar trends are observed in Japan's urban Sapporo region, where increasing bear populations lead to bear incursions into urban areas. In Scandinavia, rising attacks correlate with population growth, mostly involving hunters and outdoor workers, emphasising the need for education and awareness programmes. Conflict patterns feature encounters often involving female bears with cubs, especially during sensitive seasonal behavioural phases. Managing human-brown bear conflicts entails protecting core habitats, limiting human activity near bear areas, controlling attractants like food waste, and increasing public education to minimise risky encounters (Sıkdokur et al., 2024; Støen et al., 2018; Bombieri et al., 2019).

In Himachal Pradesh (Great Himalayan National Park), human casualties, livestock killing and agricultural loss by brown bears were reported to a large extent (Chauhan, 2003). The locals, or migratory grazers, often kill bears in retaliation to reduce livestock depredation (Sathyakumar, 2002; Rathore, 2008). In some regions of Kargil, like the Zanskar and Suru valleys, human-bear conflicts were common during the summer season, and local villagers retaliated when suffering huge property or livestock loss (Sathyakumar, 2002).

In areas with a huge degree of human-bear conflict, bears show changed behavioural responses as they perceive people as a potential risk (Ordiz et al., 2011; Baruch-Mordo et al., 2008; Johnson et al., 2015; Lewis et al., 2015). Fida et al. (2024) documented diel activity patterns showing bears increasingly overlap with human activity zones during early morning and late evening, especially near grazing pastures. It was reported that livestock depredation is the most common conflict type in the Zanskar Valley, intensified by unsecured corrals, open carcass dumping, and shrinking grazing lands (Chavan et al., 2021).

Communities with poor compensation access reported higher retaliation risks. Growing reliance on anthropogenic foods alters natural foraging behaviour and increases human-bear encounters.

Human-brown bear conflicts in the Lahaul Valley are primarily due to crop damage and livestock depredation, with incidents peaking in summer. Proximity to forests and reliance on forest resources by locals exacerbate these conflicts (Kumar et al., 2022).

A comprehensive global analysis of 664 brown bear attacks between 2000 and 2015 across North America, Europe, and East Asia revealed that attacks have increased significantly over time and were more frequent at high bear and low human population densities (Bombieri et al., 2019). The most prevalent attack scenario was an encounter with a female with cubs (47%), followed by sudden encounters (20%) and incidents involving dogs (17%) (Bombieri et al., 2019). The hidden impacts of human-wild animal conflict may be defined as costs characterised as uncompensated, temporally delayed, psychological or social. The loss of a herd of livestock to predators could effectively destroy a family's wealth and way of life, as livestock constitutes a substantial proportion of the socioeconomic capital of many rural communities in developing countries (Tjaronda, 2007; Barua et al., 2013). It is found that socioeconomic factors, such as dependence on forest resources and income levels, influence conflict vulnerability and perceptions (Liu et al., 2024). Several studies evaluated conflict mitigation measures, including electric fencing, bear-resistant containers, community watch groups, and non-lethal deterrents like scare devices and bear spray (Xu et al., 2024).

1.6 Conservation Status and Legal Protection

All the bear species found in India are listed as either vulnerable, endangered, or critically endangered. The status of brown bears varies globally, from threatened to common; thus, they are categorised as Least Concern (LR) in the 2017 IUCN Red List and placed in Appendix I of CITES. The IUCN Red List's supplementary information categorises the Himalayan brown bear, which is part of isolated populations, as 'Endangered' based on criteria 'D' (small and isolated number of mature individuals). The Wildlife (Protection) Act 1972 accorded the highest protection and classified the species in Schedule I (Rathore, 2008; Sharief et al., 2020;

Dar et al., 2021; Thakur et al., 2023) and few status and conflict surveys (Sathyakumar, 2002, 2006; Chauhan, 2003).

1.7 Conceptual Framework and Ecological Linkages

In Ladakh the Himalayan brown bear is locally called 'Denmo', and in Hindi the brown bear is called '*Bhalu*'. Lack of information on the brown bear distribution was identified as one of the limitations for conservation actions in the Himalayas. The knowledge gap regarding habitat selection (Steyaert et al., 2020), food habits, and human-brown bear interactions in the trans-Himalayan region remains unclear.

The conceptual framework linking brown bear habitat, diet, movement, and conflict reveals a cascading ecological process in which environmental productivity fundamentally shapes human-bear interactions. Habitat productivity determines the spatial and temporal availability of key natural foods, thereby influencing foraging behaviour and energetic strategies. Bautista et al. (2022) demonstrated that years of low beechnut production substantially increased bear damage incidents during hyperphagia, underscoring how nutritional deficits in natural systems push bears toward alternative resources. Such diet seasonality directly influences movement patterns: as resource distributions shift, bears adjust their space use, elevate their mobility, and often modify diel activity. Klees van Bommel et al. (2022) found that bears preferentially use areas of high vegetation productivity but expand their spatial range and increase nocturnality when seeking supplemental foods near human settlements. These behaviourally mediated responses create predictable zones of overlap between bears and human land use. Long-term demographic evidence shows that bears dispersing through landscape corridors linking wilderness and human-dominated areas face greater anthropogenic risks, even though such connectivity is vital for population persistence (Lamb et al., 2020). Takahata et al. (2014) also found a strong correlation between conflict likelihood and seasonal resource scarcity, which leads to bears moving into human spaces. Together, these findings demonstrate that habitat quality, dietary needs, and spatial behaviour cannot be understood in isolation. Instead, they form an interconnected ecological system in which fluctuations in habitat productivity cascade through foraging decisions and movement patterns to determine the frequency, geography, and intensity of human-bear conflicts.

1.8 Study Rationale and Research Problem

The core scientific problem addressed in this study is understanding the habitat ecology, diet, and human-brown bear conflict in the high-altitude region of Ladakh, which is characterised by resource-limited environments and unique landscape-level ecological dynamics. This study focuses on defining brown bear habitat use and preferences in the spatially heterogeneous and climatically extreme landscapes of Ladakh, assessing diet composition under limited natural food availability, and quantifying the extent, patterns, and drivers of human-brown bear conflicts across the landscape. The objective is to generate fine-scale ecological insights on the distribution of Himalayan brown bears that can inform effective coexistence strategies and conservation management in this high-altitude trans-Himalayan region of India.

Existing knowledge on brown bear ecology and conflict largely derives from more temperate or less extreme environments, such as the forests and alpine meadows of Himachal Pradesh, Uttarakhand, and other regions of the Western Himalaya. However, Ladakh represents a distinct ecological milieu characterised by arid and cold desert conditions, scarce water resources, low primary productivity, and patchy vegetation cover at elevations often exceeding 4000 metres asl. These factors create pronounced resource scarcity and habitat fragmentation, which likely shape brown bear distribution, foraging behaviour, and human interactions differently than in the densely forested and comparatively more productive habitats of Himachal Pradesh and Uttarakhand. Moreover, previous studies have highlighted the importance of water availability and vegetation composition in limiting bear distributions and conflict hotspots in southern range margins, but the extent to which such factors govern brown bears in Ladakh remains poorly understood.

There is substantial ecological uncertainty regarding how landscape-level habitat suitability, seasonal diet shifts, and physiological adaptations of brown bears manifest in Ladakh's extreme environments. The role of limited and patchily distributed food resources in bear movements and the risk of conflict with pastoralist and agricultural communities is also unclear, particularly given increasing anthropogenic pressures and land use changes. Additionally, unlike the western and central Himalaya, Ladakh's sparse human population, traditional livelihoods, and unique landscape connectivity necessitate region-specific assessments of conflict patterns (Can et al., 2014; IUCN BSG, 2020) and mitigation options. Hence, Ladakh's ecological uniqueness lies in its combination of high altitude, arid conditions, extreme resource limitation, and distinct anthropogenic context, which differentiates it ecologically and socioeconomically from the forested Himalayan regions of Himachal Pradesh and Uttarakhand. Addressing these gaps is critical to formulating tailored conservation and human-wildlife coexistence strategies adapted to the high-altitude, resource-limited landscapes of Ladakh.

Figure 1.2: Photo showing a Himalayan brown bear with a yearling in Drass valley, Kargil

1.9 Theoretical and Analytical Framework

This study is anchored in ecological and analytical frameworks that explain species-environment interactions in resource-limited mountain systems. Occupancy modelling (MacKenzie et al., 2017) derives from detection theory and ecological niche concepts, allowing robust estimation of site-level brown bear occurrences while correcting for imperfect detection across heterogeneous terrain.

MaxEnt modelling (Phillips et al., 2006) applies the principles of maximum entropy and niche theory to predict habitat suitability using presence-only data, making it particularly suitable for rare, low-density populations such as Himalayan brown bears. Diet analysis is grounded in optimal foraging theory and nutritional ecology, enabling interpretation of how seasonal resource availability, landscape productivity, and energetic constraints shape dietary choices in high-altitude environments. Human-bear interaction assessments draw on human-wildlife coexistence frameworks that integrate ecological drivers, spatial overlap, livelihood dependencies, and socioeconomic factors influencing conflict.

Chapter-2

Study Area, Objectives & Research Questions

2. Study Area

The Himalaya is a sublime region where the magnificence of the world's highest mountains shapes an extraordinary landscape and supports people with unique culture and heritage. The IHR comprises ten states and extends physio-graphically from the foothills of the Shivalik up to the Tibetan Plateau in the North Trans-Himalaya. Snow-clad peaks and massive glaciers dominate this region, contributing about 16.2% of India's total geographical area. People typically describe the Trans-Himalayan zone, located on the leeward side of the main Himalayan ranges, as a "High Altitude Cold Desert" (Chowdhery & Rao, 1990). The Trans-Himalayan region of Ladakh stretches over 186,200 km² and constitutes the westernmost extension of the Tibetan Plateau. It falls within Biogeographic Zone 1A: High Altitude Cold Desert, characterised by stark environmental gradients and distinctive flora and fauna (Rodgers & Panwar, 1988).

2.1 Ladakh

The Union Territory of Ladakh, covering an area of approximately 186,200 km², is the westernmost extension of the Tibetan Plateau. The high-altitude ecosystems of this area harbour globally important large mammals, including the snow leopard (*Panthera uncia*), Himalayan brown bear (*Ursus arctos isabellinus*), Tibetan wolf (*Canis lupus chanco*), Asiatic ibex (*Capra sibirica*), and Ladakh urial (*Ovis vignei*). In Ladakh, wildlife is not confined to protected areas. In turn, wild species occur across large, multi-use landscapes also used by agro-pastoral communities. This use of space by both people and wildlife corresponds to the socio-ecological fabric of Ladakh and forms a core context for this study.

Traditional agro-pastoralism remains the dominant livelihood system in Ladakh (Mishra 2000; Namgail et al. 2007). Households generally keep mixed herds of sheep, goats, cattle, yaks, and dzos (yak-cattle hybrids), with communally owned grazing lands having equal access rights within village territories (Fox et al., 1994). Shared resource systems, coupled with severe climatic constraints and scarce private arable land, make for a landscape where human-wildlife interactions are particularly strong. These interactions are more intense in western Ladakh, the Kargil region where agricultural fields, dense village clusters, and alpine pastures meet wildlife habitats.

Ladakh is a cold desert region lying between the Karakoram Range in the north and the Greater Himalaya in the south. The topography of this area consists of rugged mountains, deep valleys, glacio-fluvial terraces, high-altitude meadows, and extensive windswept plateaus (Bhattacharya 1989). Elevations range from 2,533 m in valley floors to 7,742 m at Saltoro Kangri, which is one of the highest peaks in the region. This dramatic elevational gradient produces distinct ecological zones, ranging from desert scrub on lower-elevation valley floors to alpine pasture on higher-elevation sites.

It is these sharp geoclimatic transitions across relatively short horizontal distances that dramatically demonstrate the ecological complexity of Ladakh. Rain shadow deserts are situated on permanently glaciated massifs, with intervening expanses of permafrost and intermontane basins flooded during the summer by productive meadows (Singh & Bhatla 2025). The complex microhabitat mosaic produced by such juxtapositions supports species with very different ecological niches. These microhabitats influence the distribution of wildlife and the seasonal resource-use strategies of pastoral households alike. For such a wide-ranging carnivore as the Himalayan brown bear, for example, these transitions identify movement corridors and predictable seasonal foraging hotspots. Climatic adversity and habitat heterogeneity thereby combine in structuring both the large mammal spatial ecology and the livelihood practices of human communities in Ladakh.

2.2 Demography

The physiographic features in Ladakh are delineated by steep slopes, unstable moraines, coarse scree deposits, wind-eroded ridges, and glacial valleys. Major Indus, Suru, Drass, Zanskar, and Shyok river systems cut through the region in northeasterly to northwesterly directions, creating narrow ribbons of arable land. These riparian pockets are vital in sustaining human settlements and agriculture in this otherwise barren environment.

Geologically, Ladakh is dominated by Precambrian formations: slates, phyllites, schists, quartzites, carbonaceous schist, and graphite-bearing rocks. This geological backdrop shapes soil characteristics, water retention, vegetation composition, and the distribution of wildlife habitats. At the same time, the mountainous relief contributes to the development of isolated valleys and ecological niches that harbour different plant and animal communities adapted to extreme conditions.

Figure 2.1: Landscape view of the study area

The administrative structure of Ladakh has undergone serious reorganisation in recent years. Earlier, part of the state of Jammu & Kashmir, Ladakh was created as a separate Union Territory on 31 October 2019 following the abrogation of Article 370. The region is divided into two governance structures recognised as two principal districts: Leh and Kargil

In this background, Kargil district, which has formed the intensive study area for the research, enjoys special ecological and administrative significance. The district of Kargil lies between 30° and 35° N latitude and 75° and 77° E longitude and stretches over a vast 14,036 km² area. It is basically demarcated by four major natural valleys, namely the Suru Valley, Drass Valley, Indus Valley, and the Kanji Nallah system, each determining patterns of human settlement, livestock movement, and wildlife distribution.

The district consists of 4 sub-divisions, 7 tehsils, 15 administrative blocks, 98 panchayats, and 127 villages, of which 125 are inhabited. The district implements natural resource management, wildlife conservation initiatives, and rural livelihood programmes at these levels. These layers also represent the institutional framework for deploying strategies to mitigate human–wildlife conflict. In contrast, Leh district has an approximate area of 82,665 km², including disputed territories. It comprises 6 subdivisions, 8 tehsils, 16 blocks, 95 panchayats, and 113 villages; hosts a population of 133,487; and has a literacy rate of 77.20% and a sex ratio of 690 females per 1,000 males. It is impossible to understand the ecological dynamics of the Himalayan brown bear in Ladakh without embedding them within the demographic, climatic, and land-use characteristics of the region. The statistical subsections that follow summarise key ecological and socioeconomic variables relevant to this study(https://ladakh.gov.in/).

Kargil district encompasses 14,036 km² and forms the western part of Ladakh's Trans-Himalayan landscape. Its physiography is dominated by the Suru, Drass, Indus, and Kanji Nallah valleys, carved out by glaciers and rivers. These valleys create narrow strips of relatively fertile land where settlements cluster close to water. The high-elevation terrain in the district supports extensive alpine pastures, cold-desert slopes, and glacio-fluvial terraces, all of which are critical habitats that support native wildlife and seasonal livestock grazing. The core habitat of the Himalayan brown bear encompasses the upper reaches of the Suru, Drass, and Zanskar valleys, which provide denning sites, foraging grounds, and movement corridors. The presence of these valleys, coupled with steep elevational gradients, is responsible for ecological heterogeneity, which influences brown bear behaviour and human-brown bear interactions. The 2011 Census of India provides the most recent comprehensive demographic dataset for the region. The total population in Kargil is 140,802 souls, and the population density is 10 persons per km², having a sex ratio of 810 females per 1,000 males and a literacy rate of 71.34% (https://kargil.nic.in/).

This demographic pattern reflects a sparsely populated, basically rural society with strong dependence on agriculture and pastoralism. The villages are usually located along the river valleys and foothills where water and arable land are available. In contrast, the Leh district is even more sparsely populated, with 3 persons per km², despite its greater geographic extent. These demographic features suggest that human presence is highly concentrated in limited habitable pockets, with consequent localised hotspots of human-wildlife interactions along valley floors.

In the last few decades, socioeconomic transitions have started to transform conventional land-use patterns across Kargil and wider Ladakh. Expanding road networks, improved market linkages, and rising educational attainment have driven changes away from strictly subsistence-orientated livelihoods. While pastoralism continues to be central, numerous households have started to diversify their incomes through wage labour, small trade, and government employment. These transitions influence patterns of grazing pressure, herd composition, and seasonal mobility, with potential implications for wildlife habitat use and conflict occurrence. Reduced reliance on long-distance transhumance in some valleys, for instance, has led to localised congregation of livestock, influencing pressure on limited pastures and modifying spatial patterns of bear-human interactions.

Leh District comprises the eastern part of Ladakh's Trans-Himalaya and differs considerably from Kargil in ecological structure and human settlement pattern. The district is characterised by wide, high-elevation valleys, large alluvial fans, and an arid, rainy environment in which annual precipitation is even lower than in western Ladakh. Settlements are disposed along the Indus corridor, where glacial and spring-fed irrigation makes agriculture possible and supports a relatively stable population. Pastoralism is important, but mobility patterns are less extensive compared to Kargil because of the presence of wide intermontane basins and plateau-like rangelands. Wildlife assemblages around Leh include ibex, urial, and snow leopard, while brown bear occurrence is rare and largely absent due to the district's drier desert ecology and reduced shrub and forb availability. The Leh socio-cultural landscape is unique as well, being dominated by Buddhist communities whose agricultural and monastic traditions have driven land-use practices and resource management systems for centuries (https://leh.nic.in/). These combined ecological and cultural features provide important context for understanding why the Himalayan brown bear is largely restricted to Kargil region.

2.3 Land Use

Agriculture occupies only a small fraction of the landscape due to Ladakh's harsh climate and limited water availability. In all, the net area sown is 9,540 hectares, with the gross area sown equal to 11,454 hectares and the irrigated area (net & gross): 11,754 hectares. Average landholding: 0.64 hectares per household, and the major crops grown are barley, wheat, millets, pulses and vegetables.

Agriculture is localised in irrigated river valleys, where glacial meltwater supports crop growth during the short summer growing season. Landholdings are small and fragmented, reflecting subsistence-level farming practices. Beyond cultivated fields, large areas of alpine and subalpine pastures represent main grazing areas for livestock. Such rangelands represent critical ecological interfaces where livestock and wild herbivores, as well as carnivores like brown bears, interact. Quality and seasonal availability of pastures directly affect the spatial distribution of both livestock and wildlife.

Livestock rearing is the mainstay of livelihoods in Kargil, shaping land use and human–wildlife conflicts. According to district-level statistics, the total livestock population is 32.52 lakh, and average livestock holdings are 15 animals per household. The main livestock species include sheep, goats, yaks and yak-cattle hybrids (dzo/dzomo), as well as cattle, horses, and donkeys. Seasonal herding patterns involve transhumance, where herders migrate with their animals to high-altitude summer pastures from June to September. The result increases spatial and temporal overlap with brown bear foraging areas, leading to significant depredation events. High livestock densities, along with limited pasture productivity in the cold-desert environment, also heighten competition with wild ungulates. These interactions affect predator-prey dynamics and local perceptions of carnivore presence.

The climate in Ladakh is a high-altitude cold desert climate. It has very long, severe winters and short, mild summers. The annual precipitation is very low, and the largest part falls as snowfall. The summers are short and dry; the temperature rises to 35°C in Kargil, while the winters are dominated by intense cold when the temperature usually falls below –30°C throughout the region. Drass is generally considered one of the coldest inhabited places in the world, with a record minimum of –60°C. Humidity is low throughout the year, amounting to high evapotranspiration rates and limited availability of soil moisture. Wind speeds are often high, especially over exposed plateaus and ridgelines. Cloud cover is low, permitting high levels of solar radiation during the day, with rapid heat loss at night. These combine to produce considerable diurnal ranges in temperatures, often exceeding 20°C within a single day.

The growing season, in which vegetation emerges and agriculture is possible, is limited to the months of May through August. In this brief period, the majority of the plants complete their life cycles, and pastoralists intensively graze high-altitude pastures. Winters, stretching from November to March, drive both wildlife and livestock to lower elevations, increasing interactions with human settlements.

The Suru Valley, Drass Valley, Aryan Valley, Shakar-Chiktan Valley, Wakha-Mulbek region, Kartse Valley, and Zanskar region are home to major settlement agglomerations. These valleys/villages are tightly integrated with the surrounding natural landscape. In several cases, agricultural fields reach right up to valley margins, while pastures begin almost right above settlements. The distinctive combination of climatic severity, settlement clustering, and agricultural dependency provides the underlying conditions that contribute to recurring patterns of human-wildlife interactions across the district.

Cumulative grazing pressure, shifting snowfall regimes, and expanding shrub encroachment in certain valleys have compromised rangeland health across Kargil. While many high-altitude pastures remain relatively intact due to short growing seasons and limited accessibility, others closer to settlements exhibit early signs of degradation, including reduced biomass, soil compaction, and proliferation of unpalatable species. These patterns are ecologically significant because pasture condition influences the availability of forage for both wild ungulates and livestock and thereby shapes predator-prey relationships. In areas where rangeland quality has been compromised, brown bears may increase their reliance on anthropogenic food sources, intensifying interactions with human settlements and agricultural fields.

Ladakh hosts a network of high-altitude protected areas, the largest being Hemis National Park, which encompasses over 4,400 km² and acts as a major haven for snow leopards, ibex, and other cold-desert fauna. The Changthang Wildlife Sanctuary in eastern Ladakh protects large expanses of alpine steppe and important habitats for kiang and migratory birds. While these three protected areas cover much of Ladakh's biodiversity, no protected area has been designated in Kargil district, which harbours the largest concentration of Himalayan brown bears, thereby making conservation on this front reliant upon community-managed landscapes and multi-use rangelands.

2.4 Flore

The extreme climatic conditions, steep elevational gradients, and high variability in moisture availability shape the vegetation of Ladakh. Despite being classified as a high-altitude cold desert, Ladakh supports remarkable diversity in plant species, those that are adapted to severe environmental stresses such as low temperatures, intense solar radiation, limited precipitation, and short growing seasons. The floral communities of the region vary distinctly along riparian zones, alluvial fans, mountain slopes, and alpine meadows, each contributing to the ecological fabric that is so important for both wildlife and pastoral livelihoods. Key riparian habitats along the major rivers and stream-fed valleys (for example, the Indus, Suru, and Drass) are formed by dense strips of *Hippophae rhamnoides* (sea buckthorn), *Myricaria elegans* (tamarisk), *Rosa spp*. (wild rose), and several willow-like shrubs. These water-dependent species stabilise riverbanks, increase soil organic content, and provide forage and cover for wildlife. Sea buckthorn has a particular ecological importance because it enhances soil nitrogen through nitrogen fixation, besides serving as a winter food for several bird and mammal species (Doležal et al., 2018).

Away from watercourses, the vegetation becomes sparse shrublands dominated by drought- and poor-soil-resistant species such as *Juniperus indica, Caragana spp*., and *Artemisia spp*. Scattered slopes and dry riverbeds of individuals of Rosa spp. are supplemented during summer and early fall feeding for herbivores and in a few instances for brown bears when fruiting occurs (Doležal et al., 2018). At higher elevations (3,500-4,500 m), species-rich alpine meadows exist where short-term summer warmth and snowmelt are initiating a flush of herbaceous growth. These meadows constitute an important foraging ground for the Himalayan brown bear. Dominant herbaceous taxa include *Acantholimon spp., Rhodiola spp., Thymus spp., Anaphalis triplinervis, Dactylorhiza spp.,* and *Delphinium spp.* These plants produce seasonal biomass, which in the summer supports wild herbivores as well as free-ranging livestock. Dry slopes with thin soils have open swards composed of *Prangos spp., Tanacetum spp., Cicer spp., Rheum spp., Podophyllum spp.,* and *Arnebia spp*. Plants in this group tolerate adverse conditions and form part of the traditional grazing landscape (Doležal et al., 2018).

Because of the aridity and harsh winters, tree cover in Ladakh is very poor. However, at high elevations along with snow-fed streams, isolated patches of Himalayan birch do occur, and Juniperus species appear in scattered groves along arid slopes. Tree species offer important microhabitats to wildlife and provide fuelwood, although overexploitation has reduced them in number. Ladakh boasts a rich variety of medicinal flora. Common medicinal plants include *Aconitum spp., Bergenia stracheyi, Dactylorhiza hatagirea, Ephedra gerardiana, Geranium pretence,* and *Codonopsis spp.* (Doležal et al., 2018). Most of these species are threatened by habitat degradation, overgrazing, and commercial extraction. Overall, Ladakh's floral assemblages support a web of ecological interactions. For Himalayan brown bears, the seasonal availability of herbaceous plants, roots, and berries is critical to meeting nutritional requirements, particularly for hyperphagia during late summer and autumn.

Such a brief growth season in Ladakh results in highly compressed phenological cycles, with most herbaceous species completing their growth and reproduction within eight to ten weeks. This temporal compression generates pronounced seasonal pulses of forage availability that have been key drivers of migratory and foraging behaviour among herbivores and omnivores.

2.5 Fauna

Ladakh supports a unique assemblage of cold-desert fauna, including several globally important carnivores and high-altitude ungulates. The extreme environmental conditions, together with sparse vegetation and low productivity, have shaped a wildlife community adapted to limited resources and high energy demands. Osborne et al. (1983) identified Ladakh as a "threatened stronghold of rare Himalayan mammals", observing that the region's isolation had historically protected it from rapid environmental changes.

The region harbours several top-order predators like the snow leopard (*Panthera uncia*), Himalayan brown bear (*Ursus arctos isabellinus*), and Tibetan wolf (*Canis lupus chanco*). All these carnivores share overlapping home ranges and scavenge an assortment of wild prey, livestock, and seasonally available plant matter. The Himalayan brown bear is the only bear species reported in Ladakh, and its chief distribution is confined to the western part, particularly the Suru, Drass, and Zanskar valleys (Mallon, 1991). Riparian zones and xeric alpine slopes are the home of the red fox (*Vulpes vulpes*), stone marten (*Martes foina*), mountain weasel (*Mustela altaica*), stoat (*Mustela erminea*), and the Eurasian otter (*Lutra lutra*). These carnivores are generalists in their habitats and often indirectly interact with humans through scavenging and depredation on poultry. Several cold-adapted ungulates are reported to occur in Ladakh, which include Asiatic ibex (*Capra sibirica*), Ladakh urial (*Ovis vignei*), bharal (*Pseudois nayaur*), Tibetan gazelle (*Procapra picticaudata*), Tibetan argali (*Ovis ammon*) and Tibetan antelope (*Pantholops hodgsonii*) in select areas. These ungulates form the main wild prey base for snow leopards and wolves (Khan et al., 2023).

Small mammals like the long-tailed marmot (*Marmota caudata*), Himalayan pika (*Ochotona roylei*), and various vole species also play an important ecological role. Marmots and pikas are especially vital to the Himalayan brown bear as sources of high-energy prey that supplement its primarily herbivorous diet during the pre-denning period (Schaller, 1998; Xu et al., 2006; Nawaz, 2008). The populations of burrowing rodents affect vegetation dynamics and soil turnover. Although it is not central to this study, the avifauna of Ladakh is diverse, with Himalayan griffons, lammergeiers, snow partridges, and a variety of passerines, all well adapted to high-altitude conditions. The fauna of Ladakh reflects evolutionary adaptations to extreme cold, limited forage availability, and steep, rugged terrain.

Several reasons make the high-altitude region of Ladakh an ideal site for the intensive ecological and socio-environmental research on Himalayan brown bears. Ladakh has diverse habitat types, from alpine meadows and subalpine shrublands to riverine zones and glacial valleys, all of which are essential for bear foraging, denning, and seasonal movements. Based on literature, the species is predominantly found in the western region of Ladakh, but the factors responsible for its occupancy are unknown. Thus, understanding brown bear ecology, diet, conflict dynamics, and coexistence strategies in the Indian Trans-Himalaya makes it an invaluable natural laboratory for understanding complex dynamics of human-wildlife coexistence in extreme mountain environments.

Central to the ecology of large mammals, including the Himalayan brown bear, is the rugged physiography of the region. The steep and inaccessible terrain offers denning sites; alpine meadows and subalpine shrublands offer seasonal foraging areas. River basins and valley bottoms, home to villages and agricultural fields, serve as crucial areas where humans and bears intersect.

These climatic factors directly affect the ecology of the Himalayan brown bear. Prolonged winters and limited food availability during winters push the bears nearer to human habitations in their quest for accessible crops, stored foods, and garbage. Alpine meadows, where herbaceous growth peaks following snowmelt, also concentrate summer foraging. The extreme seasonal temperature fluctuations characteristic of the region also controls the timing of den entry and emergence.

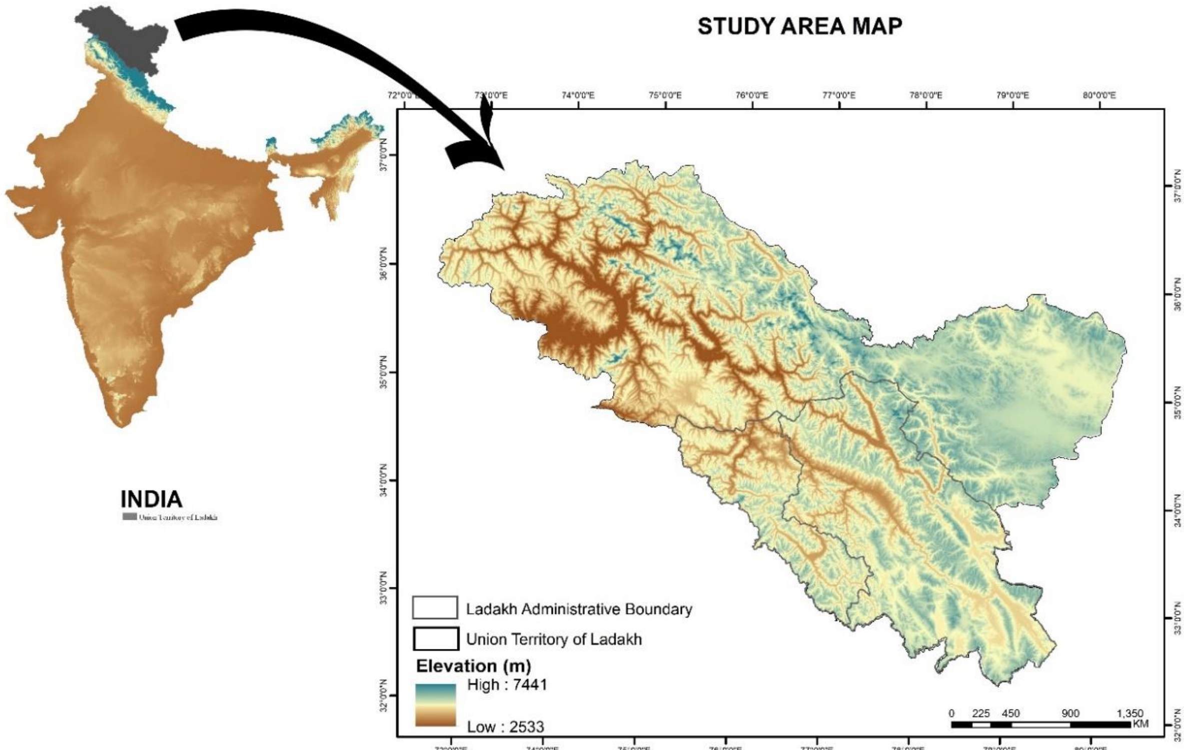


Figure 2.2: Map showing the study area with administrative boundary of Kargil and Leh (Ladakh)

2.1 Research Objectives

1. To study the habitat ecology of brown bears in trans-Himalayan region of Ladakh

2. To investigate the food habit of brown bear in the study area

3. To investigate dynamics of human-brown bear interactions, quantify magnitude and context of conflicts, assess eco-tourism potential, and develop mitigation strategies

2.2 Research Questions

1. Where do Himalayan brown bears live in the study area?

2. What is the diet of Himalayan brown bear in the study area?

3. What is the spectrum of interactions between Himalayan brown bear and humans in Ladakh region?

4. Where do humans and Himalayan brown bears come into repetitive conflict?

5. The potential for developing brown bear tourism in the study area?

Chapter-3

To study the habitat ecology of brown bears in trans-Himalayan region of Ladakh

3. Introduction:

The history of rapid development in the Himalayas has brought human habitation near to habitats close to wild animals (Fox *et al.* 1994; Mishra et al. 2001), and with humans moving towards the Anthropocene era, their utilisation of the natural resource subsequently surged. As people search for new settlements, they are destroying wildlife habitats and wild animals migrate due to the uncontrolled use of natural habitats (Rawat & Satyakumar 2002). Understanding habitat selection and suitability is crucial for the conservation of the wildlife and for formulation of conservation management policies (Doligez 2008). However, widespread extirpation of large carnivore populations has occurred in counter-response to increasing human population and anthropogenic activities (Woodroffe 2000).

Brown bears (*Ursus arctos*) (Linnaeus 1758) are found globally across North America, South America, Europe, and Asia. In Asia, their distribution spans Turkey, Iran, and Afghanistan, along the Himalayan range of Pakistan, India, Nepal, extending into northern China, Mongolia, Russia, and Japan, though they may have become extinct in Bhutan (McLellan et al. 2017). In India, a subspecies Himalayan brown bear (*Ursus arctos isabellinus) is* confined to the Greater and Trans-Himalayan regions. It inhabits alpine and subalpine regions, though in some parts of the Greater Himalaya, brown bears also use subalpine zones, creating areas of overlap with the Asiatic black bear (Sathyakumar 2006; Thakur et al. 2023). There are estimated to be just 130 to 220 brown bears in the Himalayas and Trans-Himalayan mountain ranges of India and Pakistan (Bellemain et al. 2006; Abbas et al. 2015). Sathyakumar (2006), estimated the possible range for brown bears in India to be around 36,800 km², with 28,000 km² in the northwestern and upper western Himalayan region and only 8,800 km² in the Trans-Himalayan region of Ladakh of which only 10% of within India's protected area network (Sathyakumar & Qureshi 2003).

Within the Indian Himalayan Region (IHR), brown bears are primarily distributed in Ladakh and Jammu & Kashmir, and parts of Himachal Pradesh, Uttarakhand, and upper Sikkim. In Ladakh, they occur mostly in the western region, such as the upper Suru Valley, Shargole, and Zanskar Valley (Mallon 1991). Brown bears are located in eight protected areas in Jammu and Kashmir and 10 protected areas in Himachal Pradesh. They can be found in Gangotri National Park, Govind National Park, and the Bhagirathi basin in Uttarakhand (Pal et al. 2016). Sathyakumar (2001) suggested that they reside near Kanchenjunga National Park in Sikkim.

Brown bears are large carnivores with thick, reddish-brown fur. Adult males are 150-230 cm long, while females are 137-183 cm long. Their tails are around 10 cm long on average. Male weigh between 130 and 400 kg, while females weigh between 80 and 230 kg (Prater, 1980; Huber & van Manen, 2022). They can survive for up to 25 years in the wild. They have a very good sense of smell and can run faster than humans. Most bears eat both plants and animals, but the brown bear may eat a wide range of diets. They usually live in solitary; however, they do get together to mate or while females are raising their young. During the winter, brown bears go through a phase of dormancy or torpor that lasts up to seven months. During this time, they don't eat, drink, poop, or pee (Folk et al. 1976). Their winter hibernation is an important life-history strategy in high-altitude, resource-limited areas, even though they don't strictly hibernate like ground squirrels do (Lyman et al. 1982; Johnson et al. 2017).

Denning is vital to bears survival and reproduction. Bears use den during the winter to cope the scarcity of the food and avoid harsh winter conditions and this is achieved by reducing metabolism reduced by about 70% to conserve energy (Watts and Jonkel, 1988; Seryodkin et al. 2003). Dens are usually located in natural caves or self-dug sites at higher elevations on steep, rugged slopes (Seryodkin et al. 2003; Ciarniello et al. 2005; Elfström et al. 2008; Crupi et al. 2020), and den site selection is highly sensitive to human disturbance (Linnell et al. 2000). Males attain sexual maturity between 3.5 to 7 years of age, with mating occurring from early May to mid-July. However, delayed implantation takes place around October-November, with cubs born between January and March after a gestation period of 180-270 days. Cubs typically remain with their mother for over two years, and as a result, many females breed only once every three years (Schwartz et al. 2003).

There is a substantial link between habitat productivity and the population of brown bears in a given region (Ferguson & McLoughlin 2000; Hilderbrand et al. 2018). The Asiatic brown bear is a habitat specialist that prefers low-productivity, patchy areas like the Arctic tundra, Russian boreal forests, and the Trans-Himalayas (Servheen 1999). In Alaska and North America, the utilisation of habitats changes with the seasons ranging from shrublands, alpine meadows to woodlands (Phillips 1987; Craighead & Mitchell 1982; Haroldson et al. 2021). Brown bears in the Indian Himalayas have been documented inhabiting a wide range of habitats, including as alpine grasslands, forest pockets, dry alpine scrub, marshy vegetation, and places where prey is concentrated, such marmots (Sathyakumar 2006; Rathore 2008; Nawaz et al. 2008). In Deosai National Park (Pakistan), for example, marshes with lots of vegetation and golden marmots were the best places to reside. Whereas, in Kugti Wildlife

Sanctuary, H.P. (India), brown bears use different categories of habitats viz., grasslands, agricultural fields, forest blanks, mixed forest, moist temperate forests, water bodies, dry alpine scrub distinguished by Juniperus spp, exposed rock with slope pastures and sub-alpine scrub dominated by Rhododendron spp, (Rathore 2008). The Himalayan brown bear occurs at a very low density in the alpine and subalpine areas in the elevation range of 3000 m to 5000 m in the Greater Himalaya and the Trans-Himalayan region exclusively confined to the northwestern and western Himalayan region of India (Sathyakumar 2006).

Despite their ecological importance, brown bears remain poorly studied in India, particularly in the high-altitude Trans-Himalayan landscapes where only a few valley-level assessments have been conducted (Sathyakumar & Qureshi, 2003; Chavan et al. 2021; Ali 2024). After being designated a Union Territory, the area is going through big changes in development, with big investments in infrastructure, solar energy, and transmission lines. In this situation, it is very important to know the brown bear's habitat needs and spatial ecology in order to balance conservation goals with ongoing development (Zedrosser et al. 2011; Penteriani et al. 2018).

Unlike earlier site-specific assessments (Sathyakumar & Qureshi, 2003), our study integrates occupancy and habitat suitability modelling at a landscape level research in the high-altitude, data-deficient region, providing the first comprehensive baseline for Himalayan brown bear conservation in the Trans-Himalayan region of Ladakh. Systematic, landscape level ecological studies such as this can be meaningfully guide to the policy makers, practitioners and wildlife managers in planning conservation and management strategies of the endangered species. To address this gap, the present study investigates the influence of environmental, topographic, and climatic variables on the distribution of the Himalayan brown bear in Ladakh.

The Trans-Himalayan region of Ladakh is unique in its biogeography, comprising a mix of montane ecosystems, extreme climatic conditions, and rugged terrain. Studying the habitat ecology of a flagship species like the Himalayan brown bear (Endangered as per IUCN Red List and highest protection under Schedule I of India's Wildlife Protection Act, 1972) will help us understand the distribution of the species in high-altitude ecosystem.

We propose that brown bears in Ladakh (Hypothesis 1) demonstrate a preference for particular habitat types, including alpine rangelands and river valleys (Rathore 2008); (Hypothesis 2) choose habitats based on specific topographic features such as elevation, slope, and terrain ruggedness; and (Hypothesis 3) modify their habitat utilization in response to seasonal temperature variations. The related null hypotheses assert the absence of any substantial preference in each instance. The goal of this study is to find out how environmental and topographic factors affect the habitat preferences and distribution of the Himalayan brown bear in Ladakh region.

