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Source: Ursus, 2024(35e23) : 1-10

Published By: International Association for Bear Research and Management

URL: https://doi.org/10.2192/URSUS-D-24-00004.1

Habitat selection by the Himalayan brown bear in the multiuse landscape of Lahaul Valley, India

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Abstract: The Himalayan brown bear (*Ursus arctos isabellinus*) is the largest carnivore in the Himalayan Mountain range of India, Pakistan, and Afghanistan. Distinguished by its exclusive occurrence in mountain landscapes within the Himalayas, this species is threatened by anthropogenic pressure, habitat degradation, and climate change. There is limited understanding of the habitat requirements of the Himalayan brown bear in India, so we used camera traps and sign surveys conducted from July 2018 to December 2022 to address this knowledge gap, focusing on the influence of ecogeographic variables on Himalayan brown bear habitat use within the Lahaul Valley of India. Employing a generalized linear model using presence and randomly generated pseudoabsence locations, we found a positive relationship of Himalayan brown bear habitat use with annual precipitation, the largest patch index, the Shannon diversity index, and slope. Conversely, a negative association was observed with elevation and precipitation in the driest month. The study found Himalayan brown bear preference for larger, interconnected habitat patches, highlighting the significance of these areas for resources and connectivity. Himalayan brown bear predicted presence is mainly in the subalpine and alpine regions at 2,500 m to 4,500 m elevation. Moderate to steep slopes are preferred by Himalayan brown bears, consistent with den site preferences and habitat use patterns. Resource Selection Index outcomes reveal a strong affinity for forests, and reduced use of rangeland. Given the absence of protected areas in the study landscape and prevailing threats of habitat loss to agricultural expansion, livestock grazing, and roads development, we emphasize the urgency of identifying and connecting ideal habitat patches to ensure the conservation of the Himalayan brown bear in the Lahaul Valley and adjoining areas.

Key words: camera trap, generalized linear model, habitat use, Himalayan brown bear, India, nonprotected area, resource selection, *Ursus arctos isabellinus*

DOI: 10.2192/URSUS-D-24-00004.1 ***Ursus 35:article e23 (2024)***

The study of habitat use and the influence of environmental covariates on species distribution is important in understanding the ecology of the species (Guisan and Zimmermann 2000, Nielsen et al. 2010, McClure et al. 2017) and for planning conservation strategies (Pearce and Boyce 2006, Shahnaseri et al. 2019, Mohammadi et al. 2021). The brown bear (*Ursus arctos*) is the world's second-largest terrestrial carnivore; its distribution and habitat use are mainly governed by ecological needs such as food, shelter, and opportunity to mate (Schlaepfer et al. 2002, Kristan 2003, Almpanidou et al. 2014).

The Himalayan brown bear (*U. a. isabellinus*) is considered an ancient lineage and inhabits the highlands of India, Pakistan, and Afghanistan (McLellan et al. 2017). The Himalayan brown bear is classified as endangered by the International Union for Conservation of Nature red list under criteria 'D' because of its small population size (130–220), sparse distribution, and threats of climate change, habitat loss, and anthropogenic disturbance (Sergio et al. 2008, McLellan et al. 2017, Mukherjee et al. 2021, Dar et al. 2023). In India, the Himalayan brown bear is a high conservation priority and is listed as a Scheduled-I species in India's Wildlife (Protection) Act, 1972. In India, Himalayan brown bears occupy the highlands of the Western Himalaya in Jammu and Kashmir Union Territory (JKUT), Ladakh Union Territory (LUT), and in the states of Himachal Pradesh and Uttarakhand (Sathyakumar 2006). They prefer alpine meadows and subalpine regions between 2,500–5,000 m of elevation in the Greater Himalayas of India (Sathyakumar 2001, Sharief et al. 2020). Detailed knowledge of the

