Mammals of the Bhagirathi basin, Western Himalaya: understanding distribution along spatial gradients of habitats and disturbances

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Abstract Understanding the distribution of wildlife species and their response to diverse anthropogenic pressures is important for conservation planning and management of wildlife space in human-dominated landscapes. Assessments of anthropogenic impacts on mammals of the Indian Himalayan Region have mostly been limited to locations inside protected areas. We studied the occurrence of mammals in an unexplored landscape, the 7,586 km² Bhagirathi basin, at an altitude of 500–5,200 m. The basin encompasses wilderness areas of various habitat types and protection status that are exposed to a range of anthropogenic pressures. Camera trapping at 209 locations during October 2015–September 2017 confirmed the occurrence of 39 species of mammals, nine of which are categorized as threatened (four Vulnerable, five Endangered) and four as Near Threatened on the IUCN Red List. We recorded five mammal species that were hitherto undocumented in Uttarakhand State: the argali *Ovis ammon*, Tibetan sand fox *Vulpes ferrilata*, woolly hare *Lepus oiostolus*, Eurasian lynx *Lynx lynx* and woolly flying squirrel *Eupetaurus cinereus*. In addition, we recorded two Endangered species, the dhole *Cuon alpinus* and tiger *Panthera tigris*. Threatened species such as the sambar *Rusa unicolor*, common leopard *Panthera pardus* and Asiatic black bear *Ursus thibetanus* occur in a wide variety of habitats despite anthropogenic disturbance. We recorded the snow leopard *Panthera uncia* in areas with high livestock density but temporally segregated from human activities. The musk deer *Moschus* spp. and Himalayan brown bear *Ursus arctos isabellinus* were recorded in subalpine habitats and appeared to be less affected by human and livestock presence. Our findings highlight the potential of the Bhagirathi basin as a stronghold for conservation of several threatened and rare mammal species.

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Introduction

The mammals of the Indian Himalayan Region are exceptionally diverse, and many are endemic to the region (Schaller, 1977), but they are threatened by persecution (Mishra, 1997; Naha et al., 2018), habitat loss and degradation (Namgail et al., 2007; Kittur et al., 2010), and competition with livestock (Bhatnagar, 1997; Mishra et al., 2004; Bhattacharya et al., 2012). The type and intensity of these threats often vary across the seasons (Bhattacharya & Sathyakumar, 2011).

Anthropogenic disturbance is dynamic, and responses of wildlife are likely to be influenced by human density and location at a given time, and the duration of human activity (Rogala et al., 2011; Carter et al., 2012). Understanding these dynamics facilitates conservation planning and illuminates the processes governing wildlife behaviour in human-dominated landscapes (Hojnowski, 2017). The 7,586 km² Bhagirathi basin in Uttarakhand, India, is recognized for its ecological, socio-cultural and conservation significance (Rajvanshi et al., 2012). This landscape encompasses wilderness areas of various habitat types and protection status that are exposed to a range of anthropogenic pressures. The only protected area in the Bhagirathi basin is the 2,500 km² Gangotri National Park, which provides protection to species of the Trans-Himalaya and Greater Himalaya.

Anthropogenic activities in the Bhagirathi basin include seasonal grazing (May–October) above 2,000 m altitude. There are local livestock herders and pastoral migrant communities such as Gujjar (outside the protected area) and Gaddis (in the Trans-Himalayan part of Gangotri National Park), with large herds of livestock (c. 30,000 sheep, goats and mules) grazing the alpine pastures of the National Park (Chandola et al., 2008) for 4 months annually (June–September). Anthropogenic activities in the lower and mid-altitude forests (500–2,500 m) of the Bhagirathi basin include livestock grazing, extraction of non-timber