3.1 Materials and methods:

3.2 Study Area

The Trans-Himalayan region of the Union Territory of Ladakh covers an area of186,200 km²and is categorised as 1A High Altitude Cold Desert Biogeographic Region (Rodgers & Panwar 1988). The Indian Trans-Himalaya is an extension of the Tibetan plateau covering Ladakh and Lahaul Spiti in the state of Himachal Pradesh. Elevation Ladakh varies from 2533 m in valleys to 7742 m as Saltaro Kangri. The regions characterised by low precipitation, a short growing season, low primary productivity, but having a high livestock density (Mishra 2000). The climate is harsh with cold and arid temperatures dipping below -30°C between November and March, with a short season for crop cultivation (Bagchi *et al.* 2019). The region represents an ecosystem where the common livelihood source is traditional agro-pastoralism (Ladon et al. 2023). Individual families own livestock, whereas the grazing land is common to the village with equal access (Mishra *et al.* 2001). Ladakh landscapes are unique considering that the wild animals are not restricted to protected areas but found across the landscape (Mishra *et al.* 2010).

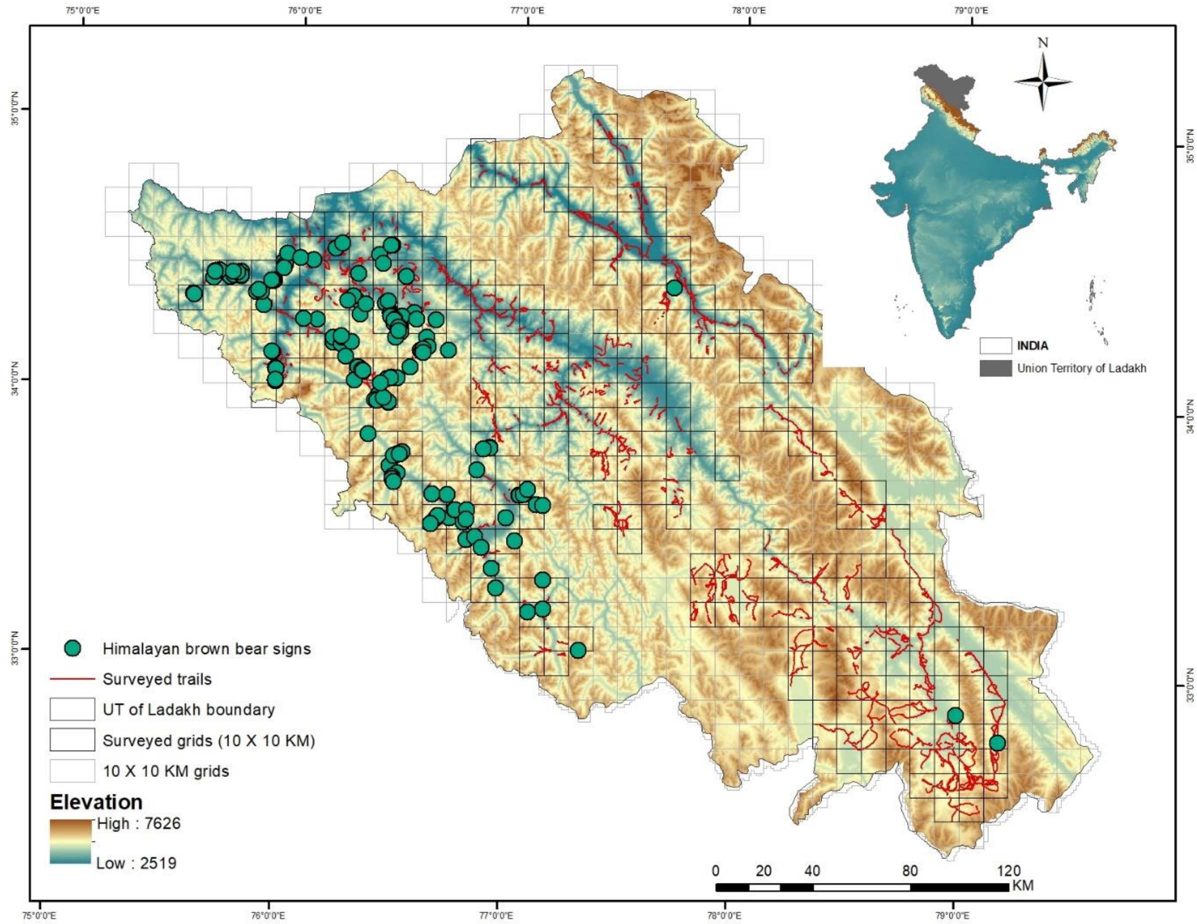


Figure 3.1: Map of the study area, sampling grids of 10x10 km², survey trails and brown bear presence locations on the Elevation background of Laddakh UT, which is the Himalayan brown bear distribution range part in India. The map was created using **ArcGIS Map 10.8.2** (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

The landscape of the area is mountainous, rugged, and interspersed with valleys drained by the river Indus and its tributaries. Ladakh has been divided administratively into seven new districts. Kargil, Leh, Drass, Zanskar, Sham, Nubra and Changthang.

This study is carried out intensively in Kargil district and extensively across Ladakh because, based on the literature and local knowledge, the Himalayan brown bear is predominantly reported from the western region (Kargil) of Ladakh.

3.3 Field Data Collection

Field sampling was carried out using ‘MSTrIPES’ digital application equipped with collecting the spatial and temporal characteristics of occupancy trails of Himalayan brown bear along with the geotagged photos of sign detections. Data captured using the app was imported into desktop programs designed for data organisation and archiving. The sample, which amounted to over 30,000 working-days (‘man-days’) over two years (2019-20), was carried out in cooperation with local field assistants and researchers and employees of the Wildlife Protection Department. We ensured that each survey team was formed up of experts in these different filed data collection methods.

3.4 Occupancy survey

Based on the accessibility of the terrain and logistics, the landscape was divided into a grid spanning 10 x 10 km. In order to account for the natural variation in habitats, the grid was further segmented into 5 x 5 km sub-grids so that our sampling could be evenly distributed across each cell. We assessed the occupancy of brown bears in each of the 25 km^2 sub-grid cells. We conducted at least one sign-search survey of about 5 km each in every sub-grid cell to record signs of the species. We targeted human trails, ridgelines, and valleys to maximise the chances of encountering signs. We recorded signs such as tracks, scats, and sightings that could be assigned to the presence of brown bears to spatially spread the search pathways. We surveyed Ladakh landscape collectively to validate the species' distribution and suitability of their habitats in the region. All field data was collected using a phone-based polygon search application developed for occupancy surveys (MSTrIPES, Qureshi *et al.* 2023). We plotted all brown bear sign locations (n=2530) to gain a preliminary understanding of the distribution of Himalayan brown bears in the Ladakh region.

3.5 Environmental Variable Collection

We used ecogeographic variables derived from multiple source(s) and generated using ArcGIS with their original spatial resolutions ranging between 10m and 1km. To ensure homogeneity and model compatibility, all predictor rasters were resampled to a uniform resolution of 1 km^2 prior to modelling.

Table 3.2: Showing variables considered for occupancy analysis extracted from different source(s) and at various resolutions (10 m - 1km). To ensure homogeneity, all the variables were resampled at a coarse scale of 1 km².

Variables	**Covariates**	**Resolution**	**Source(s)**	**Modelling Resolution**
Topographical	Digital Elevation Model (DEM)	30 m	NASA Shuttle Radar Topography Mission (SRTM) (2013). Shuttle Radar Topography Mission (SRTM) Global. Distributed by Open Topography. https://doi. org/10.5069/G9445JDF.	1km²
	Terrain Ruggedness Index	30 m	Derived from DEM data	1km²
	Slope	30m	Derived from DEM data	1km²
Geomorphological/ Hydrological	Drainage Density	1km	Hydroshed Atlas, WWF, and calculate line density toolbox through ArcGIS	1km²
	Distance to water	1km	Derived from Pekel, J.F., Cottam, A., Gorelick, N. and Belward, A.S., 2016. High-resolution mapping of global surface water and its long-term changes. Nature, 540(7633), pp.418-422. and transformed through euclidean distance toolbox in ArcGIS	1km²
	Snow/Ice	10m	Permanent, Derived from Karra, Kontgis, *et al.*	1km²

			"Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021 data	
Landscape	Rangelands	10m	Derived from Karra, Kontgis, *et al.* "Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021	1km²
	Agriculture Lands	10m	Derived from Karra, Kontgis, *et al.* "Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021 data	1km²
Bioclimatic	Land Surface Temperature	30m	Derived from Landsat-8 data for the April to October 2021 considering the active period of the brown bear in the region.	1km²
Anthropogenic	Distance to Settlement	1km²	Distance to Settlement (Derived from Karra,	1km²

			Kontgis, *et al.* "Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021 data. Built Area was extracted and transformed through euclidean distance toolbox in ArcGIS	
	Distance to Road	1km²	HDXHOTOSM, accessed on 1st July 2023 data was transformed through euclidean distance toolbox in ArcGIS	1km²

This resolution was selected as it represents an ecologically relevant scale for understanding the distribution of brown bears in the Trans-Himalayan region. The variables included those that were likely to influence the occurrence of brown bears as per our ecological knowledge of the species and our a priori hypotheses.

On the basis of our study design, we propose several hypotheses to investigate the habitat ecology of the Himalayan brown bear in the resource-limited Trans-Himalayan region of Ladakh.

Table 3.3: The ecological factors and hypothesis along with the corresponding null hypothesis.

S. No.	Ecological Factor	Hypothesis	Null Hypothesis
a	Habitat Type Preference	Brown bears in the Ladakh region exhibit a preference for specific habitat types (Rathore 2008).	Brown bears in the Ladakh region do not exhibit a preference for specific habitat types.
b	Slope and Terrain Ruggedness Preference	Brown bears in Ladakh prefer specific slope angles and rugged terrain.	Brown bears in Ladakh do not exhibit a preference for slope angle or terrain ruggedness.
c	Food Resource Availability	Food resource availability significantly impacts brown bear occupancy in Ladakh.	Food resource availability does not significantly impact brown bear occupancy in Ladakh.
d	Elevation Range Influence	Elevation influences brown bear occupancy in the Trans-Himalayan region. High-altitude permafrost and glaciers are inhospitable terrain with no food.	Elevation is not a primary determinant of brown bear occupancy in Ladakh.
e	Seasonal Variation in Habitat Preference	Brown bears in Ladakh exhibit seasonal variation in habitat preference.	Brown bears in Ladakh do not exhibit seasonal variation in terrain preference.
f	Effects of Temperature on Habitat Selection	Temperature variation affects brown bear habitat selection in Ladakh.	Temperature does not influence brown bear habitat selection in Ladakh.

We aligned our hypotheses with specific ecological predictors. For habitat preference (H1), we used rangeland cover and distance to water as indicators of vegetation and productive valleys. For topography (H2), we considered terrain ruggedness index (TRI), elevation, and slope to capture landscape structure. For temperature effects (H3), we included land surface temperature (LST) in occupancy models and bioclimatic variables (bio1, bio2, bio4) in MaxEnt to represent climatic influences.

3.6 Analytical Framework

3.6a. Habitat selection modelling

We use occupancy modelling that corrects for detection bias and model's species occurrence using relevant eco-geographical covariates (MacKenzie 2006; MacKenzie *et al.* 2017). We conducted single species single season occupancy analysis using PRESENCE software version 2.13.47 (Hines 2006). We modeled detection probability with survey effort and occupancy with site characteristics. We estimated occupancy using maximum likelihood approach and selected the most parsimonious model with the lowest Akaike Information Criterion (AIC) and used model average Akaike weights when two or models differed by less than five AIC. This approach is particularly suitable for large-scale population dynamics monitoring and habitat selection (Haroldson *et al.* 2021).

To avoid collinearity in the model we first estimated the correlation between all ecogeographical variables and then used only one of a pair of correlated variables in any given model. Following the extraction of the PRESENCE results from each model, we exported the Psi-conditional [Pr(occ | detection history)] values into Excel to normalize. We then transformed them into inverse logit, the logistic function defined by exp(x)/(1+exp(x)). The inverse logit transformation takes values on the real line and converts them to be between zero and one. We used clog-log to determine the prediction of values for spatial representation of Himalayan brown bear distribution. We processed the analysis at 100 bootstrap iterations to estimate C-hate values. A diagnostic metric called C-hat evaluates the data-fit of the model. It basically checks for overdispersion, the condition whereby the observed data variability surpasses what the model projects. A good model fit is indicated by a c-hat value of 1; values higher than 1 imply overdispersion.

When working with statistical models, beta estimates show the relationships between predictor variables and a response variable. The magnitude of the beta estimate (i.e., how far it is from zero) indicates the strength of the relationship.

3.6b. Habitat Suitability Modelling

We investigated habitat suitability to learn more about how species are spread in the western part of Ladakh by looking at occurrence data, landscape covariates, and bioclimatic variables. We used the Maximum Entropy (MaxEnt) modelling methodology (Phillips et al. 2006; Elith et al. 2011) in MaxEnt, SDM V 3.4.4, software known for robust handling of presence-only data. MaxEnt creates a probability surface showing areas with acceptable conditions for the species by integrating known occurrence locations with environmental predictors, therefore evaluating species habitat suitability.

The habitat suitability analysis was carried out exercising occurrence data and landscape covariates through the MaxEnt species distribution modelling method, SDM V 3.4.4 (Phillips et al. 2006). Employing ArcGIS v. 10.8 software, we identified 14 potential landscape covariates and transformed the variables into ASCII (American Standard Code for Information Interchange) file format. The model was trained using 80% of the locations, while the accuracy was evaluated on the remaining 20%. Additionally, the model, which integrates 34 distinct models, underwent processing and was utilised in a jackknife test to assess the significance of predictors. To ensure precise predictions, the models were executed 1, 10, and 100 times utilising bootstrap methods. The True Scale Statistics (TSS) value (MaxEnt: Background Prediction, Sample Prediction Test, and Threshold Value 10 Clog-log) was utilised to select the optimal model.

This approach enabled us to assess the probability of species presence at multiple locations by using ecological and climatic variables. Combining species occurrence records with key ecological traits like elevation, land cover, temperature, and precipitation patterns, we generated a predicted habitat suitability map for the region. We selected the final model based on True Skill Statistics (TSS) values (Hanssen & Kuipers 1965).

Table 3.4: Correlation matrix for the 14 environmental covariates selected for Occupancy modelling.

	aspect	bio1	bio2	bio4	bio5	dem	evi_march_may	evi_sept_nov	hfp2020	LST2020	lulc2020	savi2020	tri	slope
aspect	1.00	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
bio1	[illegible]	1.00	[illegible]	-0.12	0.99	-0.63	0.33	0.46	0.66	0.56	0.18	0.46	[illegible]	[illegible]
bio2	[illegible]	[illegible]	1.00		0.17	[illegible]	0.53	0.22	[illegible]	0.56	[illegible]	[illegible]	-0.36	-0.38
bio4	[illegible]	-0.12		1.00	[illegible]	[illegible]	-0.23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
bio5	[illegible]	0.99	0.17	[illegible]	1.00	-0.63	0.37	0.49	0.66	0.61	0.18	0.47	[illegible]	[illegible]
dem		-0.63	[illegible]	[illegible]	-0.63	1.00	-0.17	-0.27	-0.45	-0.33	[illegible]	-0.30	[illegible]	[illegible]
evi_march_may	[illegible]	0.33	0.53	-0.23	0.37	-0.17	1.00	0.46	0.20	0.61	[illegible]	0.26		
evi_sept_nov	[illegible]	0.46	0.22	[illegible]	0.49	-0.27	0.46	1.00	0.29	0.48	0.21	0.59	[illegible]	
hfp2020	[illegible]	0.66	[illegible]	[illegible]	0.66	-0.45	0.20	0.29	1.00	0.37	0.14	0.32		
LST2020	[illegible]	0.56	0.56	[illegible]	0.61	-0.33	0.61	0.48	0.37	1.00	[illegible]	0.35	-0.17	-0.16
lulc2020	[illegible]	0.18	[illegible]	[illegible]	0.18	-0.13	[illegible]	0.21	0.14	[illegible]	1.00	0.29	0.11	0.14
savi2020	[illegible]	0.46	[illegible]	[illegible]	0.47	-0.30	0.26	0.59	0.32	0.35	0.29	1.00	[illegible]	
tri	[illegible]	[illegible]	-0.36	[illegible]	[illegible]	[illegible]		[illegible]		-0.17	0.11	[illegible]	1.00	0.95
slope	[illegible]	[illegible]	-0.38	[illegible]	[illegible]	[illegible]				-0.16	0.14		0.95	1.00

Table 3.5: Correlation matrix of the 11 eco-geographical covariates selected for MaxEnt modelling

	Elevation	Terrain Ruggedness Index	Drainage Density	Slope	Agricultural Land	Snow/Ice	Rangelands	Distance to Road	Distance to Water	Distance to Settlement	Land Surface Temperature
Elevation	1										
Terrain Ruggedness Index	0.153622	1									
Drainage Density	-0.24595	0.423771889	1								
Slope	-0.32921	0.825709451	0.449546449	1							
Agricultural Land	-0.1805	-0.008358239	0.036933101	0.082622141	1						
Snow/Ice	0.42051	0.346224087	0.195448351	0.085769623	-0.039726336	1					
Rangelands	-0.47916	-0.106052898	0.156329746	0.136201114	0.221405237	-0.32094	1				
Distance to Road	0.447689	0.251212329	0.072121518	-0.031231133	-0.085448426	0.539067	-0.350366287	1			
Distance to Water	0.187258	-0.19330958	-0.281275545	-0.252045937	-0.040052007	0.094596	0.154905158	0.045974545	1		
Distance to Settlement	0.476047	0.138524225	-0.030356706	-0.120368741	-0.151680327	0.236345	-0.437437619	0.33192663	-0.057167496	1	
Land Surface Temperature	-0.13193	-0.13883539	0.068122598	-0.090253815	0.014466355	-0.18725	0.044119333	-0.118848856	-0.148201009	0.042595861	1

3.7 Results:

We carried out trail transects using polygon search framework in a systematic, grid-based manner covering ~35100 km² (275 grids) with 4012 trails ranging from 0.5 to 6.78 km. A total of 2530 brown bear signs were recorded across the surveyed region (Figure 3.1). Most of the eco-geographical covariates used for Occupancy and MaxEnt models were weakly correlated, except elevation and terrain ruggedness of which only one was used per model.

3.7.1 Model performance

We ran 36 candidate models (table 3.6) in PRESENCE (*v2.13.47*) following MacKenzie et al. 2017 and the naïve occupancy was 0.099. The detection history dataset included sampling covariate and site covariates. It also had field-collected covariates like wild prey, domestic animals, and wild rose. We also analysed the model using trail length as a detection covariate (p(trail length)) and found no significant results due to the high standard error. We imported the PRESENCE model output into ArcGIS, and prepared an occupancy map.

Table 3.6: The PRESENCE software was exercised to run 36 combinations of occupancy models.

Sr. no.	Models	AIC	deltaAIC	AIC wgt	Model Likelihood	No.of parameters	-2*Log Like	C-hat Value
1	psi(R+RL+DW+LST), p(.)	719.23	0.00	0.9717	1.0000	6	707.23	1.2430
2	psi(R+DS+DW+LST+E), p(.)	727.80	8.57	0.0134	0.0138	7	713.80	1.2461
3	psi(S+RL+DW+LST), p(.)	728.47	9.24	0.0096	0.0099	6	716.47	1.2274
4	psi(E+RL+DW+S).p(.)	731.2	11.97	0.0024	0.0025	6	719.2	1.3126
5	psi(DW+R+RL).p(.)	731.43	12.2	0.0022	0.0022	5	721.43	1.2771
6	psi(DW+LST).p(.)	734.98	15.75	0.0004	0.0004	4	726.98	1.1597
7	psi(DW+R).p(.)	737.19	17.96	0.0001	0.0001	4	729.19	1.3293
8	psi(E+DS+DW+LST).p(.)	737.57	18.34	0.0001	0.0001	6	725.57	1.2762
9	psi(S+RL+DW).p(.)	739.47	20.24	0.0000	0.0000	5	729.47	1.2773
10	psi(DW+DD).p(.)	740.63	21.4	0.0000	0.0000	4	732.63	1.2553
11	psi(E+DW+S).p(.)	742.36	23.13	0.0000	0.0000	5	732.36	1.3358
12	psi(DW).p(.)	743.48	24.25	0.0000	0.0000	3	737.48	1.2804
13	psi(S+DS+DW).p(.)	743.87	24.64	0.0000	0.0000	5	733.87	1.2766

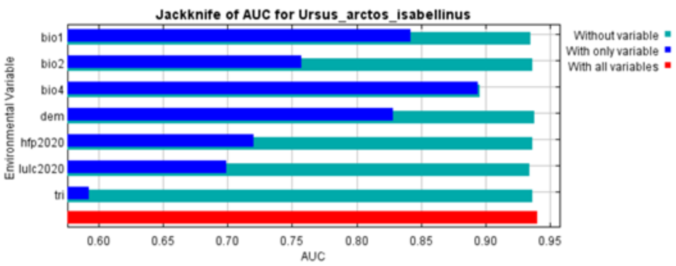
14	psi(E+DW).p(.)	744.25	25.02	0.0000	0.0000	4	736.25	1.3454
15	psi(DW+DS).p(.)	745.27	26.04	0.0000	0.0000	4	737.27	1.2341
16	psi(R+RL+DD+LST).p(.)	753.16	33.93	0.0000	0.0000	6	741.16	1.3736
17	psi(DD+R+RL).p(.)	773.11	53.88	0.0000	0.0000	5	763.11	1.3437
18	psi(LST+R+RL).p(.)	774.01	54.78	0.0000	0.0000	5	764.01	1.3637
19	psi(R).p(.)	774.91	55.68	0.0000	0.0000	3	768.91	1.4199
20	psi(R+RL).p(.)	775.76	56.53	0.0000	0.0000	4	767.76	1.3755
21	psi(S).p(.)	783.7	64.47	0.0000	0.0000	3	777.7	1.3757
22	psi(SI+E).p(.)	783.87	64.64	0.0000	0.0000	4	775.87	1.2694
23	psi(DD).p(.)	784.06	64.83	0.0000	0.0000	3	778.06	1.3005
24	psi(S+E).p(.)	785.55	66.32	0.0000	0.0000	4	777.55	1.3575
25	psi(S+RL).p(.)	785.7	66.47	0.0000	0.0000	4	777.7	1.3957
26	psi(E+RL+S).p(.)	787.52	68.29	0.0000	0.0000	5	777.52	1.3548
27	psi(AL+DS).p(.)	789.15	69.92	0.0000	0.0000	4	781.15	1.3072
28	psi(SI).p(.)	790.07	70.84	0.0000	0.0000	3	784.07	1.3405
29	psi(AL).p(.)	791.15	71.92	0.0000	0.0000	3	785.15	1.3024

30	psi(LST).p(.)	795.32	76.09	0.0000	0.0000	3	789.32	1.3620
31	psi(LST+DS).p(.)	796.24	77.01	0.0000	0.0000	4	788.24	1.4524
32	psi(DR).p(.)	800.65	81.42	0.0000	0.0000	3	794.65	1.3830
33	psi(.).p(.)	802.53	83.3	0.0000	0.0000	2	798.53	1.3966
34	psi(E).p(.)	803.85	84.62	0.0000	0.0000	3	797.85	1.2585
35	psi(RL).p(.)	803.89	84.66	0.0000	0.0000	3	797.89	1.3421
36	psi(.).p(TL)	804.17	84.94	0.0000	0.0000	3	798.17	1.3462

Abbreviations: LST=Land Surface Temperature, DW=Distance to Water, DS=Distance to Settlement, RL=Rangelands, R=Terrain Ruggedness Index, E= Digital Elevation Model, S=Slope, AL=Agricultural Land, TL=Trail Length, DD=Drainage Density, DR=Distance to Road, SI= Snow/Ice.

To complement occupancy modelling, we conducted species distribution modelling using MaxEnt (v3.4.4). A total of 34 models were run using 80% of occurrence points for training and 20% for testing. Fourteen environmental variables were extracted and processed in ASCII format in ArcGIS (v10.8). The best MaxEnt model had strong performance (mean AUC = 0.950 ± 0.007; TSS = 0.71). The ROC curve (figure 3.8) shows the model's strong discriminatory ability. Jackknife tests (figure 3.7) identified temperature seasonality (bio4), annual mean temperature (bio1), and elevation (DEM) as the most influential predictors.

Figure 3.7: Jackknife of AUC for Himalayan brown bear generated from MaxEnt SDM



3.7.1 H1: Habitat Preference

Occupancy models supported the hypothesis that habitat type influences brown bear presence. Rangelands (Table 3.9) had a large positive effect on occupancy (ß=0.45, SE=0.18), whereas distance to water had a strong negative effect (ß=-2.35, SE=0.49). This means that bears are more likely to be found in valleys with vegetation and prey availability. The occupancy map showed that valley systems like Drass, Suru, and Zanskar had a higher chance of being occupied. The results from MaxEnt were consistent, with land use land cover (rangelands: 11.2%) of the model (Table 2). This shows that rangelands and valleys are important habitats (figure 3.1). Bears avoided places with a high Human Footprint Index (figure 3.19) and instead preferred places with a low to moderate disturbance (HFP = 5–25), which is in line with earlier research that showed they were sensitive to human activity (Elfström et al. 2014).

Parameter	Model	ß estimate	SE
Ψ	**Intercept**	**-2.43**	**0.37**
Ψ	**Terrain Ruggedness Index**	**0.82**	**0.26**
Ψ	**Rangelands**	**0.45**	**0.18**
Ψ	**Distance to Water**	**-2.35**	**0.49**
Ψ	**Land Surface Temperature**	**0.77**	**0.22**
P	**Detection-Intercept**	**-0.06**	**0.11**

Table 3.8: Himalayan brown bear occupancy model. First model parameter estimates Himalayan brown bear occupancy (Ψ) and detection (P) in Ladakh. The sign and magnitude of the ß estimate indicates the relative influence of the ecological variables on Himalayan brown bear occupancy.

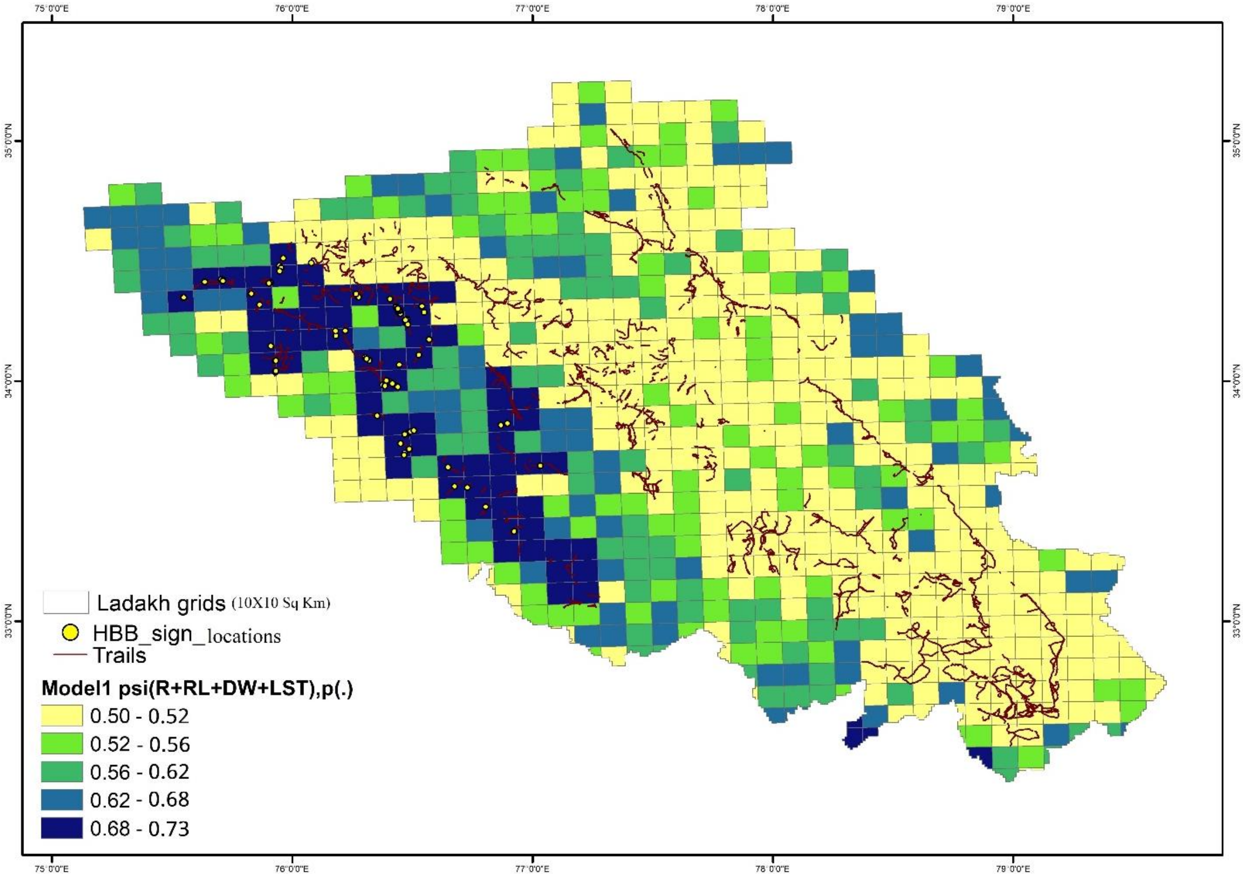


Figure 3.9: Occupancy probability map for the Union Territory of Ladakh was generated to visualize the spatial patterns of species occurrence. This map represents the outputs of the best-fitting occupancy model, identified by the lowest Akaike Information Criterion (AIC) value, from surveys conducted during the 2019-2020 field season. Occupancy probabilities were spatially classified using the Natural Breaks (Jenks) method, with specific break values presented as percentages. The entire mapping process, including spatial data visualization and classification, was performed using **ArcMap 10.8.2** software (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

The occupancy model (Figure 3.9) provided a spatial representation of habitat selection for the Himalayan brown bear in Ladakh with probabilities ranging from 0.50 to 0.73. The dark blue grids (0.68-0.73) indicate core zones which offers the conditions most favourable for the brown bear (Bojarska & Selva, 2012; Delgado et al. 2018). The C-hat value of the first model was adequate ($\hat{c} = 1.24$).

The details of the 2nd and 3rd best model is given below:

Model 2: psi(R+DS+DW+LST+E),p(.)

Parameter	Models	ß estimate	SE
Ψ	**Intercept**	**-2.09**	**0.33**
Ψ	**Terrain Ruggedness Index**	**0.76**	**0.26**
Ψ	**Distance to Settlement**	**-0.05**	**0.20**
Ψ	**Distance to Water**	**-2.04**	**0.47**
Ψ	**Land Surface Temperature**	**0.79**	**0.22**
Ψ	**Elevation**	**0.06**	**0.25**
P	**Detection-Intercept**	**-0.07**	**0.11**

Table 3.10: Showing 2nd best occupancy model parameter estimates Himalayan brown bear occupancy (Ψ) and detection (P) in Ladakh.

With seven parameters the second model identified the lowest AIC value (727.80), delta-AIC (8.57), AIC weight (0.0138), and model likelihood (0.0138). With the detection covariate as a constant, we hypothesised that "ruggedness," "distance to settlement," "distance to water," "land surface temperature," and "elevation," all impact the likelihood of a brown bear occupying a place. The data below allow us to deduce from the beta estimations and accompanying standard errors what the occupancy model requires. Along with a standard error of 0.26, the beta estimate for ruggedness was 0.76, suggesting a preference of brown bears for places defined by rocky terrain. Brown bears will find rugged environments intriguing because they provide improved shelter, protection for young, and different foraging chances.

The distance to settlement showed a beta estimate of -0.05 together with a standard error of 0.20. This value shows how close brown bears live to human areas influences their occupancy. The projection of -0.05 shows a minor negative effect on occupancy as bears approach communities. This implies that bears could avoid areas near to human activity. This result is environmentally important as brown bears usually avoid areas close to human activities. Along with a standard error of 0.47, the distance to water generated a beta estimate of -2.04, suggesting a declining brown bear occupancy as distance from water bodies increased.

The land surface temperature provided a beta estimate of 0.79 with a standard error of 0.22, implying that it has a positive association with brown bear occupancy. This could be due to seasonally variable preferences; bears may prefer warmer areas during certain times of the year, such as foraging in higher elevation meadows during the spring and summer. The beta estimate for elevation was 0.06 with a standard error of 0.25 when it was used with other variables. This means that higher elevations are slightly more likely to have brown bears living in them. Ecologically, this could be linked to factors like less human disturbance and specific habitat preferences of brown bears in Ladakh's high-altitude regions. The C-hat value of the model psi(R+DS+DW+LST+E), p(.) is 1.25.

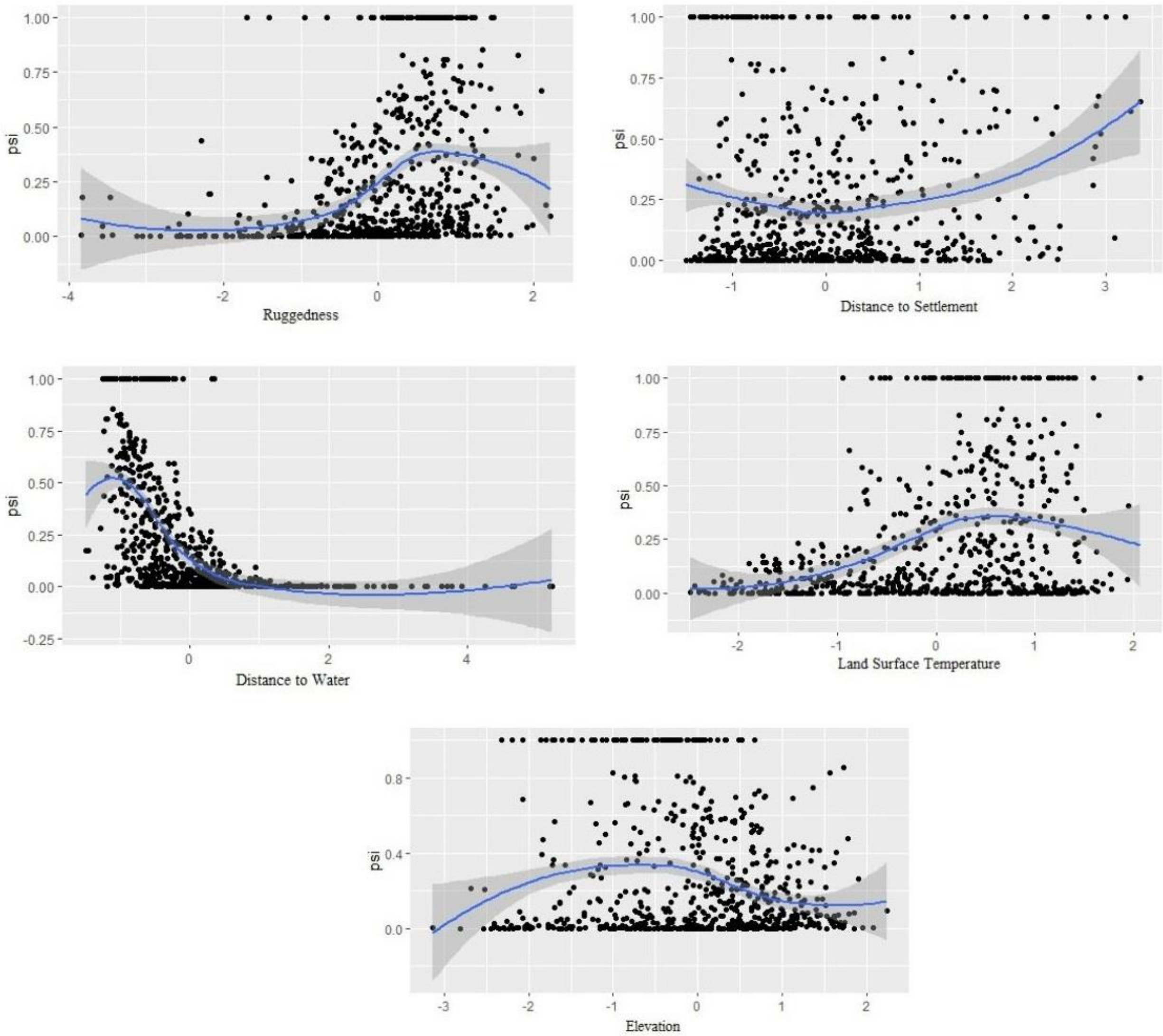


Figure 3.11: Relationships between Himalayan brown bear and environmental variables. Occupancy probability of brown bears in Ladakh in response to a) Terrain Ruggedness Index,

b) Distance to settlement, c) average grid distance to perineal water source, and d) Land surface temperature between April - October season and e) Elevation.

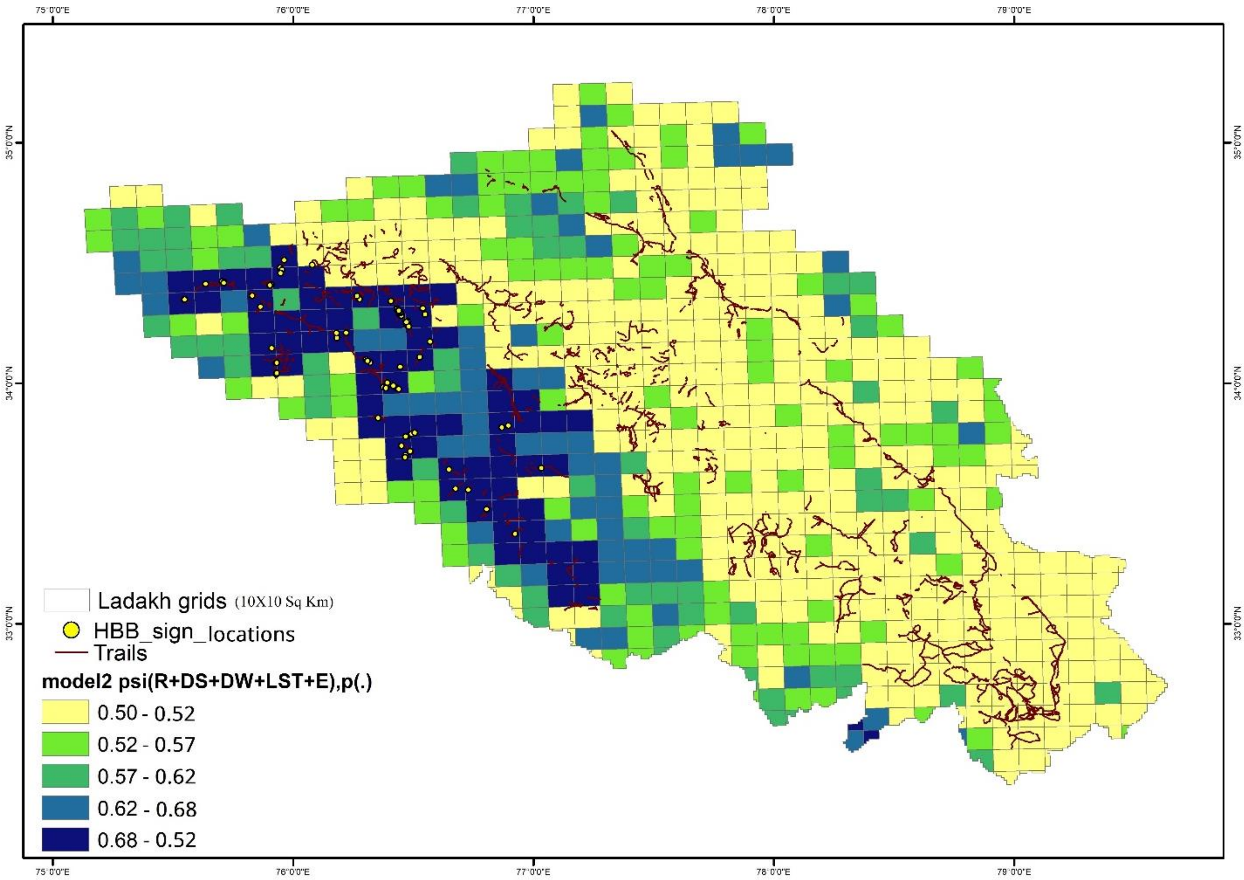


Figure 3.12: The second strongest model (the one with the second-lowest AIC score) to show where Himalayan Brown Bear are likely to be found in the study area. This map, built on data we gathered from 2019-20, paints a picture of how these animals use different parts of their habitat. We've grouped these habitat areas by their 'suitability score' using a method called Natural Breaks (Jenks), and you'll see those scores as percentages. All the mapping and analysis work was done using ArcMap 10.8.2 (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

Model 3: psi(E+RL+DW+S),p(.)