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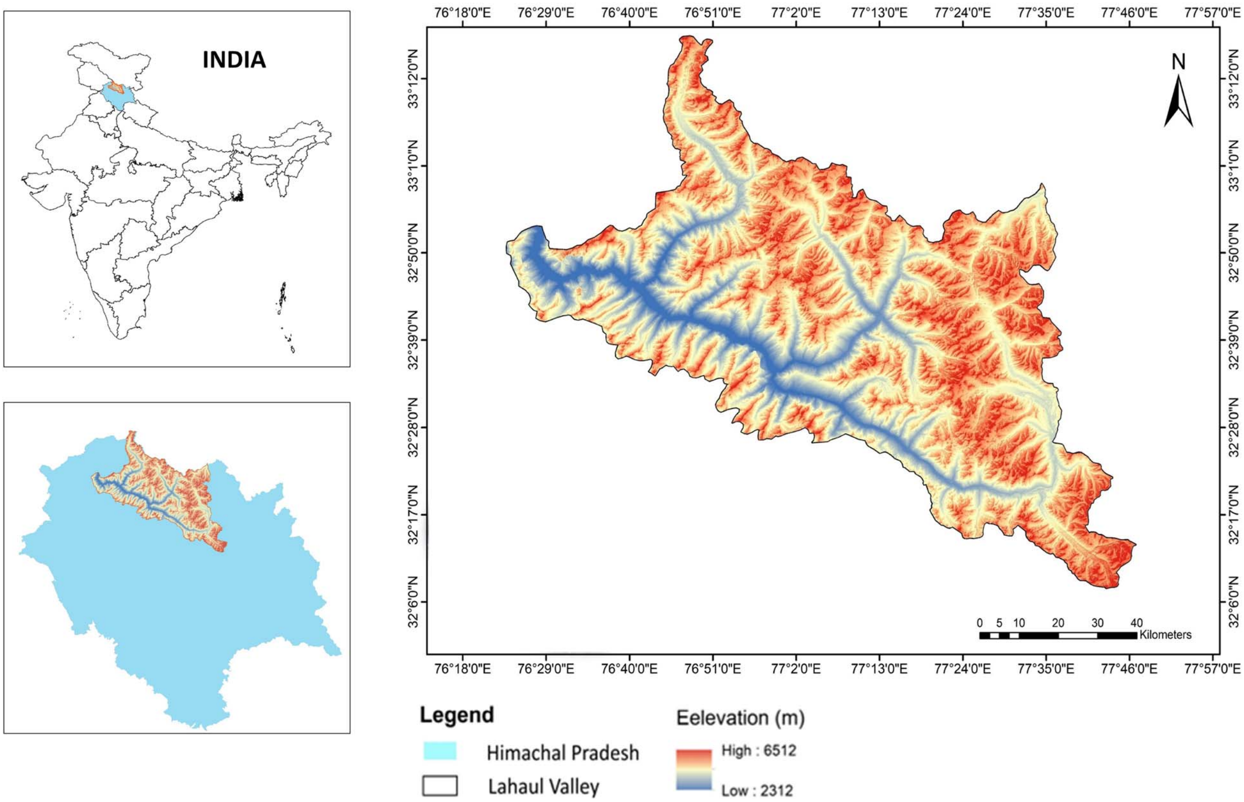

Fig. 1. Map of Lahaul Valley study area showing elevational detail, and location of study area within India (upper left) and in the State of Himachal Pradesh (lower left) where we examined Himalayan brown bear (*Ursus arctos isabellinus*) habitat requirements based on camera-trapping and sign surveys conducted from July 2018 to December 2022.

species' habitat use is essential for its conservation given that it occupies a multiuse landscape subject to human-caused disturbance. We studied habitat use by the Himalayan brown bear from 2018 to 2022 in the multiuse landscape of Lahaul Valley, India. We used a Generalized Linear Model (GLM; Austin 1987, Thuiller 2003, Guisan et al. 2006) to examine the influence of ecogeographic and anthropogenic covariates on habitat use by the Himalayan brown bear in the human-modified landscape. Our goal was to provide habitat use information that will assist in designing effective management strategies to conserve this species.

Study area

The Lahaul Spiti district is located in the northeastern part of Himachal Pradesh and consists of 2 valleys, Lahaul Valley and Spiti Valley, totaling 13,841 km^2. The study was conducted in the Lahaul Valley (6,651 km^2; Fig. 1). The area is characterized by rugged mountains with steep slopes, and elevations ranging from 2,300 m to 6,500 m. The climate of the area is temperate. In winter, from October to March, the temperature is $<10°C$ and occasionally reaches $-15°C$; average snowfall is 47 to 69 cm; and in summer temperatures range from 18°C to 30°C.