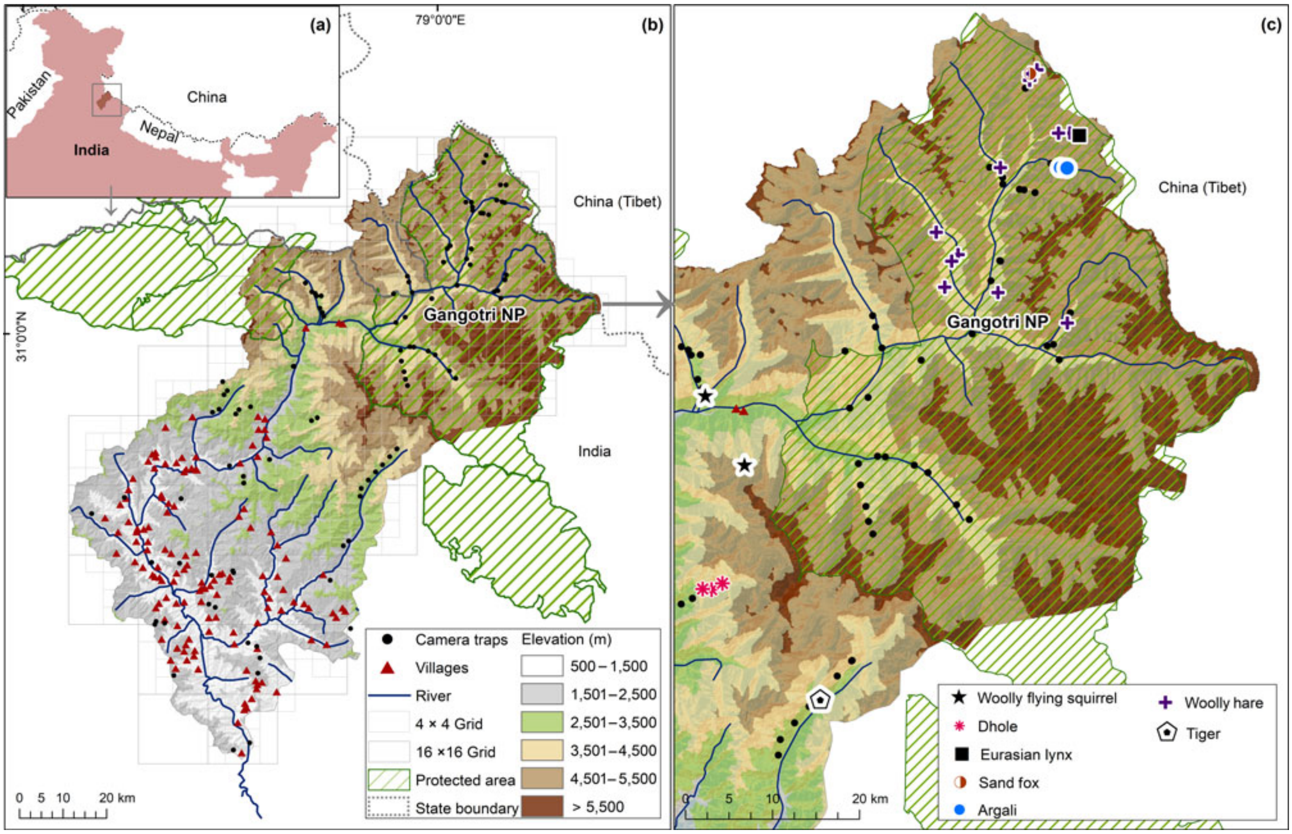

FIG. 1 (a) Location of the Bhagirathi basin in Uttarakhand state, Western Himalaya, India. (b) Camera-trap locations and permanent human settlements along an elevation gradient in the Bhagirathi basin. (c) Location of some of the new records of species reported in this study.

forest products and collection of fuelwood, activities that have been conducted for centuries (Awasthi et al., 2003; Rana et al., 2007). Additionally, tourism, mountaineering, and pilgrimage attract numerous visitors during April–November. As the northern boundary of the Bhagirathi basin also forms the international border with the Tibet region of China, patrol camps and small settlements of the Indo-Tibetan Border Police and other security agencies are present in the area. Recurrent deliberate burning of hill slopes to stimulate regrowth of grasses has altered the vegetation structure and composition of the Bhagirathi basin (Mehta, 1996; Gurumni, 2000).

The conservation importance of the Bhagirathi landscape, and that of its mammals in particular, has been described in an environmental impact assessment of hydropower projects (Rajvanshi et al., 2012) and several short-term surveys (Uniyal & Ramesh, 2004; Bhardwaj & Uniyal, 2009). These studies are based on observations of species or evidence encountered during trail and ridge walks. However, the distribution of mammals in this area has not yet been assessed with robust scientific methods such as camera trapping and genetic sampling.

Here, we describe (1) the occurrence of mammal species in the Bhagirathi basin, (2) the occurrence of threatened mammals in relation to human activities, and (3) conservation prospects for threatened mammals under the existing protection measures in the Bhagirathi landscape.

Study area

The 7,586 km^2 Bhagirathi basin in Uttarakhand State, India, is drained by the Bhagirathi river (c. 217 km) and its tributaries. The study area encompasses altitudes of 500–5,200 m (Fig. 1). The major habitat types of the basin are (1) subtropical deciduous forest (500–2,000 m) characterized by broad-leaved and needle-leaved species such as *Pinus roxburghii*, (2) temperate forest (2,000–3,500 m) with montane broad-leaved and conifer species such as *Quercus semecarpifolia*, *Quercus floribunda, Abies pindrow*, *Cedrus deodara*, and *Pinus wallichiana*, (3) high altitude alpine and subalpine vegetation (3,500–5,000 m) with *Rhododendron* spp., *Betula utilis* and alpine herb and forb species, and (4) Trans-Himalayan landscape (3,500–5,200 m) with alpine dessert steppe plants such as *Eurotia* sp., *Caragana* sp., *Lonicera* sp. and *Rhamnus* sp. Summer (or monsoon, April–September) and winter (November–February) are more pronounced than the short autumn (October) and spring (March–April) seasons. The economy of the region is largely dependent on agriculture. There are 134 villages in the Bhagirathi basin, mostly below 2,000 m.

