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Blue Sheep Resource Selection in Alpine Grasslands of a Western Himalayan Landscape – A Point Process Approach

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In-depth knowledge of distribution and factors influencing it is important for species conservation and management. Many forms of such data have led to the development of new analytical techniques for better interpretation. For mountainous terrains with certain limitations, species data are obtained in the presence-only form. The point process model is one of the recent approaches for modelling such data, taking care of pseudo-absences and spatial independence. For conservation in regions with limited resources and species with similar ecological requirements, it is important to properly assess the extent of competition extent between wild and domestic species. We attempted to use point process framework to estimate the function of resource selection in blue sheep (*Pseudois nayaur*) in areas influenced by pastoralism in a western Himalayan region. Our study is the first attempt to use this framework to estimate resource selection on a dataset not collected using radio-telemetry. Spatial locations of blue sheep and livestock and a background sample of random points with six topographic covariates were used to model resource selection probability via intensity function. Blue sheep showed its predicted presence in areas with open vegetation coinciding with alpine meadows, influenced by southern aspect keeping a threshold distance of 600–1000 m from cliffs (escape terrain). Livestock, also showed presence probability in open vegetation, but at lower altitudes, mainly on valley floors. Our results suggest that though blue sheep continued to use the same habitat type after livestock arrival, they selected different resources based on topographic factors. Livestock were in areas where it was convenient for pastoralists to establish campsites and where nutritious grasses were present, making it feasible to graze. Thus, we argue that the probable shift in habitat for blue sheep from optimal areas occurs due to livestock presence, which might disturb their nutritional balance. Our study provides helpful insights for managing rangelands, which when tied with dietary patterns will give a better idea for proper conservation measures in the future.

Key words: Uttarakhand, Johar valley, Pastoralism, *Pseudois nayaur*, Mountain ungulates.

BACKGROUND

Long term conservation of a species requires an understanding of the population genetics and ecology of that species through in-depth analysis of their distribution and the factors that influence that distribution (Franklin 2010; Zhai et al. 2017). Distribution of a species is dependent upon particular biotic and abiotic factors of their habitat, which together are considered resources. Hence, distribution and resource selection of a species are closely related entities. Resource selection occurs in a hierarchical manner, starting broadly from the geographic range of species to selection of particular elements within the general features of their habitats

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within their home range (Manly et al. 2002). Ungulate species with overlapping distribution ranges and similar ecological requirements are known to compete for these resources (Namgail 2001; Darmon et al. 2011). Various forms of distribution data like presence-absence, presence only, use-availability and count data have been used for development of specialized analytical techniques through machine learning (Aarts et al. 2012). Such studies have gained huge popularity in recent years, inviting ecologists to better understand species ecology using these methods. New techniques in the framework of older ones are being developed to provide better interpretations by accounting for the major shortcomings such as sampling bias, data deficiency, and spatial independence and other limitations (Warton and Shepherd 2010; Aarts et al. 2012; Renner et al. 2015).

Such limitations are more acute in mountainous regions where terrain, accessibility, logistics and elusiveness of the species restrict movement of observers. For such terrains, information on species distribution mostly comes as occurrence data, *i.e.*, locations where species have been observed. The presence-only data lacks any corresponding information about species absence (Renner et al. 2015). A common approach for analysing such data is randomly chosen background points or pseudo absences (Phillips and Elith 2013). Though there are several ways to model such data, *e.g.*, maximum entropy (MaxEnt) modelling of species distributions (Phillips et al. 2006; Phillips and Dudík 2008; Elith et al. 2011), and the logistic regression model along with its various generalizations (Austin 2002; Elith et al. 2006), most of them are limited by various shortcomings. These include model specification by not including prior construction of pseudo absences, leading to problems in interpretation as the model parameters are functions of the number of pseudo absences (Warton and Shepherd 2010). The point process model is one of the recent approaches to modelling that uses presence-only data (Warton and Shepherd 2010; Aarts et al. 2012; Hooten et al. 2013; Johnson et al. 2013; Renner et al. 2015). This model addresses the weaknesses of randomly chosen pseudo-absences (Warton and Shepherd 2010) by focusing on the observed data. This model assumes locations of point events to be independent, and the intensity (expected number of presence per unit area) at those points can be modelled as a function of the explanatory variables. Thus it takes into account the locations of the organism from where it has been reported rather than where it occurs. This framework has been linked to the common approaches for fitting presence-only models over the past five years. The point process model provides advances to these models by having the criteria for choice of pseudo-absences, checking assumptions and accounting for observer bias for better ecological insights (Renner et al. 2015). In this study, we used this framework to analyse the resource selection function of a mountain ungulate in an upland valley of Western Himalaya, which is heavily grazed by migratory livestock during summer-monsoon season. Blue sheep (*Pseudois nayaur*) is a widely distributed mountain ungulate forming the main prey base for the endangered Snow leopard (*Panthera uncia*) (Schaller et al. 1987; Oli et al. 1993; Chundawat and Rawat 1994). There is a considerable overlap in the distribution of these two species across the Himalayan region, and thus presence of one species indicates the occurrence of other.