Cover types in the study area include temperate conifer forest, alpine and subalpine vegetation, rangeland (grassland interspersed with shrubs), and barren land (rocky areas or exposed soil with very sparse to no vegetation—above 4,500 m) as well as agricultural lands (Joshi et al. 2001, Mehta and Julka 2001, Sharief et al. 2020). Local people of the valley are mostly agrarian, exhibit a human density of 2.8 individuals/km^2 distributed across 198 villages, and rely significantly on crops and livestock (total count 38,136 whole district). The Lahaul Valley is home to many threatened mammals, including the Asiatic black bear (*Ursus thibetanus*), snow leopard (*Panthera uncia*), Kashmir musk deer

(*Moschus cupreus*), Tibetan wolf (*Canis lupus*), Himalayan tahr (*Hemitragus jemlahicus*), and Himalayan ibex (*Capra sibirica*; Joshi et al. 2020), but there are no designated, protected areas in the valley.

Methods

Data collection

We divided the study areas into 2 × 2-km blocks. We established grids that were physiologically feasible for the species and logistically possible to survey to collect data on Himalayan brown bear. We collected Himalayan brown bear presence data through camera-trapping and sign survey conducted from July 2018 to December 2022, except for the period from January to April each year. We used camera traps because of their usefulness with rare and elusive species (Burton et al. 2015, Caravaggi et al. 2017). We deployed 111 camera traps, with most active for 30 days, though some operated for 28 days because of specific field conditions, resulting in 3,303 trap-nights. The camera traps were deployed along natural trails, riverbeds, near agricultural lands, and in other sites having signs of bear presence. We placed cameras at elevations of 2,460 m to 5,650 m. Camera traps were installed 40–60 cm above the ground and 2–3 m away from trails. For our field survey, we walked 116 trails of lengths varying from 2 to 6 km, for a total of 672 km. Signs such as scats, footprints, and direct sightings were noted along with their Global Positioning System locations and habitat characteristics.

We obtained 181 presence locations: 153 from our field surveys and 28 from cameras. We used spatial filtration to reduce spatial autocorrelation in presence points by spatially rarified locations at 1 × 1-km distance using Spatially Rarify Occurrence Data tools in SDMtoolbox (Brown 2014). Furthermore, we randomly generated pseudoabsence locations at a spatial distance of 2 km, while also excluding pseudoabsence points that fell within a defined buffer around the presence of data (Hirzel et al. 2001, Sahlsten et al. 2010). After postspatial rarefication, we retained 79 presence locations and 500 pseudoabsence locations, which were used in the regression model.

Predictor variables

We selected 5 categories of covariates that primarily govern habitat use of brown bears (Table 1): land cover, topographic, bioclimatic, landscape, and anthropogenic disturbance (McGarigal et al. 2012, Habibzadeh and Ashrafzadeh 2018, Dar et al. 2023). We acquired the land cover variables from the ESRI Inc. (Redlands, California, USA) 2022 ESRI Land Cover dataset (https://www.esri.com). Using Earth Explorer, we acquired a digital elevational model (DEM) with 30-m resolution from Shuttle Radar Topographic Mission (SRTM) data (https://earthexplorer.usgs.gov/). The DEM was used to generate the raster layers of slope and aspect (using the surface Tool in the Spatial Analyst Tools). The toolbox for gradient metrics and geomorphometry was used to acquire a raster layer of roughness index (Evanset al. 2014). We downloaded bioclimatic variables from WorldClim Version 2 (https://worldclim.org/; Fick and Hijmans 2017). We calculated the raster of landscape variables using FRAGSTATS v 4.2. (McGarigal et al. 2012). We used distance to road (diva-gis.org/gdata) and the Human Influence Index (HII) as a human disturbance variable (Sanderson et al. 2002).

Prior to raster value extraction for analysis, we resampled all covariate rasters to a uniform 100-m resolution

Table 1. Predictor variables used in Generalized Linear Model for Himalayan brown bear (*Ursus arctos isabellinus*) in Lahaul Valley, India, based on camera-trapping and sign surveys conducted from July 2018 to December 2022.