Methods

After a 3-month reconnaissance survey (July–September 2015), we conducted a camera-trap study at 209 locations, using 130 Cuddeback C1 (Cuddeback, De Pere, USA) camera traps, during October 2015–September 2017. We positioned camera traps along an elevational gradient (500–5,200 m) representing various habitats. At each site, camera traps were deployed in locations likely to be used by animals, affixed to trees or, in alpine meadows, to a pile of stones, at a height of c. 30–45 cm above the ground (Sathyakumar et al., 2011; Bashir et al., 2013). To survey evenly across the various habitats, we divided the basin into 38 grid cells of 256 km^2 each (16 × 16 km), which corresponds to the average home range of the largest mammal in the area, the Himalayan brown bear *Ursus arctos isabellinus*. We subdivided these cells into 4 × 4 km cells and deployed camera traps in 3–4 of these smaller cells within each 256 km^2 cell (Fig. 1, Table 1). In the fragmented forests of the lower areas, 30 camera traps were stolen, which prevented adequate coverage in all grid cells (Fig. 1, Table 1).

We examined all camera-trap photographs of large and medium-sized mammals (except families Muridae and order Chiroptera) and identified species with the help of Prater (1971) and Menon (2014). We assessed the elevational range (minimum and maximum elevation of occurrence) and habitat types used by each identified species based on camera-trap locations where they were captured. We calculated photo-capture rates as the number of captures per 100 trap days, following Bashir et al. (2013; Table 2), and camera trapping days as the number of 24-hour periods from placement of the camera until the memory card was full or the camera was retrieved. Multiple captures of the same species within 1 hour at a camera site were excluded from trap rate calculation (Sathyakumar et al., 2011). We used photo-capture rates (mean ± SE) to assess the relative abundance of each species and anthropogenic disturbances (people, dogs and livestock).

We examined the effect of habitat and human disturbance with generalized linear mixed models, using the *glmmTMB* package (Magnusson et al., 2017) in *R 3.6.2* (R Core Team, 2019). For the generalized linear mixed models we used cameras (124 locations, 12,558 trap nights) that were active in both seasons or either summers (April–September 2016) or and winters (November–February 2015–2016 and 2017). Some of the smaller grid cells had more than one camera location. We therefore tested for spatial autocorrelation among sampled locations, using the weighted correlation coefficient of Moran (Moran's *I*) in *ArcGIS 10.4* (Esri,

TABLE 1 Distribution of camera traps used for surveys of large and medium-sized mammals along an altitudinal gradient in the Bhagirathi basin, Uttarakhand State, India (Fig. 1). We carried out surveys across two seasons per year (summer: April–August; winter: November–February) during October 2015–September 2017.

Elevation (m)	Vegetation/ habitat type	Area (%)	Summer (115 cameras, 6,677 trap nights) No.	Mean ± SE trapping days	Mean ± SE distance (m) (range)	Winter (102 cameras, 5,881 trap nights) No.	Mean ± SE trapping days	Mean ± SE distance (m) (range)	Protection status
500–1,500	Subtropical deciduous forest	29	8	61.5 ± 11.6	7,249 ± 535 (1,056–14,864)	7	40.0 ± 16.3	7,234 ± 645 (300–14,655)	Not protected
1,501–2,500	Temperate forest	22	20	65.4 ± 9.1	24,789 ± 833 (400–75,853)	22	35.8 ± 6.5	18,381 ± 526 (254–47,774)	Not protected
2,501–4,500	Alpine & subalpine habitat	34	55	50.0 ± 4.9	22,525 ± 276 (339–70,991)	40	66.5 ± 4.8	24,360 ± 418 (300–70,991)	Protected (summer: 11; winter: 11) & not protected (summer: 44; winter: 29)
3,501–5,200	Dry alpine steppe (cold desert)	15	32	65.6 ± 4.5	8,814 ± 187 (420–29,931)	33	67.2 ± 5.1	10,797 ± 232 (425–31,676)	Protected

Table 2 List of mammals recorded (photo-captured and/or sighted) in the Bhagirathi basin, showing their Red List status, mean ± SE photo-capture rates (independent photographs/100 trap days) in four habitat types, and elevation range. Species with < 10 photo captures are indicated as 'present' in a particular habitat.