Parameter	Models	ß estimate	SE
Ψ	Intercept	-2.05	0.34
Ψ	Elevation	0.76	0.25
Ψ	Rangelands	0.75	0.22
Ψ	Distance to Water	-2.97	0.55
Ψ	Slope	0.29	0.19
P	Detection-Intercept	-0.06	0.11

Table 3.13: Himalayan brown bear occupancy of 3rd model. Third model parameter estimates Himalayan brown bear occupancy (Ψ) and detection (P) in Ladakh

We identified the third model with the lowest AIC value (728.47), delta AIC (9.24), AIC weight (0.0099), and model likelihood (0.0099) with six parameters. With the detection covariate held constant, p(.), we thought that "Elevation," "Rangelands," "Distance to Water," and "Slope" would all affect the chance of a brown bear being at a site. The results shown below show what we can infer from the beta estimates and the standard errors that go with them for the occupancy model. A beta estimate of 0.76 with a standard error of 0.25 suggests that higher elevations are linked to a slightly higher brown bear population when other variables are considered. The rangelands had a beta value of 0.75 and a standard error of 0.22; this means that ecologically, places with rangelands are linked to having more brown bears. Distance to water gave a beta estimate of -2.97 with a standard error of 0.55, suggesting that as the distance to water sources increases, brown bear occupancy decreases. It means that as you move farther away from water sources, the likelihood of brown bear occupancy decreases. The slope generated a beta value of 0.29 together with a standard error of 0.19, implying that brown bear occupancy is favourably influenced by angle. Brown bears probably find more concealment and foraging chances from the presence of rocky terrain and mild slopes.

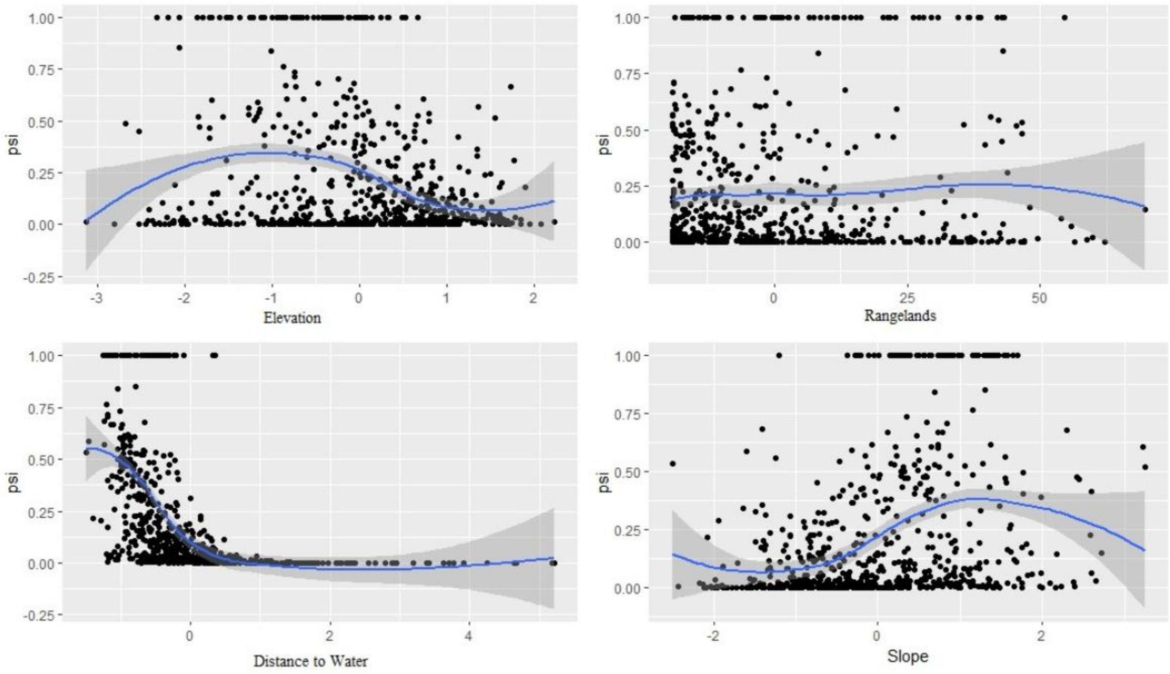


Figure 3.14: Relationships between Himalayan brown bear and environmental variables. Occupancy probability of brown bears in Ladakh in response to a) Elevation, b) proportion of Rangeland in a grid, c) average grid distance to perineal water source, and d) Slope.

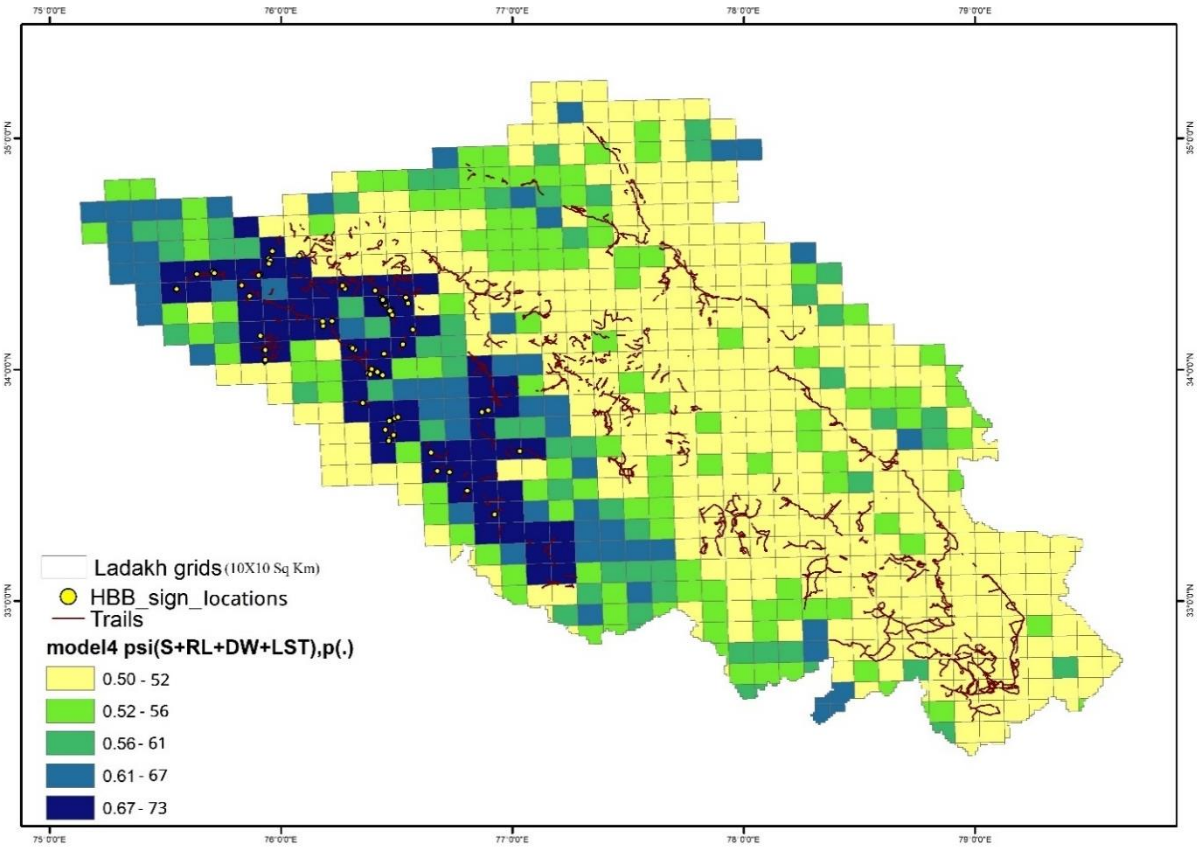


Figure 3.15: The third strongest one (the one with the second-lowest AIC score) to show where Himalayan Brown Bear are likely to be found in the study area. This map, built on data we gathered from 2019-20, paints a picture of how these animals use different parts of their habitat. We've grouped these habitat areas by their 'suitability score' using a method called Natural Breaks (Jenks), and you'll see those scores as percentages. All the mapping and analysis work was done using ArcMap 10.8.2 (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

3.7.2 H2: Topographic influence

Our second hypothesis mentioned that topography influences bear distribution in high altitude region was also supported. Terrain Ruggedness Index (TRI) had a significant positive effect in the occupancy models (ß = 0.82, SE = 0.26), suggesting preference for moderately rugged terrain (Table 3.8). MaxEnt response curves further showed that suitable habitats occurred within TRI values of 50-150 m and elevations between 3000-4500 m asl, with Digital Elevation Model (DEM) contributing to model predictions (Figure 3.19). These results highlighted that bears favor mid-elevation landscapes with moderate ruggedness.

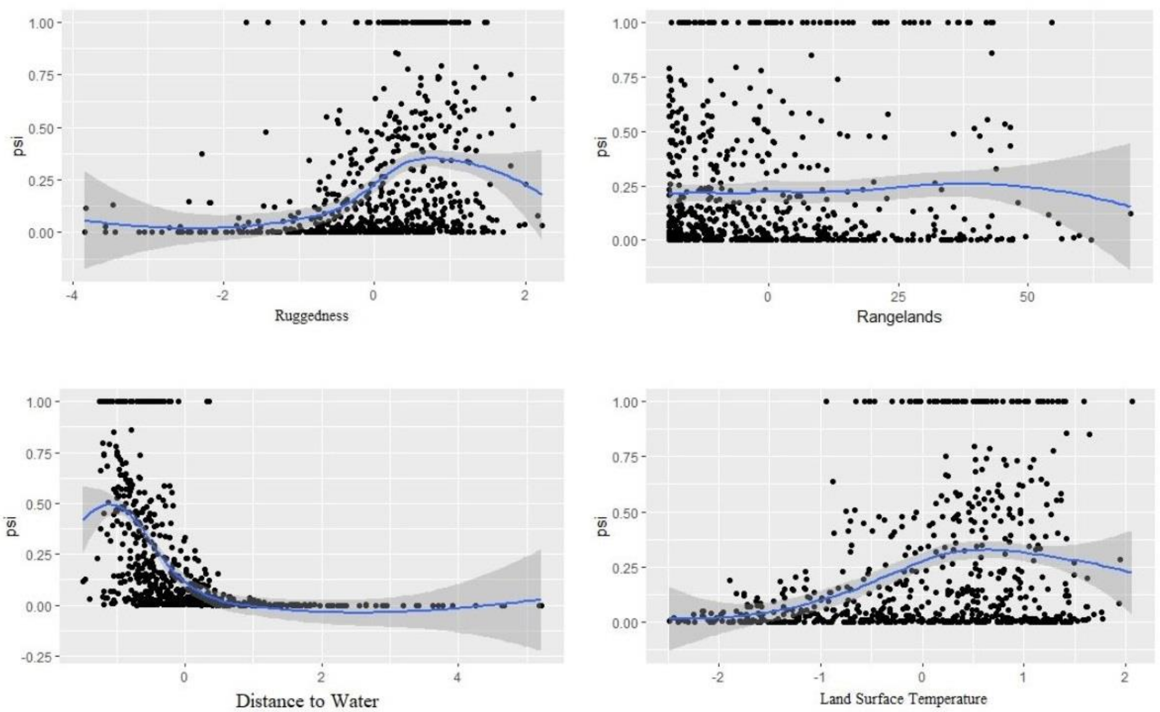


Figure 3.16: **Relationships between Himalayan brown bear and environmental variables.** Occupancy probability of brown bears in Ladakh in response to a) Terrain Ruggedness Index,

b) proportion of Rangeland in a grid, c) average grid distance to perineal water source, and d) Land surface temperature between April - October season.

3.7.3 H3: Temperature effect

Temperature emerged as strong determinant of habitat suitability through MaxEnt. In occupancy models (Table 3.8), land surface temperature (LST) was positively associated with occupancy (ß = 0.77, SE = 0.22). MaxEnt models reinforced this, with temperature seasonality (bio4) contributing 47.7 % and annual mean temperature (bio1) 32.3% to habitat suitability predictions. Bears showed a preference for areas with significant seasonal variation (Figure 3.19), particularly in the western Ladakh, where climatic conditions support resource availability and denning opportunities. Mean diurnal temperature range (bio2) also influenced suitability reflecting preference for moderate daily thermal variation (10–13°C).

Variables	**Percent contribution**	**Permutation importance**
1. Bioclimatic (bio4)	47.7	32.5
2. Bioclimatic (bio1)	32.3	52
3. Land Use Land Cover (LULC)	11.2	1.7
4. Bioclimatic (bio2)	4.1	5.9
5. Terrain Ruggedness Index (TRI)	1.8	2.5
6. Human Footprint Index (HFP)	1.5	2.7
7. Digital Elevation Model (DEM)	1.5	2.7

Table 3.17: Relationship between Himalayan brown bear and environmental variables. Bioclimatic variables (bio4 (highest contribution), bio1 and bio2), Land Use Land Cover (LULC), Terrain Ruggedness Index (TRI), Human Footprint Index (HFP) and Digital Elevation Model (DEM) with percent contribution and permutation importance.

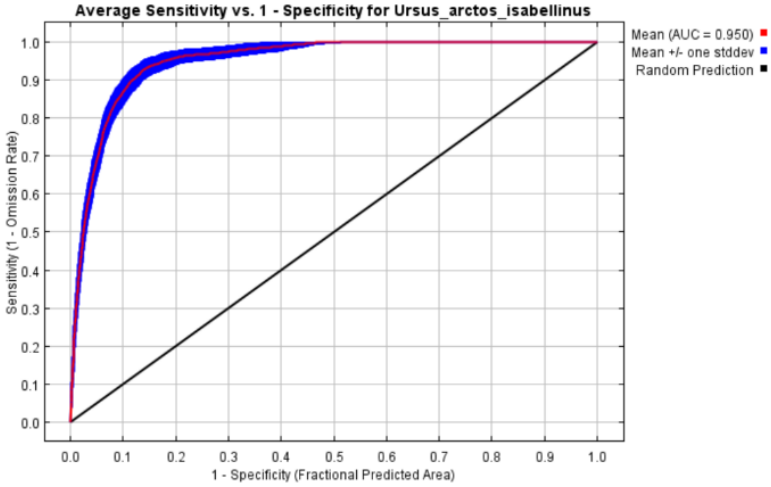


Figure 3.18: The graph illustrates the Receiver Operating Characteristic (ROC) curve for MaxEnt model predicting habitat suitability of Himalayan brown bear in Ladakh. The curve shows model sensitivity vs specificity (fractional predicted area). The AUC is 0.950, indicating excellent predictive accuracy of the model for the Himalayan brown bear in Ladakh.

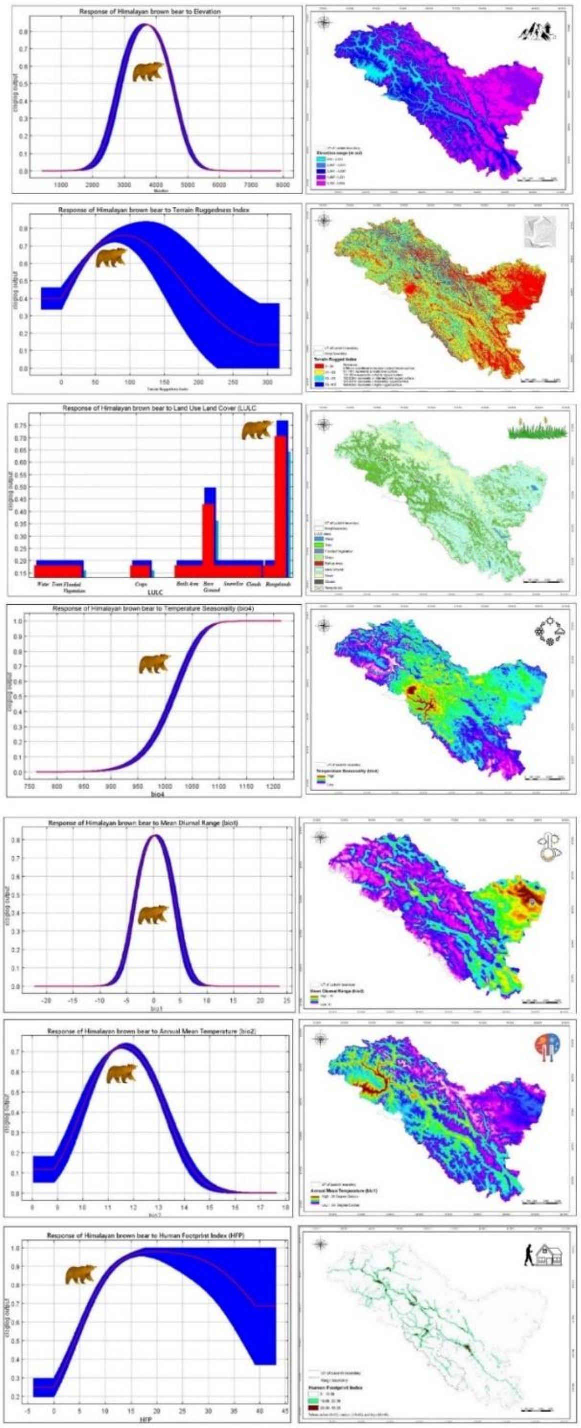


Figure 3.19: MaxEnt response curves of Himalayan brown bear and the spatial representation of environmental in Ladakh. Graphs: Himalayan brown bear response to environmental variables (Digital Elevation Model (DEM), Terrain Ruggedness Index (TRI), Land Use Land Cover (LULC), Temperature Seasonality (bio4), Annual Mean Temperature (bio1), Mean Diurnal Range (bio2), and Human Footprint Index (HFP-2020). Maps: Mapping of respective environmental variables in the Ladakh.

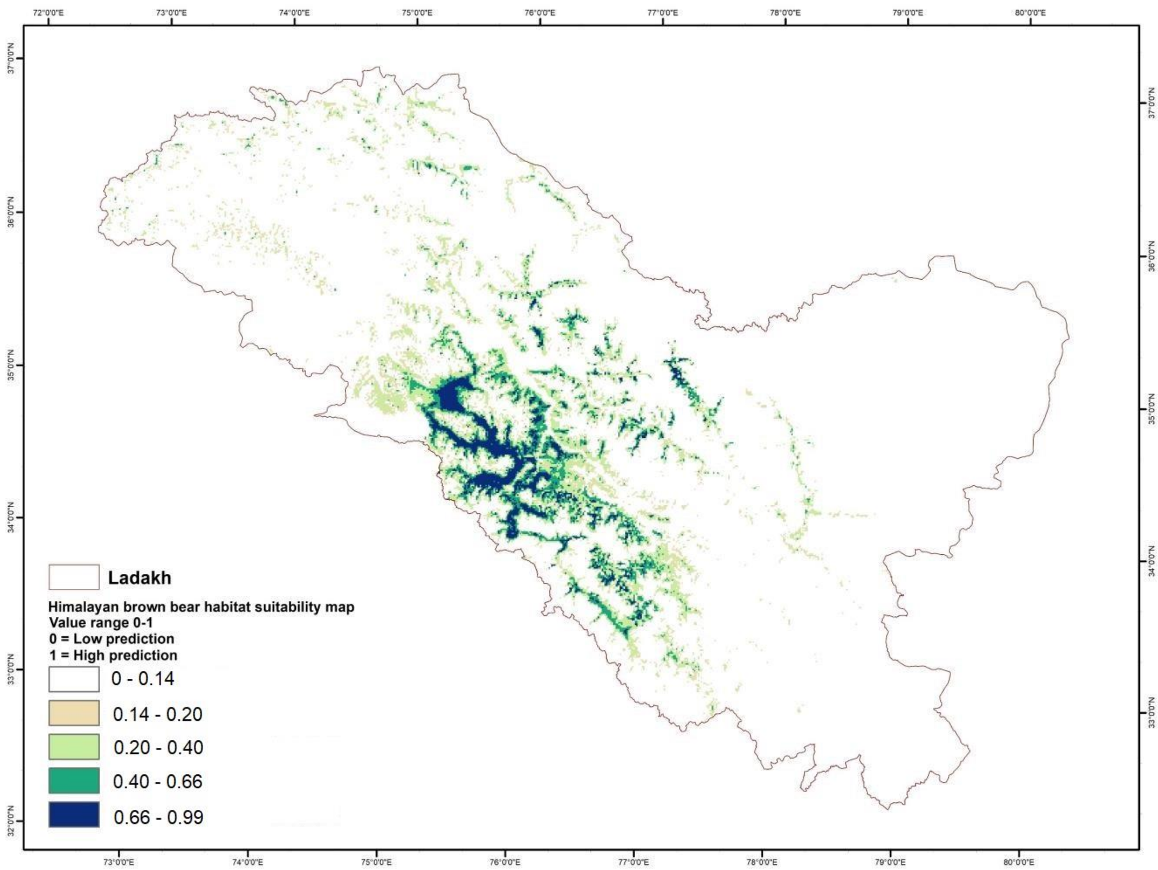


Figure 3.20: Habitat suitability map was developed for the Himalayan brown bear (*Ursus arctos isabellinus*) across the Ladakh landscape to identify and visualize potential habitat areas. This map was generated using the MaxEnt (Maximum Entropy) modelling approach, incorporating survey data collected during the 2019-2020 period. The output depicts the spatial distribution of habitats, categorized by various degrees of suitability, which reflect the integrated influence of selected environmental, topographic, and anthropogenic factors. All spatial processing and map finalization were conducted using **ArcMap 10.8.2** software (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

Habitat suitability map was developed for the Himalayan brown bear (*Ursus arctos isabellinus*) across the Ladakh landscape to identify and visualize potential habitat areas. This map was generated using the MaxEnt (Maximum Entropy) modelling approach, incorporating survey data collected during the 2019-2020 period. The output depicts the spatial distribution of habitats, categorized by various degrees of suitability, which reflect the integrated influence of selected environmental, topographic, and anthropogenic factors. All spatial processing and map finalization were conducted using **ArcMap 10.8.2** software

Across both modelling approaches, the strongest predictors of Himalayan brown bear distribution were rangelands, water proximity, terrain raggedness, and temperature variation, supporting all three hypotheses and indicate that western Ladakh has predominantly the most suitable habitats. Occupancy models (Figure 3.9) highlighted fine-scale site use, while MaxEnt (Figure 3.20) provided complementary landscape-level insights, together reinforcing the ecological drivers of brown bear distribution in the high-altitude region.

3.8 Discussion

This is the first landscape-level ecological assessment of Himalayan brown bear distribution in the Trans-Himalayan region of Ladakh, integrating occupancy and MaxEnt frameworks to provide a conservation baseline in a data-deficient, high-altitude regions. The dual framework strengthens confidence in our findings and demonstrates the value of integrating multi-modelling approaches for conservation planning in data-deficient landscapes (Phillips et al. 2006; MacKenzie et al. 2017). The results have direct implications for the conservation planning by policymakers and managers in executing management strategies for crucial habitats in Drass, Suru, Shargole, and Zanskar Valleys (which do not have designated protected areas) to sustain brown bear populations in Ladakh.

Our results provide robust support for the first hypothesis (H1) which align with previous research suggesting that alpine meadows and valley systems offer essential fodder and prey resources for brown bears (Rathore, 2008; Bojarska & Selva, 2012; Ansari & Ghoddousi, 2018). In Ladakh, rangelands are productive at certain times of the year and sustain a wide range of herbaceous plants, small mammals, and livestock. These are all important parts of the brown bear's diet (Nawaz, 2008; Rathore, 2008; Dar et al. 2021).

The highlights vulnerability in western Ladakh currently face pressure from rapid linear-infrastructural developmental activities, overgrazing and unregulated tourism. Protecting these valley systems is therefore essential, not only for bears but also for other sympatric species that depend on the rangeland ecosystem.

The second hypothesis (H2) suggesting that topography shapes brown bear habitat selection (Ferguson & McLoughlin, 2000; Sharief et al. 2020). Rugged terrain may act as a refuge, offering shelter for cubs and concealment from human activity, while also supporting diverse foraging opportunities (Riley et al. 1999; Nellemann et al. 2007; Crupi et al. 2020).

Comparable finding has been reported in European and North American brown bear populations, where mid-elevation, moderately rugged landscapes were associated with higher occupancy and penology (Elfström et al. 2014; Friebe et al. 2014). In Ladakh, such landscape coincides with lower human footprint, reinforcing the importance of topography in mitigating anthropogenic pressures.

Conservation planning should therefore prioritize rugged mid-elevation zones as potential denning habitats and corridors, especially given the increasing road development and defense presence in Ladakh's valleys and plateaus.

Temperature variation emerged as a dominant driver of brown bear distribution, supporting our third hypothesis (H3). Bears were particularly associated with areas exhibiting pronounced seasonal variation which is found in western Ladakh, where climate conditions likely enhance forage productivity and facilitate thermoregulation (Nawaz et al. 2014; Delgado et al. 2018; Dai et al. 2019). The tendency towards temperature variation during the day time seems to represent the optimal temperature variability preference (Rodríguez et al. 2007).

These results underscore the role of climate in determining brown bears distribution in high-altitude ecosystem. Similar patterns have been documented in alpine carnivores, where seasonal variation governs foraging dynamics and denning behavior (Zarzo-Arias et al. 2021). Notably, suitability declined towards eastern Ladakh, where reduced seasonal variability and harsher arid conditions limit resource availability. Changes in temperature and rainfall patterns may force the species to move its thermal niche to higher elevations, where there are fewer places to survive (Su et al. 2018; Elsen & Tingley, 2015).

Our findings reveal that western Ladakh, especially the Drass, Suru, Rangdum, Shargole, and Zanskar Valleys, are important areas for the Himalayan brown bear. These regions are also among the most susceptible to human disruption, owing to grazing pressure, agricultural development, linear infrastructure, mining and human-bear conflict (Chavan et al. 2021; Ali, 2024). An isolated presence in Nubra Valley necessitates additional examination of potential habitat corridors and subpopulations.

This study underscores the intricate habitat necessities of the Himalayan brown bear and stresses the necessity for adaptive conservation methods to secure the enduring existence of this endangered subspecies in the Trans-Himalayan region. The findings have significant implications for conservation of bears in Ladakh. Identifying priority habitats, especially in western Ladakh, would help us come up with more effective conservation plans.

Our results may have a concrete impact on wildlife conservation policies in Ladakh. To keep bear populations healthy, it's important to safeguard rangelands, valleys beds, and limit development-induced fragmentation in areas critical for bears. Conservation initiatives must find a balance between protecting habitats and community engagements. This includes predator-proof corral pens, regulating rangeland, improvising waste management, promoting ecotourism based on brown bears, and raising awareness.

Despite the intensive assessment, the study faced limitations inherent to high-altitude fieldwork. Detection probabilities were low reflecting the elusive nature of brown bears and logistical constraints of surveying in rugged terrain interlinked with large streams and high passes. Some ecological factors, such as prey abundance and human disturbance information's, were not fully qualified, and should be integrated in future research. Additionally, while our study provides a spatial baseline under the current climatic conditions, projecting habitat suitability under future climate change scenarios will be critical to anticipate range shifts. Incorporating camera-trap for density estimation and behavioral study, scat-DNA based population estimation and diet, and multi-season occupancy models could further enrich understanding of population dynamics, corridors, and ecological interactions in the region.

Chapter 4- To study the food habit of brown bear in the study area

4. Introduction

Dietary ecology provides a fundamental basis for understanding ecological roles, energetic strategies, movement patterns, and the interactions of large carnivores with human societies. In this regard, the Himalayan brown bear is outstanding because of its extreme ecological specialisation, fragmented distribution, and persistence in challenging high-altitude environments. Trans-Himalayan Ladakh is at the intersection of the Greater Himalaya and the Karakoram mountain ranges and represents one of the most physiologically demanding bear habitats globally. The cold-arid conditions, extreme seasonality, poor vegetation cover, and paucity of prey diversity in this region impose severe constraints on the foraging behaviour of animals and therefore make dietary analyses an important aspect of species conservation in this region (Dvorský et al., 2011; Phartiyal et al., 2022).

The Himalayan brown bear is a member of a species that is known worldwide for its extraordinary ability to adapt to varied diets. In North America, Europe, and Asia, brown bears ingest an impressively wide range of foods, including graminoids, roots, berries, nuts, insects, fish, small mammals, ungulates, and carrion, and not infrequently exhibit seasonal shifts toward the most energy-rich items available (Stirling et al., 1990; Clevenger et al., 1992; Hilderbrand et al., 1999; Gunther et al., 2014). Global syntheses suggest that environmental productivity and climatic harshness are among the most influential determinants of diet composition, with populations in low-productivity, high-latitude, or alpine regions consuming greater proportions of animal matter as a result of limited digestible vegetation being available (Bojarska et al., 2012). In contrast, populations that inhabit temperate forests, Mediterranean ecosystems, or coastal zones often exploit seasonally abundant fruits, nuts, and salmon, which yield large energetic returns (Erlenbach et al., 2014; Ciucci et al., 2014; Fortin et al., 2007).

However, this general pattern becomes highly complicated in the Himalaya-Karakoram system. The Himalayan brown bear, distributed across the Hindu Kush, Pamir, Ladakh, Uttarakhand, Himachal Pradesh, Nepal, and Xinjiang, persists within a mosaic of ecological extremes. The species occupies the upper elevational limits of brown bear distribution worldwide, where plant productivity is inherently low, seasonality is more pronounced, and the winter dormancy period is prolonged. As a result, regional variation in diet is often more pronounced than in temperate populations. Studies from Himachal Pradesh show overwhelmingly herbivorous diets dominated by Rumex nepalensis, Chaerophyllum reflexum, and alpine forbs (Rathore et al., 2014), whereas the Deosai National Park population consumes a broader mix of graminoids, Polygonaceae, Cyperaceae, and small mammals – especially marmots (Nawaz et al., 2019). In Upper Mustang (Nepal), where vegetation is sparse and alpine deserts predominate, brown bears exhibit an unusually carnivorous diet, with small mammals comprising up to 75% of the food items recorded in scats (Aryal et al., 2012). This extreme variability emphasises the need to understand dietary adaptations at fine spatial scales, more so in landscapes as heterogeneous as Ladakh.

Diet is a matter of particular concern for Himalayan brown bears because it underpins fat gain, reproductive success, and overwinter survival. In high-altitude cold deserts, the foraging season may be as short as four or five months, in which time bears must gain sufficient calories to sustain denning periods that may exceed several months. Research in North America and Europe suggests that, to maximise mass gain before winter torpor, bears need to achieve an optimal macronutrient balance, often around 17% protein and 83% carbohydrates (Erlenbach et al., 2014; Hilderbrand et al., 1999). In contrast, such a balance is far harder to achieve in the TransHimalayan region, where carbohydrate-rich fruits are rare, graminoids are only available for short windows in the summer, and vertebrate prey populations are naturally limited. Under these conditions, brown bears will primarily feed upon roots, forbs, graminoids, insects, and carrion and increasingly utilise anthropogenic subsidies in the form of livestock, crops, and waste, with a resultant rise in human-brown bear conflict.

Ladakh is an illustrative example of such dynamics. The region is characterised by extremely low primary productivity, hard winters, and nomadic livestock pastoralism, which is the most prevalent occupation. This socio-ecological landscape translates into brown bears commonly sharing space with the human settlements, pastures used for livestock grazing, and livestock corrals. In Ladakh, bear–human interactions have risen considerably in the last few decades, with reports of depredation of livestock, foraging in crops, and regular raids on garbage pits and army ration dumps. Such interactions indicate that bears supplement native diets with anthropogenic food sources when the former are inadequate; this is a pattern in many global populations habituated to human-provided foods (Kavčič et al., 2015; Pereira et al., 2021). However, empirical dietary evidence from Ladakh has remained scarce and thus precludes understanding how local bears rely on natural versus anthropogenic sources of food.

Interpreting brown bear diet in Ladakh is further complicated by the presence of multiple sympatric carnivores, especially snow leopard, wolf, red fox, and free-ranging dogs – which produce scats that can overlap in size, colour, and content. Field-based identification of carnivore scats is notoriously unreliable, with misidentification rates ranging from 30% to over 50% in complex carnivore communities (Janecka et al., 2008; Farrell et al., 2000; Mondal et al., 2012). Dietary inferences may therefore be flawed in the absence of molecular verification, particularly for regions such as the Trans-Himalaya, where species often have overlapping distributions and similar prey bases. Non-invasive genetic techniques, especially mitochondrial cytochrome b sequencing, offer a robust solution by allowing unambiguous species classification from faeces samples (Taberlet et al., 1999). These methods are now widely employed in carnivore ecology, offering accurate species identification, individual genotyping, and population assessment (Kelly et al., 2012; Rodgers & Janecka, 2013). For the Himalayan brown bear, however, such tools assume greater significance given the fragmented nature of its distribution, coupled with the need for precise ecological information for effective conservation.

Despite growing ecological interest in Himalayan brown bears elsewhere in South Asia, no systematic study of diet had been conducted in the Indian Trans-Himalaya before the present work.

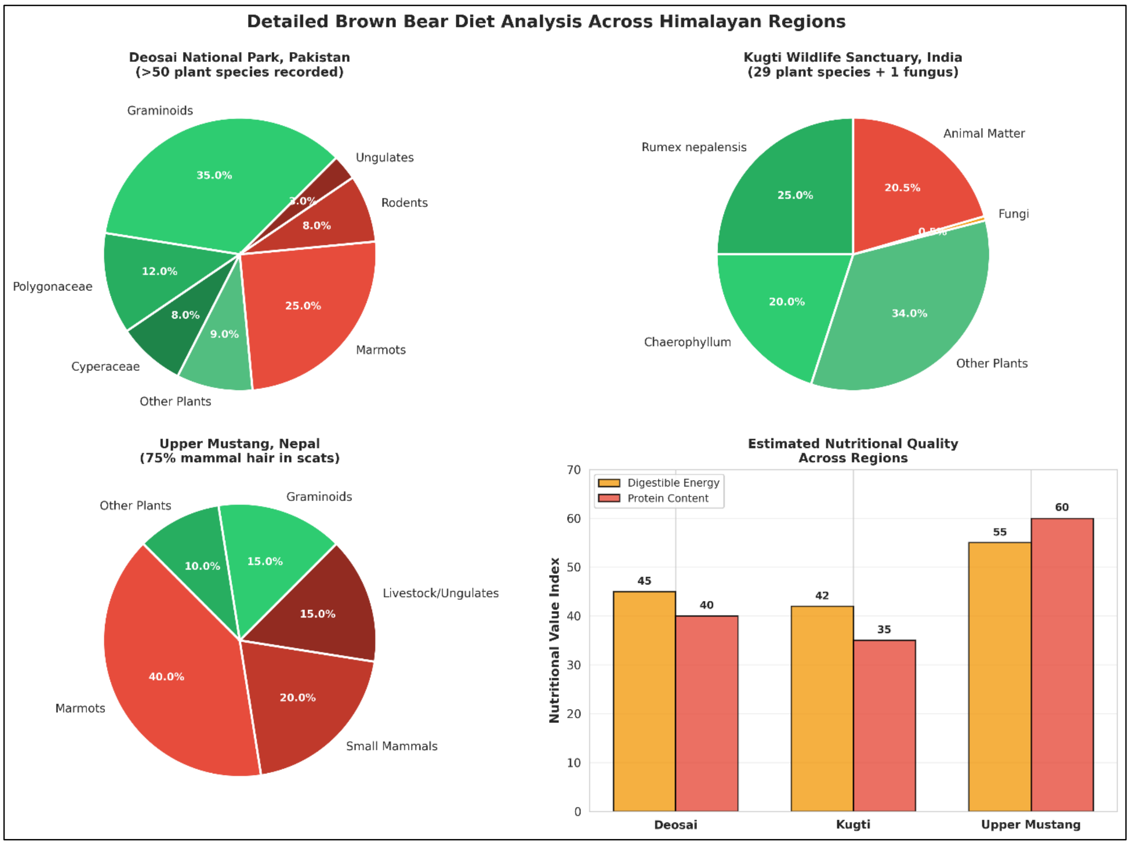


Figure 4.1: Regional differences in Himalayan brown bear diet composition across Pakistan, India, and Nepal.

The present study, in this context, integrates large-scale field sampling, molecular species identification, and detailed micro-histological diet analysis in a comprehensive assessment of the feeding ecology of the Himalayan brown bear in Ladakh. Synthesising non-invasive genetic techniques with fine-scale dietary quantification, the research aims at a scientifically sound and spatially explicit understanding of the brown bear's trophic ecology in one of the harshest environments in the world. The results provide important clues on resource use patterns, seasonal dietary shifts, reliance on livestock and anthropogenic subsidies, and ecological constraints shaping the persistence of Himalayan brown bears in the Trans-Himalayan region. This chapter thus fills a critical knowledge gap and lays the essential foundation for conservation planning, conflict reduction, and long-term monitoring of this endangered subspecies in India.

4.1 Materials and Methods

4.2 Study Area

This study was conducted in the high-altitude region of Ladakh, a cold-arid desert environment with ecological peculiarities in the Trans-Himalayan zone between the Greater Himalaya and the Karakoram ranges. The landscape features extreme environmental conditions such as low atmospheric pressure, severe cold, strong winds, low precipitation, and high solar radiation (Bhasin et al., 2002). Elevations range from 3,000 to 5,500 m asl, thus depicting steep altitudinal gradients in vegetation, climate, and resource availability.

Vegetation in Ladakh consists of a mosaic of diverse vegetation types that supports a diverse assemblage of wildlife. In total, eight main categories of vegetation have been recognised in the region: salt marshes, semi-deserts and steppes, shrublands, alpine scree and boulder fields, alpine grasslands, water bodies, subnival zones, and animal resting habitats (Dvorský et al., 2011). Of these, scree habitats and alpine grasslands are the most species-rich in terms of their overall number of species and provide key foraging habitats for herbivores and omnivores. Alpine pastures, valley bottoms, riverine scrub, and anthropogenic habitats around remote settlements introduce additional ecological heterogeneity.

The region harbours a guild of large and meso-carnivores, including the Himalayan brown bear (*Ursus arctos isabellinus*), snow leopard (*Panthera uncia*), grey wolf (*Canis lupus chanco*), red fox (*Vulpes vulpes*), and large populations of free-ranging domestic dogs. Such a multiplicity of sympatric carnivores complicates field-based identification of scats themselves (Mishra et al., 2017; Rathore, 2008), necessitating molecular confirmation techniques. Livestock-based agro-pastoralism is the dominant livelihood across the region, leading to significant spatial overlap between wildlife and herder communities. The resulting potential for livestock depredation complicates the determination of natural vs. anthropogenic dietary sources.

Field sampling was conducted over four key protected areas and their associated landscapes:

1. Hemis National Park (HNP)

2. Changthang Cold Desert Wildlife Sanctuary (CCDWS)

3. Karakoram Wildlife Sanctuary (KWS)

4. Kargil and Zanskar landscapes

Taken together, these regions form a large environmental gradient in which dietary variation can be explored over a range of habitat types and pastoralist systems.

4.3 Methodology

A systematic, non-invasive sampling protocol was implemented in consultation with the Wildlife Protection Department, Ladakh. For the 2019-2020 field season, scat samples were collected using a grid-based survey design to ensure that there was spatially unbiased coverage across the vast and topographically complex landscape.

4.3.1 Grid-Based Spatial Sampling Framework

A 5 × 5 km grid, that is, 25 km² per cell, was overlaid on the study area independent of any prior knowledge regarding species presence. The design ensured that search effort was systematically distributed and minimised the likelihood of sampling bias. From the landscape, a total of 275 grid cells surveyed amounted to the equivalent of 100 km² across all accessible terrain within logistic constraints.

4.3.2 Transect Surveys

Three or more randomly oriented transects were surveyed within each selected grid cell. Transects followed:

• Wildlife trails

• Livestock movement paths

• River valleys

• Ridge lines and saddles

• Areas known to be used by bears based on ranger knowledge

• Camera trap locations and historical conflict areas

All the transects were systematically surveyed for direct and indirect carnivore signs such as scats, tracks, scrapes, digs, hair, feeding signs, carcass remains, etc. In the case of Himalayan brown bear, the scats were differentiated by size, segmentation, volume, color, and contents based on morphological criteria given by Rathore (2008) and Menon (2014). Few brown bears signs were collected from Changthang WLS and Nubra valley.