Ecogeographic variables	Data source
Land cover	ESRI-LULC[a]
Forest	
Rangeland	
Barren land	
Topographic	SRTM-USGS[b]
Slope	
Aspect	
Elevation	
Roughness	
Distance to river	
Bioclimatic	WorldClim-2[c]
Annual mean temperature (Bio1)	
Annual precipitation (Bio12)	
Precipitation of driest month (Bio12)	
Precipitation of warmest quarter (Bio18)	
Landscape variables	ESRI-FRAGSTAT software 4.2
Largest patch index (lpi)	
Largest patch index forest (lpi_2)	
Largest patch index rangeland (lpi_11)	
Shannon diversity index (shdi)	
Gyrate area-weighted mean (Gyrate_am)	
Percentage of landscape_forest (PLAND_2)	
Disturbance (anthropogenic)	DIVA-GIS[d]
Distance to road	

[a]ESRI-LULC is ESRI Inc. (Redlands, California, USA) Land Use Land Cover Data.
[b]SRTM is Shuttle Radar Topographic Mission and USGS is U.S. Geological Survey.
[c]WorldClim Version 2 (https://worldclim.org/).
[d]DIVA Geographic Information System software.

using Geographic Information System (https://www.esri.com/en-us/home; ArcGIS 10.6). Initially, 28 variables that can potentially influence brown bear habitat use were selected based on literature (Clevenger et al. 1997, Piedallu et al. 2017, Su et al. 2018, Almasieh et al. 2019, Sharief et al. 2020, Dar et al. 2021, Mukherjee et al. 2021, Ashrafzadeh et al. 2022). To avoid multicollinearity, we conducted a Pearson correlation test and excluded highly correlated variables with Pearson coefficient >0.7 (Brun et al. 2020). We retained 19 variables for further analysis (Table 1).

Data analysis

Influence of predictor variables on Himalayan brown bear habitat use

We used a generalized linear model (GLM) with a binomial logit link function to understand the impact of the ecogeographic variables on Himalayan brown bear habitat use. The GLM is a linear regression that fits binary data (Salas et al. 2017). We used the presence and pseudo-absence locations as the response variable using the "glm" function in Program R (R Core Team 2019). For model selection and averaging, we used the "MuMIn" package from R software libraries, for automated model selection and model averaging using Akaike's Information Criterion (AIC_c; Burnham and Anderson 2002). We used the lowest AIC_c value to select the best model that predicts the effect of predictor variables on habitat use of Himalayan brown bears in the landscape.

Habitat use versus availability

We used Design I of Manly's Resource Selection Function (Manly et al. 2007) to understand how the Himalayan brown bear uses different cover types and whether it exhibits preferences. The presence locations represented used cover types, while pseudoabsence locations represented available cover types (Manly et al. 2007). Following Manly's (1974), resource selection index (Wi), we evaluated the resource selection: $\mathrm{Wi} = \mathrm{oi}/\widehat{\pi \mathrm{i}}$, where "oi" signifies the observed sample proportion of used units within the category i, while "$\widehat{\pi \mathrm{i}}$" estimates the sample proportion of available units within the same category i. The analysis was conducted using the "adeHabitatHS" package in R.

Results

We selected the model with the lowest AIC_c value of 183.79 and the highest wAIC (Wi $= 0.280$) value as the top model (Table 2). The top model indicates that the habitat use of Himalayan brown bear is positively influenced by the predictors annual precipitation (Bio12), largest patch index (LPI), Shannon diversity index (SHDI), and slope, and is negatively associated with elevation, precipitation of driest month (Bio14), and precipitation of warmest quarter (Bio18; Table 2, Fig. 2).

The results of the Resource Selection Index (Wi) also revealed that Himalayan brown bear showed strong affinity toward forests, using them to an extent greater than availability ($P = 0.009$). Conversely, rangeland was utilized to a lesser degree than its availability ($P = 0.004$), whereas no significant difference was observed in use versus availability of barren land ($P = 0.301$; Table 3).