Species	Red List status[1]	Subtropical	Temperate	Alpine–subalpine	Trans-Himalaya	Elevation range (m)
Carnivora/Felidae						
Snow leopard *Panthera uncia*	Vulnerable			4.57 ± 0.80 (N = 193)	2.05 ± 0.50 (N = 53)	2,961–4,528
Common leopard *Panthera pardus*	Vulnerable	7.24 ± 2.80 (N = 79)	8.39 ± 4.90 (N = 122)	0.34 ± 0.14 (N = 3)		509–3,663
Leopard cat *Prionailurus bengalensis*	Least Concern	2.50 ± 0.70 (N = 35)	2.50 ± 0.80 (N = 77)	0.58 ± 0.18 (N = 23)		500–3,600
Tiger *Panthera tigris*	Endangered		Present (N = 1)			2,910
Jungle cat *Felis chaus*	Least Concern	Present (N = 4)	Present (N = 1)			1,072–2,069
Eurasian lynx *Lynx lynx*	Least Concern				Present (N = 1)	4,880
Carnivora/Ursidae						
Himalayan brown bear *Ursus arctos isabellinus*	Endangered[2]		0.08 ± 0.05 (N = 3)	0.84 ± 0.30 (N = 27)		2,800–4,400
Asiatic black bear *Ursus thibetanus*	Vulnerable	0.95 ± 0.44	3.43 ± 1.50 (N = 61)	0.20 ± 0.10 (N = 8)		500–3,500
Carnivora/Canidae						
Red fox *Vulpes vulpes*	Least Concern	1.70 ± 0.70 (N = 35)	10.89 ± 3.81 (N = 171)	45.90 ± 8.80 (N = 1,946)	43.23 ± 16.59 (N = 670)	1,072–5,181
Tibetan wolf *Canis lupus chanco*	Least Concern				3.80 ± 0.90 (N = 123)	3,861–5,181
Tibetan sand fox *Vulpes ferrilata*	Least Concern				Present (N = 3)	5,110
Dhole *Cuon alpinus*	Endangered		Present (N = 8)	2.05 ± 0.12 (N = 11)		3,006–3,573
Golden jackal *Canis aureus*	Least Concern	Present (N = 2)	Present (N = 8)			2,069–3,262
Carnivora/Mustelidae						
Stone marten *Martes foina*	Least Concern			2.33 ± 0.59 (N = 41)	Present (N = 5)	3,000–4,571
Pale weasel *Mustela altaica*	Least Concern			Present (N = 9)	Present (N = 5)	
Yellow throated marten *Martes flavigula*	Least Concern	1.50 ± 0.36 (N = 47)	2.29 ± 0.73 (N = 43)	1.70 ± 1.06 (N = 41)		940–3,663
Siberian weasel *Mustela sibirica*	Least Concern		Present (direct sighting, N = 2)	Present (direct sighting, N = 1)		2,594–4,505
Carnivora/Viverridae						
Masked palm civet *Paguma larvata*	Least Concern	1.83 ± 0.80 (N = 37)	0.34 ± 0.16 (N = 11)			1,325–3,274
Artiodactyla/Bovidae						
Blue sheep *Pseudois nayaur*	Least Concern			1.19 ± 0.45 (N = 27)	8.42 ± 3.60 (N = 118)	2,961–5,181
Himalayan tahr *Hemitragus jemlahicus*	Near Threatened		4.40 ± 2.62 (N = 87)	0.60 ± 0.34 (N = 27)		2,384–4,074
Goral *Naemorhedus goral*	Near Threatened	1.36 ± 0.74 (N = 38)	8.42 ± 2.50 (N = 245)	0.49 ± 0.23 (N = 39)		509–4,074
Himalayan serow *Capricornis thar*	Near Threatened	Present (N = 5)	0.93 ± 0.06 (N = 34)	0.32 ± 0.21 (N = 17)		1,680–3,663
Argali *Ovis ammon*	Near Threatened				Present (N = 4)	4,471–4,608

Table 2 (*Cont.*)

Species	Red List status[1]	Subtropical	Temperate	Alpine–subalpine	Trans-Himalaya	Elevation range (m)
Artiodactyla/Cervidae						
Barking deer *Muntiacus muntjak*	Least Concern	27.01 ± 6.25 (N = 425)	4.44 ± 1.74 (N = 193)			509–3,090
Sambar *Rusa unicolor*	Vulnerable	7.70 ± 2.50 (N = 72)	17.85 ± 4.06 (N = 651)	3.55 ± 1.29 (N = 140)		500–3,500
Artiodactyla/Moschidae						
Musk deer *Moschus* spp.	Endangered		Present (N = 7)	2.18 ± 0.90 (N = 36)		2,915–3,878
Artiodactyla/Suidae						
Indian wild boar *Sus scrofa*	Least Concern	3.85 ± 1.50 (N = 124)	5.17 ± 1.73 (N = 192)			509–3,663
Rodentia/Hystricidae						
Indian porcupine *Hystrix indica*	Least Concern	4.80 ± 1.75 (N = 59)	2.25 ± 1.09 (N = 56)			509–3,274
Rodentia/Sciuridae						
Red giant flying squirrel *Petaurista petaurista*	Least Concern	Present (N = 3)	Present (N = 10)	Present (N = 5)		1,500–3,000
Woolly flying squirrel *Eupetaurus cinereus*	Endangered		Present (N = 1)			2,700
Himalayan marmot *Marmota himalayana*	Least Concern				11.17 ± 7.94 (N = 88)	4,180–4,608
Five-striped palm squirrel *Funambulus pennantii*	Least Concern	Present (direct sighting, N = 1)				500–1,300
Primates/Cercopithecidae						
Central Himalayan langur *Semnopithecus schistaceus*	Least Concern	2.83 ± 1.72 (N = 88)	12.49 ± 4.50 (N = 344)	2.15 ± 0.69 (N = 125)		509–3,663
Hanuman langur *Semnopithecus entellus*	Least Concern	Present (direct sighting, N = 2)				500
Rhesus macaque *Macaca mulatta*	Least Concern	2.42 ± 1.32 (N = 27)	Present (N = 3)	2.14 ± 1.23 (N = 16)	Present (N = 2)	509–4,505
Lagomorpha/Ochotonidae						
Royale's pika *Ochotona roylei*	Least Concern			Present (direct sighting, N = 20)		
Tibetan woolly hare *Lepus oiostolus*	Least Concern				3.80 ± 0.90 (N = 61)	3,875–5,181
Large eared pika *Ochotona curzoniae*	Least Concern				Present (direct sighting, N = 5)	4,000–4,400
Black naped hare *Lepus nigricollis*	Least Concern		Present (N = 3)			2,169–2,298