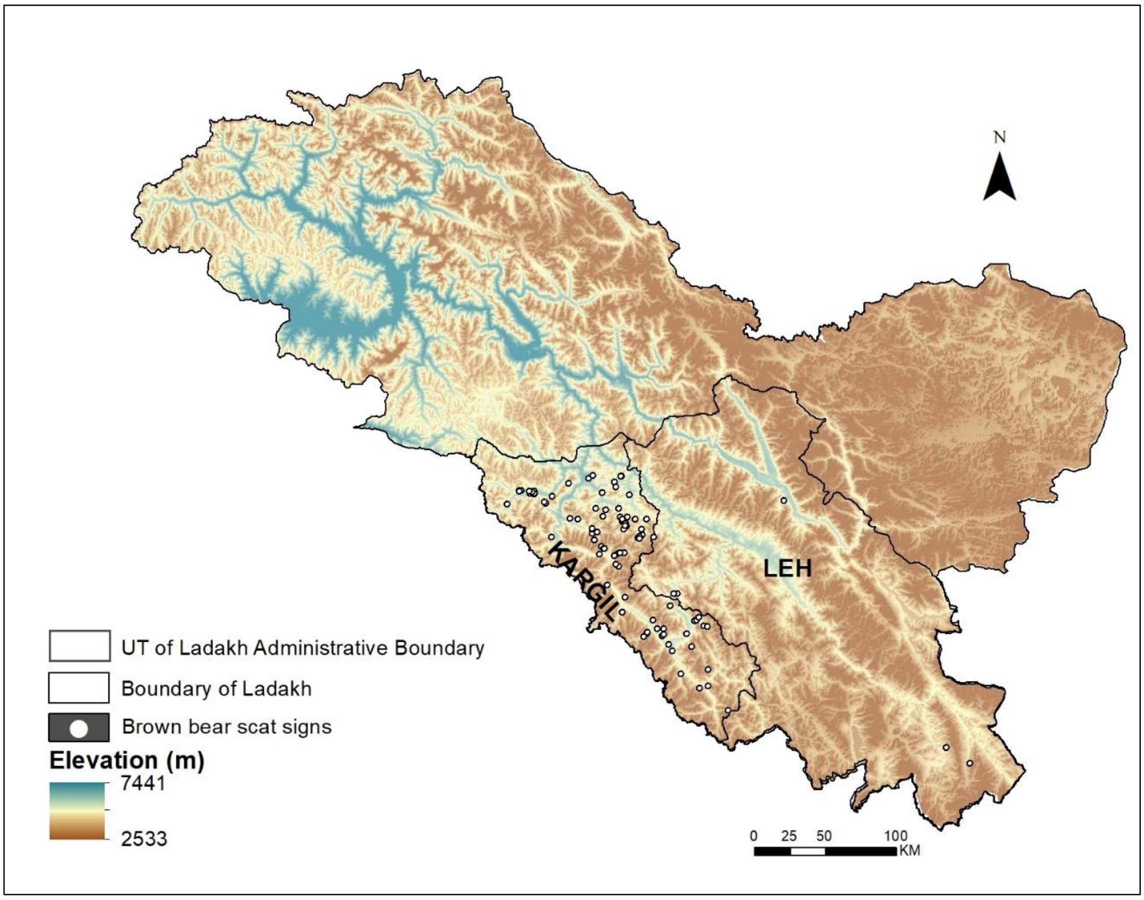


Figure 4.2: Spatial distribution of scat signs of the Himalayan brown bear across the Union Territory of Ladakh. Points reflect confirmed locations of scats that are primarily concentrated in Kargil District, aligning with known brown bear home ranges.

4.3.3 Scat Preservation

Within these 275 surveyed grids, 1,380 carnivore scats were collected. Of these, 408 scats were identified in the field as putative brown bear scats. Fresh scats were sub-sampled using sterile spatulas to collect the mucosal layer, which is the primary source of host DNA. Samples were then placed in individual zip-lock or paper bags, labelled with GPS coordinates, elevation, date, collector name, substrate type, and visual descriptors. Silica desiccant was used to keep dry scats. All samples were stored at low temperatures and transported to the Molecular Ecology and Conservation Genomics Laboratory, Wildlife Institute of India, Dehradun, for genetic analysis. This protocol follows established guidelines for non-invasive genetic sampling (Waits & Paetkau, 2005; Taberlet et al., 1999; Murphy et al., 2002).

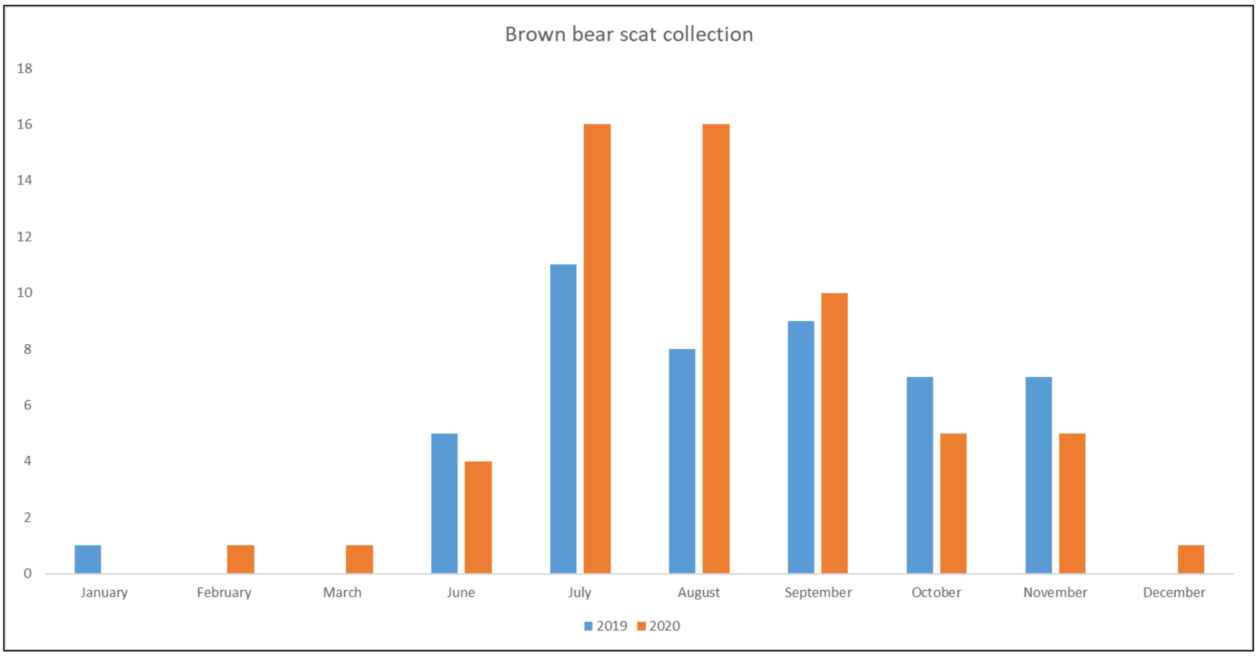


Figure 4.3: Monthly brown bear scat collections during 2019 and 2020 show pronounced seasonal peaks during summer and early autumn. These increased collections between July and September reflect higher bear activity and better scat detectability during peak foraging periods.

4.4 DNA Extraction and Species Identification

Because of the high potential for misidentification in multi-carnivore landscapes, all putative brown bear scats underwent molecular species confirmation with mitochondrial DNA markers. Universal marker was used.

4.4.1 DNA Extraction

Two extraction protocols were employed according to scat condition:

1. QIAamp DNA Stool Mini Kit (Qiagen, Germany)

• Standard protocol that will be modified to enhance inhibitor removal.

• Extracted about 200 mg of outer-layer scat.

2. Guanidinium thiocyanate-silica (GuSCN) methThis is particularly useful for old or degraded samples (Boom et al., 1990). Negatives were extracted for each batch.

4.4.3 mtDNA Amplification

Species identification was performed using universal mitochondrial cytochrome b (MCB) primers (Irwin et al., 1991). The reaction mixture of PCR (10–25 µL) contained:

• 1× PCR buffer

• 0.25 µL 25 mM dNTPs

• 1.0 µL BSA

• 0.125 µL DreamTaq polymerase

• 0.50 µL each of forward and reverse primers

• 2 µL template DNA

Cycling conditions:

• 95°C for 15 min (initial denaturation)

• 40 Cycles:

• 95°C 30 s

• 50°C 30 s

• 72°C 60 s

• Final extension: 72°C 10 min

The products from the PCRs were then visualized on 2% agarose gels. Successful amplicons were sequenced bi-directionally on an ABI 3500XL system.

4.4.4 Sequence Validation

Chromatograms were cleaned manually using Geneious/Chromas and compared to GenBank using BLASTn (Altschul et al., 1990). A sequence was considered a confirmed brown bear sample when showing ≥98% identity to brown bears.

4.4.5 Final dataset:

Of these 408 putative scats, only 107 were genetically confirmed to be brown bear (26.2%). This constitutes a high field misidentification rate, which is comparable to other similar studies (Janecka et al., 2008; Mondal et al., 2012). Only these 107 genetically confirmed samples formed the dataset for dietary analysis.

4.5.6 Scat Processing and Micro-Histological Diet Analysis

Diet analysis was conducted by micro-histological examination of hair, and the plant remains were identified according to Brunner & Coman, 1974), Kshirsagar et al., 2009 and Bahuguna et al., 2010.

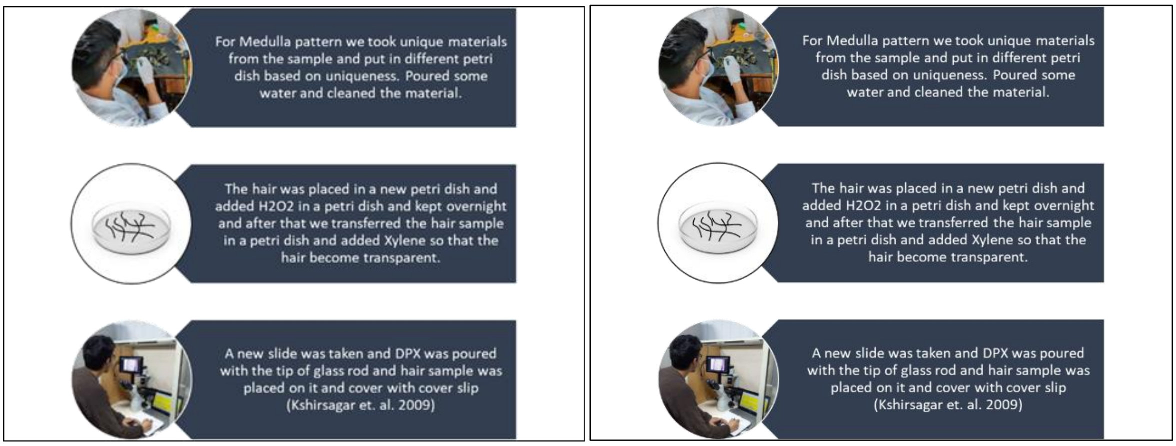


Figure 4.4: Workflow of hair sample preparation to view medulla patterns, including cleaning, chemical clearing, and slide mounting that effectively renders the hair structure transparent for microscopic observation to be conducted with accuracy according to set guidelines.

Each confirmed scat was weighed, measured, and photographed for record. Careful examination using forceps of food particles such as hair, bone/teeth, seeds, vegetative fibres, insects, and man-made fragments: plastic, thread, and paper. All fractions were set aside for microscopic examination with expert identification.

4.5.7 Hair Identification

Hair fragments were analyzed using:

• Cuticular scale patterns were determined using nail-polish impressions, according to Quadros & Monteiro-Filho, 2006.

• The medullary patterns were enhanced by a chemical bleaching procedure using H_2O_2, xylene and then DPX.

Each hair sample was compared with:

A hair reference library for the wild and domestic mammals of Ladakh was developed (Bahuguna et al., 2010) and a list of 35 mammals guard hair prepared by the Wildlife Protection Department, Ladakh team.

4.5.8 Plant Material Identification

Plant remains were identified by using:

• Flora of Ladakh by Dvorsky et al. 2018.

Expert consultation: Dr. G.S. Rawat

• Comparative morphological traits include epidermal patterns, silica bodies, and stomatal architecture.

• Identification of species was done to the closest possible taxonomic level: species > genus > family.

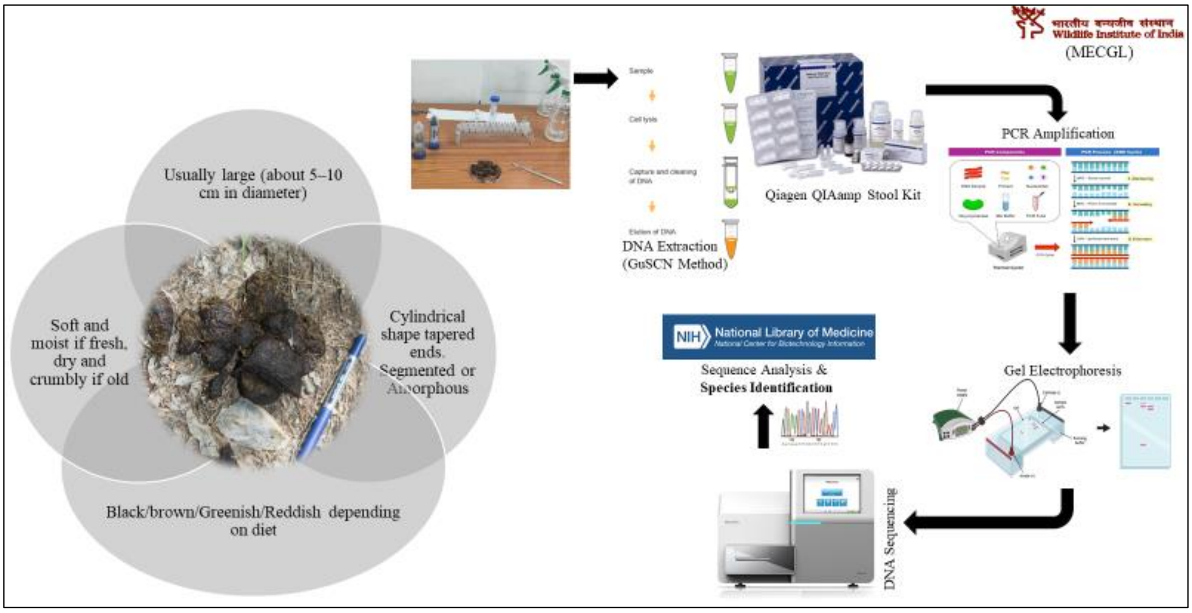


Figure 4.5: General overview of the field identification features of brown bear scats and subsequent laboratory workflow for genetic analysis. The diagram summarizes scat characteristics, DNA extraction, PCR amplification, electrophoresis, sequencing, and species confirmation procedures.

Quantifying diet composition

Dietary composition was assessed by:

Frequency of Occurrence (FOC)

FOC was calculated as:

$$FOC = \frac{\text{Number of scats containing item i}}{\text{Total number of scats} \times 100}$$

Although, as Klare et al. (2011) pointed out, the FOC can overrepresent small items, it is the most used metric worldwide in studies of bear diets.

Seasonal Classification

Scats were sorted into collection date:

• Summer: May-August

• Autumn: September-November

Spring samples were insufficient and excluded.

Minimum Sample Size

Sufficient sample size was assessed by Trites & Joy (2005), which suggest that ≥59–94 samples for reliable seasonal diet estimation in bears. In our study 108 DNA positive brown bear samples were used comprising of 61 scats (summer) and 48 scats (Autumn).

4.6 Ethical Considerations and Permissions

All field sampling was conducted under:

• Wildlife Protection Act, 1972 with permission granted by Wildlife Protection Department, Ladakh

• The work is supported by Department of Wildlife Protection, Leh and implemented under the National Mission for Himalayan Studies (No. NMHS/2016-17/MG13/06) in Union Territory of Ladakh.

• Institutional approvals from the WII - Wildlife Institute of India

Figure 4.6: Examples of key dietary remains recovered from Himalayan brown bear scats, including intact faecal matter, plant seeds, mammalian hair, small mammal bones, and microscopic hair medulla structures.

4.7 Results:

Large-scale non-invasive sampling across Ladakh yielded a sizable dataset for analysing the dietary ecology of the Himalayan brown bear. Overall, 1,380 carnivore scats were collected from 275 grid cells sampled during the 2019-2020 field season. Field-based morphological screening identified 408 samples as putative brown bear scats. However, since Ladakh supports a multi-carnivore assemblage that also comprises wolves, foxes, snow leopards, and free-ranging dogs, and given the high degree of overlap in scat size, shape, and content, putative identifications required genetic confirmation. Molecular screening using mitochondrial markers revealed that only 107 of the 408 putative brown bear scats (26.2%) were correctly identified in the field, and the remaining were from sympatric carnivores. This high misidentification rate confirms earlier studies conducted in multi-carnivore landscapes

(Janecka et al., 2008; Farrell et al., 2000; Mondal et al., 2012) and reinforces the importance of genetic validation. Dietary analysis proceeded using only the 107 genetically confirmed scats.

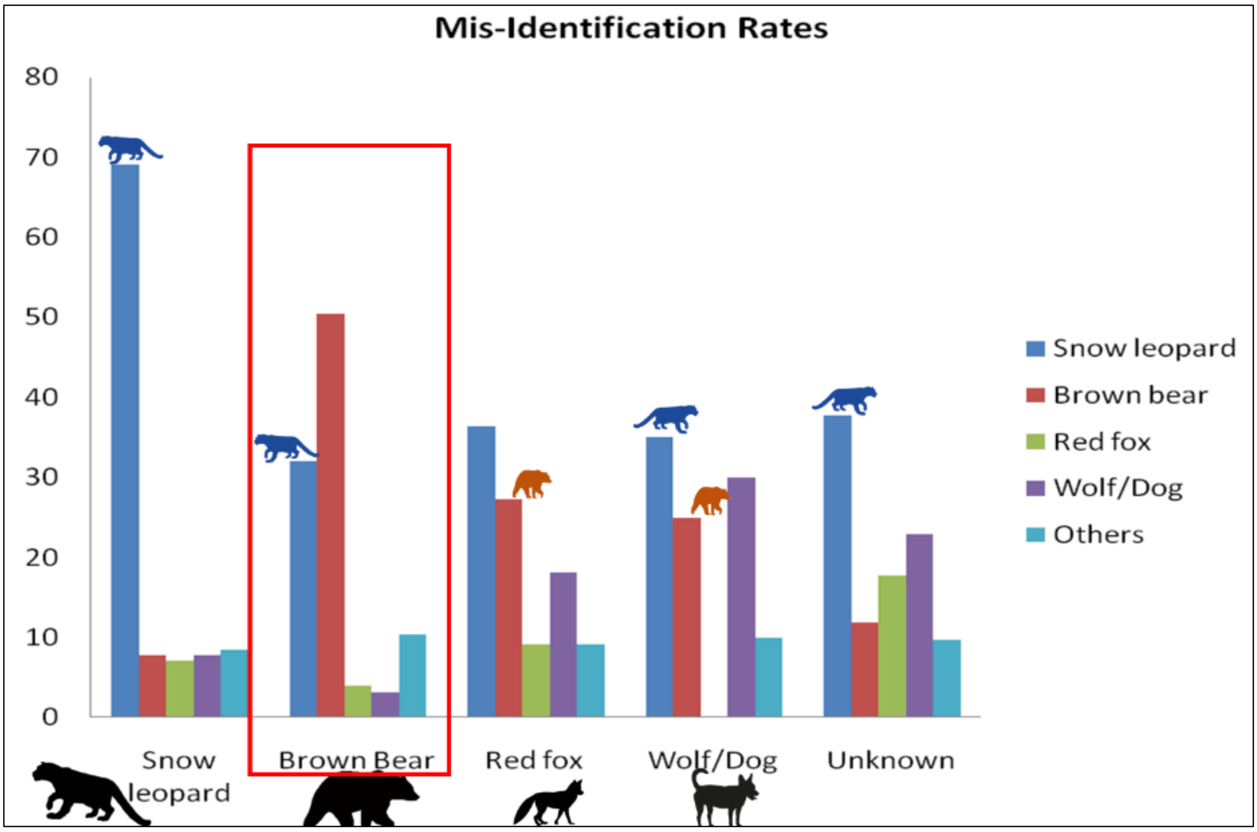


Figure 4.7: Comparison of field-based misidentification rates of carnivore scats among species, emphasizing particularly high errors for brown bear samples. These findings emphasize how genetic validation is necessary to correctly identify sympatric carnivore species within mountainous landscapes.

Analysis of the complete dataset showed that the Himalayan brown bear in Ladakh exhibited a wide omnivorous feeding strategy dominated by plant-based foods but supplemented with significant animal-derived components. In the pooled sample across seasons, plant matter formed the largest share of dietary items in 46% of all scats analysed. This high reliance on vegetation agrees with global patterns observed in brown bears, where plant foods often make up the dominant diet component when vertebrate prey is scarce. Vegetative items included graminoids, shrubs, forbs, seeds, and fruiting bodies, identifying the array of alpine and subalpine flora encountered by the bears in their foraging season. Grasses were the most common plant item encountered and occurred in 33.33% of scats, while Rosa species occurred in 25% of scats. Other plant taxa, including Salix, Poa, Artemisia, Carex, and Elymus, occurred at lower frequencies but once again cumulatively contributed to the herbivorous diet composition.

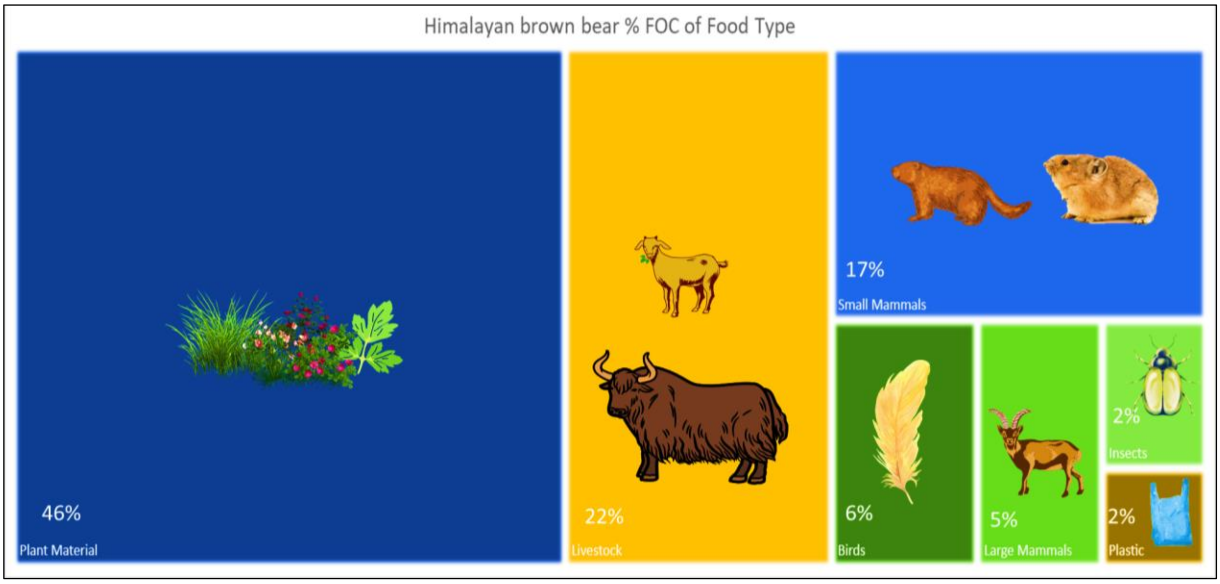


Figure 4.8: Proportional contribution of major food categories to the diet of the Himalayan brown bear: dominance of plant material, followed by livestock and small mammals. This treemap visualizes the relative frequency of occurrence, indicating the general omnivorous foraging strategy of the species.

Animal matter also made up an important component of the diet. Livestock remains, mostly from goats, sheep, yaks, and dzo, were recorded in about 22% of scats, representing significant interaction between brown bears and pastoralist systems. The presence of livestock-derived hair, bone fragments, hooves, and teeth suggest both scavenging of carcasses and possible predation events. Our result is an important finding given the socioeconomic importance of pastoralism in Ladakh and reinforces local perceptions of brown bears as contributors to livestock loss. Small mammals comprised 17% of the diet, and marmots, pikas, voles, and unidentified rodents formed the majority of wild prey species detected. The prevalence of small mammals in the diet reflects their accessibility in alpine meadows and steppe habitats, particularly during summer months when marmot colonies are active. Large wild mammals such as ibex and bharal appeared infrequently, at 5%, and their presence likely reflects scavenging rather than active predation, given the energetic costs associated with hunting large ungulates in steep terrain. Birds composed 6% of the diet, primarily through feathers, bone fragments, and occasional eggshell remains. Although their overall contribution was modest, the presence of bird material indicates opportunistic predation on ground-nesting species or scavenging of bird carcasses.

Insects were present in 2% of the scats, and most of them were beetles and grasshoppers. Their frequency of occurrence was low, but consumption of such invertebrates is common among alpine and temperate brown bears and may be an important source of micronutrients during the early summer. Of more specific ecological and conservation concern, plastic was found in 2% of scats. The presence of plastic fragments, along with incidental pieces of cloth, thread, and other anthropogenic debris, suggests that bears forage close to human settlements, garbage pits, tourist camps, or army ration dumps. This finding underlines an increasing impact of human refuse on wildlife diets within remote high-altitude ecosystems and points out a need for better waste disposal in sensitive habitats.

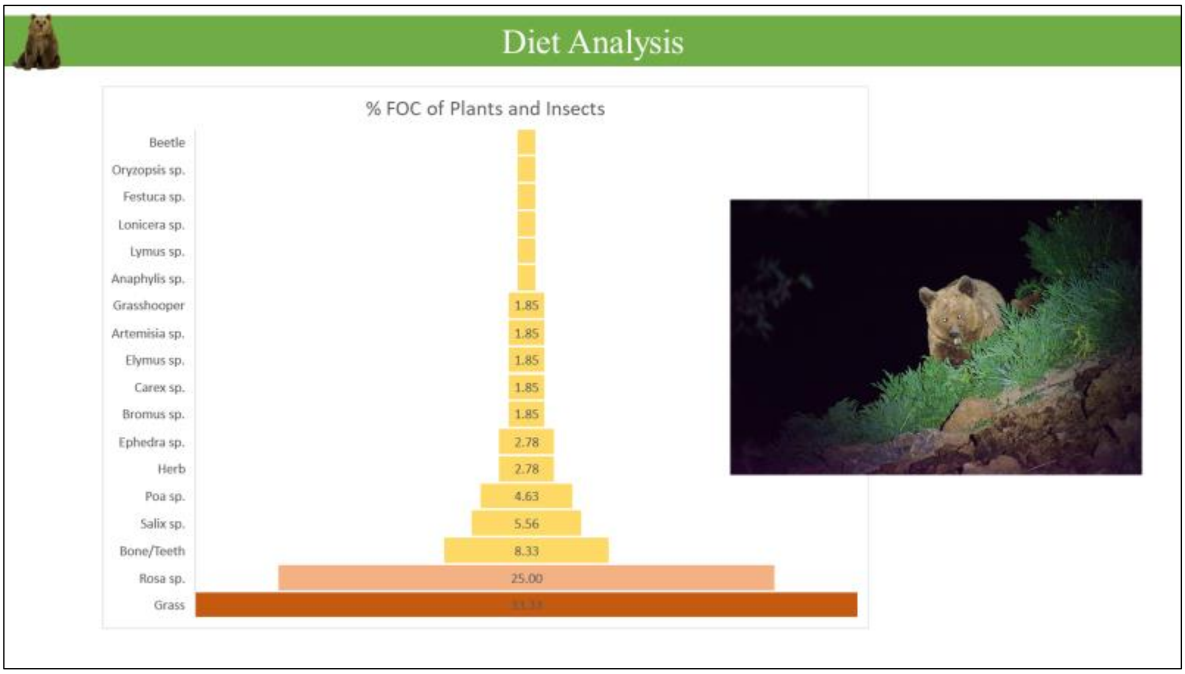


Figure 4.9: Frequency of occurrence of plant and insect taxa in Himalayan brown bear scats, with grasses and Rosa species being the dominant dietary components. The chart shows the relative contribution of each taxon, thereby showing dependence of the species upon various alpine vegetation.

4.7.1 Seasonal Diet

The dietary composition varied sharply among seasons. In summer (May-August), vegetation is at peak productivity, and marmots, as well as other small mammals, are active; brown bears showed the widest dietary breadth. The summer diet included a wide array of plant species such as graminoids (Poa, Festuca, Elymus), shrubs (Rosa, Salix, Lonicera), forbs, and seeds. Grasses and seeds dominated these and represented important carbohydrate-rich resources during post-hibernation recovery. Plant material in general constituted more than half of the dietary items found, showing the abundance and digestibility of early-season vegetation. Animal-derived items also appeared but with lower frequencies. Small mammals, marmots, birds, insects, and occasional remains of livestock occurred irregularly in summer scats and together only represented a modest fraction of the total diet. The relative rarity of animal items in the summer would suggest that bears rely heavily on easily accessible vegetation to support metabolic recovery and rebuild body mass after hibernation.

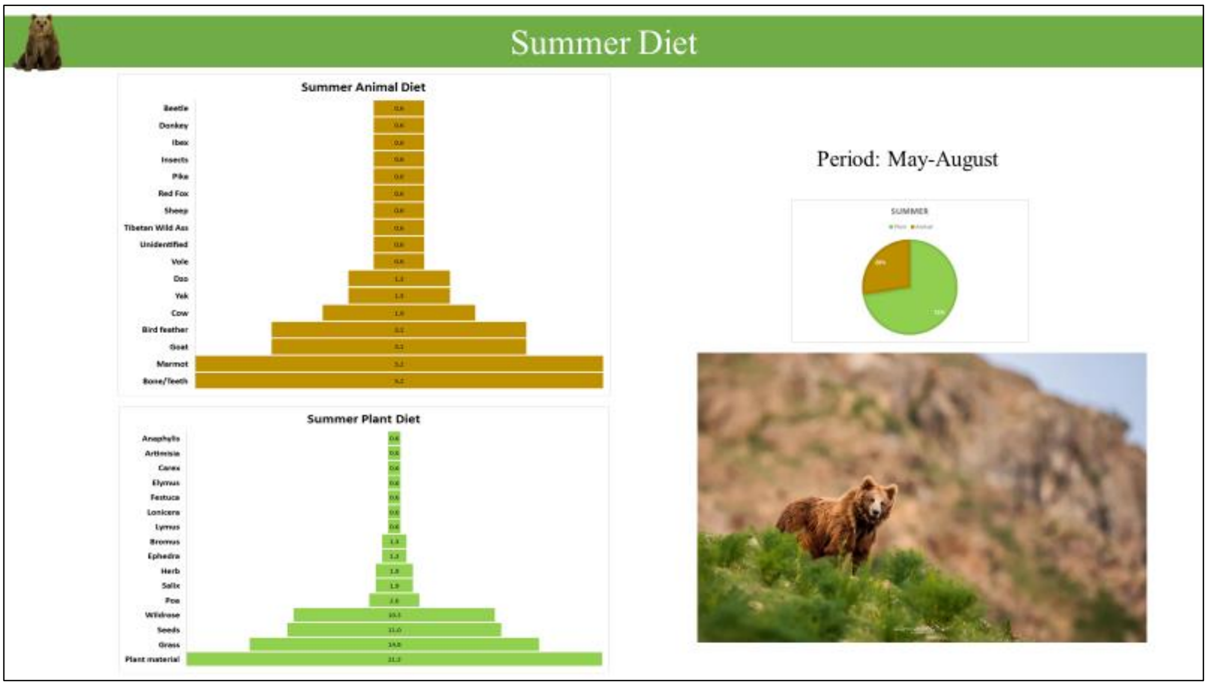


Figure 4.10: Seasonal composition of the Himalayan brown bear's summer diet, showing a predominance of plant material alongside key animal prey like marmots and livestock.

In contrast, the autumn period was characterised by a more selective and nutritionally focused diet. Plants dominated the diet, comprising c. 80% of dietary detections, but diversity of plant taxa decreased from summer. Graminoids (21%) and Rosa spp. (18%) remained important, while seeds, Urtica, Artemisia, and remains of woody shrubs comprised other plant-based food items. This reflects the senescence of many herbaceous taxa and an increased importance of energy-rich plant parts - seeds and woody shrubs - as the region transitions to winter. Animal matter increased during this period, relative to summer. Remains of livestock increased to 12% of all occurrences and likely reflect increased scavenging opportunities during livestock migration, accidental mortalities, and carcass discard practices. Small mammals contributed 9%, while large mammals comprised 5%, indicating a slight intensification of carnivorous behaviour, as bears built fat reserves prior to denning. Anthropogenic material, including plastic, continued to persist in autumn samples, further documenting bears' use of human-dominated landscapes during times of declining natural food availability.

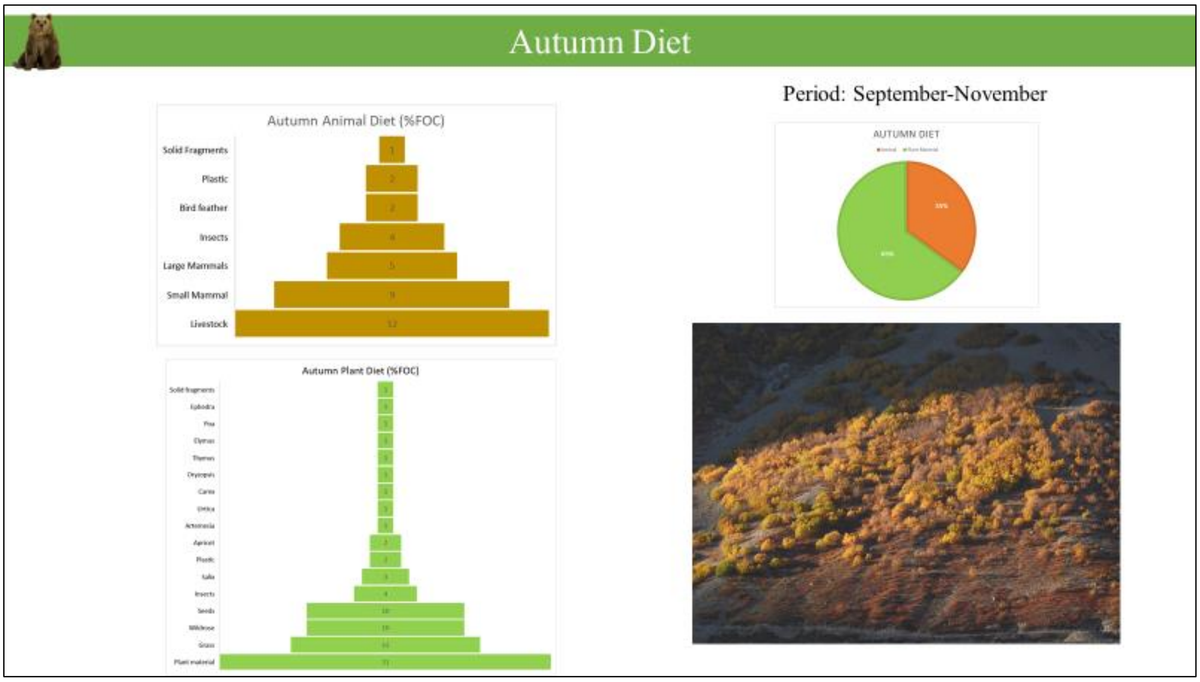


Figure 4.11: Autumn dietary composition of the Himalayan brown bear, highlighting increased reliance on livestock and small mammals alongside diverse plant resources. This shift from September to November corresponds to pre-hibernation foraging strategies driven by energy maximization and resource availability.

Spatial analysis of diet composition across different valleys revealed marked regional variation. Plant material was the dominant dietary component in all regions but varied in proportional contribution. In Shargole-Khangral Valley, plants appeared in 63% of scats and reflected the relatively higher availability of shrub and grass vegetation. Both Zanskar and Kargil valleys also showed high plant frequencies at 59 and 48%, respectively, whereas Suru Valley showed somewhat lower plant contributions due to greater dependency on livestock areas. Small mammals contributed substantially to Kargil Valley (24%) and Zanskar (15%), consistent with the presence of extensive marmot populations in these regions. Livestock contributions were highest in Suru Valley (29%) and Zanskar (18%), suggesting greater overlap between bears and pastoralist communities in these areas. Shargole-Khangral (14%) and Drass (13%) also revealed moderate levels of livestock consumption, while Kargil Valley showed relatively lower but still notable livestock signals at 10%. Bird remains showed up sporadically across all regions, with the exception of Drass Valley, where no avian material was detected. These regional differences reflect heterogeneity in rangeland systems, prey distribution, vegetation composition, and intensity of human-bear interactions in Ladakh.

The FOC analysis of each food item also reflected the diversity of the diet of the Himalayan brown bear in Ladakh. Among the plant items, grasses had the highest frequency of occurrence at 33.33%, followed by Rosa at 25%. The presence of many low-frequency taxa like Artemisia, Carex, Anaphyllis, Festuca, and Ephedra depicts the wide spectrum of plant species consumed, even in small amounts. Similarly, detection of two types of insects, namely grasshoppers and beetles, together with several large mammal species and diverse small mammals, indicated a wide omnivorous tendency typical of brown bears in highly seasonal environments.

These findings collectively suggest a flexible and opportunistic foraging strategy of Himalayan brown bears in Ladakh, driven by extreme seasonality, spatial heterogeneity of resources, and high overlap with human systems. Predominance of plant matter is supplemented by significant contributions from livestock, small mammals, and anthropogenic materials, indicating that this species is adapting to the resource-limited environment while opportunistically utilising both natural and human-derived food sources. Understanding these dietary patterns constitutes an integral part of ecological pressures exerted on this threatened subspecies and builds a foundation for interpreting the causes of human-bear conflict and possible impacts of environmental change on brown bear foraging behaviour in the Trans-Himalayan region.

Genetic confirmation highlighted significant patterns in field misidentification: of the 408 scats labelled as brown bears based on morphology, the majority were reassigned to snow leopard, and a large number were assigned to wolf/dog and red fox; only 26.2% were, in fact, bear scats, confirming that size-, segmentation-, and content-based identification alone are unreliable in a multi-carnivore system such as Ladakh. We further observe that scats collected from rocky substrates or valley-bottom areas show the highest frequencies of misidentification, probably due to overlap in dietary components such as vegetation fibres and hair of small mammals. These findings underscore the need for molecular validation in dietary studies and illustrate the fact that conventional field-based identification, if used in the absence of genetic confirmation, would have considerably inflated the estimates of carnivory and livestock depredation.

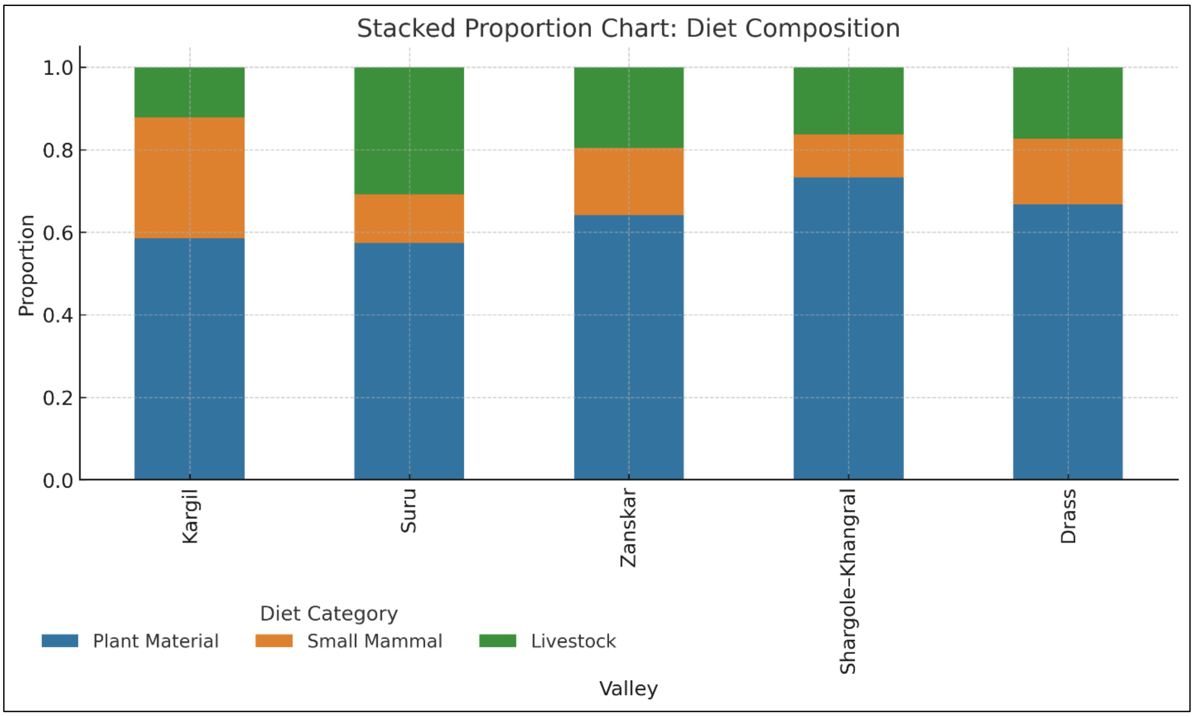


Figure 4.12: Comparative dietary composition of Himalayan brown bears across five valleys, showing consistent dominance of plant material with variable contributions from small mammals and livestock.