Discussion

Our findings shed light on key factors shaping habitat use of Himalayan brown bears. Among our predictors, the largest patch index and Shannon diversity index are significant contributors in predicting habitat use of the Himalayan brown bear. These findings emphasize that brown bears exhibited a preference for larger, interconnected habitat patches. This inclination may arise from the advantages associated with larger, suitable habitat patches because they offer greater resources, escape cover, and connectivity (Servheen et al. 1998). The results of the resource selection index (Wi) also depict a preference for forested areas. In our study area, forest patches are interspersed with subalpine and alpine meadows, and hence are ideal habitat and escape cover for Himalayan brown bears as has been found for other brown bear populations (Clevenger et al. 1992, Kobler and Adamic 2000, Swenson et al. 2000, May et al. 2008, Ziółkowska et al. 2016, Pop et al. 2018, Cimatti et al. 2021, Mohammadi et al. 2021, Bogdanović et al. 2023).

Himalayan brown bear habitat use showed positive association with the Shannon diversity index, corroborating the findings of Cimatti et al. (2021). This index pertains to the heterogeneity and relative occurrence of land cover types (Shannon 1948, McGarigal et al. 2012). Brown bears are opportunistic omnivores with a significant portion of their diet consisting of plant matter (Herrero 1972, Rathore and Chauhan 2014); therefore, we infer that diversity of cover types and plant communities will provide feeding opportunities for brown bears. This inference points out the importance of habitat diversity in sustaining the species.

Elevation and slope were topographic predictors of habitat use of Himalayan brown bears. The Himalayan

Table 2. β-coefficient values[a] of the top 5 Generalized Linear Model models selected based on the Akaike's Information Criterion (AIC_c) for Himalayan brown bear (*Ursus arctos isabellinus*) in Lahaul Valley, India, based on camera-trapping and sign surveys conducted from July 2018 to December 2022.

Covariates	Model 1	Model 2	Model 3	Model 4	Model 5
(Intercept)	10.897	10.852	10.864	11.739	11.324
SE	(6.758)	(6.763)	(6.730)	(−6.796)	(6.848)
Bio12	0.055**	0.055**	0.054**	0.056**	0.054**
SE	(0.018)	(0.018)	(0.018)	(−0.018)	(0.018)
Bio14	−2.208**	−2.195**	−2.196**	−2.251**	−2.207**
SE	(0.723)	(0.721)	(0.718)	(−0.716)	(0.725)
Bio18	−0.075***	−0.075***	−0.075**	−0.077***	−0.075**
SE	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Elevation	−0.004***	−0.004***	−0.004***	−0.004***	−0.004***
SE	(0.001)	(0.001)	(0.001)	(−0.001)	(0.001)
Gyrate_am	−0.030	−0.029	−0.027	−0.031	−0.029
SE	(0.017)	(0.017)	(0.16)	(−0.016)	(0.017)
LPI	0.154***	0.151***	0.146***	0.157***	0.155***
SE	(0.046)	(0.045)	(0.044)	(−0.046)	(0.046)
LPI_2	0.052			0.062*	0.051
SE	(0.029)			(−0.029)	(0.029)
Shdi	5.743**	5.653**	5.630**	5.417**	5.884**
SE	(1.912)	(1.905)	(1.900)	(−1.891)	(1.951)
Slope	0.079*	0.078*	0.078*		0.079*
SE	(0.031)	(0.031)	(0.078)		(0.031)
PLAND_2		0.048			
SE		(0.028)			
Forest			4.685		
SE			(2.964)		
Dist_river					0.000
SE					(0.001)
Roughness				0.001*	
SE				(0.000)	
AIC	183.79	184.05	184.5	184.84	185.6
ΔAIC[b]	0.00	0.26	0.71	1.05	1.81
wAIC	0.280	0.246	0.196	0.165	0.113

[a] ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.
[b] ΔAIC is the relative difference between the best model (which has a ΔAIC of zero) and each other model in the set.

brown bear showed affinity for moderate to steep slopes, consistent with findings for Iranian brown bears (Almasieh et al. 2019). Rugged and steep areas are preferred by brown bears, especially females accompanied by their cubs (Ziółkowska et al. 2016, Zarzo-Arias et al. 2019). The preference for steep rugged areas by brown bear might be attributed to anthropogenic pressure in the alpine areas, such as livestock grazing by nomadic shepherds and medicinal plant collection by the local community. A similar trend was observed by Thakur et al. (2023) in Great Himalayan National Park, Himachal Pradesh, where brown bears altered their habitat use pattern to avoid similar anthropogenic pressure. Brown bears also prefer moderate to steep slopes for den sites (Crupi et al. 2020). Conversely, habitat use showed a negative association with elevation; habitat use was mainly at elevations of 2,500 m to 4,500 m and further decreased at higher elevations. The results are consistent with previous research (Su et al. 2018) and can be attributed to food scarcity above 4,500 m.