[1]According to the IUCN Red List of Threatened Species (IUCN, 2020).
[2]The brown bear *Ursus arctos* is categorized as Least Concern at species level, but the Himalayan brown bear *U. arctos isabellinus* is Endangered according to a separate subpopulation assessment (McLellan et al., 2016).

Redlands, USA). We used data from repeated sampling at the same sites (summer and winter) and incorporated site as a random effect variable. We used captures of species as the response variable and number of trap days (log-transformed) as offset, to account for variation in the trapping effort between sites. Habitat features (elevation, ruggedness, slope) and anthropogenic pressures (capture rate of humans, dogs and livestock) were used as fixed predictor variables (Table 3). We acquired data on elevation from Shuttle Radar Topography Mission (Jarvis et al., 2008), at a resolution of 1 × 1 km pixels. Slope and ruggedness were calculated from the elevation layer in *ArcGIS*. For the brown bear, we examined only summer data as they hibernate in winter, using a Poisson-distributed generalized linear model. We tested for the presence of over dispersion in the dataset and selected the appropriate error distribution (i.e. Poisson, negative binomial). We also evaluated the data for zero-inflation. We used Akaike's information criterion adjusted for sample size (AICc) to rank models, and we considered the best supported models to

TABLE 3 Description of the variables used in the generalized linear mixed models.

Variables	Name of variable	Type	Range
Response	Species captures	Count	Musk deer (1–47), Himalayan brown bear (1–6), snow leopard (1–28), common leopard (1–18), Asiatic black bear (1–16), sambar (1–67)
Offset	Trap effort	Scale	10–273 days (summer & winter combined)
Random effect	Site	Categorical	Musk deer (47), Himalayan brown bear (49), snow leopard (51), common leopard (80), Asiatic black bear (73), sambar (73)
Fixed effect	Human photo-capture	Scale	1–2,356 captures/100 days
	Livestock photo-capture	Scale	1–1,063 captures/100 days
	Dog photo-capture	Scale	1–88 captures/100 days
	Elevation	Scale	Musk deer (2,800–4,000 m), Himalayan brown bear (2,800–4,400 m), snow leopard (3,200–5,000 m), common leopard (500–3,600 m), Asiatic black bear (500–3,500 m), sambar (500–3,500 m)
	Ruggedness	Scale	5.5–84.2
	Slope	Scale	0.6–4.9
	Season	Categorical	Summer, winter

be those with ΔAICc values < 2 units (Arnold, 2010). To examine any multicollinearity between predictor variables, we performed Pearson correlation tests, correlated variables (Pearson correlation coefficient > 0.7) were not used in the same model. We decided on the suitable habitat for each species based on the elevation range and habitats in which camera traps recorded them (Table 2). For example, we used greater Himalayan and Trans-Himalayan habitats (3,200–5,000 m) for snow leopard analysis, and temperate, sub-alpine and alpine habitats (2,800–4,000 m) for musk deer. Based on the time stamp on the camera trap images, we assessed temporal overlap between each threatened species and occurrence of human disturbance (records of people, livestock and domestic dogs) using the kernel density method (Ridout & Linkie, 2009) in *R*.

Results

The total number of camera-trap days was 33,057, with a mean of 108 trap days per camera. We recorded 39 species of mammals belonging to 13 families in five orders (Table 2). Carnivora was the most diverse order with 18 species, followed by Artiodactyla (9), Rodentia (5), Lagomorpha (4) and Primates (3). Of the 39 species recorded, nine are categorized as threatened (four Vulnerable, five Endangered), four as Near Threatened and 26 as Least Concern on the IUCN Red List (IUCN, 2020).