Regional diet composition suggests that the Himalayan brown bears have significant spatial dietary plasticity driven by valley-level differences in vegetation, prey availability, livestock density, and human influence. Plant material prevails as the dominant and most stable food resource throughout the region. Small mammals and livestock create important secondary components, with livestock reliance particularly raised within the Suru, Zanskar, and Shargole-Khangral valleys with intensive pastoral systems. Plastic and bird feathers are critical dietary signals of human presence and scavenging behaviour. The land-use map indicates that areas dominated by barren land and rangeland cover limit the natural forage available, probably forcing bears into greater contact with the human landscape and livestock resources.

Table 4.13: Percentage Frequency of Occurrence (% FOC) of plant and insect food items in genetically confirmed Himalayan brown bear scats.

Sr. No.	Food Item(s)	% FOC
1	Grass	33.33
2	*Rosa* spp.	25.00
3	Bone/Teeth	8.33

4	*Salix* spp.	5.56
5	*Poa* spp.	4.63
6	Herb	2.78
7	*Ephedra* spp.	2.78
8	*Bromus* spp.	1.85
9	*Carex* spp.	1.85
10	*Elymus* spp.	1.85
11	*Artemisia* spp.	1.85
12	Grasshopper	1.85
13	*Anaphyllis* spp.	1.85
14	*Lymus* spp.	1.85
15	*Lonicera* spp.	1.85
16	*Festuca* spp.	1.85
17	*Oryzopsis* spp.	1.85
18	Beetle	1.85

Direct observations of brown bears feeding on plants such as Heracleum spp., Salix spp., Lonicera spp., Prongos spp., and Rosa spp. was uncovered throughout the study.

4.8 Discussion:

The plant-based feeding strategy is dominant in the dietary analysis of the Himalayan brown bear, where vegetation represents 46% of total occurrences and is further supported by the high frequency of specific plant items like grass, at 33.33%, and Rosa species at 25%. Animal-derived components comprise livestock, 22%; small mammals, 17%; large mammals, 5%; and birds, 6%. This shows an omnivorous but strongly herbivorous-leaning trophic pattern and points out the ability of the species to exploit natural and opportunistic food resources effectively. Plastic detection in 2% of scats draws attention to an emerging anthropogenic influence on feeding behaviour and may suggest access to human-derived food subsidies that can carry ecological and physiological risks. Across valleys, this consistent high fraction of plant matter in the diet reiterates the role of vegetation as a key dietary element for brown bears across the Trans-Himalayan region. Collectively, these findings make the Himalayan brown bear not only an omnivorous forager but also a potential ecological engineer contributing to seed dispersal, nutrient redistribution, and vegetation regeneration in this fragile high-altitude ecosystem.

In contrast, brown bears in Spain's Cantabrian Mountains showed plant material comprising 84.1% of total volume during spring but with greater seasonal variation and higher animal protein consumption during other seasons (Clevenger et al., 1992). Scandinavian populations show much higher animal protein consumption, with some populations deriving 65-87% of their annual energy from ungulates (Dahle et al., 1998). The extreme herbivorous tendency of Himalayan brown bears likely reflects the peculiar constraints of high-altitude ecosystems where animal protein sources are limited and plant productivity is concentrated into brief growing seasons. This is a remarkable example of dietary specialisation within a species renowned for its omnivorous flexibility.

The dietary analysis showing 46% vegetation occurrence with high frequencies of grass (33.33%) and Rosa species (25%) is in strong agreement with the already established research in the feeding ecology of the Himalayan brown bear. Rathore et al. (2014) reported that plant matter occurred in 79% of scat within the Kugti Wildlife Sanctuary, stating that bears lead a "predominantly herbivorous lifestyle". Further justification for this herbivorous tendency emanates from Nawaz et al., 2019, who found bears consuming over 50 plant species in Deosai National Park, with graminoids making up the bulk of the diet across eight major plant families, including Poaceae, Polygonaceae, and Cyperaceae.

Animal matter ingredients identified include 22% livestock, 17% small mammals, 5% large mammals, and 6% birds; this points to the omnivorous capacity of the species, with herbivorous dominance maintained. According to Nawaz et al., 2019, while animal matter comprised 36% of the diet content, it contributed about half of the digestible energy because of its higher nutritional value. Of interest was their identification of golden marmots as the primary source of meat for bears within their study area. However, regional differences are considerable. For instance, Aryal et al., 2012 reported a different pattern in Upper Mustang, Nepal, where the bear was “predominately carnivorous”, with only 8% of the faecal volume constituted by plant matter, with the hair of small mammals being identified as the most common item inside the faecal matter (75%). This difference underlines the adaptive feeding strategy of Himalayan brown bears across diverse ecological scenarios.

Plastic found in 2% of the scats manifests a disturbing anthropogenic impact on feeding. As was proven by Kavčič et al., 2015, access to human-subsidised food may change the large-scale composition of bear diets and behaviour. Supplemental food in Slovenia represented 34% of annual estimated dietary energy content and thus showed that human impacts can fundamentally reshape bear feeding ecology. The presence of livestock in the diet (22%) indicates potential for human-bear conflict, as documented by Rathore et al., 2014, who noted that "overuse by livestock, decline in local herbs, and excessive extraction of high-altitude medicinal plants" pose threats to fragmented brown bear populations.

The frugivorous habits of Himalayan brown bears well support their status as potential ecological engineers. García□Rodríguez et al. (2021) have demonstrated that brown bears that consume fleshy-fruited plants - 56% of faeces - play a "key role as seed dispersers" despite high levels of human disturbance. Shakeri et al. 2018 quantified this role, showing bears dispersed 12 fruit species with individual scats containing thousands of seeds, providing significant nutritional resources for granivorous small mammals.

The Himalayan brown bear is an important ecological engineer in high-altitude landscapes, playing a critical ecological role mainly through their contributions to seed dispersal and vegetation regeneration. The presence of numerous Rosa spp. seeds in bear scats and the appearance of seedlings at deposition sites provide evidence for effective long-distance dispersal and enhanced germination in nutrient-rich microsites generated by scat deposition. This leads to the persistence and spread of wild rose shrubs that are ecologically valuable and are widely utilised by diverse taxa, from pollinators up to large herbivores, and by local communities for rosehips, leaves, and stems. Brown bears disperse seeds throughout sparsely vegetated alpine terrain and redistribute nutrients, facilitating the recruitment of plants and increasing habitat heterogeneity, thereby reinforcing their functional importance within the Trans-Himalayan ecosystem.

High plant material proportion across valleys points to broader environmental constraints on brown bear diet. Bojarska et al. (2012) found that, at the global level, temperature and snow conditions were the most important factors determining diet composition in brown bear populations. Indeed, they reported that populations in sites with deeper snow and lower temperatures ate significantly more vertebrates and fewer invertebrates. Dietary patterns observed suggest sophisticated foraging strategies. Coogan et al., 2014 demonstrated that brown bears optimise their macronutrient intake by combining nutritionally complementary foods and that most available foods are high in protein relative to lipids or carbohydrates. This nutritional constraint offers one explanation for high plant consumption, as bears seek to balance protein-rich animal foods with carbohydrate-rich vegetation.

The findings have wide ramifications for conservation planning in the Trans-Himalayan region. Nawaz et al., 2019 said that due to a lack of fruits and relatively lower meat content, the estimated digestible energy available to brown bears in Deosai was the lowest documented for brown bear populations, which can account for the very low reproductive potential of this population. Fragile high-altitude ecosystem context underlines the importance of keeping natural food resources intact. Rathore et al., 2014 warned that habitat degradation through livestock overuse and medicinal plant extraction is threatening the very food base essential for the survival of the brown bear. The overall diet analysis confirms that the Himalayan brown bears are highly adaptable omnivores but with very strong herbivorous tendencies, therefore playing a crucial ecological role in seed dispersal and nutrient cycling against an increasing backdrop of anthropogenic pressures that require careful conservation management.

The high-altitude environment of Himalayan brown bears introduces many complications that have a direct bearing on food security and dietary strategies. Generally speaking, climate change threatens these populations because rising temperatures alter the distribution and phenology of alpine vegetation. Given altered precipitation patterns, snowfall, or changed timing of monsoons, plant growth and hence food may be seriously affected. Some of the key threats to food security observed for the bears in Kugti Wildlife Sanctuary included overuse by livestock, decline in local herbs, and high-altitude medicinal plants due to excessive extraction (Rathore, 2008). Thus, human-induced pressures add to natural challenges posed by the high-altitude environment and may pose formidable threats to this already fragmented population of brown bears. Livestock grazing in alpine meadows competes directly with the bears for vegetation resources, with possible reductions in the availability of favoured plant species during critical periods of foraging. The intensity of grazing pressure is likely to alter plant community composition, favouring those that are less palatable or nutritious for the bear while reducing populations of preferred forage plants.

Another major threat to Himalayan brown bear food security is the commercial collection of medicinal plants. Many high-altitude plants have medicinal value and are collected for traditional medicine or for commercial trade. Such extraction pressure might lower populations of plants that are also important bear food sources, adding further stress on already restricted food resources. Knowledge of the dietary ecology aids in conservation planning and habitat management. Their heavy reliance on plant materials places them in a vulnerable condition toward habitat degradation and disturbance in the composition of plant communities. Conservation efforts should focus on the protection of alpine meadows and forest ecosystems that provide vital vegetation resources. Habitat connectivity is another imperative for conservation. In mountainous terrain, suitable habitat is often fragmented and requires bears to move between different areas to access seasonal food resources. Maintaining corridors that allow safe movement between foraging areas is crucial to population viability and genetic diversity.

Improved Identification Techniques Hair-based identification with the use of reference slides is traditionally based on morphological features. However, DNA metabarcoding (Hacker et al., 2024) and molecular scatology (Laguardia et al., 2015) are used more frequently in modern studies for better species and prey identification. Valentini et al., 2009 show that DNA barcoding of the trnL approach identifies ~50% of plant taxa to species level from degraded samples. Analytical Considerations Your calculations of frequency of occurrence should be augmented with estimates of biomass. Klare et al., 2011 stress the fact that frequency methods are misleading and provide recommendations for the use of biomass calculations for more ecologically meaningful results. Overlapping bear and human uses, such as agriculture and livestock grazing, need special management to reduce conflicts and ensure the food security of both the bears and the people. Indeed, developing strategies that allow coexistence in a sustainable manner is indispensable for long-term conservation success.

4.8.1 Limitations

In turn, the dietary analysis benefits from advances in molecular techniques. Barba et al. (2014) developed DNA metabarcoding approaches that considerably enhance the accuracy of diet assessment to identify ≥60% of taxa to the genus/species level. This advance in methodology enhances our understanding of the complex dietary relationships documented in the Himalayan brown bear populations and shall be applied in future studies. The dietary ecology of the Himalayan brown bear in Ladakh reflects a complicated combination of environmental constraints, seasonal fluctuations, prey availability, and increasing interaction with human systems. This study provides the first genetically validated large-scale assessment of brown bear diet in the Indian Trans-Himalayan region and thus fills a critical knowledge gap with respect to the species' trophic strategy in one of its most challenging habitats. Results confirm that the Himalayan brown bears of Ladakh retain the global pattern of omnivory characteristic of *Ursus arctos* but with a peculiar dietary structure modulated due to the extreme environmental and socio-ecological conditions of the Trans-Himalayan landscape.

One salience of our findings is the preponderance of plant-based foods in the bears' diet, with vegetation collectively constituting nearly half of all dietary occurrences. This reliance on graminoids, shrubs, forbs, seeds, and other vegetative components is coherent with global studies showing that plant material often forms the majority in brown bear diets, even in carnivore-dominated systems (Bojarska et al., 2012). However, the specific composition of plant items, particularly the predominance of grasses (33.33%) and Rosa spp. (25%), is strongly reflective of Ladakh's cold-desert environment. Though spatially restricted, alpine grasslands and shrub patches provide highly accessible and digestible resources during a very short growing season. Diet compositions while consuming diverse herbaceous and shrub taxa agree with general trends in other Himalayan brown bear populations, for example, in Himachal Pradesh, where there has been a reported high reliance on forbs and roots (Rathore et al., 2014). These also contrast with those in more productive temperate systems, where fruits, berries, and nuts dominate a seasonal diet (Clevenger et al., 1992; Hilderbrand et al., 1999). The rarity of carbohydrate-rich fruits at high altitude can be one reason why Ladakh bears depend more heavily on grass and shrub species, which are common through summer but senesce rapidly before winter approaches them.

Integration of molecular techniques in this study reveals a far more detailed ecological narrative. The high rate of field misidentification, with only 26.2% of putative scats confirmed as bear, highlights one of the major problems in multi-carnivore landscapes. Misidentified scats often belonged to snow leopards, wolves, red foxes, and dogs, species that share overlapping habitats and sometimes similar prey bases. In the absence of genetic confirmation, dietary conclusions would have been biased toward overestimation of carnivory and livestock depredation, as in earlier studies where morphological identification alone inflated carnivore dietary overlap (Janecka et al., 2008; Mondal et al., 2012). The genetic component enhances the reliability of dietary inferences and sets a methodological benchmark for future research in the region.

Despite the high reliance on vegetation, animal-derived components comprised a substantial portion of the diet, with livestock making up 22% of occurrences and small mammals 17%. The strong presence of livestock is one of the most ecologically and socially significant findings. In a landscape where pastoralism is the principal livelihood, the utilisation of domestic species, whether through predation or scavenging, drives conflict and frames local perceptions of brown bears. While this study cannot distinguish predation from scavenging, the regular presence of livestock hair and bones suggests frequent use of domestic animals.

Seasonal patterns suggest further that livestock becomes particularly important during autumn-winter, when natural foods decline and carcasses from seasonal livestock movements become more available. Analogous patterns have been recorded in Deosai, where bears exploit livestock carcasses and seasonal hunting remains (Nawaz et al., 2019). Ecologically, the behaviour makes sense, large mammal carcasses are a source of highly digestible protein and fat, crucial for pre-denning energy accumulation, but it does increase dependency on human systems and heighten conflict risk.

Small mammals became an important natural prey group, featuring in 17% of all scats. Of these, the marmots and pikas that are known to be particularly abundant in alpine meadows were the most common detected species. Marmots, in particular, represent energetically profitable prey and a core diet component for brown bears both in Deosai and Mustang. The Ladakh scats showed the moderate but consistent presence of marmots, reflecting their availability and opportunistic predation by bears. However, compared to Deosai, their relative contribution seemed low in Ladakh, likely due to reduced marmot densities or different behavioural manifestations of bear foraging. Only 5% of scats showed large wild ungulate remains, a result which corroborates the fact that bears seldom hunt large game in this terrain but may scavenge on, or opportunistically feed on, carcasses. This is in keeping with global patterns where bears rarely hunt ungulates except under peculiar conditions such as predation on calves or when the latter are weakened.

Seasonal variation in diet reflects some of the most important adaptive strategies. The summer diet is the broadest, encompassing a wide variety of plant taxa and scattered animal items, a consequence of the abundance of fresh vegetation, insects, small mammals, and carrion. This season coincides with post-hibernation recovery, when bears have to replenish reserves of fat and restore gut microflora. Early summer dominance of grasses and seeds reveals that bears will switch quickly to whatever plant biomass is available; in northern European populations, for example, spring diets tend to be dominated by emergent graminoids (Stenset et al., 2016). The low incidence of animal matter in summer implies that bears focus on rapid consumption of easily digested vegetation at a time of year when metabolic demands are high and plant resources are plentiful.

In contrast, the autumn period is typified by a narrower dietary niche dominated by fewer plant species and, simultaneously, a greater proportion of animal matter. With vegetation senescence, bears increasingly rely on the carrion of livestock and small mammals and on the seeds. This pattern corresponds to global observations about a switch toward protein- and fat-rich food items in preparation for denning and building fat reserves (Erlenbach et al., 2014). The higher consumption of livestock in this season might be related to increased scavenging opportunities supported by greater energetic demands. The presence of anthropogenic material throughout all seasons points to the fact that bears forage close to human settlements, garbage pits, and army camps - an increasingly reported trend from other high-altitude regions facing expanding tourism and military deployment.

Spatial variation in diet across valleys further exemplifies ecological heterogeneity in Ladakh. High fractions of plant material were detected in the Shargole-Khangral and Zanskar valleys, reflecting easy access to grasslands and shrub patches there. In contrast, the Suru Valley, which had the most intensive pastoralism, showed the highest dependency on livestock, representing the high conflict potential. Variations among valleys in the contribution of small mammals, mainly marmots, matched their respective distribution on alpine meadows and scree slopes. These spatial variations emphasise the role of local-scale ecological and anthropogenic factors in driving the foraging decisions of bears and argue against treating Ladakh as a uniform ecological unit.

Although the detection rate of plastic in scats may seem minor at 2%, it has major ecological and conservation implications. Plastic ingestion indicates direct interaction with human waste and reflects expanding anthropogenic influence into previously remote areas. The physiological risks of plastic ingestion include intestinal blockage, reduced nutrient assimilation, and toxic exposure. These cases are parallel to observations reported for other regions where bears increasingly consume refuse due to deficient waste management. The presence of plastic, besides making the bears dependent on livestock, indicates a wider pattern of anthropogenic subsidisation that could affect natural foraging behaviours and eventually lead to decreased fitness over longer time spans. Overall, these dietary patterns reflect the broader ecological constraints of the Trans-Himalayan environment, which are characterised by limited, patchily distributed, and highly seasonal food resources. Brown bears in Ladakh adopt a flexible omnivorous strategy, conditioned by the short growing season, limited fruit production and high-quality vegetation, and the availability of abundant livestock and human-associated resources.

Chapter-5

To investigate dynamics of human-brown bear interactions, quantify magnitude and context of conflicts, assess eco-tourism potential, and develop mitigation strategies

5. Introduction:

Human-brown bear interactions are rising across the Himalayas, reflecting a wider global trend where large carnivores increasingly encounter human-dominated landscapes. As anthropogenic pressures expand in remote mountain ecosystems, the dynamics between humans and wildlife are becoming increasingly complex, leading to heightened conflict, altered behavioural responses, and significant implications for conservation. Globally, brown bear attacks and conflict situations have increased markedly over the past two decades, with 664 documented attacks across North America, Europe, and Asia between the years 2000 and 2015 (Bombieri et al., 2019). Although fatal attacks remain rare, increased encounter frequency reflects deeper ecological tensions arising from land-use change, infrastructure expansion, habitat fragmentation, attractant availability, and shifting human livelihood patterns (Can et al., 2014). These rising human-carnivore interactions epitomise some of the challenges that conservation managers face in balancing rural livelihood needs against biodiversity protection.

Conflict with brown bears is reported throughout Eurasia, from Scandinavia and Eastern Europe, through the Caucasus and Central Asia, to the Qinghai-Tibet Plateau and the Hindu Kush-Himalayan arc, reflecting the species' wide ecological tolerance and ability to persist in modified habitats. This persistence generally entails a suite of behavioural adaptations, including greater reliance on human-derived food sources, more frequent incursions into settlements, and exploratory investigations into new ecological niches that are often fraught with risk. Across North America and Europe, there are many examples showing that brown bears frequently exploit garbage dumps, attractants near rural dwellings, carcasses of livestock, and unsecured beehives, with structured patterns emerging for repeat visitation and high-probability conflict zones. Patterns emerging across the Himalaya echo these wider global trajectories, offering windows into bear responses even when cultural and ecological contexts change.

The Himalaya forms one of the most critical brown bear conservation landscapes within South Asia. Within India, the subspecies is confined to high-altitude areas of the Union Territories of Ladakh and Jammu & Kashmir, as well as to Himachal Pradesh. Conflicts are very high in plural sites despite their critically endangered status and small, fragmented populations. In Himachal Pradesh, for instance, a study in Lahaul Valley found that 64.8% of the total respondents reported bear-related conflict, dominated by crop depredation (30.6%) and livestock predation (6.2%) (Kumar et al., 2022). The authors further showed that houses within 500 m from the forest and the ones between elevations of 2,700 and 3,000 m recorded very significant conflict rates. Successive work by Kumar et al., 2025 further elaborates that the occupancy of brown bears in Himachal Pradesh is strongly governed by cold microclimates with reduced snow cover and alpine habitats, all conditions that are changing rapidly under climate change. These findings suggest that climate-induced changes in ecology can culminate in reduced hibernation duration, altered patterns of activity, and thus an increase in the overlap between bears and human settlements.

Similar trends continue across the broader Himalayan region. In Pakistan's Kalam Valley, Ali et al. (2020) estimated that brown bears comprised nearly a third of all large carnivore-associated livestock losses, placing substantial financial burdens on households reliant on high-altitude pastoralism. On the Qinghai-Tibet Plateau, conflict between humans and brown bears has surged within the Sanjiangyuan region, where over 92% of surveyed families report bear incursions largely targeting winter homes, grain stores, and livestock sheds (Dai et al., 2020). These conflicts are not an artefact of natural prey scarcity; behavioural research has shown that bears are increasingly selecting anthropogenic food sources, regardless of marmot density or the availability of natural forage (Dai et al., 2021). This combination of behavioural plasticity and expanded human infrastructure leads to the creation of feedback loops that further reinforce conflict.

These pressures are especially sharp in Ladakh. Road expansion, military infrastructure, tourism growth, hydropower development, and changing settlement patterns are reshaping the fragile high-altitude ecosystems of the region. Such developments impact brown bear ecology in many ways. First, habitat fragmentation disrupts traditional movement corridors and displaces bears from natural foraging areas. Second, the increased availability of human-generated waste and livestock carcasses near villages acts as an attractant, contributing to behavioural shifts and dependence on anthropogenic resources. Third, infrastructure like electric lines and roads increases accidental mortality, stress-induced movements, and the risk of retaliatory killing (Hertel et al., 2024).

Records of conflict maintained by the Wildlife Protection Department quantify this problem: during early 2001-2007, 2-4 incidents were recorded annually, indicating low interaction; from 2008 onwards, this increased gradually to consistently staying over 90 incidents annually from 2015-2022, touching a peak of 112 in 2021. The pattern in livestock depredation is pretty similar: from negligible levels during the early 2000s, loss numbers surged steadily to reach all-time highs of 447-737 livestock killed annually between 2016 and 2018. These trends suggest that brown bears in Kargil more frequently enter settlements and cause increasingly severe economic loss.

Spatial analyses across Ladakh revealed clear hotspots of conflict, which were concentrated in Drass, Suru, and parts of Zanskar, that contained most of the livestock depredation, crop damage, and property break-ins. These spatial clusters matched relatively well with the location of high-elevation agrarian villages, livestock corrals, seasonal transhumance routes, and availability of accessible garbage or stored fodder. Similar to conflict hotspots reported from Zanskar and Himachal Pradesh, these hotspots thus represent an interplay between ecological suitability, resource availability, and human land-use intensity.

While fear and negative perception of bears are common, local communities across Ladakh often reflect nuanced attitudes. Thus, research in Zanskar shows that while 95% of the respondents expressed fear, almost the same percentage supported the conservation of brown bears (Chavan et al., 2021). Such support reflects the cultural, spiritual, and traditional values associated with wildlife in Himalayan societies, together with recognition of the ecological role of carnivores. In the absence of adequate mitigation, however, growing risks of conflict will likely erode tolerance and drive retaliatory actions, a widely reported issue throughout bear landscapes in Europe and Central Asia.

It is against this complex background that potential wildlife-based ecotourism in Ladakh has gained increasing attention. Wildlife ecotourism, defined here as responsible travel to relatively undisturbed natural areas that conserves biodiversity and sustains local community well-being (Bragg et al., 2019), can yield significant economic incentives for conservation. In areas such as Spiti, Kibber, and parts of Himachal Pradesh, snow leopard ecotourism has shown potential to transform livelihoods, improve wildlife stewardship, and reduce retaliatory killing. However, ecotourism remains nascent in Kargil despite favourable landscapes, charismatic species, and rich cultural heritage. Preliminary surveys suggest that less than a handful of households run homestays or have any direct involvement with tourism, and most respondents reported no economic benefits from wildlife, suggesting considerable unmet potential for community-based ecotourism that could help diversify livelihoods and reduce conflict through incentive structures.

It is also important to note that anthropogenic infrastructure and human activities consistently disrupt ecological dynamics for the Himalayan brown bears in Ladakh. Habitat fragmentation and a push from natural foraging areas have a huge influence on the behaviour of the species. This is reflected in Morales□González et al.'s work, 2020. Severe effects of those altered movement patterns, leading to humans causing mortality due to collision, electrocution, retaliatory killing, or stress-induced accidents - can significantly affect small populations that have been isolated, diminishing genetic viability and long-term population resilience. This is according to Hertel et al., 2024. Underdeveloped development activities do not just reshape spatial behaviour but also contribute to enhanced mortality risks and reduced ecological stability for the brown bear population in the region.

Figure 5.1: Himalayan brown bears foraging in a snow-covered landscape with high-tension transmission infrastructure, and a confirmed mortality event of a Himalayan brown bear through vehicle collision.

Despite growing conflict incidents, Kargil District is one of the least studied regions in the Indian Himalaya concerning human-bear conflicts. The few studies conducted so far are fragmented or geographically limited and, therefore, leave large knowledge gaps with respect to ecological drivers of conflict, spatial distribution patterns, socioeconomic risk factors, and community attitudes.

The current study attempts to fill in some critical knowledge gaps by documenting the dynamics and magnitude of human-brown bear interactions across the landscape of Kargil region. Identifying the hotspots of spatial conflict across the district and analyzing the ecological, seasonal, and socio-economic predictors of conflict using GLMMs. Assess community perceptions, livelihood impacts, and coping mechanisms; and review the potential of ecotourism to be a complementary means of conservation.

The present study integrates quantitative modelling with qualitative socio-ecological insight to provide the first comprehensive assessment of human-brown bear conflict in Kargil. Its findings contribute toward the broader Himalayan conservation discourse, offering actionable guidance for designing targeted, evidence-based mitigation strategies that balance the imperatives of conservation with rural livelihood security.

Brown bear conflict records in the district of Kargil, maintained by the Wildlife Protection Department from 2001 to 2022, indicate a definite increase in the frequency as well as intensity of incidents. The incidence of conflict during the early years from 2001 to 2007 was found to be minimum, with reportedly just two to four incidents annually, indicating limited interaction between bears and human settlements. Since 2008, there is an increase that started showing up, and annual incidents during 2010-2014 ranged between 11 and 60. The conflict increased considerably during 2015-2022, when annual records consistently exceeded 90 incidents, reaching a maximum of 110 in the year 2018 and 112 in 2021, establishing this period as the phase of highest conflict.

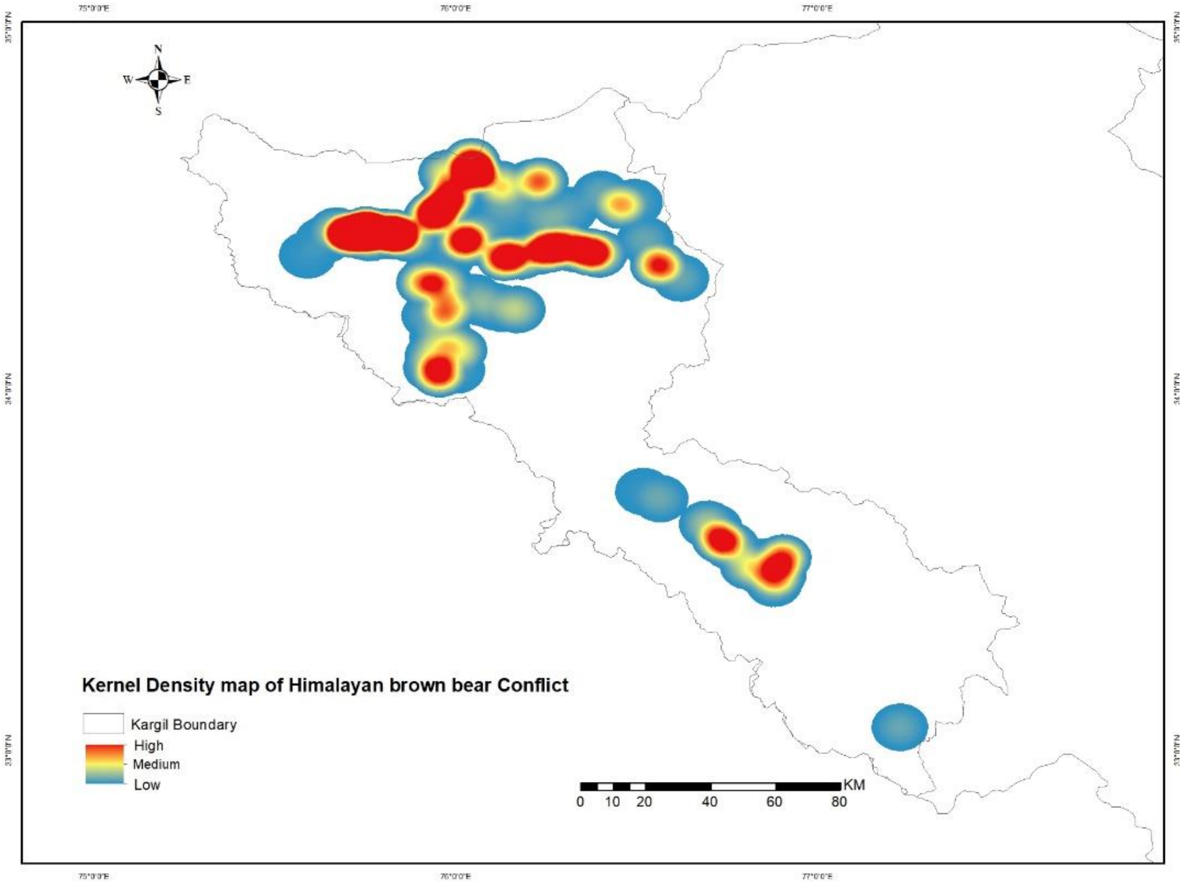


Figure 5.2: The kernel density map shows three distinct hotspots of the Himalayan brown bear conflict concentrated in the northern and central parts of Kargil District, with other smaller clusters in the southeastern belt. The high-intensity zones fall in the areas of concentrated human settlement, livestock rearing, and accessible foraging sites (WLPD conflict data).

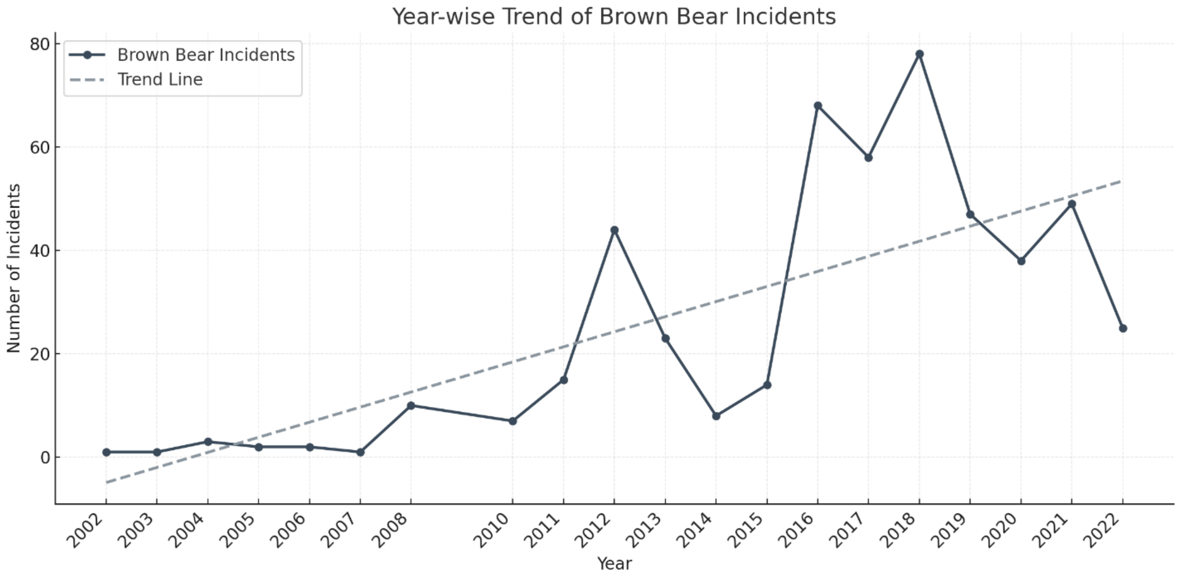


Figure 5.3: Yearly trend in reported Himalayan brown bear incidents in Ladakh from the year 2002 to 2022, showing an increasing trend in events over time and large inter-annual fluctuations, with a fitted trend line indicating an overall increasing trajectory. (Data: Wildlife Protection Department, Kargil)

The livestock depredation followed a similar trend: the losses were negligible in the early years, 3-30 animals annually up to 2004, but rapidly increased thereafter, to 142 animals in 2005, and continued to oscillate between 80 and 180 animals during 2010-2014. The worst depredation took place from 2016 to 2018, with 447 livestock killed in 2016, 455 in 2017, and an unprecedented 737 in 2018. The high level of loss continued throughout 2019-2022, with losses averaging more than 200 animals per year. Cattle were the main target of brown bear attacks, followed by horses and small ruminants like goats and sheep, which further signifies the opportunistic nature of livestock depredation caused by brown bears in the region (Chavan et al., 2021). These combined trends indicate that there is considerable economic impact due to brown bear conflict and that site-specific mitigation strategies need to be focused in the hotspots that have been identified.

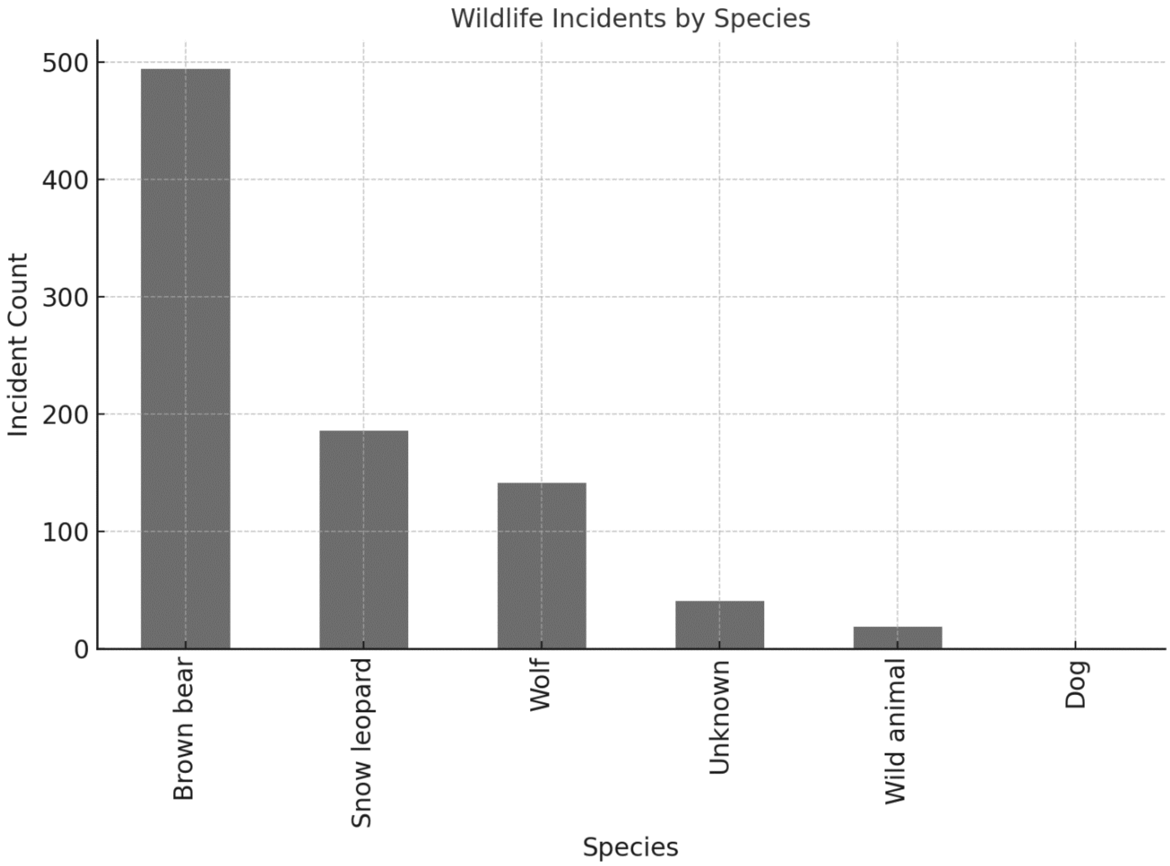


Figure 5.4: Species-wise distribution of reported incidents of wildlife-people conflict in the Ladakh region has been depicted, showing the share contributed by Himalayan brown bears as the highest, followed by snow leopards and wolves, with unidentified species, other wild animals, and free-ranging dogs contributing very few cases. (WLPD)

These accentuate the critical role played by this species in causing economic loss and reiterate the need for site-specific mitigation measures in brown bear conflict hotspots. Spatial patterns of conflict incidents showed strong clustering within the Drass block; this region, therefore, has emerged as a chronic conflict hotspot. Overall, results point towards a definite temporal intensification of human-brown bear conflict with an expanding spatial footprint and disproportionately high economic losses in peak years.

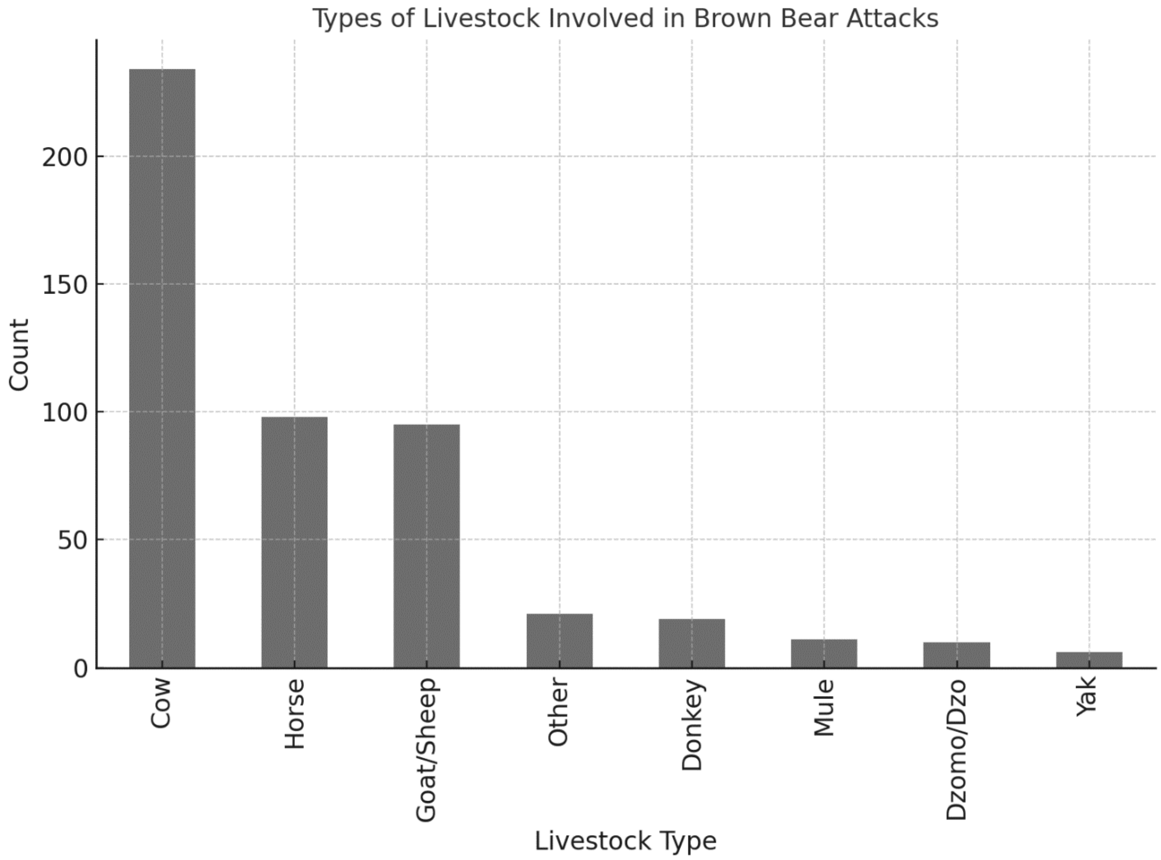


Figure 5.5: Categories of livestock affected in Himalayan brown bear depredation events in Ladakh, showing that cattle (cows) are the highest losses reported, followed by horses and goats/sheep, while relatively few cases involve donkeys, mules, dzomo/dzo, yaks, and other forms of livestock. (WLPD)

Human-bear conflicts in Kargil are on the rise due to the growing competition between both species for space, resources, and habitat, a trend that is in tune with the wider patterns reported for the Himalayan region. This knowledge assumes even greater importance in Kargil since brown bears are responsible for a substantial share of conflict incidents. Brown bears accounted for about 40% of the livestock depredation incidents, causing nearly 74% livestock loss, besides damaging property (21%) and crops or wild plants (5%). These conflict incidents translate into high economic losses estimated at 932,250 INR annually. Defining these emerging challenges, on-ground empirical documentation of human-bear interactions remains limited, as reflected by sparse and fragmented studies on this topic. The few studies include those by Sathyakumar (2003), Chavan et al. (2021), and Ali (2024). In fact, such a scanty record of systematic research underlines the need for focused conflict assessments with a view to evidence-based management and mitigation strategies in Kargil.