The alpine rangelands in Himalaya provide a wide range of habitat mosaics supporting unique arrays of biodiversity and ecosystem services. Transhumant pastoralism is one such service that has thrived here for centuries (Bhasin 2013). In the last few decades, changes in livestock holdings, loss of traditional grazing patterns and knowledge systems (Farooquee and Nautiyal 1999) have greatly affected the wildlife, especially the wild ungulates (Bagchi et al. 2004; Mishra et al. 2004; Namgail et al. 2007). In light of current landscape approaches to conservation, it is becoming important to assess the pressures of pastoralism across a landscape and degree of competition of livestock with wild ungulates based on available resources for a proper monitoring/management plan for rangelands. Previous studies in the Himalayan region have shown that wild ungulates tend to avoid areas that are heavily used by domestic livestock (Kala et al. 2002; Bagchi et al. 2004; Mishra et al. 2004; Namgail et al. 2007; Shrestha and Wegge 2008; Kittur et al. 2010). In the sub-alpine and alpine zones of the Greater Himalaya, optimal resources are confined to specific patches and available only for a short duration (June–September) (Bhasin 1988; Sharma et al. 2003). Wild ungulates may be forced to forage in sub-optimal habitats due to livestock grazing in the limited optimal habitats. By sub-optimal we mean habitats which are more rugged and which require more energy consumption by the species. This might disturb their nutritional balance as they spend more energy avoiding the livestock grazed areas, and consequently they may be competitively excluded from better habitats (Schaller 1977; Mishra et al. 2004; Namgail et al. 2007). Thus, resource selection patterns of wild ungulates in the presence or absence of livestock grazing need to be analysed to evolve site specific management strategies for effective conservation of these species. Estimating resource selection is one powerful methods for identifying areas within a landscape that are highly used by a population of animals. It is generally assumed that if a species selects certain habitat units or food resources disproportionately to their availability or 'patches' with certain characteristics, it improves their fitness, reproduction, or survival (McDonald et al. 2013). This justifies actions to manage natural resources targeting such characteristic patches and monitor population distributions of species in these areas.

Species distribution patterns are strongly influenced by the availability of habitat resources during various seasons and the presence of predator and prey species. According to the habitat selection theory (Hutchinson 1957; Orians and Wittenberger 1991), sympatric species with overlapping niches show behavioural characteristics that separate them spatially or temporally within the same range (Namgail 2001; Darmon et al. 2011). Prior knowledge about the distribution of various resources on which the species depend allows people to characterize the distribution and abundance of these species by resource selection functions (RSFs). RSF yield values are proportional to the probability of use of a resource and helps in determining the probability that a habitat is being used by the animal (Boyce and McDonald 1999; Boyce et al. 2002). This study aimed to find the resource selection probability of blue sheep and the factors that influence this in areas influenced by pastoralism. We chose to determine whether, in presence of livestock, wild ungulates selected resources based on topographic factors and avoided optimal habitats. We also chose to see which factors govern the resource selection probability of blue sheep in pastoralism influenced areas. Under given topographic conditions and pastoralism activities, a resource item for a species could be highly favoured but difficult to access, and hence less utilized. Conversely, less favoured resources might comprise a large portion of used resources out of necessity if they are the only ones available to the species (Manly et al. 2002). This pattern might lead to a probable shift or avoidance of better resource areas by the wild ungulates. We estimated the resource selection through point process model. Here, the resource selection function is proportional to the expected density of observations (Aarts et al. 2012), which provides more accurate insights into relative patterns of species abundances in data-deficient areas. This study is a first attempt to use the point process framework to estimate resource selection on a dataset not collected using radio-telemetry.