We recorded five mammal species (Fig. 1) that were hitherto not known to be present in Uttarakhand State: the argali *Ovis ammon*, Tibetan sand fox *Vulpes ferrilata*, woolly hare *Lepus oiostolus*, Eurasian lynx *Lynx lynx*, and woolly flying squirrel *Eupetaurus cinereus*. Argali, sand fox, woolly hare and lynx were recorded in the Trans-Himalayan landscape (4,000–5,200 m) of Nelong valley in Gangotri National Park, which is a typical cold desert characterized by rock fields with sparse vegetation (Fig. 1). The woolly hare was captured widely (14 locations) and regularly (156 captures) throughout the survey, whereas the sand fox was captured on only three occasions, Argali on four occasions and Eurasian lynx on one occasion. The woolly flying squirrel was captured once, during the sampling period in temperate habitat at 2,700 m in Harsil valley (Pal et al., 2018a). Apart from these new records, we also captured photographs of the dhole *Cuon alpinus* and tiger *Panthera tigris*. A tiger was photographed only once, in February 2017 (at 2,910 m altitude) in subalpine broadleaved forest dominated by *Quercus semecarpifolia*.

Six threatened species were captured regularly throughout the survey: the Himalayan brown bear, Asiatic black bear, snow leopard, common leopard, musk deer and sambar. Records of Himalayan brown bears (n = 30, 18 locations), musk deer (n = 43, 26 locations) and snow leopards (n = 408, 66 locations) were confined to elevations > 2,500 m in the Trans-Himalayan areas, alpine and subalpine forests. Asiatic black bears (n = 69, 31 locations) were distributed throughout the study area except for dry Trans-Himalayan scrub, and sambar (n = 863, 64 locations) were captured in all forest types up to 3,600 m. The common leopard was the most frequently captured (n = 204, 62 locations) large carnivore, in the subtropical forest and temperate habitats (500–3,600 m).

Seasonal comparison of capture rates of people, livestock and dogs showed that during the winter there was a comparatively low presence of people and associated activities in both protected and non-protected areas. During summer, photo-capture rates of people inside the National Park (mean 79.4 ± SE 18.9) were lower than outside (122.2 ± 39.5) but captures of livestock (46.6 ± 11.2) and dogs (11.1 ± 2.2) were higher inside the National Park than outside (livestock 32.9 ± 12.7, dogs 3.1 ± 1.2). Anthropogenic disturbance

TABLE 4 Results of Moran's *I* test to examine whether camera-trap sites were independent. Spatial autocorrelation was insignificant for all species across the sites (all *Z*-scores between −1.96 and 1.96).

Species	Season	Index	*Z*-value	P
Sambar	Summer	−0.07	−0.13	0.89
	Winter	0.72	1.43	0.15
Musk deer	Summer	0.05	0.26	0.79
	Winter	−0.02	−0.22	0.90
Asiatic black bear	Summer	0.04	0.19	0.80
	Winter	0.06	0.15	0.80
Leopard	Summer	0.09	0.37	0.70
	Winter	0.09	−0.01	0.18
Snow leopard	Summer	0.50	0.89	0.36
	Winter	0.39	0.46	0.64
Himalayan brown bear	Summer	0.25	0.39	0.69

in high altitude Trans-Himalaya was higher in summer (people 47.4 ± 12.3, livestock 84.8 ± 20.8) than winter (people 5.2 ± 1.1, no livestock). We observed a similar seasonality in alpine and subalpine habitats, with disturbance being higher in summer (people 132.4 ± 53.9, livestock 27.8 ± 18.3) than in winter (people 12.8 ± 4.2, no livestock). In temperate habitats, disturbance was high in summer (people 115.0 ± 40.2, livestock 30.1 ± 9.3) but only slightly less in winter (people 81.1 ± 42.3, livestock recorded in only 3 of 31 locations). In subtropical habitats, mean photo-capture rates of people were similar in summer (81.5 ± 28.0) and winter (108 ± 43.4).

The Pearson test showed a significant correlation between livestock and dogs (r = 0.7) and between ruggedness and slope (r = 0.9), and therefore these variables were not used together in the models. Spatial autocorrelation (Table 4) was insignificant for all species across sites (all *Z*-scores were between −1.96 and 1.96). The most supported model (Tables 5 & 6) showed that sambar, common leopard and Asiatic black bear occurred in areas with high levels of human disturbance. Asiatic black bears had lower capture rates in winter (Supplementary Fig. 1), when they hibernate (Sathyakumar et al., 2013). The sambar and Asiatic black bear avoided steep slopes and rugged areas, respectively (Supplementary Fig. 1). Musk deer and brown bear were found in narrow elevation zones of subalpine habitats. In winter, musk deer capture rates declined with increasing elevation (Supplementary Fig. 1), which could be associated with snowfall at high altitudes. Snow leopards were recorded in areas with high human presence and showed a negative response to livestock (Supplementary Fig. 1). They occurred at an altitude of 3,500–4,500 m, with lower capture rates at higher elevations (Supplementary Fig. 1), and were rarely detected in the high elevation plateau habitat of the National Park. Snow leopard capture rates were higher in winter, when there was less disturbance by livestock and people (Supplementary Fig. 1).