The descriptive statistics and GLMM were used in the analysis to address the complex, multi-layered nature of human-wildlife conflict data because of several interconnected advantages of the latter. GLMMs encompass regressions, ANOVAs, generalised linear models, and equivalent models with both random and fixed effects within a single framework. Hebblewhite & Merrill (2007) have shown the application of mixed-effects resource selection functions in drawing inferences about the relationship between wildlife and humans using wolves as a case study.

Bolker et al. (2009) emphasise that GLMMs provide flexibility in the analysis of non-normal data with the presence of random effects, thus tackling the explosion of challenges facing research in ecological applications. According to Hedeker et al., 2005, GLMMs add value to clustered and longitudinal data by adding random effects which account for correlation commonly seen in studies of wildlife across villages or households and across time. Bautista et al. (2021) presents a real application of the use of generalised additive models in studying brown bear damage to apiaries as an approach through which multi-scale ecological and management correlates can be investigated from the household to the landscape levels.

5. 2 Materials and Methods:

5.2.1 Study Area:

The study was conducted across the Kargil district of Ladakh, comprising two major sub-regions: Kargil and Zanskar. This study adopted a holistic socio-ecological research design to study the patterns of human-brown bear interactions across Kargil district. The area represents a mountainous landscape with elevations ranging from circa 2,533 m to 7,441 m asl, having high topographical heterogeneity. Villages are spread across valleys and mid-elevation zones where human settlements exist along the tributaries of the Indus.

Seasonal movement of brown bears towards human-dominated areas, induced by limited food availability, climatic harshness, and habitat fragmentation, often brings them in proximity with villages and livestock corrals. The majority of households rely upon agro-pastoralism, combining small-scale agriculture, mainly of barley, wheat, peas, and horticulture in suitable pockets, with livestock rearing of sheep, goats, yaks, and cattle. Seasonal transhumance and open-grazing practices continue to be significant components of household income and subsistence. Economic opportunities other than from agriculture are limited, as employment is concentrated largely in government services, the Indian Army, small local businesses, traditional crafts, and emerging tourism activities. Remoteness of the district, limitations of waste management infrastructure, and rapid expansion of roads and power lines further amplify both attractants and risks.

Population density remains low, and settlement distribution is decidedly linear and river-valley orientated, with villages primarily situated along the Suru, Drass, Wakha-Mulbek, Aryan Valley, Stod, Lungnak and adjacent tributary valleys where water availability, cultivable soils, and mobility corridors intersect. These villages tend to be small- to moderately-sized, kin-structured households that are characterised by extended family arrangements and labour divisions which follow agricultural and pastoral production cycles. Overall, the demographic composition for the district exhibits a largely rural population with modest population growth, relatively young age structures in many settlements, and improving but spatially uneven access to education, healthcare, and formal employment.

5.2.2 Methodology:

Information on human-brown bear interactions was collated from primary surveys through a structured field questionnaire survey (Figure 5.6) and secondary data from the records at the wildlife protection department, local administrative reports, and previously documented incidents. Primary data was collected by using semi-structured questionnaires based on established methodologies for assessing human-wildlife conflict (Chauhan 2003; Rathore 2008). The semi-structured questionnaires consisted of open-ended questions that captured narratives, perceptions, and qualitative experiences, and close-ended questions that captured quantifiable measures of conflict frequency, livestock holdings, crop loss, mitigation measures, and attitude. A stratified random sampling framework as recommended by Kiogora et al., 2021, targeting approximately 10-15% of the sampling units within each village, was considered to ensure that representative coverage across the heterogeneous landscape of Kargil district was captured. This provided an adequate representation of ecological gradients, settlement distribution, and demographic variation.

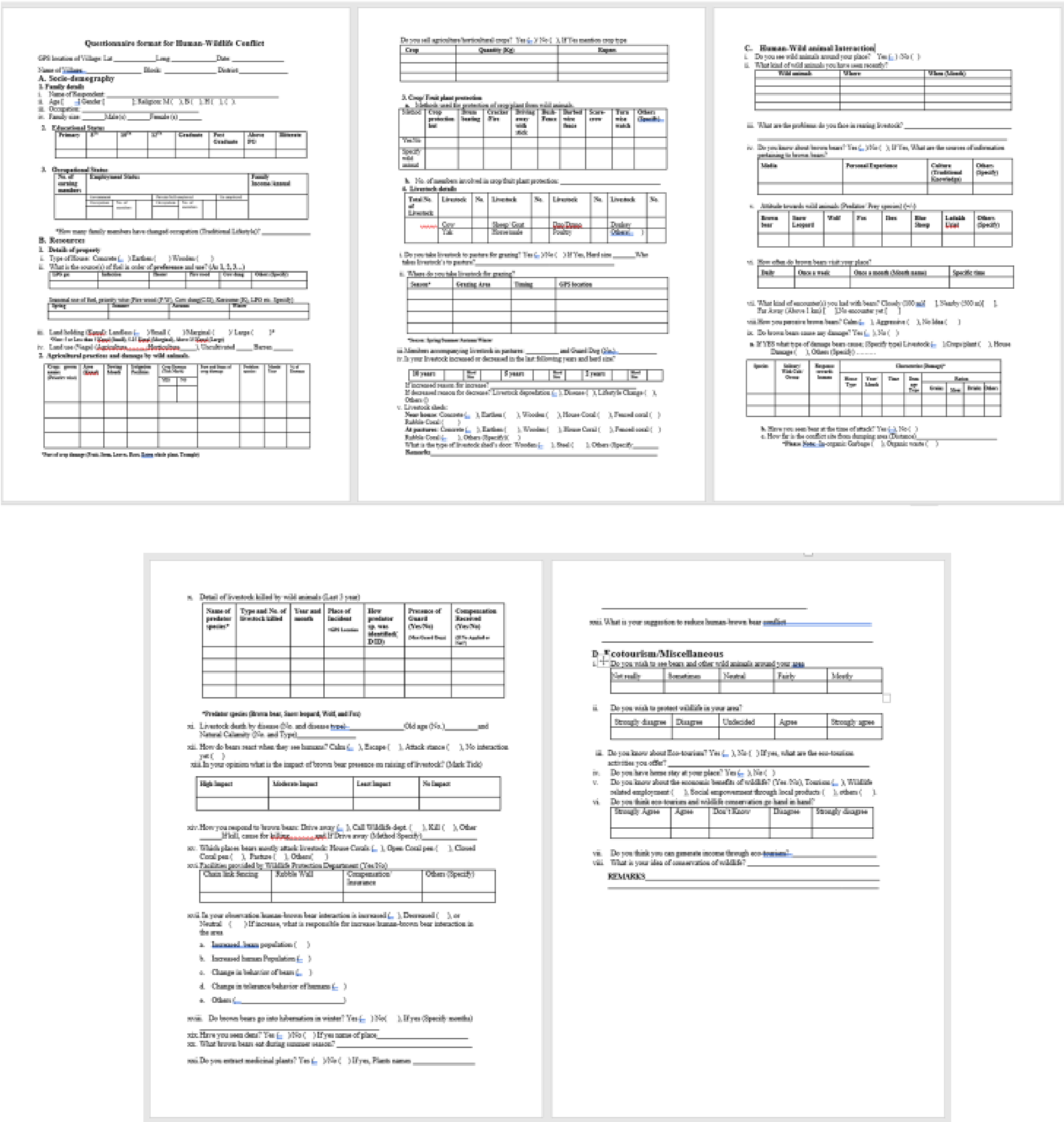


Figure 5.6: Open and close ended questionnaire format for household level interview

In addition to household-level data, a village head questionnaire was conducted in each of the sampled villages. This tool provided community-level information on historical patterns of brown bear presence, collective memory of conflict events, local governance structures, compensation processes, and traditional mitigation practices. This type of cross-scalar information strengthens the potential for analysing individual experiences in light of broader village-level dynamics.

Descriptive statistics were carried out to understand the nature, context, and magnitude of human-bear interactions as part of the analytical procedures. Further, comparative analyses and multivariate statistical methods were used to identify spatial, temporal, and ecological patterns. Such an analysis enabled the study to compare differences at conflict and non-conflict sites, seasonal variation in bear activity, and associations between bear densities, habitat characteristics, and human interaction patterns. In general, the methodology integrates rigorous sampling design, multi-source data acquisition, and robust statistical analysis in figuring out the complexities of human-bear interactions in high-altitude Ladakh.

Stratified random sampling is a probability-based sampling in which the overall population is divided into distinct non-overlapping groups of strata, as argued by Sechidis et al. (2011). The strata are formed based on factors related to the research issue that may pertain to geography, habitat type, administrative boundaries, or demographic categories. Subsequently, after stratification, a random sample of each group is selected proportionally or equally, whichever fits the objective of the research.

Stratified random sampling ensures adequate representation of the main population subgroups in the sample. A sampling design such as this maximises the statistical precision of estimates, minimises sampling bias, and strengthens the comparability of findings across strata. According to Hankin et al. (2019), stratification will help capture variability associated with settlement type, wildlife exposure, elevation, or land-use patterns that improve the robustness and reliability of generalisable findings in human-wildlife conflict studies.

The questionnaire sheet prepared for the study is a comprehensive tool to document sociodemographic characteristics, livelihood dependence, patterns of human-wildlife interactions, and community perceptions about human-Himalayan brown bear interaction in the region. It has several sections:

1. **Socio-demographic profile**

It also collects information at the household level on age, education, occupation, family size, income sources, and landholding to evaluate both social and economic vulnerabilities to conflict.

2. **Resource use and livelihood dependence**

The system logs the number of livestock, the type of agriculture, the species of crops, the collection of fuel-wood, the pattern of grazing, and the reliance on natural resources. These components are essential in risk exposure assessments and livelihood impacts.

3. **Human-wild animal interactions**

It captures data related to the incidence of conflict in the form of livestock depredation, crop damage, property losses, encounters, and the seasonality of these events. Similarly, it covers information on compensation received, presence of predators, and respondent attitude towards different species of wildlife.

4. **Perceptions, coping strategies, and behavioural responses.**

It documents the community's perceptions of brown bear behaviour, population trends, and perceived changes in interaction intensity. Additionally, it discusses mitigation actions at the household and village levels, as well as the tolerance levels and perceived effectiveness of these various measures.

5. **Ecotourism and conservation attitudes**

To measure knowledge of ecotourism and attitudes toward ecotourism, benefits from tourism, conservation awareness, willingness to conserve wildlife, and perceived pathways for community involvement in conservation initiatives.

6. **Open-ended recommendations**

This approach enables the respondents to offer suggestions for effective strategies to reduce human-bear conflict and promote coexistence.

We used the Likert scale, which represents one of the most fundamental and widely adopted psychometric tools in the context of social science research, having been developed by Rensis Likert back in 1932 as a method to understand the perception of people in relation to the Himalayan brown bear. In fact, this measurement instrument was specifically designed to quantify attitudes defined as "preferential ways of behaving/reacting in a specific circumstance rooted in relatively enduring organisation of belief and ideas" (Joshi et al., 2015).

For the analysis of socio-ecological determinants of human-brown bear conflict in Kargil, a comprehensive suite of candidate GLMMs was formulated, each reflecting a distinct ecological hypothesis concerning the mechanism behind conflict risk. The simplest of these hypotheses is that conflict is primarily structured by seasonal variation, reflecting temporal shifts in bear foraging behaviour and household exposure (Model 8). More complex hypotheses integrated the role of the location of conflict (mountain versus village), assuming that the site of encounters influences risk through differential access to anthropogenic resources (Model 2, Model 4). Livestock composition independently or jointly affects conflict, according to several models (Model 1, Model 3), grounded in the expectation that certain types of livestock, such as poultry or small stock, are more vulnerable to predation. Interaction models hypothesised that the effect of conflict sites varies seasonally as bears adjust habitat use and foraging patterns across the year (Model 5). Other hypotheses were the influence of husbandry infrastructure, in particular livestock shed types, on depredation probability (Model 7), and the impact of guarding strategies, be it human guarding or the use of dogs, on reducing risk (Model 6). Yet broader socio-ecological hypotheses incorporated human perception, encounter history, medicinal plant extraction, knowledge about hibernation, and the type of damage as potential drivers of conflict (Model 10-Model 16). Finally, the most integrative model combined ecological, behavioural, and husbandry variables, representing the hypothesis whereby conflict emerges from the interplay of seasonal bear ecology, spatial exposure, livestock vulnerability, and human management practices (Model 18). Therefore, this candidate model set captures a gradient of ecological hypotheses - from simple seasonal drivers through to complex socio-ecological interactions, which enables the robust evaluation of competing explanations for observed conflict patterns in the region.

Table 5.7: Ecological hypotheses represented by each candidate GLMMs.

Model ID	Hypothesis	Key Predictors	Ecological Rationale
m1	Conflict is jointly shaped by season, site, and livestock composition	Season, conflict site, livestock type	Bears track seasonal food availability; site and livestock determine exposure.
m2	Conflict patterns driven mainly by season and encounter location	Season, conflict site	Temporal activity patterns and proximity to settlements.
m3	Livestock species drive conflict risk independent of site	Season, livestock type	Prey-size and species-specific vulnerability.
m5	Effect of conflict site varies seasonally	Season × conflict site	Bears shift habitat use across seasons.

m7	Husbandry (shed type) alters conflict vulnerability	Season, site, livestock type, shed type	Shed construction influences livestock accessibility.
m18	Full socio-ecological model	Season, site, livestock, shed type, guard type	Conflict emerges from combined ecological and behavioural factors.

The socio-economic survey was utilized for collecting information on ecotourism opportunities in order to understand the scope of wildlife ecotourism-an increasing tourism sector that focuses on experiencing wildlife in their natural settings with the aim of promoting conservation and supporting the local communities. Ecotourism is defined by Bragg et al., 2019 as “*responsible travel to natural areas that conserves the environment and improves the well-being of local people.*”

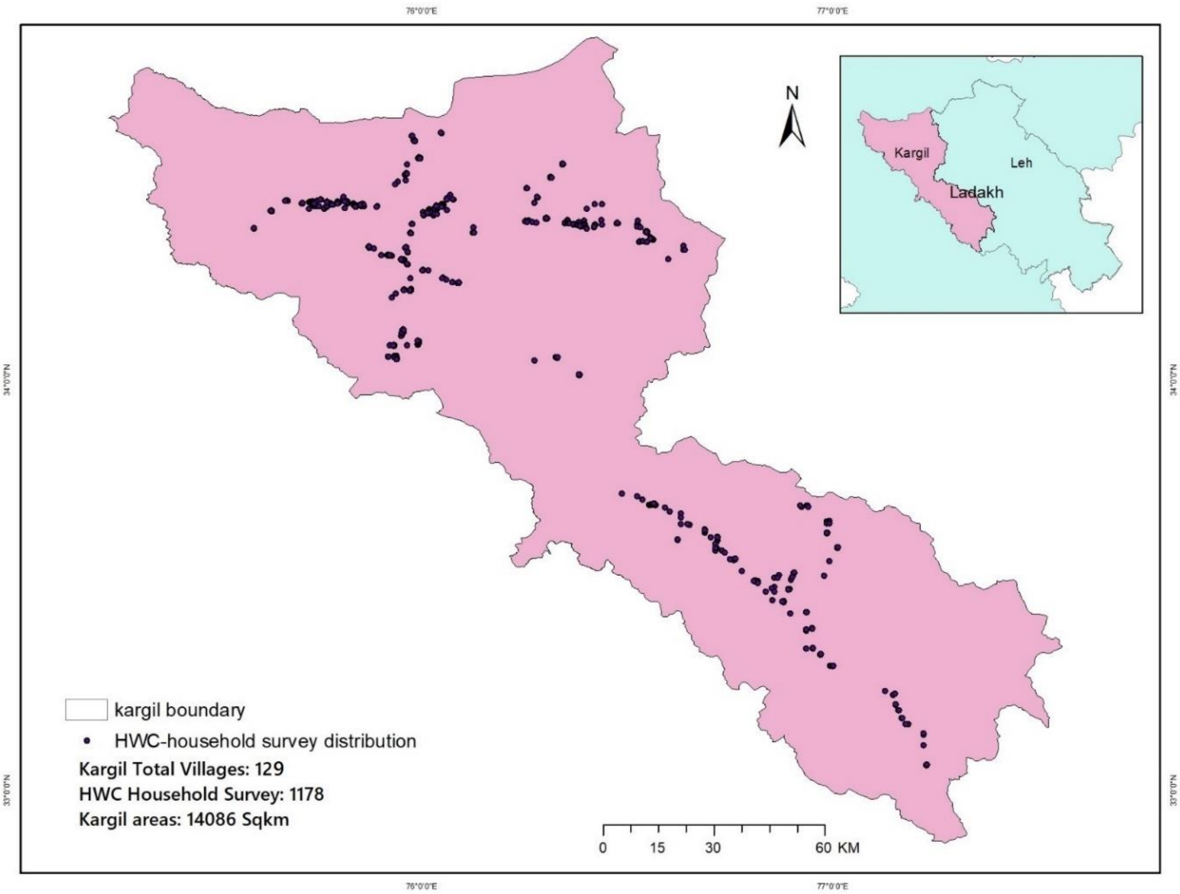
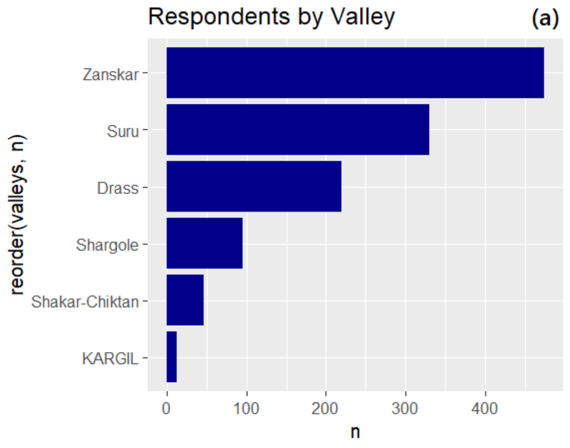


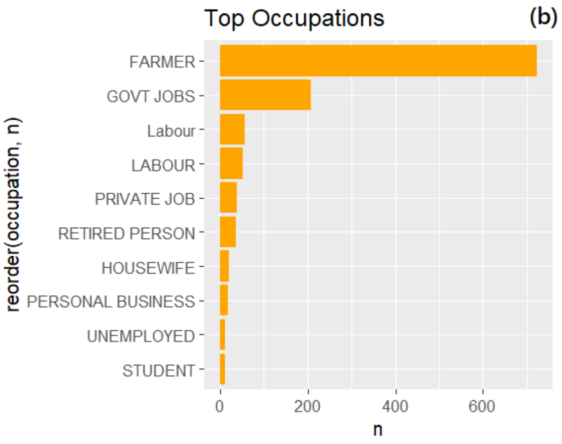
Figure 5.8: Spatial distribution of the surveyed households reporting human-wilflife conflct across Kargil district, showing the geographical coverage of 1,178 household interviews

conducted in 129 villages over an area of approximately 14,086 km² within the Union Territory of Ladakh.

5.3 Results:

In Kargil, 84 villages were randomly selected from a total of 129 villages for the questionnaire survey, and 1,178 individual responses were obtained. For the adjoining Zanskar region of Kargil, the total surveyed villages are 24, with 495 respondents to provide perspectives from the most remote and sparsely populated settlements. This stratification most likely accounted for administrative units, population distribution, or ecological gradients so as to ensure that communities exposed to varying environmental and wildlife-related contexts are adequately represented. The survey dataset shows wide participation across demographic groups, with the majority of respondents in middle adulthood, and households are characteristic of extended mountain families. The age group was approximately 40-60 years, while family size is right-skewed, with most households falling within the range of 5-10 members. Religion-wise, the sample is almost evenly divided between the two predominant sectarian groups of the region, with 619 Muslims and 558 Buddhists, respectively. Participation was male-dominated, with 989 males and 165 females interviewed. Spatially too, the survey has achieved wide valley-level coverage, with the highest responses coming from Zanskar (474), followed by Suru (330), Drass (220), Shargole (95), Shakar-Chiktan (47), and a smaller number of 12 from the Kargil town region. Collectively, these distributions demonstrate that the dataset achieves the demographic and geographical diversity that is required to analyse human-bear conflict dynamics in the district.





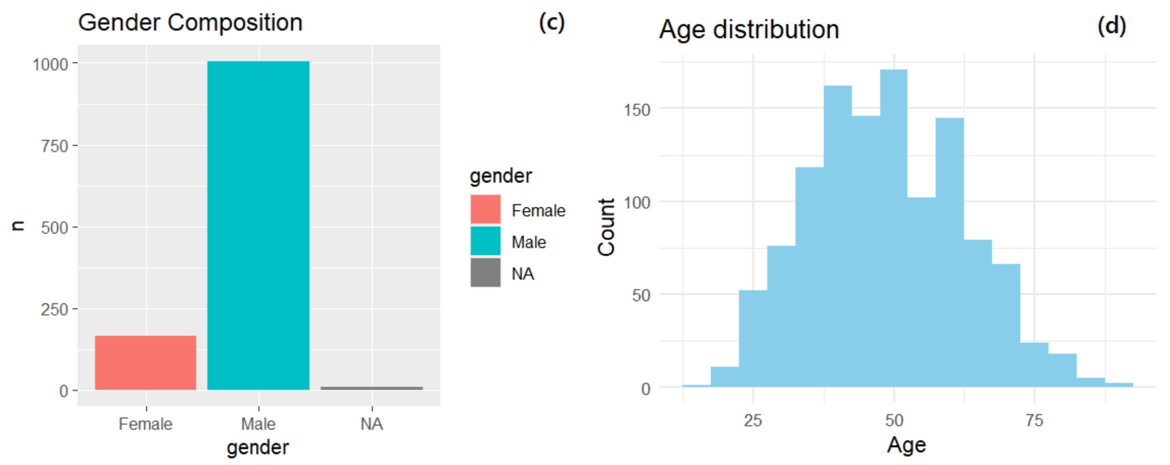


Figure 5.9: Demographics of respondents for the entire study area: a) Valley-wise distribution - it is seen that Zanskar has the highest number of respondents followed by Suru and Drass. b) Occupational composition (farming is the dominant occupation, with small contributions from government and labour sectors). c) Gender composition: strong male dominance, reflecting the local engagement in outdoors and livestock-related work. d) Age classes - middle-aged adults, typically the main decision-makers concerning household as well as livestock management.

The analysis is done by applying RStudio, version 2025.05.1, to generalised linear mixed models. GLMMs (McCulloch, 1996) are a strong statistical approach in understanding human-wildlife conflict, as they consider hierarchical data structures and non-Gaussian response variables normally encountered in ecological research. Such models are effective in conflict data analysis, where observations are nested within groups, households within villages and response variables follow other distributions than normal.

Quantifying the ecological and anthropogenic determinants of human-brown bear conflict in Kargil required an extensive modelling framework using Generalized Linear Mixed Models in R. The analysis leveraged a broad set of statistical packages available, including but not limited to lme4, glmmTMB, DHARMa, broom.mixed, ggeffects, MuMIn, lmerTest, performance, and ggplot2. Each of them has specific analytical or diagnostic functions. These tools collectively enabled data preparation, model fitting, distributional assessment, selection among competing models, visualisation of effects, and inferences about fixed and random structures.

Table 5.10: Description of predictor variables used in GLMM analyses of human–brown bear conflict in Kargil.

Variable	Type	Levels / Units	Coding in Model	Rationale
Season	Categorical	Winter, Spring, Summer, Autumn	Factor (Winter = reference)	Captures temporal variation in bear activity and human resource use.
Conflict site	Categorical	Mountain, Village	Factor (Mountain = reference)	Distinguishes natural vs. human-dominated foraging contexts.
Livestock type	Categorical	Poultry, Farmed ruminants, Odd-toed ungulates, Reference livestock	Factor	Species-specific vulnerability to depredation.
Total livestock	Numeric	Number of animals	log(total_livestock) as offset	Controls for exposure — conflict rate per head.
Guard type	Categorical	Dog, Human, No response	Factor	Tests influence of guarding strategies on conflict rates.
Shed type	Categorical	Wood, Kutcha, Open, Fenced, House, etc.	Factor	Evaluates husbandry design on livestock vulnerability.
Village	Grouping (Random)	117 villages	Random intercept	Controls spatial clustering and hotspot structure.
Year	Grouping (Random)	2012-2021	Random intercept	Controls annual variation due to

				climate, mast cycles, or reporting.

The response variable, which involved count data (the number of brown bear conflict events), led to the fitting of initial models that assumed a Poisson error structure using the lme4 package. However, tests for overdispersion (Pearson residual-based) indicated substantial deviation from Poisson assumptions. Consequently, subsequent modelling focused on an NB and ZINB framework using glmmTMB, which better accommodates overdispersed and zero-inflated ecological datasets. Because counts of conflict events often include many zeros, when multiple households or seasons have no events, the presence of excess zeros was evaluated formally using the DHARMa package; zero-inflation tests supported the fit of ZINB models in several instances.

These candidate models were designed to incorporate different ecological hypotheses through various combinations of fixed effects. These fixed effects included:

1. Seasonal effects: Incorporating temporal variation into bear foraging behaviour and human exposure.
2. Competition site typology, including settlement, pasture, and livestock shed, reflects spatial heterogeneity in vulnerability.
3. The type of livestock and total livestock holdings reflect the availability and attractivity of prey to bears.
4. The type of shed, husbandry strategies for guarding, pasture habits, etc., all affect livestock protection.
5. Human perception variables, socio-demographic predictors, and predator guild covariates reflect broader socio-ecological interactions.

Table 5.11: Model comparison for GLMMs predicting human-brown bear conflict in Kargil.

Model ID with rank	Model Description (Fixed Effects)	AIC	AICc	BIC	ΔAICc	Akaike Weight
m18	Season + conflict site + livestock type + shed type + guard type	1994.4	1998.4	2159.9	0.00	0.761

m7	Season + conflict site + livestock type + shed type	1997.3	2000.7	2149.2	2.32	0.239
m15	Season + conflict site + livestock type + encounters + medicinal plants	2142.1	2143.1	2236.4	145.0	2.4×10^{-32}
m6	Season + conflict site + livestock type + guard type	2143.0	2143.9	2208.2	145.4	2.3×10^{-32}
m1	Season + conflict site + livestock type	2147.1	2147.1	2199.0	148.7	3.1×10^{-33}
m5	Season × conflict site + livestock type	2150.2	2150.9	2215.0	152.0	$6.6 \times 10^{-3\square}$
m3	Season + livestock type	2151.3	2151.3	2198.5	153.0	$4.9 \times 10^{-3\square}$
m8	Season	2153.0	2153.3	2195.4	155.0	$1.9 \times 10^{-3\square}$
m2	Season + conflict site	2155.4	2155.4	2192.4	157.0	$6.7 \times 10^{-3\square}$
m4	Conflict site + livestock type	2158.2	2158.8	2196.0	160.4	$1.2 \times 10^{-3\square}$
m14	Damage type + bear population trend	2170.0	2171.0	2245.0	173.0	$2.5 \times 10^{-3\square}$
m16	Bear perception + response behaviour	2177.0	2178.0	2257.0	180.0	$6.2 \times 10^{-\square\square}$
m13	Season + conflict site + hibernation category	2214.0	2214.0	2256.0	216.0	$9.1 \times 10^{-\square\square}$

We applied glmmTMB across models, with random intercepts for village and year, while recognising that the intensity of conflict is inherently clustered in local environmental conditions and varies between years. Such random effects allowed these models to partition unexplained variance associated with spatial and temporal structure, thus making the inference more accurate. Lastly, we extracted random-effect values at village and yearly levels of variation using the broom.mixed package and visualised them as caterpillar plots that highlighted hotspots of conflict and anomalous years.

Model selection was done using the AIC, AICc, and BIC calculated through MuMIn, which enabled an objective comparison of the full suite of ecological hypotheses. Akaike weights were further visualised to convey the relative support of each model. This model selection process consistently identified that amongst the strongest predictors of conflict occurrence are season, conflict site and livestock type. Effects were interpreted as incidence rate ratios, computed by exponentiating regression coefficients, and plotted in forest plots using ggplot2. These IRRs allowed a direct ecological interpretation, such as whether specific seasons or livestock categories significantly raise conflict risk per head of livestock.

Table 5.12: Fixed-effect estimates from the selected negative-binomial GLMM predicting human-brown bear conflict.

Predictor	**Estimate (β)**	**SE**	**z**	**p**	**IRR**	**95% CI (IRR)**
(Intercept)	-4.254	0.392	-10.86	<0.001	-	-
Spring	1.158	0.290	3.99	<0.001	**3.18**	1.80-5.62
Summer	1.001	0.298	3.36	<0.001	**2.72**	1.52-4.88
Autumn	0.756	0.300	2.52	0.012	**2.13**	1.18-3.84
Village site	0.572	0.239	2.39	0.017	**1.77**	1.11-2.83
Farmed ruminants	0.435	0.178	2.45	0.014	**1.54**	1.09-2.19
Odd-toed ungulates	-0.074	0.289	-0.26	0.80	0.93	0.53-1.63
Poultry	1.272	0.430	2.96	0.003	**3.57**	1.54-8.28

Marginal effects for key variables were estimated using ggeffects, which produced intuitive visualisations of predicted conflict rates across differing seasons, sites or livestock categories. These effect plots reveal clear temporal peaks in conflict, clear spatial differences between conflict sites and differential vulnerability among livestock types. These predictive surfaces offer practical insights, in combination, into the design of season-specific, site-specific conflict mitigation strategies.

5.3.1 Model performance and selection

The first Poisson GLMM was highly overdispersed ($\chi^2/df = 3.36$, $p < 0.001$), not at all surprising given that these conflicting data are not well modelled with a Poisson distribution. An NB GLMM fitted using glmmTMB greatly reduced variance relative to the Poisson (AIC from 2560.76 to 2147.10). Zero-inflation diagnostics using the DHARMa test did not suggest zero-inflation was significant, and the zero-inflated model had a slightly poorer AIC (ZINB AIC = 2149.10). Based on these reasons, the NB GLMM is selected as the final model.

Table 5.13: Summary of model diagnostics using DHARMa.

Diagnostic	Test	p-value	Interpretation
Dispersion	TestDispersion	$p > 0.05$	No residual overdispersion detected.
Zero inflation	TestZeroInflation	$p > 0.05$	No excess zeros beyond NB expectation.
Outliers	TestOutliers	$p > 0.05$	No influential outliers detected.

A wider model comparison among 18 competing ecological and socio-economic hypotheses ranked model m18 as the best-supported model (AICc = 1998, weight = 0.761). In this model, season, conflict site, livestock type, shed type, and guarding strategy were predictor variables, while random intercepts were for village and year.

Final Negative Binomial GLMM (Model m18)

Random effects

The random intercepts reflected appreciable spatial clustering:

• Village variance = 2.04 (SD = 1.43)

• Year variance = 0.055 (SD = 0.236)

This means that conflicts vary strongly between villages, creating sharp "conflict hotspots," while variation across years is relatively small.

Fixed effects

All estimates of parameters below come directly from your model output and are incidence rate ratios [IRR = exp(est)].

Seasonal patterns

Table 5.14: All seasons but winter significantly raised conflict risk:

Season	Estimate	IRR	Interpretation
Spring	1.297	3.66× higher conflict	Highly significant ($p < 0.001$)
Summer	1.083	2.95× higher conflict	Significant ($p < 0.01$)
Autumn	0.943	2.57× higher conflict	Significant ($p < 0.05$)

Winter was used as the reference category. Overall, conflict probability increases strongly during the active foraging and pre-hibernation months.

Conflict site

The risk of conflict varied markedly between mountain and village settings:

• **Village = IRR 2.01 (estimate = 0.6999; $p < 0.05$)**

This suggests that livestock in or near the settlements are about twice as likely to be attacked than those at mountainous sites.

Livestock type

Table 5.15: The vulnerability of livestock varied substantially:

Type	IRR	p-value	Interpretation
Farmed ruminants	IRR = 1.70	$p = 0.014$	Highly vulnerable
Poultry	IRR = 4.77	$p = 0.003$	Most vulnerable group
Odd-toed ungulates	IRR ≈ 0.79	$p = 0.79$	Not significant

Poultry depredation risk is about five times higher than cattle (reference), which is consistent with small body size and open enclosures.

Husbandry (Livestock Shed Type)

Most of the shed-type categories were not significant, but a few patterns emerged.

• **Concrete-Wooden sheds** (estimate = 0.929; IRR = 2.53) increased the risk of conflict.

• **Kutcha-Fenced combinations,** estimated at 1.235 with an IRR of 3.44, also evidenced increased risk.

Many extreme estimates, such as -16 to -22, are products of very small sample sizes for certain shed categories and should be interpreted cautiously.

Guarding strategy

Table 5.16: Guarding type showing strong influence:

Guard type	Estimate	IRR	Interpretation
Dog guarding	2.837	17.1× higher	Strongly associated with higher conflict
Human guarding	-0.016	0.98	No effect
No response	0.402	1.49	Moderate increase

The very high IRR for dog guarding likely reflects reverse causality-that is, dogs are more frequently used in high-conflict villages, making guarding "predictive" of conflict rather than protective.

Marginal effects

Marginal predictions ggeffects showed a strong upward trend from winter → autumn, peaking in spring. Village sites always yield higher predicted events than mountains and poultry have the steepest rise, followed by farmed ruminants. These patterns are visually captured in the saved effect plots.

5.3.2 Model comparison

The best supported model was m18 (AICc weight 0.761), followed by m7 (AICc weight 0.239). All other seasonal-only or site-only models received far less support (ΔAICc > 150).

To understand the conflict hotspots, we determined kernel density-based heat maps using Arc GIS. Human-brown bear conflict in Kargil is concentrated within well-defined hotspots, and most incidents are recorded from Drass, Suru, and central Zanskar. These are sites of repeated depredation and property damage, as villages, livestock corrals, seasonal grazing routes, and easily accessible food or waste attractants are in close proximity. Drass consistently records the highest frequency and intensity of incidents, followed by Suru Valley, where widely spaced nighttime livestock shelters and dense grazing by people and livestock increase vulnerability. Zanskar forms a third major conflict belt related to transhumance and increased human use associated with its expanding sedentary belt close to habitats with high bear densities. Three more small-scale hotspots occur in Shargole, Bodkharbu and Lungnak valley. Overall, the intensity of conflict is severe wherever human activities overlap tightly with the core foraging areas of bears, underlining the need for targeting mitigation efforts in these high-conflict zones.

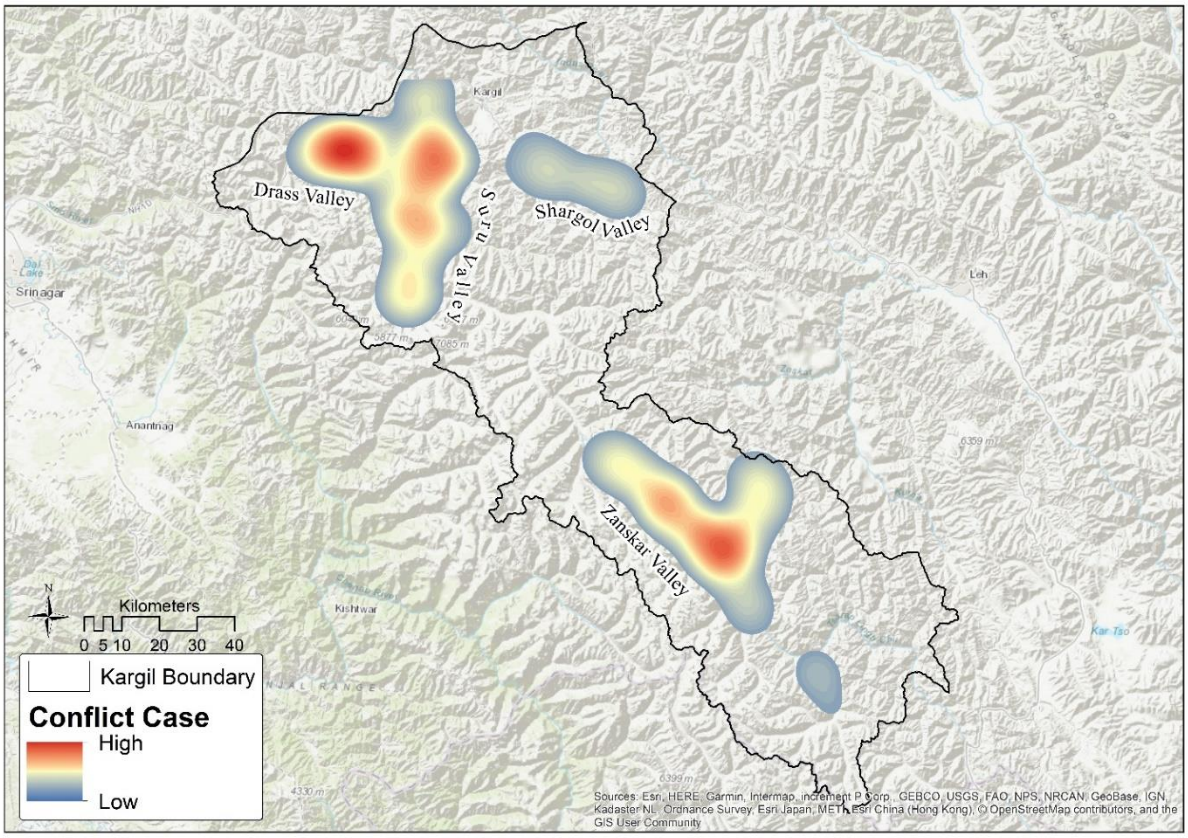


Figure 5.17: Kernel density-based heat map of the spatial distribution of human-brown bear conflict incidents across Kargil District. High conflict zones are represented by red areas and blue areas showing low-intensity areas. The high conflict is shown in Drass and Zanskar valley.

The NB GLMM demonstrates that the pattern of conflict in Kargil is jointly determined by seasonal foraging ecology, livestock vulnerability, and village-specific socio-ecological conditions. Such findings provide a statistically robust basis for appropriately targeted mitigation strategies.These results yield coherent and biologically plausible relationships, structuring our prior knowledge on the ecology of brown bears in the trans-Himalayan region.