MATERIALS AND METHODS

Study area

The ~950 km^2 study area forms the upper catchment of the Gori River, referred to as the Johar Valley. It lies between 80° to 81°5'E Longitudes, and 29°5' to 30°N Latitudes in Uttarakhand state of Western Himalaya (Fig. 1a b c). The valley covers an elevation range of 1918–6727 m and falls in the Biogeographic Province 1C under the Trans-Himalayan biogeographic zone of India (Kumar et al. 2017). This forms a transition zone of biogeographical elements of western

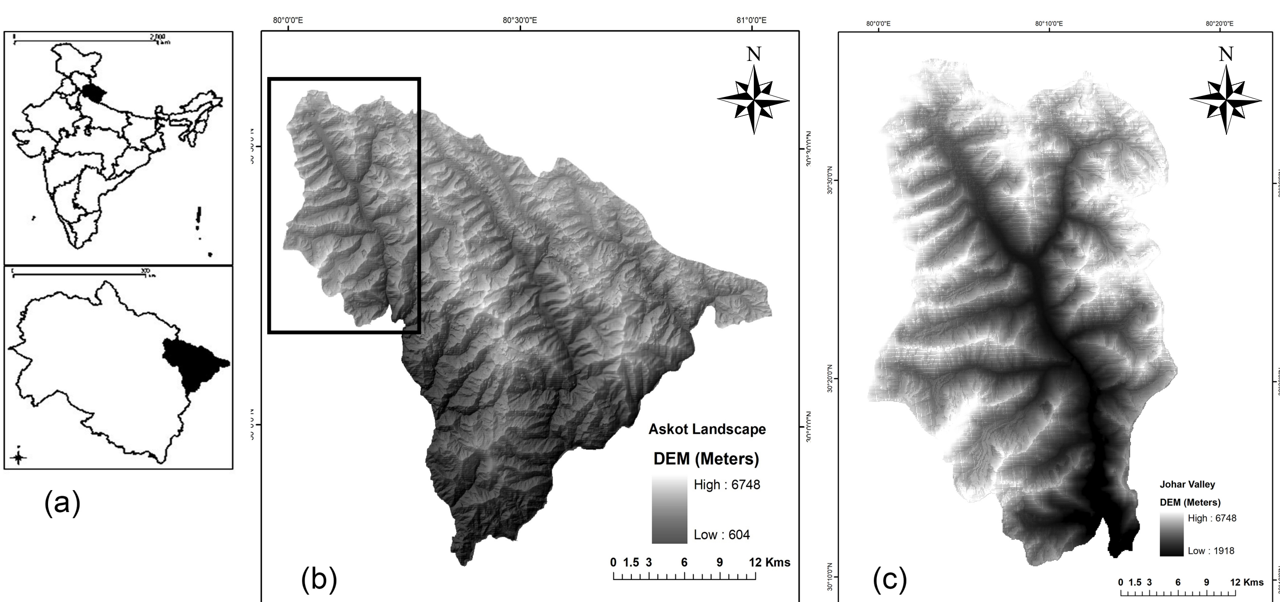

Fig. 1. Study area map showing (a) Location of Askot landscape in India and Uttarakhand; Digital Elevation Model (DEM) of (b) Askot landscape and (c) Johar Valley.

Himalaya and the Tibetan plateau. The variation in altitude creates habitats with sub-alpine and alpine birch (*Betula utilis*) forests associated with alpine shrubs and sciophytic herbs, Krummholz zones of *Rhododendron campanulatum* and *Juniper* scrub, widespread moist (Greater Himalayan area) and dry (Trans Himalayan area) alpine habitats (locally known as *bugyals*), beyond which lie the glaciers and cold desert merging with the Tibetan plateau (Government of India 2011; Negi 2010). Major ungulate species include Himalayan goral (*Naemorhedus goral*), Himalayan tahr (*Hemitragus jemalhicus*), Himalayan musk deer (*Moschus chrysogaster*) and blue sheep. These rangelands provide livelihood opportunities for the local communities in the form of high value medicinal herbs such as caterpillar fungus (*Ophiocordyceps sinensis*) and grazing resources for domestic livestock (sheep and goat) during the summer monsoon months. The main pastoralist community is *Bhotiya*, who seasonally migrate to the higher pastures (Sharma et al. 2003). The prominent fodder plants in the alpine habitats are *Danthonia* spp. and *Festuca* spp., several species of *Stipa* spp., *Carex* spp., *Selinum* spp., etc. These are important nutritious foraging grounds for both wild and domestic ungulates (Kala et al. 2002; Suryawanshi et al. 2009). The subalpine zones of birch forests and Krummholz zones serve as good cover for the wild ungulates. The movement of pastoralists with their livestock continues between sites in a regular pattern (Sharma et al. 2003).