Human presence in the Bhagirathi basin was comparatively low in winter. We therefore analysed temporal overlap between each of the six regularly detected threatened species and people only for the summer. Temporal overlap during summer was highest between the Himalayan brown bear and livestock and domestic dogs (Fig. 2), followed by the Asiatic black bear and livestock and domestic dogs (Fig. 2). There was also considerable overlap between musk deer and domestic dogs (Fig. 2). The snow leopard, common leopard and sambar showed minimal temporal overlap with any anthropogenic disturbance (Fig. 2).

Discussion

Human encroachment on wildlife habitats has caused the decline of large mammals globally (Ceballos & Ehrlich, 2002). Some species persist in human-dominated landscapes by changing their behaviour in response to human presence (Frid & Dill, 2002). The Bhagirathi basin is one such landscape, where large mammals, including some threatened species, occur across a gradient of habitat types and human disturbances.

Our model did not show a significant influence of anthropogenic pressures on the Himalayan brown bear, but the high capture rates of livestock and high temporal overlap with livestock suggest there could be a high probability of livestock depredation by the species, which could lead to retaliatory killings. Such incidents are relatively common in Himachal Pradesh (Rathore, 2008; Sathyakumar et al., 2016). Similarly, temporal overlap with domestic dogs in the summer can negatively affect musk deer, which occur in subalpine habitat. Studies in Mongolia (Young et al., 2011), Lahual Spiti (Pal, 2013) and other areas (Home et al., 2018) describe the need for the exclusion of feral dogs from critical wildlife habitats. Musk deer are also vulnerable to poaching, but we could not quantify this and hence did not include poaching in our analysis. Camera-trap photographs of people with guns in subalpine and temperate forests outside the protected area (N = 5) and presence of snares that we found during monitoring of camera traps (N = 6) in subalpine habitats showed that hunting occurs in this region. Frequent removal of individuals can increase the chance of local extirpation of the remaining subpopulations. Snow leopard habitats, which generally consist of alpine areas, are under pressure from livestock grazing in the summer even inside the National Park.

In comparison with Gangotri National Park and high altitude areas (> 1,500 m), lower, non-protected areas of Bhagirathi basin are more fragmented and more densely populated by people. Three species were found in areas of high human activity: the common leopard, sambar and Asiatic black bear. The leopard and Asiatic black bear are hunted and their body parts traded (Sathyakumar & Choudhury, 2007; Raza et al., 2012). The populations of all three species are declining as a result of habitat

TABLE 5 Best generalized linear mixed models examining relationships between relative abundance of six regularly detected threatened large mammals, habitat and anthropogenic pressures in the Bhagirathi basin with each model's Akaike information criterion adjusted for small sample size (AICc), difference in AICc from the best-performing model (ΔAICc), and Akaike weight. Models with ΔAICc values < 2 units were averaged.

Species	Best models	AICc	ΔAICc	Weight
Asiatic black bear	~ Season + Livestock + Ruggedness	203.4	0	0.62
Common leopard	~ Human + Elevation + Season	414.5	0	0.22
	~ Human × Elevation	415.1	0.57	0.17
Sambar	~ Livestock + Elevation × Slope + Season	542.3	0	0.21
Snow leopard	~ Elevation + Livestock	332.2	0	0.47
Himalayan brown bear	~ Elevation	105.8	0	0.49
Musk deer	~ Elevation + Slope	179.0	0	0.28
	~ Elevation × Season	180.4	1.34	0.14

TABLE 6 Summary of fixed effect estimates for supported models (ΔAICc values < 2) of six regularly detected threatened large mammals in the Bhagirathi basin.

Species	Predictor variable	Estimates	SE	*Z*-value	P-value
Asiatic black bear	Season	−1.16	0.43	−2.67	0.008
	Livestock	0.33	0.10	3.25	0.001
	Ruggedness	−0.23	0.10	−2.23	0.026
Common leopard	Human	0.72	0.22	3.27	0.001
	Elevation	−0.55	0.21	0.22	0.011
	Season	0.78	0.36	2.14	0.032
	Elevation × Human	−0.49	0.26	1.85	0.064
Sambar	Livestock	−4.07	1.56	−2.61	0.009
	Elevation	4.55	1.21	3.75	0.001
	Slope	−64.81	22.46	−2.89	0.004
	Season	−0.80	0.37	−2.20	0.028
	Elevation × Slope	−37.31	12.88	−2.90	0.004
Snow leopard	Elevation	−0.60	0.12	−4.90	< 0.0001
	Livestock	−1.27	0.28	−4.41	< 0.0001
Himalayan brown bear	Elevation	0.70	0.24	2.98	0.003
Musk deer	Elevation	1.12	0.53	2.31	0.021
	Slope	0.78	0.38	2.01	0.045
	Season	−0.50	0.62	0.79	0.430
	Elevation × Season	−1.72	0.80	2.13	0.033

degradation and increased interactions with humans (Sathyakumar, 2006; Bhattacharya & Sathyakumar, 2011; Athreya et al., 2013; Khan & Johnsingh, 2013).