The GLMM analysis thus uncovers that Kargil conflict is strongly ordered by seasonal foraging behaviour, livestock husbandry practices, and spatial exposure of animals to high-risk sites. Considerable heterogeneity at the village level indicates that this conflict is localized within the landscape rather than uniformly distributed. The final model explains the major ecological and livelihood drivers of human-brown bear interactions and provides a robust statistical basis for designing targeted evidence-based conflict mitigation strategies in Kargil.

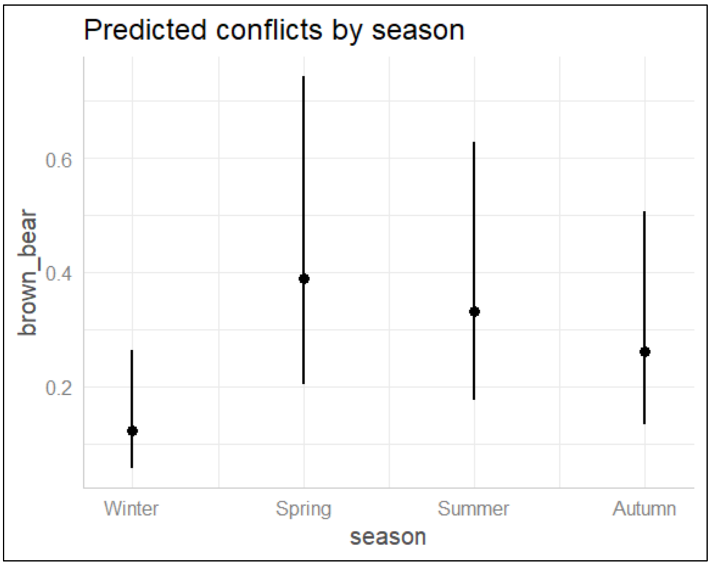


Figure 5.18: Predicted conflicts by season: Predicted human-brown bear conflict rates across seasons from the final negative binomial GLMM. Points show marginal means and vertical bars represent 95% confidence intervals (CI). Conflicts peak in spring and summer, while winter shows the lowest predicted risk.

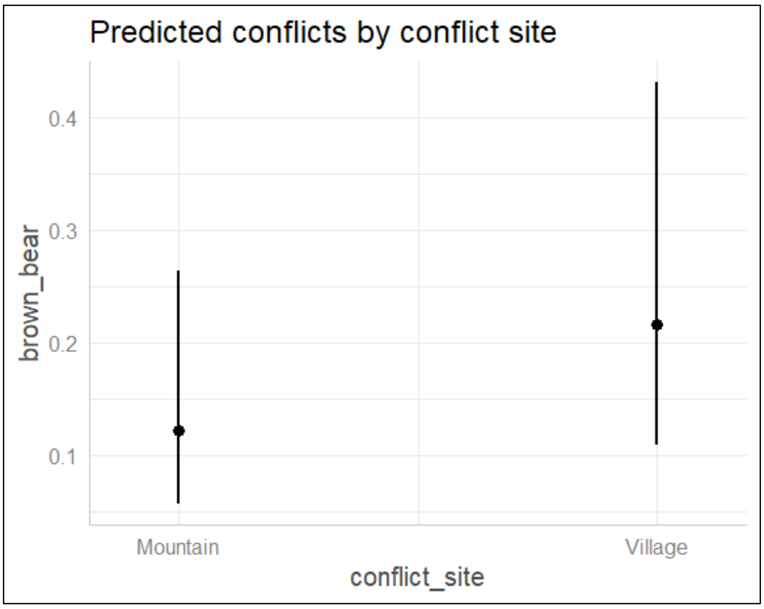


Figure 5.19: Predicted conflicts by conflict site: Model-predicted conflict rates for mountain versus village sites. Marginal means with 95% CI indicates that there is a higher probability of conflict within village areas. This is indicative of increased bear incursions into settlement areas where food resources are more accessible.

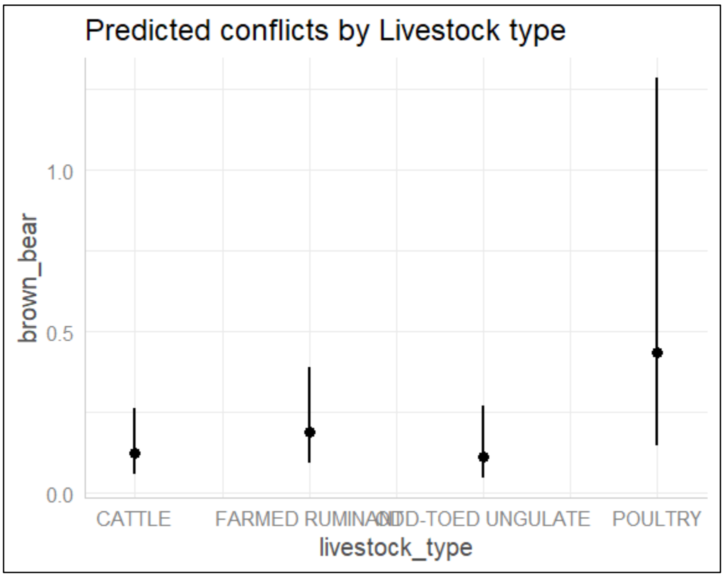


Figure 5.20: Predicted conflicts by livestock type: Predicted conflict probabilities for different livestock types from the final GLMM. Poultry has the highest risk, followed by farmed ruminants, while odd-toed ungulates show the lowest vulnerability. Error bars show 95% CI.

5.4 Ecological and socio-economic interpretation:

1. Seasonality consistent with bear ecology: Large spring and summer increases likely reflect the time of increased bear activity and food searching, such as post-den emergence and pre-hibernation increased foraging, and greater overlap with human resource use, including grazing and fodder collection. Autumn remains elevated but less than spring, perhaps because some food resources become available later in the year, or due to herd management practices that vary across months.

2. Village exposure is high: Higher rates of conflict per head in village settings indicate that one or more attractants-stored fodder, household waste, poultry, unsecured sheds-or husbandry practices within or near settlements increase risk. This undermines the notion that only remote pastures are dangerous.

3. The vulnerability of livestock is species-specific; poultry and small ruminants (sheep/goats) are most exposed and, hence, liable to depredation. Interventions that target these classes of animals likely yield the greatest reductions in losses (night corrals, predator-proof coops).

4. Guarding and shed design matter: The positive association between dog-guarding and conflict most likely reflects that dogs are being deployed where conflict is already high; dogs might still provide some deterrence, but they are not a silver bullet. Shed types show signal in some categories, though many categories have low replication, and require cautious interpretation.

5. Spatial targeting is paramount: Random-effect heterogeneity indicates that a subset of villages produces most incidents and should be prioritized for intensive mitigation.

Wildlife ecotourism is increasingly seen as a route toward improving rural livelihoods while concurrently enhancing local support for conservation, particularly in remote mountain landscapes where economic opportunities are scarce. Community perceptions in the current study reflect this broader potential, with the overwhelming majority of respondents reporting positive attitudes toward wildlife conservation. However, the results also show a clear disconnection between conservation support and tangible livelihood benefits: most respondents reported ‘no economic gains’ associated with wildlife or tourism, indicating that ecotourism remains largely underdeveloped in Kargil. The limited uptake of homestays, as reflected in the low number of households operating them and their sparse geographic distribution, further underlines how tourism integration within the region remains nascent. Despite strong normative support for conservation, only a minority of the respondents currently participate in or directly benefit from wildlife-linked economic activities. These findings suggest considerable untapped opportunity for community-based ecotourism initiatives capable of simultaneously advancing conservation and diversifying local income streams.

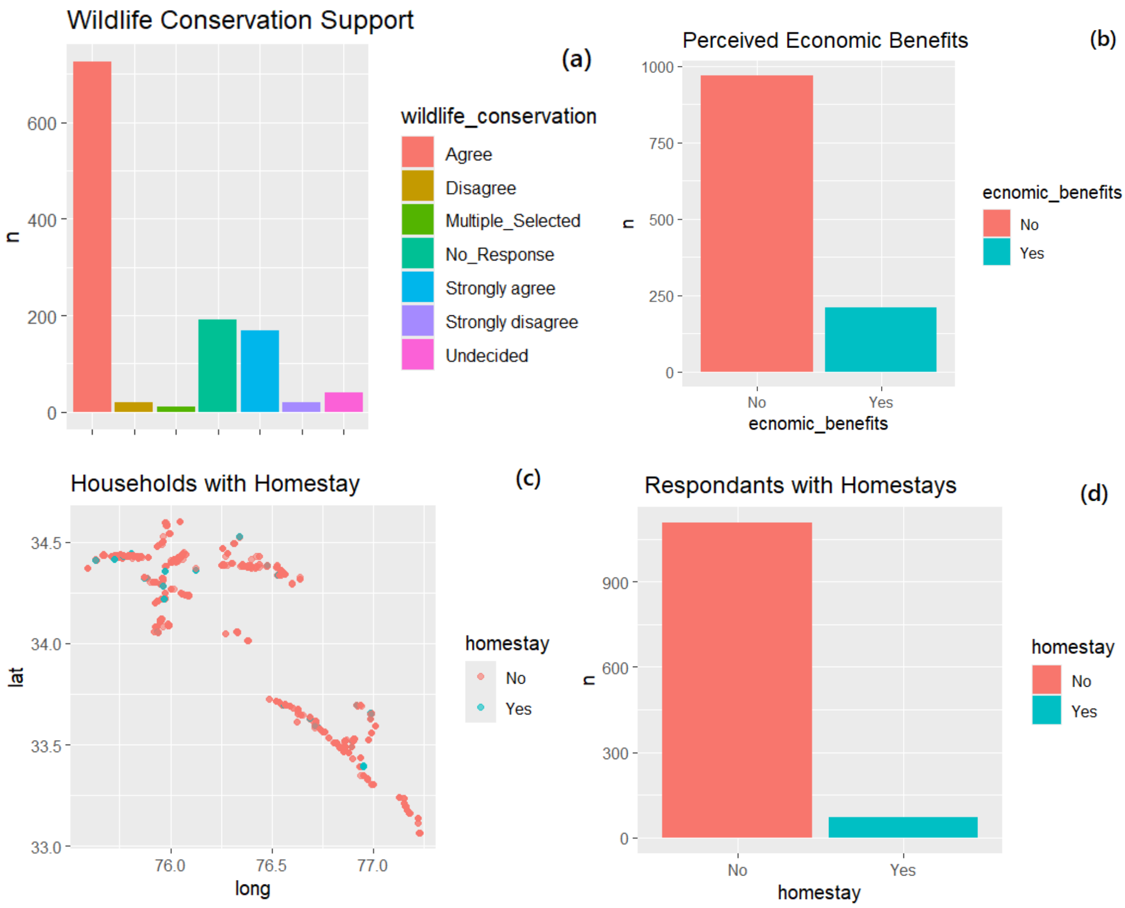


Figure 5.21: Community perceptions of wildlife conservation and ecotourism potential: (a) Levels of support for wildlife conservation, reflecting overall strong support, with the majority of respondents in agreement or strong agreement. (b) Perceived economic benefits from wildlife or tourism, indicating that the majority of respondents do not report financial benefits. (c) Spatial distribution of households operating homestays, showing their minimal and dispersed distribution within the study area. (d) Proportion of respondents with homestays, indicating few respondents are currently involved in accommodation-based tourism activities.

We further modelled spatial and distributional patterns of the ecotourism Engagement Index, which suggests significant heterogeneity in community participation within the study landscape. The Engagement Index is a composite measure scaled from 0 to 100, designed to quantify household-level involvement in ecotourism-related activities by drawing on indicators such as homestay participation, tourism services, conservation awareness, and willingness to engage with nature-based tourism. Spatially, the map clearly illustrates how high-engagement households (index >75) are concentrated mainly in a few accessible settlement pockets, while the majority of villages exhibit low to moderate engagement. This is corroborated in the histogram: the majority of the households are around an index of zero, indicating little engagement with ecotourism opportunities. Only a small subgroup indicates medium levels of engagement (30-70), and only a very small fraction attains high levels of participation (>90). These findings together indicate that despite there being ecotourism potential, community engagement remains heterogeneous and focused, thus underlining the need for area-targeted capacity-building and equitable tourism development strategies.

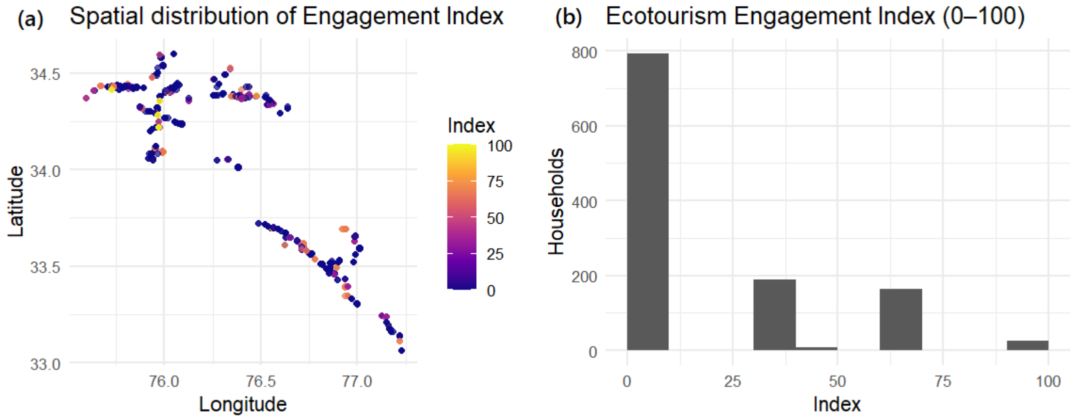


Figure 5.22: Ecotourism Engagement Index: (a) Spatial distribution of household Engagement Index values (0-100) showing highly clustered pockets of moderate to high ecotourism participation. (b) Frequency distribution of Engagement Index, showing that most households have a low engagement, with a small proportion reaching a moderate or high level.

The attitude toward wildlife conservation in the sampled population was dominantly positive, as the highest proportion indicated agreement, followed by a smaller yet striking share reporting strong agreement. It includes only a small share of the total for negative attitudes, such as disagree and strongly disagree, or non-substantive responses, including undecided, multiple selections, or no response. The bar chart based upon counts emphasizes this pattern, with "Agree" being by far the most frequent category, and all other categories occurring at substantially lower frequencies. These figures taken together suggest a strong general endorsement of wildlife conservation, for which there is only limited opposition or uncertainty among respondents; this would indicate a broad social foundation for the conservation initiatives.

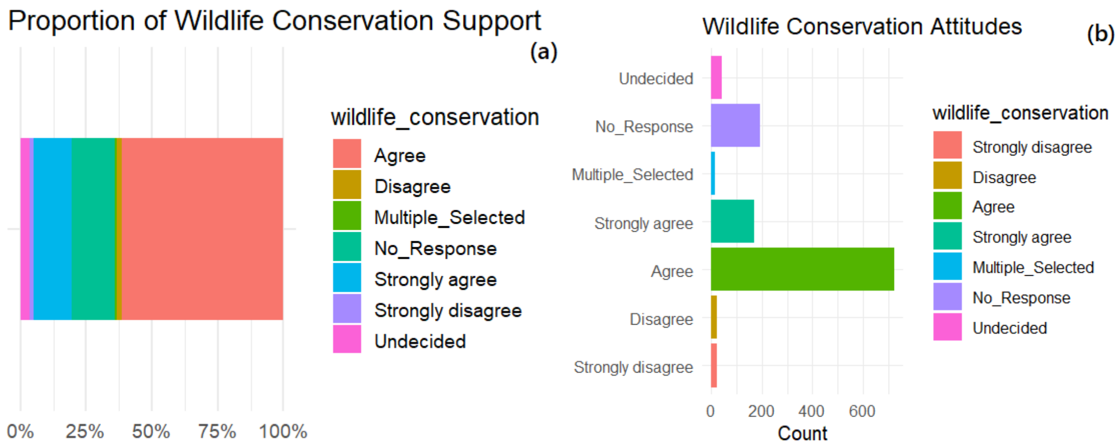


Figure 5.23: (a) Proportion of respondents across wildlife conservation attitude categories. A dominant share of the respondents falls in the category of agreement. (b) Distribution of response counts: strong overall support with a majority constituting "Agree" and "Strongly agree".

Community-based outreach awareness activities cover a total of 24 programmes, structured sessions of awareness at the village level, wherein local villagers, students, and herders are being informed about the Himalayan brown bear ecology, conflict-prevention measures, and safety protocols through presentations, discussions, and distribution of literature on do's and don'ts. These programs were aimed at enabling local capacity building, risk awareness, and informed coexistence practices.

Figure 5.24: Community-based awareness and outreach conducted throughout the District of Kargil, (n=24), consisted of educational sessions, village meetings, and the distribution of information materials regarding Himalayan brown bear and safety practices translated into local languages.

This ecotourism initiative demonstrates how the conservation-linked livelihoods opportunities can help reduce the pressures of conflict through the facilitation of Himalayan brown bear expeditions in identified hotspots. These local community members are trained and employed as bear spotters, guides, and field assistants, hence enabling them to obtain direct economic incentives from wildlife. Moreover, the adoption of homestay models increases the local income further, with the stewardship of species and habitat being encouraged. The synergistic framework of outreach and ecotourism initiatives enhances awareness, reduces hostility toward wildlife, and positions communities as key partners in the conservation effort of the brown bear.

5.5 Discussions:

The findings of this study reveal that human-brown bear conflict in Kargil is driven by a multifaceted interplay of seasonal bear ecology, livestock vulnerability, settlement-level attractants, and behavioural adaptation, patterns that closely mirror the broader Himalayan and global literature on bear-human interactions. The strong seasonal influence detected by the GLMM, with conflict peaking in spring and summer, aligns with well-documented brown bear biology wherein post-den emergence nutritional deficits and pre-hibernation hyperphagia prompt extensive foraging movements and increased contact with human activity zones (Charoo et al., 2011; Dai et al., 2020). Globally, similar temporal peaks have been identified, including across Europe and North America where attack frequencies correlate with periods of intensified bear mobility and resource searching (Bombieri et al., 2019). Spatially, the significantly higher conflict probability within villages compared to mountain sites demonstrates an accelerating behavioural shift in Kargil's brown bear population toward anthropogenic food sources, a pattern consistent with studies from the Qinghai-Tibet Plateau where bears have systematically learned to exploit household food stores and garbage (Dai et al., 2021), and with research from Himachal Pradesh indicating positive associations between bear occupancy and human-modified agricultural landscapes (Sharief et al., 2020; Kumar et al., 2022). The strong village-level clustering observed in random effects further supports global evidence that conflict hotspots often form in predictable settlement pockets characterized by livestock density, attractant availability, and inadequate waste management, as observed in Pakistan's Kalam Valley (Ali et al., 2020) and the Zanskar region (Chavan et al., 2021). Livestock vulnerability also played a major role, with the disproportionately high risk to poultry and small ruminants reflecting patterns reported in Eurasian and Himalayan studies, where small-bodied livestock held in weak, kutcha or wooden enclosures are consistently the most depredated (Bautista et al., 2021; Kumar et al., 2022). The elevated probability of conflict around certain shed types highlights the influence of husbandry practices in structuring bear behaviour, particularly as repeated successful predation events reinforce spatial memory and long-term site fidelity in bears, a behavioural mechanism widely documented across carnivore literature (Can et al., 2014; Støen et al., 2018). Intriguingly, dog-guarding was positively associated with conflict risk, best understood as reflecting reverse causality given that guard dogs are usually deployed in high-conflict zones, a pattern similarly reported in Indian carnivore systems, where the presence of dogs signals higher baseline risk rather than deterrence (Saberwal et al., 1994). The socio-economic impacts of severe livestock losses and recurrent property damage seen in Kargil agree with conflict-related livelihood disruptions across the Himalaya, where rural households with few alternative sources of income are disproportionately vulnerable (Ali et al., 2020; Chavan et al., 2021). Yet despite these pressures, community attitudes in Kargil continue to reveal a nuanced coexistence ethic as also seen in other Himalayan societies, where a mix of cultural values, religious norms, and conservation awareness fosters tolerance even as conflict rises (Kumar et al., 2022). However, as documented globally, this tolerance is tenuous, can erode rapidly without effective mitigation and timely compensation, and can lead to retaliatory killing, a major threat for small, genetically fragile brown bear populations (Can et al., 2014; Hertel et al., 2024). Finally, the limited but promising ecotourism Engagement Index suggests substantial latent potential for wildlife-based ecotourism to generate community incentives for coexistence, echoing successful snow leopard ecotourism models in Spiti and Hemis (Bragg et al., 2019). These findings affirm the urgent need for targeted evidence-based interventions, such as season-specific mitigation, strengthened livestock protection, enhanced waste management, hotspot-focused strategies, and community-based ecotourism initiatives that develop and build coexistence and reduce conflict in one of the most ecologically sensitive and socioeconomically vulnerable brown bear habitats of the Indian Himalaya.

This evolution from traditional to advanced mitigation strategies that are employed in Ladakh for the reduction of human-brown bear conflict is examined here. In contrast, while traditional measures comprise a few improvised barriers, noise or fire-based deterrents offer limited protection on a short-term basis. Advanced measures use technology-based, structured solutions comprising automated deterrent systems, predator-proof corrals, solar lighting, improved schemes for compensation, organic-waste composters, and homestays linked with wildlife. All these together point to a movement toward more effective integrated community-supported coexistence.

Chapter-6

Management and Conservation Recommendations for the Himalayan Brown Bear in Kargil, Ladakh

6. Habitat Management and Landscape-Level Conservation

The Himalayan brown bear inhabits fragile high-altitude landscapes in Ladakh that are undergoing rapid transformation. Recent research in Kargil District exposes growing habitat pressure due to expanding infrastructure (roads, military installations, and tourism facilities) and grazing, which fragment and degrade bear habitats. Seasonal shifts in natural food availability and new anthropogenic attractants (such as waste and livestock carcasses) are altering bear foraging patterns. The incidents of conflict have risen sharply, thus inflicting substantial livestock losses and economic burdens on the local communities. These findings bring to the fore the urgency of updating the conservation strategies with site-specific scientific insights to guide bear management.

Management of habitat must prioritize integrity of alpine meadows, subalpine slopes, and river valleys that support brown bears. Studies have identified western Ladakh valleys, such as Drass, Suru, Rangdum, Zanskar, and Shargole, as high-priority areas, but these are subject to various pressures arising from roads, powerlines, grazing, and expanding tourism. Strengthen conservation policies by protecting these core habitats, especially Drass, Suru Valley, Rangdum, Shargole, Bodkharbu, and Zanskar Valley, which significantly support Himalayan brown bear occupancy. Identify the areas as Community Reserve (CR). The protection and connectivity of these core habitats are important. Key measures include:

1. **Protect Critical Habitats:** Designate and protect alpine grasslands, meadow complexes, and riparian corridors identified as critical for bear foraging and denning.

2. **Infrastructure Impact Assessment:** Implement strict ecological impact assessments for all new infrastructure projects (roads, power lines, hydropower, military facilities) so that planned routes avoid important bear habitats and seasonal movement routes.

3. **Grazing Management:** Establish sustainable livestock stocking limits; implement rotational grazing to avoid overuse of high-value alpine meadows. This requires coordination with pastoralists so that grazing timing can be arranged to fit bear forage needs.

4. **Habitat Restoration:** Actively restore degraded rangelands by planting native vegetation, controlling erosion, and protecting streamside vegetation. Limit activities in known denning areas, especially during summer and autumn, to avoid disturbance.

5. **Habitat Connectivity:** Retain and advance connectivity between valleys regarding wildlife corridors through underpasses or buffer zones; this will help in the safe movement of bears

across the landscape. Prioritize the linkage of fragmented patches in Drass-Suru and other high-conflict zones.

6.1 Dietary Ecology and Food Resource Management

Dietary studies indicate that Ladakh Himalayan brown bears are primarily herbivorous, consuming a wide variety of wild vegetation, although they also use livestock and human-derived foods when natural forage is limited. During summer, bears feed extensively on high-quality alpine grasses, herbs, and roots. Throughout autumn and the pre-denning period, they progressively consume more carrion and livestock products. The presence of plastic and refuse in bear scats reflects their direct attraction to human refuse. Conservation actions should therefore ensure robust natural food supplies while minimising access to anthropogenic foods. Key measures include:

1. **Improve Natural Forage:** Conserve and, when necessary actively seed native forage species in alpine meadows (graminoids, forbs, shrubs). Protect significant berry-producing shrubs (e.g., wild roses) that provide high energy.

2. **Livestock Carcass Protocols:** Institute strict disposal protocols for livestock carcasses, such as deep burial or incineration away from villages, to avoid creating predictable food sources for bears. Educating the community on how to dispose of carcasses reduces unintentional feeding opportunities.

3**. Waste management:** Enhancing waste disposal systems within the villages, army camps, and tourist areas with bear-proof garbage containers, regular refuse collection, and strict fines against littering would go a long way in helping reduce attractants. Camping and trekking sites should be kept clean. Adoption of the organic waste composter machines by the Defence and the local administration.

4. **Crop/Fodder Security:** Prevent raiding by securing stored crops, fodder, and domestic fruits through fencing or safe storage. In areas where bear raids on small farms or orchards do occur, encourage the planting of less palatable varieties or the use of temporary fencing during harvests.

6.2 Human-Brown Bear Conflict Mitigation Strategies

Human-bear conflict is increasing in Ladakh and requires community-based as well as technical intervention. Most incidents, including attacks on livestock and occasional damage to property, occur at hotspots like the Drass and Suru valleys. Advanced techniques should be implemented to reduce the conflicts: predator-proof coral pens, animal deterrent lights, concertina wire fences, organic waste composter machines, and animal deterrent systems. In order to reduce encounters and losses:

1. **Rapid Response Teams**: Establish trained local teams that are prepared to safely drive bears away from villages and respond in the event of bear sightings. Community alert networks-watch groups, mobile alerts-can serve as an early warning system for herders and villagers.

2. **Predator-Proof Corrals:** Provide or subsidise sturdy iron corrals and night shelters for livestock- cattle, horses, goats, and sheep, in particular in areas of high conflict. Reinforce corrals with either iron rod mesh and keep them closed during the night. Encourage herders to actively guard flocks during summer and autumn.

3. **Non-Lethal Deterrents:** Install deterrents like solar-powered flashing lights, motion-activated sirens (Aniders), or livestock-guard dogs around vulnerable areas. Community-wide implementation of such measures can help condition bears to avoid settlements.

4. **Revise Compensation and Incentives:** Ease compensation processes to ensure timely payment for verified losses and digital tracking of the process. Increment compensation for preventive measures by giving priority or bonuses to herders using improved corrals and bear-safe practices. In this way, proactive coexistence is rewarded.

5. **Education and Outreach:** Implement awareness programs at the local school and community level on bear behavior, for instance, active hours, how to avoid encounters, safety in terms of proper ways to handle encounters, and their role in the ecology. Building positive attitudes reduces retaliatory killings and encourages bear-based ecotourism in the region as an alternative livelihood.

4. Integrated Landscape Strategy for Himalayan Brown Bear Conservation

An effective conservation strategy integrates bear protection with local livelihoods, tourism, and cultural values. Land-use planning needs to consider the traditional pastoral movements and community needs while securing bear habitats. Wildlife-based ecotourism development could ensure economic incentives for conservation. In this relation, the following elements are important:

1. **Collaborative Governance**: Establish joint management committees that include representation from the wildlife authorities, local panchayats, herder communities, tourism operators, and the military to coordinate land-use policies, grazing plans, and tourism development.

2. **Integration of Pastoral Route:** Identify and integrate seasonal grazing routes and sacred/cultural sites into the conservation plan and supervise overgrazing and avoid overlap with other species. Aligning bear migration corridors with safe livestock passages minimises unintentional encounters.

3. **Community Ecotourism**: Promote community-led ecotourism focused on high-altitude wildlife, including the brown bear, and on cultural experiences including guided bear-watching treks, birding tours, and homestays. In 2021, WLPD, Kargil has distributed 90 homestays in Kargil under Homestay Policy. Such schemes should be part of ecotourism promotion every year. These initiatives are to be developed in a sustainable manner, with visitor limits and local training, to provide alternative incomes and a sense of pride in the conservation of wildlife.

4. **Spatial Planning:** Utilise conflict and habitat maps to guide infrastructure development and tourism. Major projects should be shifted away from core bear areas. Village development and agriculture need to be focused in zones of low suitability for bears. Give priority to restoration in the identified important bear habitats.

6.3 Monitoring, Research, and Policy Recommendations

Ongoing monitoring and supportive policy frameworks are at the core of adaptive management. Since exact population size and its distribution of Himalayan brown bear in Ladakh is not clear, regular monitoring and research will inform the management. At the same time, policy reforms will embed bear-friendly practices into law. Key actions:

1. **Population Monitoring:** Systematic surveys include camera trapping, genetic analyses of scats, and GPS collar studies to estimate population size, distribution, and connectivity. This information will track trends and locate new populations and dispersal.

2. **Conflict Data Management:** Keep a central record of bear-human conflicts that involves detailing. Analyze the data annually for seasonal and spatial patterns and assessment of mitigation measure success.

3. **Policy Integration:** Update and implement policies to reinforce recommendations. For instance, institute into municipal ordinances the bear-proof garbage disposal, incorporate bear habitat concerns in tourism rules and regulations, compensation for infrastructure damage by bears and implement grazing regulations within the brown bears hotspot areas.

4. **Research on Change Impacts:** Support studies on the impacts of climate change and land-use changes on bear food resources, denning habitat, and range. Planning for adaptive management needs to be made under plausible future scenarios, such as changing pasture calendars or securing high-elevation corridors.

5. **Regional Biodiversity Initiatives:** Integrate the conservation of the Himalayan brown bear into larger ecosystem and climate resilience programmes. Emphasise the bear's role as a keystone species-seed disperser and as an indicator of ecosystem health to obtain funding and political backing. Coordination with adjacent regions, such as Himachal Pradesh, and Uttarakhand, would give rise to enhanced connectivity of landscapes and greater conservation impact.

6.4 Limitations and challenges:

Despite the comprehensive field effort and multi-method analytical framework undertaken in the present study, several limitations and operational challenges are inherent to such study designs, which can affect data completeness, detection efficiency, and, consequently, inferential power. The few notable challenges were:

1. The hostile terrain and extreme climatic conditions of the Trans-Himalayan region constrained the survey coverage. Most of the high-altitude or distant grids were not accessible during winters and early spring, which impaired spatial uniformity in sampling effort.

2. Species detection from non-invasive scat sampling is inherently limited by misidentification during field collection, DNA degradation due to ultraviolet exposure, and variable amplification success, which may result in underestimates of true occurrence. While laboratory validation reduces error, imperfect detection remains a limiting factor.

3. Deployment was constrained by logistic feasibility, availability of flat terrain to ensure safe installation, and risk of camera theft or malfunction. Thus, sampling intensity varied among grids, which could influence encounter rates and estimates of detection probability.

4. The far-ranging behaviour and low population density of Himalayan brown bears means the likelihood of capturing individuals or collecting fresh scats is small, thus introducing spatial and temporal heterogeneity into the dataset.

5. If used, the environmental DNA and dietary metabarcoding approaches have methodological biases, like primer mismatch, taxonomic assignment errors, and unequal amplification across prey taxa, that could affect dietary diversity estimates and proportional read abundance.

6. Statistical modelling frameworks include occupancy models, GLMMs, and RSF/ENM approaches, which generally assume independence, adequate sample size, and accurate covariate measurement. In practice, remotely sensed environmental covariates may differ in their spatial resolution and/or temporal relevance to the biological process being studied, which can affect model precision. Multicollinearity among habitat variables can mask true ecological relationships.

Lastly, socio-political and logistical constraints, such as limited accessibility around international borders, limited manpower, and short field seasons, further restricted the ability to achieve uniform sampling across all grid cells. Such limitations have to be considered when interpreting the results and extrapolating findings beyond the surveyed landscape.

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Annexure

Details of Publications, outreach programmes, national and international conferences.

- **Research article publication from the thesis in Scientific Reports Journal**

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Spatial patterns and ecological determinants of Himalayan brown bear distribution in the Trans-Himalayas of India

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The Trans-Himalayan region of Ladakh is home to the endangered Himalayan brown bear, a species that remains understudied in high-altitude environments. In the Indian Himalayas, brown bears are threatened by low population densities, and isolated, insular populations. Brown bear presence points in this landscape were collected through trail transects using polygon search framework in a systematic, grid-based manner covering ~ 35,100 km^2 (275 grids) with 4012 trails ranging from 0.5 to 6.78 km. A total of 2530 brown bear signs were recorded across the logistically possible surveyed region of the total 680 grids (10 X 10 km^2). We employed occupancy framework to understand the environmental and anthropogenic factors influencing brown bear distribution while accounting for imperfect detection. The best occupancy model (selected from 36 candidate models based on AIC) indicated a significant positive influence of terrain ruggedness, rangelands and water availability, and land surface temperature to brown bear occupancy in the study region. Further, we used MaxEnt to model potential brown bear habitats in the Trans-Himalayan landscape. The best-performing model (out of 35 models, evaluated using AUC and TSS) showed that temperature seasonality, elevation, human footprint, and land use/land cover best explained the suitable brown bear habitats in the study area. Our study provides first comprehensive landscape-scale baseline assessment on the distribution of Himalayan brown bear in high-altitude region, and highlights the key environmental driver, particularly terrain and temperature variation, influencing its occupancy and distribution. These findings are expected to inform policymakers and conservation practitioners in formulating targeted strategies to mitigate the potential impacts of climate change on this endangered species.

Keywords Habitat selection, Habitat suitability, Kargil, Occupancy, Presence, MaxEnt

The history of rapid development in the Himalayas has brought human habitation near to habitats close to wild animals[1],[2]], and with humans moving towards the Anthropocene era, their utilisation of the natural resource subsequently surged. As people search for new settlements, they are destroying wildlife habitats and wild animals migrate due to the uncontrolled use of natural habitats[3]. Understanding habitat selection and suitability is crucial for the conservation of the wildlife and for formulation of conservation management policies [[4]]. However, widespread extirpation of large carnivore populations has occurred in counter-response to increasing human population and anthropogenic activities[5].

Brown bears (*Ursus arctos*)[6] are found globally across North America, South America, Europe, and Asia. In Asia, their distribution spans Turkey, Iran, and Afghanistan, along the Himalayan range of Pakistan, India, Nepal, extending into northern China, Mongolia, Russia, and Japan, though they may have become extinct in Bhutan[7]. In India, a subspecies Himalayan brown bear (*Ursus arctos isabellinus*) is confined to the Greater and Trans-Himalayan regions. It inhabits alpine and subalpine regions, though in some parts of the Greater Himalaya, brown bears also use subalpine zones, creating areas of overlap with the Asiatic black bear[8,9]. There are estimated to be just 130 to 220 brown bears in the Himalayas and Trans-Himalayan mountain ranges of India and Pakistan[10,11]. Sathyakumar[8], estimated the possible range for brown bears in India to be around 36,800 km^2,

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with 28,000 km^2 in the northwestern and upper western Himalayan region and only 8800 km^2 in the Trans-Himalayan region of Ladakh of which only 10% of within India's protected area network[12].

Within the Indian Himalayan Region (IHR), brown bears are primarily distributed in Ladakh and Jammu & Kashmir, and parts of Himachal Pradesh, Uttarakhand, and upper Sikkim. In Ladakh, they occur mostly in the western region, such as the upper Suru Valley, Shargole, and Zanskar Valley[13]. Brown bears are located in eight protected areas in Jammu and Kashmir and 10 protected areas in Himachal Pradesh. They can be found in Gangotri National Park, Govind National Park, and the Bhagirathi basin in Uttarakhand[14]. Sathyakumar[15] suggested that they reside near Kanchenjunga National Park in Sikkim.

Brown bears are large carnivores with thick, reddish-brown fur. Adult males are 150–230 cm long, while females are 137–183 cm long. Their tails are around 10 cm long on average. Male weigh between 130 and 400 kg, while females weigh between 80 and 230 kg[16,17]. They can survive for up to 25 years in the wild. They have a very good sense of smell and can run faster than humans. Most bears eat both plants and animals, but the brown bear may eat a wide range of diets. They usually live in solitary,however, they do get together to mate or while females are raising their young. During the winter, brown bears go through a phase of dormancy or torpor that lasts up to seven months. During this time, they don't eat, drink, poop, or pee[18]. Their winter hibernation is an important life-history strategy in high-altitude, resource-limited areas, even though they don't strictly hibernate like ground squirrels do[19,20].

Denning is vital to bears survival and reproduction. Bears use den during the winter to cope the scarcity of the food and avoid harsh winter conditions and this is achieved by reducing metabolism reduced by about 70% to conserve energy[21,22]. Dens are usually located in natural caves or self-dug sites at higher elevations on steep, rugged slopes[21,23–25], and den site selection is highly sensitive to human disturbance[26]. Males attain sexual maturity between 3.5 and 7 years of age, with mating occurring from early May to mid-July. However, delayed implantation takes place around October–November, with cubs born between January and March after a gestation period of 180–270 days. Cubs typically remain with their mother for over two years, and as a result, many females breed only once every three years[27].

There is a substantial link between habitat productivity and the population of brown bears in a given region[28,29]. The Asiatic brown bear is a habitat specialist that prefers low-productivity, patchy areas like the Arctic tundra, Russian boreal forests, and the Trans-Himalayas[30]. In Alaska and North America, the utilisation of habitats changes with the seasons ranging from shrublands, alpine meadows to woodlands[31–33]. Brown bears in the Indian Himalayas have been documented inhabiting a wide range of habitats, including as alpine grasslands, forest pockets, dry alpine scrub, marshy vegetation, and places where prey is concentrated, such marmots[8,34,35]. In Deosai National Park (Pakistan), for example, marshes with lots of vegetation and golden marmots were the best places to reside. Whereas, in Kugti Wildlife Sanctuary, H.P. (India), brown bears use different categories of habitats viz., grasslands, agricultural fields, forest blanks, mixed forest, moist temperate forests, water bodies, dry alpine scrub distinguished by Juniperus spp, exposed rock with slope pastures and sub-alpine scrub dominated by Rhododendron spp,[35]. The Himalayan brown bear occurs at a very low density in the alpine and subalpine areas in the elevation range of 3000 m to 5000 m in the Greater Himalaya and the Trans-Himalayan region exclusively confined to the northwestern and western Himalayan region of India[8].

Despite their ecological importance, brown bears remain poorly studied in India, particularly in the high-altitude Trans-Himalayan landscapes where only a few valley-level assessments have been conducted[12,36,37]. After being designated a Union Territory, the area is going through big changes in development, with big investments in infrastructure, solar energy, and transmission lines. In this situation, it is very important to know the brown bear's habitat needs and spatial ecology in order to balance conservation goals with ongoing development[38,39].

Unlike earlier site-specific assessments[12], our study integrates occupancy and habitat suitability modelling at a landscape level research in the high-altitude, data-deficient region, providing the first comprehensive baseline for Himalayan brown bear conservation in the Trans-Himalayan region of Ladakh. Systematic, landscape level ecological studies such as this can be meaningfully guide to the policy makers, practitioners and wildlife managers in planning conservation and management strategies of the endangered species. To address this gap, the present study investigates the influence of environmental, topographic, and climatic variables on the distribution of the Himalayan brown bear in Ladakh.

The Trans-Himalayan region of Ladakh is unique in its biogeography, comprising a mix of montane ecosystems, extreme climatic conditions, and rugged terrain. Studying the habitat ecology of a flagship species like the Himalayan brown bear (Endangered as per IUCN Red List and highest protection under Schedule I of India's Wildlife Protection Act, 1972) will help us understand the distribution of the species in high-altitude ecosystem.

We propose that brown bears in Ladakh (Hypothesis 1) demonstrate a preference for particular habitat types, including alpine rangelands and river valleys[35], (Hypothesis 2) choose habitats based on specific topographic features such as elevation, slope, and terrain ruggedness; and (Hypothesis 3) modify their habitat utilization in response to seasonal temperature variations. The related null hypotheses assert the absence of any substantial preference in each instance. The goal of this study is to find out how environmental and topographic factors affect the habitat preferences and distribution of the Himalayan brown bear in Ladakh region.

Results

We carried out trail transects using polygon search framework in a systematic, grid-based manner covering ~ 35,100 km^2 (275 grids) with 4012 trails ranging from 0.5 to 6.78 km. A total of 2530 brown bear signs were recorded across the surveyed region (Fig. 1). Most of the eco-geographical covariates used for Occupancy and MaxEnt models were weakly correlated, except elevation and terrain ruggedness of which only one was used per model (see Supplementary Tables S3 and S4).