Various studies of Asian brown bears emphasize the importance of bioclimatic variables in the bears' distribution and habitat use (Su et al. 2018, Dai et al. 2019, Penteriani et al. 2019, Dar et. al 2021, Mukherjee et al. 2021, Ashrafzadeh et al. 2022). Our study showed a significant positive association between annual precipitation and habitat use of Himalayan brown bears, corroborating previous findings (Su et al. 2018; Mohammadi et al. 2021; Ara et al. 2022; Ashrafzadeh et al. 2022, 2023). Our study also revealed a negative relationship between precipitation in the driest month and Himalayan brown bear habitat use, consistent with a previous study (Hosseini et al. 2022).

Habitat loss due to human activities such as hydroelectric projects, roads, livestock grazing, and expansion of human settlement and agriculture poses the

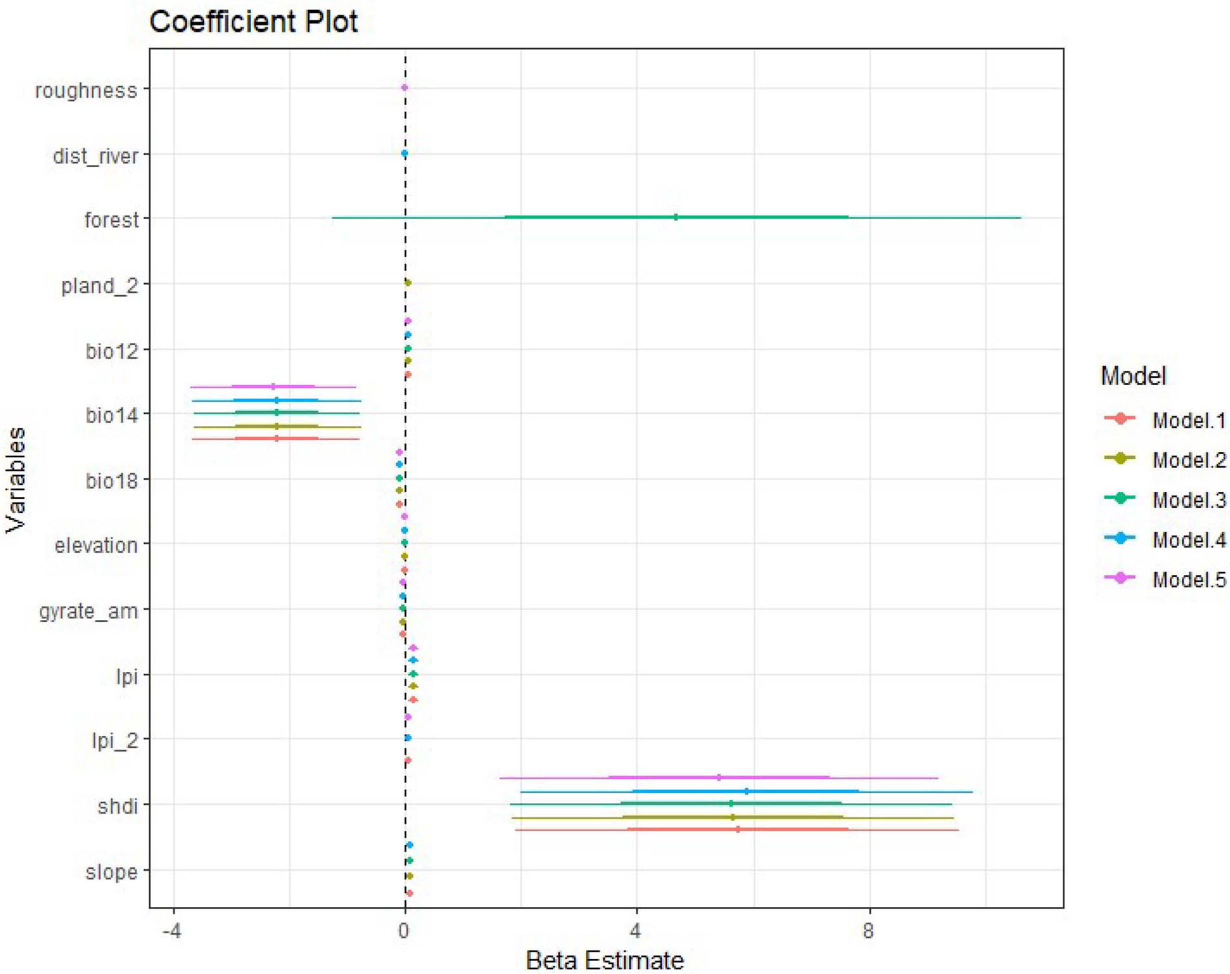

Fig. 2. Coefficient plot of predictor variables used in Generalized Linear Model to understand habitat use by Himalayan brown bear (*Ursus arctos isabellinus*) in Lahaul Valley, India, based on camera-trapping and sign surveys conducted from July 2018 to December 2022.

main threat to the Himalayan brown bear (Su et al. 2018; Dar et al. 2021, 2023; Kumar et al. 2022). Climate change may also lead to habitat loss for the species (Mukherjee et al. 2021). Hence, fine-scale habitat management is required for effective conservation and long-term survivorship of the Himalayan brown bear and other species in the landscape.

Although our results highlight a positive association between the largest patch index of cover type and Himalayan brown bear habitat use, we did not identify cropland as a significant predictor of bear presence. Previous studies, however, have suggested associations with cropland, and thus raised concerns about the potential for human–brown bear conflict in the valley (Sharief et al. 2020, Kumar et al. 2022). Conflicts with bears can lead to economic loss for people and pose threats to the long-term survival of the brown bear. To minimize such conflict, it is imperative to identify and delineate the ideal habitat patches within the landscape. Effective management of these areas, including the facilitation of connectivity between habitat patches with minimal chances of interaction with people, is crucial to minimizing the chances of interactions between bears and people. The establishment of clear demarcation between brown bear habitat and human settlement is needed to minimize human–bear interaction (Takahata et al. 2017). These measures will significantly minimize human–bear conflict and contribute to the long-term conservation of the Himalayan brown