Because of its rugged terrain and inaccessibility, the Bhagirathi basin contains some areas with little or no direct human disturbance, which may act as refugia for some threatened and rare species. We recorded four typical Trans-Himalayan mammals (argali, Tibetan sand fox, woolly hare and Eurasian lynx) and the woolly flying squirrel in the Bhagirathi basin. The Near Threatened argali has declined significantly (Harris & Reading, 2008). The Tibetan sand fox, although categorized as Least Concern, occurs in low densities (Harris, 2014). The woolly hare has been assessed as Endangered in India (Molur et al., 2005). The population of the Eurasian lynx is declining and the species is believed to be close to extinction in India (Breitenmoser et al., 2015). The population of the woolly flying squirrel is believed to have declined by 50% during the last decade, largely because of deforestation and grazing pressure (Zahler, 2010). In addition to these threatened species, we recorded two Endangered large carnivores, the dhole and tiger, which were hitherto not known from the area. These new records and the high mammal diversity in the Bhagirathi basin are a result of a wide range of habitats, including many areas with low anthropogenic pressures. In the Indian Himalayan Region, information on the distribution of the dhole (Bashir et al., 2013; Johnsingh & Acharya, 2013; Pal et al., 2018b) and tiger (Gopi et al., 2014; Bhattacharya & Habib, 2016) is limited. Presence of the wild dog was recently reported from sub-alpine and temperate habitats of Uttarkashi district in Uttarakhand (Pal et al., 2018b). The presence of these two Endangered carnivores in high-altitude forests emphasizes the need for regular monitoring of these areas

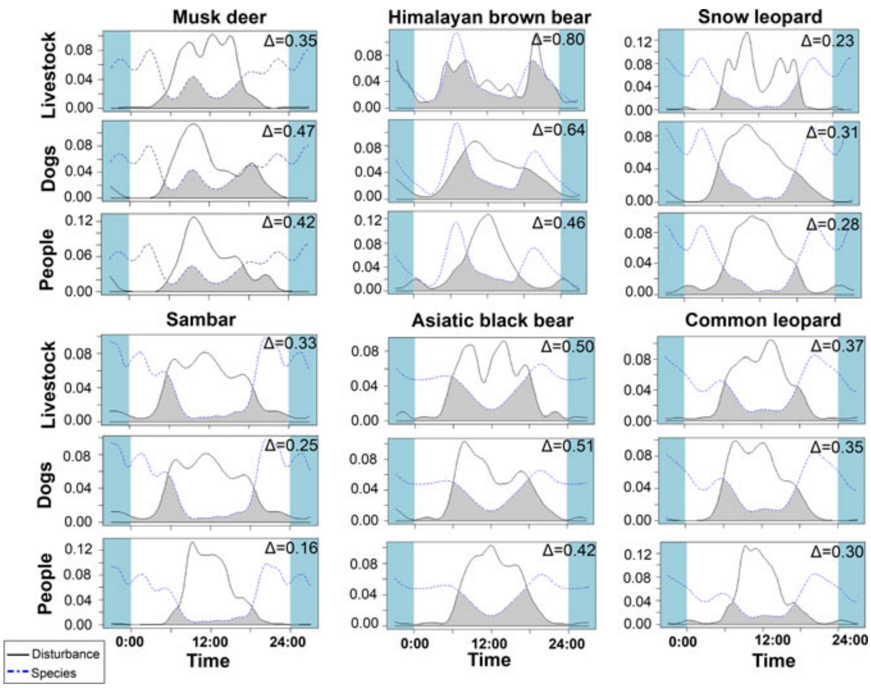

Fig. 2 The activity overlap (grey area) and overlap coefficient (Δ) of anthropogenic disturbance (people, livestock and domestic dogs) with musk deer, Himalayan brown bear, Asiatic black bear, sambar, snow leopard and common leopard in Gangotri National Park and outside during summer in the Bhagirathi basin.

over a longer period. Long-term monitoring could elucidate if and how these species persist in these habitats and climatic conditions.

Our findings highlight the potential of the Bhagirathi basin as a stronghold for several threatened and rare mammal species. Persistence of these species can be attributed to the presence of remote, rugged and undisturbed habitats, and seasonal absence of people and livestock. Nonetheless, the distribution of threatened species overlaps with human activities both spatially and temporally, and thus these species remain vulnerable to anthropogenic pressures. A better understanding of their distribution, abundance and resource utilization, and of the anthropogenic pressures they are exposed to, is required for conservation planning.

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Author contributions Conception of study: SSK; field survey and design: SSK, TB, RP, ST, SA; data collection: RP, ST, SA; analysis: RP, TB. Writing: TB, RP, ST, SSK.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards. All field work was carried out with prior permission from Uttarakhand Forest Department (Letter no. 836/5-6).

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