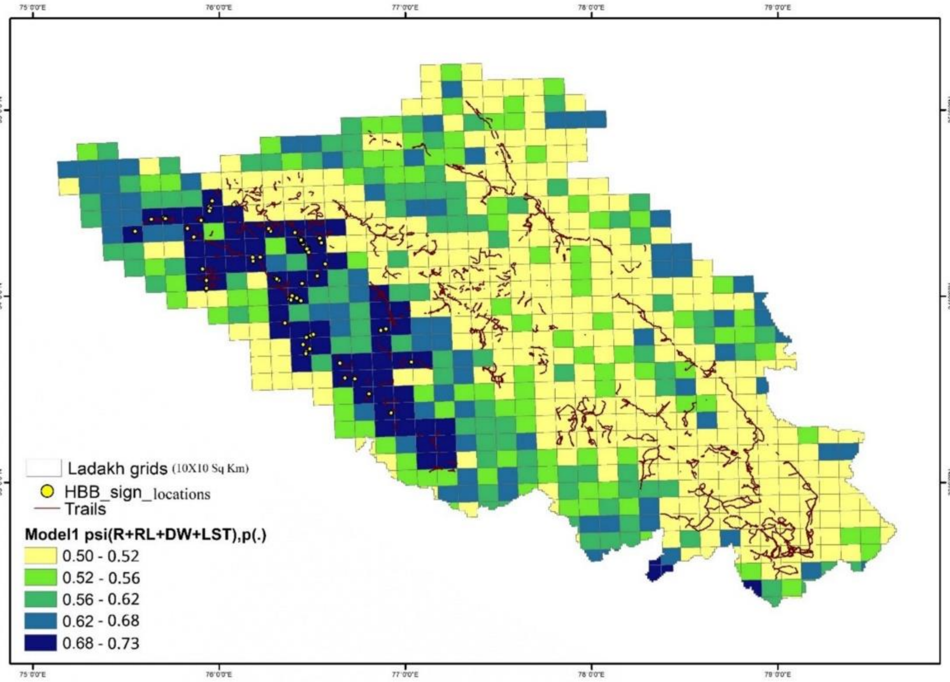

Fig. 1. Occupancy probability map for the Union Territory of Ladakh was generated to visualize the spatial patterns of species occurrence. This map represents the outputs of the best-fitting occupancy model, identified by the lowest Akaike Information Criterion (AIC) value, from surveys conducted during the 2019–2020 field season. Occupancy probabilities were spatially classified using the Natural Breaks (Jenks) method, with specific break values presented as percentages. The entire mapping process, including spatial data visualization and classification, was performed using ArcMap 10.8.2 software (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

Model performance

We ran 36 candidate models (Supplementary Table S5) in PRESENCE (*v2.13.47*) following[40] and the naïve occupancy was 0.099. The detection history dataset included sampling covariate and site covariates. It also had field-collected covariates like wild prey, domestic animals, and wild rose. We also analysed the model using trail length as a detection covariate (p(trail length)) and found no significant results due to the high standard error. We imported the PRESENCE model output into ArcGIS, and prepared an occupancy map.

To complement occupancy modelling, we conducted species distribution modelling using MaxEnt (v3.4.4). A total of 34 models were run using 80% of occurrence points for training and 20% for testing. Fourteen environmental variables were extracted and processed in ASCII format in ArcGIS (v10.8). The best MaxEnt model (Table 2) had strong performance (mean AUC = 0.950 ± 0.007; TSS = 0.71). The ROC curve (Fig. 2) shows the model's strong discriminatory ability. Jackknife tests (Supplementary Graph S7) identified temperature seasonality (bio4), annual mean temperature (bio1), and elevation (DEM) as the most influential predictors.

H1: Habitat preference

Occupancy models supported the hypothesis that habitat type influences brown bear presence. Rangelands (Table 1) had a large positive effect on occupancy (ß = 0.45, SE = 0.18), whereas distance to water had a strong negative effect (ß = -2.35, SE = 0.49). This means that bears are more likely to be found in valleys with vegetation and prey availability. The occupancy map showed that valley systems like Drass, Suru, and Zanskar had a higher chance of being occupied. The results from MaxEnt were consistent, with land use land cover (rangelands: 11.2%) of the model (Table 2). This shows that rangelands and valleys are important habitats (Fig. 3). Bears avoided places with a high Human Footprint Index (Fig. 4) and instead preferred places with a low to moderate disturbance (HFP = 5–25), which is in line with earlier research that showed they were sensitive to human activity[41].

The occupancy model (Fig. 1) provided a spatial representation of habitat selection for the Himalayan brown bear in Ladakh with probabilities ranging from 0.50 to 0.73. The dark blue grids (0.68–0.73) indicate core zones

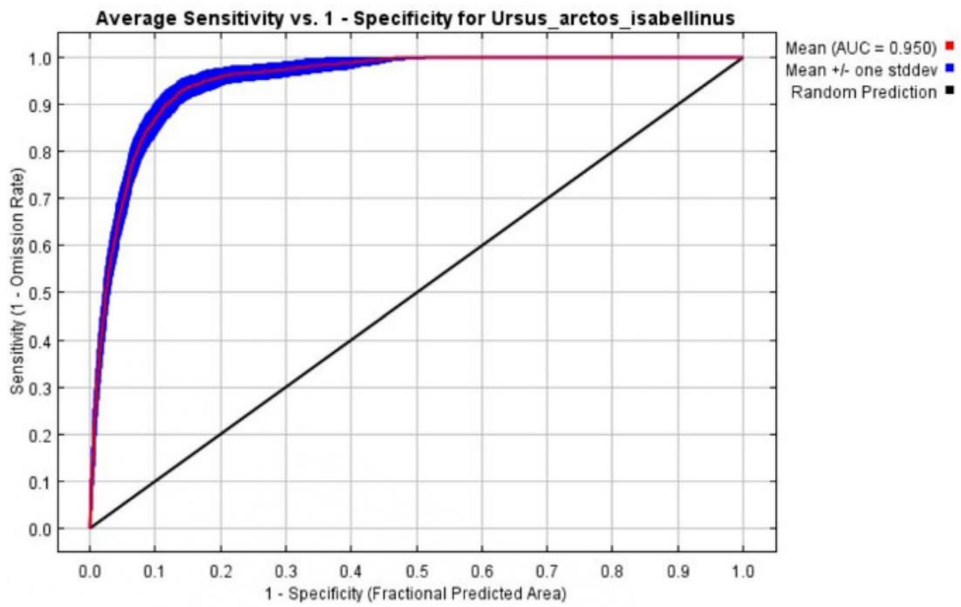

Fig. 2. The graph illustrates the Receiver Operating Characteristic (ROC) curve for MaxEnt model predicting habitat suitability of Himalayan brown bear in Ladakh. The curve shows model sensitivity vs specificity (fractional predicted area). The AUC is 0.950, indicating excellent predictive accuracy of the model for the Himalayan brown bear in Ladakh.

Parameter	Model	ß estimate	SE
Ψ	Intercept	−2.43	0.37
Ψ	Terrain Ruggedness Index	0.82	0.26
Ψ	Rangelands	0.45	0.18
Ψ	Distance to water	−2.35	0.49
Ψ	Land surface temperature	0.77	0.22
P	Detection-intercept	−0.06	0.11

Table 1. Himalayan brown bear occupancy model. First model parameter estimates Himalayan brown bear occupancy (Ψ) and detection (P) in Ladakh. The sign and magnitude of the ß estimate indicates the relative influence of the ecological variables on Himalayan brown bear occupancy.

which offers the conditions most favourable for the brown bear[42,43]. The C-hat value of the first model was adequate ($\hat{c}$ = 1.24),details of additional models are provided in Supplementary Data S6.

H2: Topographic influence
Our second hypothesis mentioned that topography influences bear distribution in high altitude region was also supported. Terrain Ruggedness Index (TRI) had a significant positive effect in the occupancy models (ß = 0.82, SE = 0.26), suggesting preference for moderately rugged terrain (Table 1). MaxEnt response curves further showed that suitable habitats occurred within TRI values of 50–150 m and elevations between 3000 and 4500 m asl, with Digital Elevation Model (DEM) contributing to model predictions (Fig. 4). These results highlighted that bears favor mid-elevation landscapes with moderate ruggedness.

H3: Temperature effect
Temperature emerged as strong determinant of habitat suitability through MaxEnt. In occupancy models (Table 1), land surface temperature (LST) was positively associated with occupancy (ß = 0.77, SE = 0.22). MaxEnt models reinforced this, with temperature seasonality (bio4) contributing 47.7% and annual mean temperature

Variables	Percent contribution	Permutation importance
1. Bioclimatic (bio4)	47.7	32.5
2. Bioclimatic (bio1)	32.3	52
3. Land Use Land Cover (LULC)	11.2	1.7
4. Bioclimatic (bio2)	4.1	5.9
5. Terrain Ruggedness Index (TRI)	1.8	2.5
6. Human Footprint Index (HFP)	1.5	2.7
7. Digital Elevation Model (DEM)	1.5	2.7

Table 2. Relationship between Himalayan brown bear and environmental variables. Bioclimatic variables (bio4 (highest contribution), bio1 and bio2), Land Use Land Cover (LULC), Terrain Ruggedness Index (TRI), Human Footprint Index (HFP) and Digital Elevation Model (DEM) with percent contribution and permutation importance.

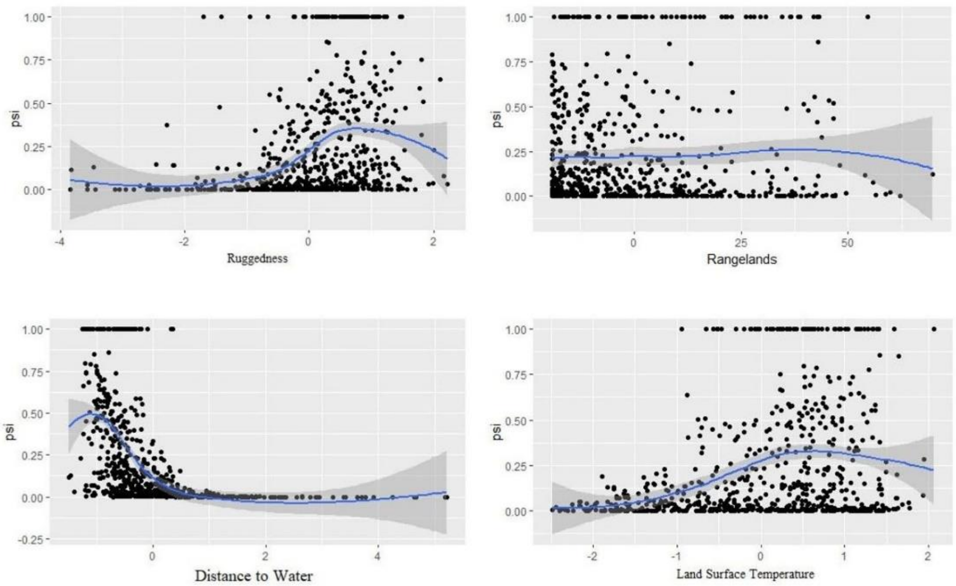

Fig. 3. Relationships between Himalayan brown bear and environmental variables. Occupancy probability of brown bears in Ladakh in response to (**a**) Terrain Ruggedness Index, (**b**) proportion of Rangeland in a grid, (**c**) average grid distance to perineal water source, and d) Land surface temperature between April–October season.

(bio1) 32.3% to habitat suitability predictions. Bears showed a preference for areas with significant seasonal variation (Fig. 4), particularly in the western Ladakh, where climatic conditions support resource availability and denning opportunities. Mean diurnal temperature range (bio2) also influenced suitability reflecting preference for moderate daily thermal variation (10–13 °C).

Across both modelling approaches, the strongest predictors of Himalayan brown bear distribution were rangelands, water proximity, terrain raggedness, and temperature variation (Figs. 3, 4), supporting all three hypotheses and indicate that western Ladakh has predominantly the most suitable habitats. Occupancy models (Fig. 1) highlighted fine-scale site use, while MaxEnt (Fig. 5) provided complementary landscape-level insights, together reinforcing the ecological drivers of brown bear distribution in the high-altitude region (Fig. 6).

Discussion

This is the first landscape-level ecological assessment of Himalayan brown bear distribution in the Trans-Himalayan region of Ladakh, integrating occupancy and MaxEnt frameworks to provide a conservation baseline

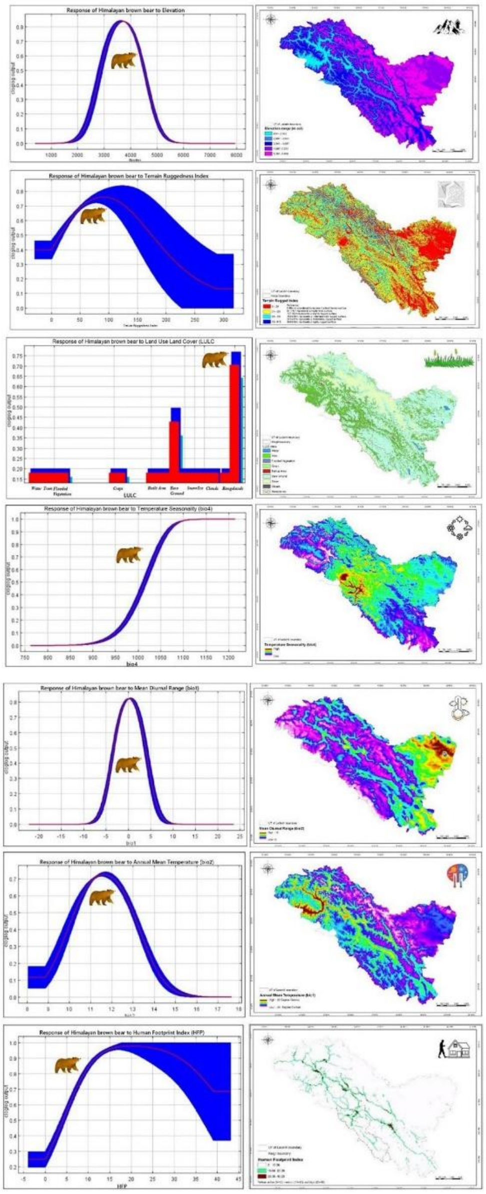

Fig. 4. MaxEnt response curves of Himalayan brown bear and the spatial representation of environmental in Ladakh. Graphs: Himalayan brown bear response to environmental variables (Digital Elevation Model (DEM), Terrain Ruggedness Index (TRI), Land Use Land Cover (LULC), Temperature Seasonality (bio4), Annual Mean Temperature (bio1), Mean Diurnal Range (bio2), and Human Footprint Index (HFP-2020). Maps: Mapping of respective environmental variables in the Ladakh.

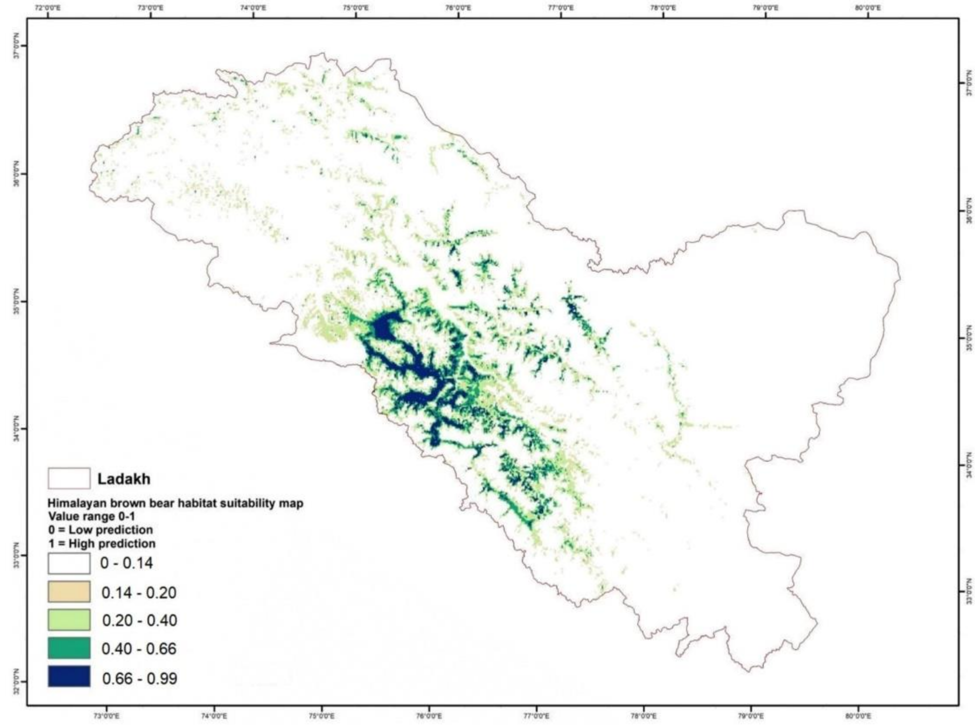

Fig. 5. Habitat suitability map was developed for the Himalayan brown bear (*Ursus arctos isabellinus*) across the Ladakh landscape to identify and visualize potential habitat areas. This map was generated using the MaxEnt (Maximum Entropy) modelling approach, incorporating survey data collected during the 2019–2020 period. The output depicts the spatial distribution of habitats, categorized by various degrees of suitability, which reflect the integrated influence of selected environmental, topographic, and anthropogenic factors. All spatial processing and map finalization were conducted using ArcMap 10.8.2 software (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

in a data-deficient, high-altitude regions. The dual framework strengthens confidence in our findings and demonstrates the value of integrating multi-modelling approaches for conservation planning in data-deficient landscapes[40,44]. The results have direct implications for the conservation planning by policymakers and managers in executing management strategies for crucial habitats in Drass, Suru, Shargole, and Zanskar Valleys (which do not have designated protected areas) to sustain brown bear populations in Ladakh.

Our results provide robust support for the first hypothesis (H1) which align with previous research suggesting that alpine meadows and valley systems offer essential fodder and prey resources for brown bears[35,42,45]. In Ladakh, rangelands are productive at certain times of the year and sustain a wide range of herbaceous plants, small mammals, and livestock. These are all important parts of the brown bear's diet[35,46,47].

The highlights vulnerability in western Ladakh currently face pressure from rapid linear-infrastructural developmental activities, overgrazing and unregulated tourism. Protecting these valley systems is therefore essential, not only for bears but also for other sympatric species that depend on the rangeland ecosystem.

The second hypothesis (H2) suggesting that topography shapes brown bear habitat selection[28,48]. Rugged terrain may act as a refuge, offering shelter for cubs and concealment from human activity, while also supporting diverse foraging opportunities[24,49,50]. Comparable finding has been reported in European and North American brown bear populations, where mid-elevation, moderately rugged landscapes were associated with higher occupancy and penology[41,51]. In Ladakh, such landscape coincides with lower human footprint, reinforcing the importance of topography in mitigating anthropogenic pressures.

Conservation planning should therefore prioritize rugged mid-elevation zones as potential denning habitats and corridors, especially given the increasing road development and defense presence in Ladakh's valleys and plateaus.

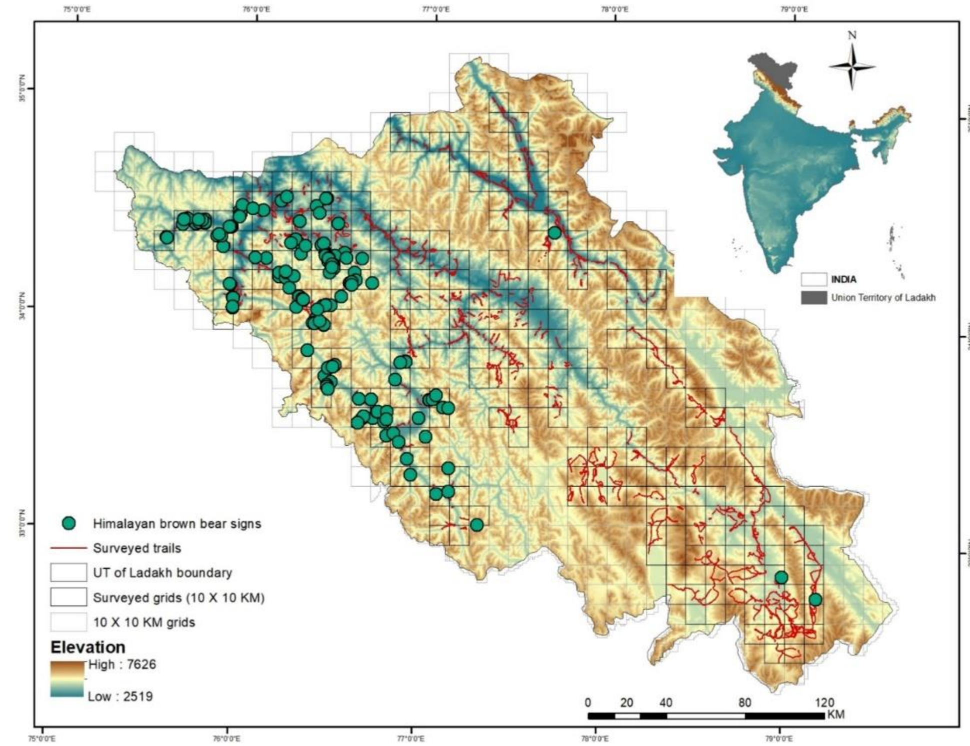

Fig. 6. Map of the study area, sampling grids of 10 × 10 km², survey trails and brown bear presence locations on the Elevation background of Laddakh UT, which is the Himalayan brown bear distribution range part in India. The map was created using ArcGIS Map 10.8.2 (https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview).

Temperature variation emerged as a dominant driver of brown bear distribution, supporting our third hypothesis (H3). Bears were particularly associated with areas exhibiting pronounced seasonal variation which is found in western Ladakh, where climate conditions likely enhance forage productivity and facilitate thermoregulation[43,52,53]. The tendency towards temperature variation during the day time seems to represent the optimal temperature variability preference[54].

These results underscore the role of climate in determining brown bears distribution in high-altitude ecosystem. Similar patterns have been documented in alpine carnivores, where seasonal variation governs foraging dynamics and denning behavior[55]. Notably, suitability declined towards eastern Ladakh, where reduced seasonal variability and harsher arid conditions limit resource availability. Changes in temperature and rainfall patterns may force the species to move its thermal niche to higher elevations, where there are fewer places to survive[56,57].

Our findings reveal that western Ladakh, especially the Drass, Suru, Rangdum, Shargole, and Zanskar Valleys, are important areas for the Himalayan brown bear. These regions are also among the most susceptible to human disruption, owing to grazing pressure, agricultural development, linear infrastructure, mining and human-bear conflict[36,37]. An isolated presence in Nubra Valley necessitates additional examination of potential habitat corridors and subpopulations.

This study underscores the intricate habitat necessities of the Himalayan brown bear and stresses the necessity for adaptive conservation methods to secure the enduring existence of this endangered subspecies in the Trans-Himalayan region. The findings have significant implications for conservation of bears in Ladakh. Identifying priority habitats, especially in western Ladakh, would help us come up with more effective conservation plans.

Our results may have a concrete impact on wildlife conservation policies in Ladakh. To keep bear populations healthy, it's important to safeguard rangelands, valleys beds, and limit development-induced fragmentation in areas critical for bears. Conservation initiatives must find a balance between protecting habitats and community engagements. This includes predator-proof corral pens, regulating rangeland, improvising waste management, promoting ecotourism based on brown bears, and raising awareness.

Despite the intensive assessment, the study faced limitations inherent to high-altitude fieldwork. Detection probabilities were low reflecting the elusive nature of brown bears and logistical constraints of surveying in rugged terrain interlinked with large streams and high passes. Some ecological factors, such as prey abundance and human disturbance information's, were not fully qualified, and should be integrated in future research. Additionally, while our study provides a spatial baseline under the current climatic conditions, projecting habitat suitability under future climate change scenarios will be critical to anticipate range shifts. Incorporating camera-trap for density estimation and behavioral study, scat-DNA based population estimation and diet, and multi-season occupancy models could further enrich understanding of population dynamics, corridors, and ecological interactions in the region.

Materials and methods

Study area

The Trans-Himalayan region of the Union Territory of Ladakh covers an area of186,200 km^2 and is categorised as 1A High Altitude Cold Desert Biogeographic Region[58]. The Indian Trans-Himalaya is an extension of the Tibetan plateau covering Ladakh and Lahaul Spiti in the state of Himachal Pradesh. Elevation Ladakh varies from 2533 m in valleys to 7742 m as Saltaro Kangri. The regions characterised by low precipitation, a short growing season, low primary productivity, but having a high livestock density[59]. The climate is harsh with cold and arid temperatures dipping below -30 °C between November and March, with a short season for crop cultivation[60]. The region represents an ecosystem where the common livelihood source is traditional agro-pastoralism[61]. Individual families own livestock, whereas the grazing land is common to the village with equal access (Mishra et al. 2001). Ladakh landscapes are unique considering that the wild animals are not restricted to protected areas but found across the landscape[62].

The landscape of the area is mountainous, rugged, and interspersed with valleys drained by the river Indus and its tributaries. Ladakh has been divided administratively into seven new districts. Kargil, Leh, Drass, Zanskar, Sham, Nubra and Changthang.

This study is carried out intensively in Kargil district and extensively across Ladakh because, based on the literature and local knowledge, the Himalayan brown bear is predominantly reported from the western region (Kargil) of Ladakh.

Field data collection

Field sampling was carried out using 'MSTrIPES' digital application equipped with collecting the spatial and temporal characteristics of occupancy trails of Himalayan brown bear along with the geotagged photos of sign detections. Data captured using the app was imported into desktop programs designed for data organisation and archiving. The sample, which amounted to over 30,000 working-days ('man-days') over two years (2019–20), was carried out in cooperation with local field assistants and researchers and employees of the Wildlife Protection Department. We ensured that each survey team was formed up of experts in these different filed data collection methods.

Occupancy survey

Based on the accessibility of the terrain and logistics, the landscape was divided into a grid spanning 10 × 10 km. In order to account for the natural variation in habitats, the grid was further segmented into 5 × 5 km sub-grids so that our sampling could be evenly distributed across each cell. We assessed the occupancy of brown bears in each of the 25 km^2 sub-grid cells. We conducted at least one sign-search survey of about 5 km each in every sub-grid cell to record signs of the species. We targeted human trails, ridgelines, and valleys to maximise the chances of encountering signs. We recorded signs such as tracks, scats, and sightings that could be assigned to the presence of brown bears to spatially spread the search pathways. We surveyed Ladakh landscape collectively to validate the species' distribution and suitability of their habitats in the region. All field data was collected using a phone-based polygon search application developed for occupancy surveys (MSTrIPES,[63]). We plotted all brown bear sign locations (2530) to gain a preliminary understanding of the distribution of Himalayan brown bears in the Ladakh region.

Environmental variable collection

We used ecogeographic variables derived from multiple source(s) and generated using ArcGIS with their original spatial resolutions ranging between 10 m and 1 km (see Supplementary Table S1). To ensure homogeneity and model compatibility, all predictor rasters were resampled to a uniform resolution of 1 km^2 prior to modelling. This resolution was selected as it represents an ecologically relevant scale for understanding the distribution of brown bears in the Trans-Himalayan region. The variables included those that were likely to influence the occurrence of brown bears as per our ecological knowledge of the species and our a priori hypotheses (see Supplementary Table S2). We aligned our hypotheses with specific ecological predictors. For habitat preference (H1), we used rangeland cover and distance to water as indicators of vegetation and productive valleys. For topography (H2), we considered terrain ruggedness index (TRI), elevation, and slope to capture landscape structure. For temperature effects (H3), we included land surface temperature (LST) in occupancy models and bioclimatic variables (bio1, bio2, bio4) in MaxEnt to represent climatic influences.

Analytical framework

Habitat selection modelling

We use occupancy modelling that corrects for detection bias and model's species occurrence using relevant eco-geographical covariates[40,64]. We conducted single species single season occupancy analysis using PRESENCE software version 2.13.47[65]. We modeled detection probability with survey effort and occupancy with site characteristics. We estimated occupancy using maximum likelihood approach and selected the most parsimonious model with the lowest Akaike Information Criterion (AIC) and used model average Akaike weights when two or models differed by less than five AIC. This approach is particularly suitable for large-scale population dynamics monitoring and habitat selection[32].

To avoid collinearity in the model we first estimated the correlation between all ecogeographical variables and then used only one of a pair of correlated variables in any given model. Following the extraction of the PRESENCE results from each model, we exported the Psi-conditional [Pr(occ | detection history)] values into Excel to normalize. We then transformed them into inverse logit, the logistic function defined by $\exp(x)/(1+\exp(x))$. The inverse logit transformation takes values on the real line and converts them to be between zero and one. We used clog-log to determine the prediction of values for spatial representation of Himalayan brown bear distribution. We processed the analysis at 100 bootstrap iterations to estimate C-hate values. A diagnostic metric called C-hat evaluates the data-fit of the model. It basically checks for overdispersion, the condition whereby the observed data variability surpasses what the model projects. A good model fit is indicated by a c-hat value of 1; values higher than 1 imply overdispersion.

When working with statistical models, beta estimates show the relationships between predictor variables and a response variable. The magnitude of the beta estimate (i.e., how far it is from zero) indicates the strength of the relationship.

Habitat suitability modelling

We investigated habitat suitability to learn more about how species are spread in the western part of Ladakh by looking at occurrence data, landscape covariates, and bioclimatic variables. We used the Maximum Entropy (MaxEnt) modelling methodology[44,66] in MaxEnt, SDM V 3.4.4, software known for robust handling of presence-only data. MaxEnt creates a probability surface showing areas with acceptable conditions for the species by integrating known occurrence locations with environmental predictors, therefore evaluating species habitat suitability.

The habitat suitability analysis was carried out exercising occurrence data and landscape covariates through the MaxEnt species distribution modelling method, SDM V 3.4.4[44]. Employing ArcGIS v. 10.8 software[68], we identified 14 potential landscape covariates and transformed the variables into ASCII (American Standard Code for Information Interchange) file format. The model was trained using 80% of the locations, while the accuracy was evaluated on the remaining 20%. Additionally, the model, which integrates 34 distinct models, underwent processing and was utilised in a jackknife test to assess the significance of predictors. To ensure precise predictions, the models were executed 1, 10, and 100 times utilising bootstrap methods. The True Scale Statistics (TSS) value (MaxEnt: Background Prediction, Sample Prediction Test, and Threshold Value 10 Clog-log) was utilised to select the optimal model.

This approach enabled us to assess the probability of species presence at multiple locations by using ecological and climatic variables. Combining species occurrence records with key ecological traits like elevation, land cover, temperature, and precipitation patterns, we generated a predicted habitat suitability map for the region. We selected the final model based on True Skill Statistics (TSS) values[67].

Data availability

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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Author contributions
PR, BP, YVJ designed the research and obtained funding. NHK and PR conducted the study, NHK AS and DJ exercised the data analysis, interpretation and wrote the manuscript of the paper with significant contributions by YVJ, BP and PR. RAA helped in field data collection strategies and logistics in western Ladakh. All authors provided comments and suggestions that significantly improved the manuscript and approved the last version.

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Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to N.H.K.

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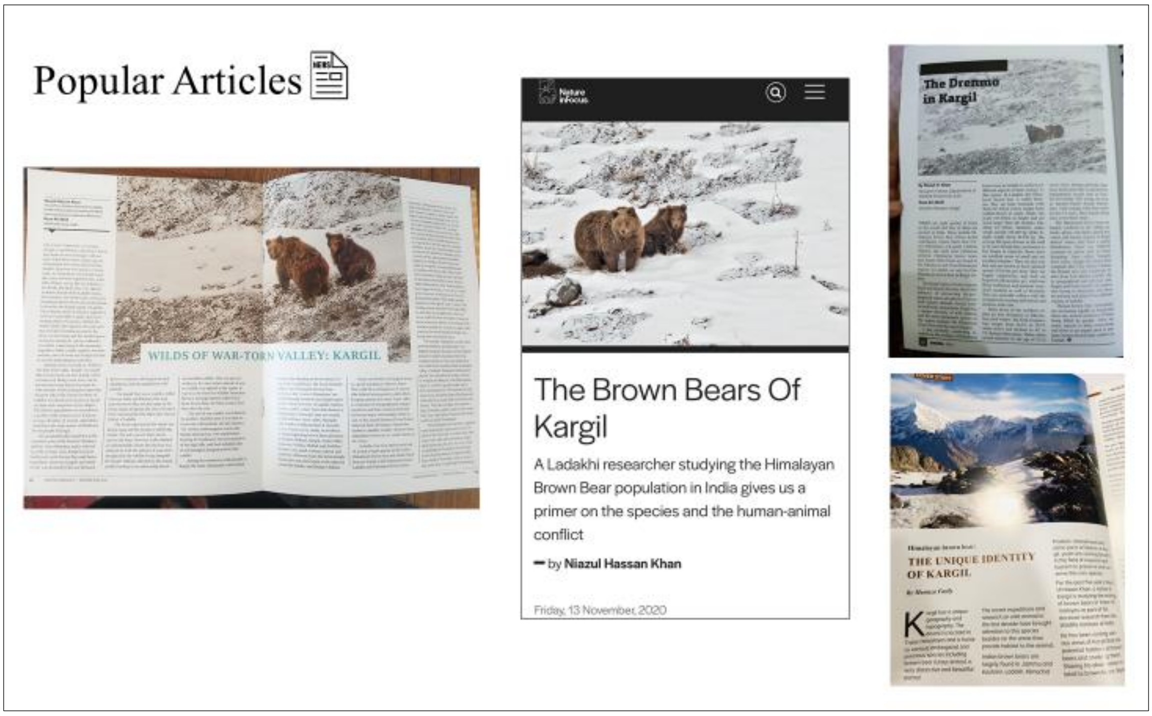
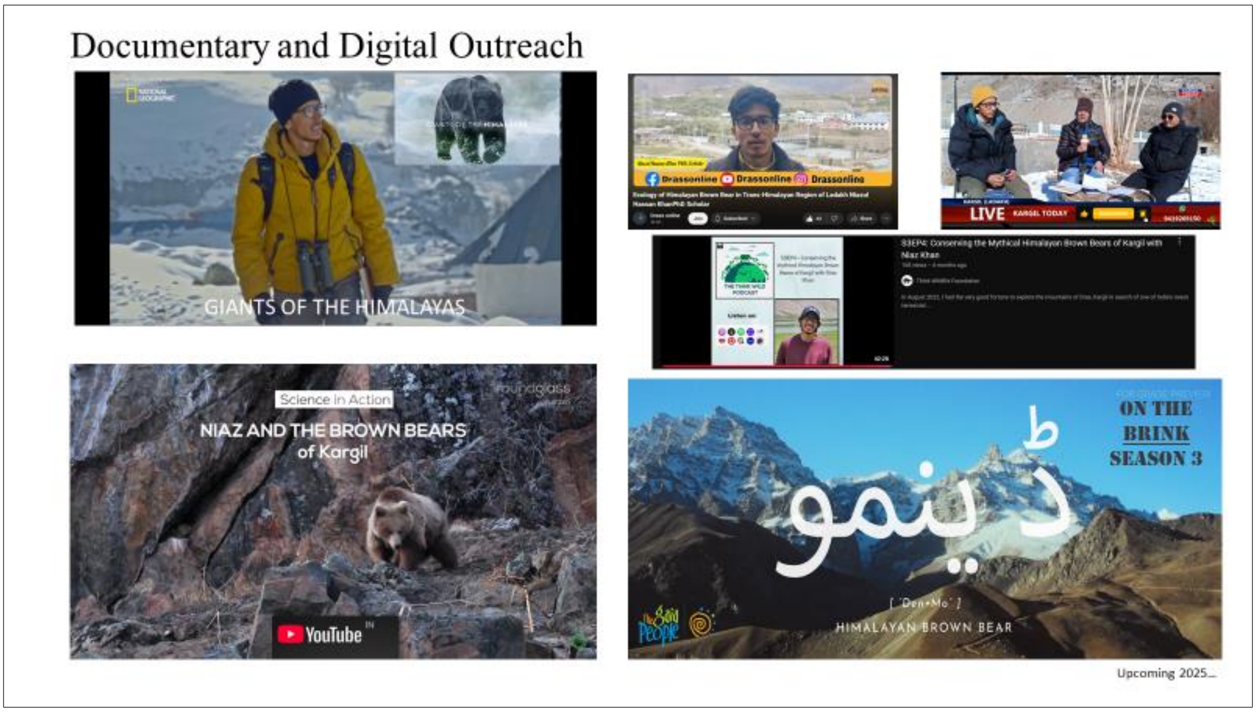
- **List of popular articles published in national and local magazines on Himalayan brown bear**

I have authored several popular articles that highlight the ecological significance of the Himalayan brown bear and the unique landscapes of Kargil. My published works, including The Brown Bears of Kargil in Nature inFocus, Wilds of War-Torn Valley in Stawa magazine, The Dremmo in Kargil in Jungwa magazine and The Unique Identity of Kargil in Kargil Nama. I've been able to advocate for my homeland's wildlife, share its voice, and add to a larger national dialogue on Himalayan conservation by writing these articles.



- List digital outreach on Hialayan brown bear: The Himalayan brown bear conservation importance was highlighted in National Geographic documentary '*Giants of the Himalayan*', Roundglass Sustain 'Science in Action' and other local media channels. A documentary specially dedicated to Himalayan brown bear conservation in Kargil named '*Denmo*' will be telecasted in the On The Brink (Season III).



List of International and National Conferences attended:


IRALE CONFERENCE 2024

21-23 FEBRUARY | MURTI, WEST BENGAL

Certificate of Presentation

to

NIAZUL HASSAN KHAN

of Wildlife Institute of India

for presenting a paper entitled

Bear necessities: Navigating the Himalayan brown bear's habitat in Trans-Himalayan region of Ladakh

DEBAJIT DATTA
Chair | IRALE Conference 2024

RAMESH KRISHNAMURTHY
President | IRALE

INDIAN REGIONAL ASSOCIATION FOR LANDSCAPE ECOLOGY

विकसित भारत अभियान
1947 TO 2047

THE ADMINISTRATION OF UNION TERRITORY OF LADAKH

INSTITUTION'S INNOVATION COUNCIL
(Ministry of HRD Initiative)

National Conference

LADAKH CLIMATE CHANGE SCENARIO & ENVIRONMENTAL SUSTAINABILITY

LCCSES-2024

12-13 SEPTEMBER 2024

University of Ladakh

CERTIFICATE OF PARTICIPATION

This is to certify that Prof/Dr/Mr/Ms. NIAZUL HASSAN KHAN

of WILDLIFE INSTITUTE OF INDIA

has actively Participated/Presented (oral/poster) on BEARING IN HIGH ALTITUDE: HIMALAYAN BROWN BEAR HABITAT ECOLOGY IN THE TRANS-HIMALAYAN REGION OF LADAKH

In the National Conference organized by University of Ladakh and Co-Organized by NAMO Medical Education & Research Institute, Silvassa at Taru Campus, Leh.

Dr. Amjad Hussain
Organizing Secretary
LCCSES-2024

Dr. Subrat Sharma
Convenor
LCCSES-2024

Prof. S. K. Mehta
Vice Chancellor
University of Ladakh

Indian Ecological Society International Conference

Transforming Agrifood Systems in the Face of Climate Changes and Energy Transitions

(November 12-15, 2024)

CERTIFICATE

This is to certify that

Niazul H. Khan, Wildlife Institute of India, Dehradun, India

has participated and made oral presentation of the research paper entitled

Human-Brown Bear Interactions in Western Ladakh

in the Indian Ecological Society International Conference-2024 (IESIC-2024) held at Punjab Agricultural University, Ludhiana, India

IESIC-2024
NOVEMBER 12-15, 2024

Vijay Kumar	Adhawan	Gosal
Dr Vijay Kumar **Organizing Secretary IESIC-2024** **Principal Entomologist** **PAU, Ludhiana**	**Dr AK Dhawan** **Co-Chair IESIC-2024** **President IES** **PAU, Ludhiana**	**Dr SS Gosal** **Chair IESIC-2024** **Vice Chancellor** **PAU, Ludhiana**

CERTIFICATE OF ATTENDANCE

This is to certify that

Niazul Hassan Khan

has attended the **"8th International Congress on Zoology and Technology"** on 13.12.2024 - 16.12.2024

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Chair of Congress

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