Table 3. Selection Index (Wi) use versus available across different cover types in Lahaul Valley, India, for Himalayan brown bear (*Ursus arctos isabellinus*) based on camera-trapping and sign surveys conducted from July 2018 to December 2022.

Cover type	Wi	SE of Wi	Significance (P-value)[a]
Forest	4.345	1.282	0.009***
Rangeland	0.866	0.047	0.004***
Barren land	2.012	0.023	0.301

[a]***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

bear. The present study represents the first attempt in the region to study habitat use pattern of Himalayan brown bear in the remote mountainous area of Lahaul Valley. The landscape is devoid of protected areas where the Himalayan brown bear shares space with local communities encompassing agricultural land, villages, and alpine landscape type. The present study has limitation due to the relatively small sample size, and studying brown bear in this rugged landscape is challenging. Hence, we suggest that future studies should be more intensive, incorporating larger sample size for developing a finer scale understanding of the habitat ecology in the landscape. Furthermore, seasonal habitat use studies will bring better insights into habitat use and selection by the Himalayan brown bear in this landscape.

Acknowledgments

We express our gratitude to the Chief Wildlife Warden, Forest Department, Himachal Pradesh, and the Himachal Pradesh government for granting the necessary permission to undertake field surveys. The authors are thankful to the Divisional Forest Officers, Lahaul Forest Divisions for their consistent support during the field study. The authors are also thankful to the Zoological Survey of India team for their logistic support. We acknowledge the National Mission for Himalayan Studies, Ministry of Environment, Forest and Climate Change (MoEF&CC) for funding support under Grant No NMHS/2017-18/LG09/02. Finally, we thank the Associate Editor and reviewers for their insightful comments, which have greatly improved this manuscript.

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Received: January 15, 2024
Accepted: August 6, 2024
Associate Editor: D. Hamer