Field Methodology

Prior to the field visit, the entire study area was divided into 38 large grids 5 × 5 km using Arc GIS 9.3 (Esri Inc 2008). The grid size was chosen in a way to incorporate the average daily movement distance (Garland 1983) of blue sheep (2.9 ± 0.5 km) to avoid sampling duplicates across grids. The grids were placed for sampling feasibility, maintaining the optimal distance between spatial replicates to avoid autocorrelation. Random and stratified random sampling approaches were used to conduct the study for three years (2015–2017) during the summer-monsoon season (May–September).

Direct observations

During the field study, vantage points with maximum visibility were selected in each grid depending on accessibility and logistics. Maximum visibility was ensured by visiting each sampling grid and surveying for elevated locations with ~ 360-degree visibility of the surroundings. Point counts of 10 minutes each were conducted from each vantage point with binoculars (10 × 50). Twenty out of the 38 grids were sampled with 40 vantage points (two in each grid), and thirteen repeated point counts were done at each vantage point per day at an hour's interval (6 am to 6 pm). Along with this, pre-existing trails of two to 11 km (n = 24) en route to the vantage points and sampling grids were surveyed for direct evidence. Two trails per day were sampled and the trails were walked in the mornings (6 am to 9 am) and evenings (3 pm to 6 pm). There were three replicates of trail sampling in three years. To avoid inter-observer bias, all field observations were made by a single observer. When encountered, species type (blue sheep or livestock), projected sighting locations, date and time were recorded. Only sheep and goat were considered as livestock for the study.

Experienced and reliable pastoralists (n = 45) were interviewed with open-ended semi structured questionnaires regarding locations of blue sheep as observed and remembered in the past five years. These are the only pastoralist groups that graze their livestock every year in pre-determined alpine patches and have over 20 years of experience in the study area. Probable areas were surveyed to accumulate sighting locations from the pastoralist community. Twenty-three sighting locations were recorded from the herders, out of which direct sightings were obtained in 14 of the locations (~60%). Based on this, we considered the herders' locations to be correct. The information collected from the herders contributed to around 17% (n = 9) of the direct data in the study. This information was included as direct evidence in the analysis.

Indirect observations

Thirty alpine pastures (regular encampments) and areas *en route* to these, which are used for livestock grazing, were sampled for pellet enumeration of blue sheep and livestock (sheep and goat). The area of each pasture ranged from ~2 to 200 km^2. Random circular plots each of 10 m in radius (n = 304) and separated by at least 300 m were placed across the selected pastures as well as adjoining areas and areas en route to these pastures. Previous studies suggested that belt transects are relatively more prone to missed groups error of pellets than circular plots for large ungulates (Neff 1968). The smaller plot may have a greater proportion of perimeter pellet groups, making its inclusion or exclusion a topic for discussion. Also in order to capture the richness of the species present, smaller plots would need to be much more numerous, but this process would be too time consuming. The disadvantage of using larger plots is the chance of missing pellet groups (Smith 1968; Noor et al. 2010). The optimal size for plots was found to be ~10 m in radius (Smith 1968). Since the study area terrain was not suitable for a systematic sampling, we placed the circular plots (10-m) randomly, covering all possible habitat types. Information on the number of pellet groups, species, and locations was recorded. Blue sheep pellets were recognized in areas devoid of livestock presence and seen visiting their previously observed presence locations in those areas. Blue sheep pellets were distinguished from pellets of other wild ungulates by their size and shape. Distinguishing blue sheep pellets from those of livestock (sheep and goat) was confusing initially. However, after careful study and consultation with experienced herders, this problem was resolved. We further collected blue sheep pellets in zip lock bags for future verification.

Analytical methods

Preparation of geospatial layers

Vegetation/land use data on western Himalaya were acquired from a vegetation type map of India from the Biodiversity Information System portal of the Indian Institute of Remote Sensing (http://bis.iirs.gov.in) at a resolution of 23.5 m (Roy et al. 2015). We clipped the vegetation categories according to our study area. The vegetation data have 20 classes for our study area, from which we selected the most relevant for the study species and clubbed the least relevant categories as miscellaneous. Twelve categories were generated for the final layer which were moist alpine pasture, wet grasslands, dry alpine scrub, barren land, snow, *Rhododendron*, sub alpine, dry deciduous scrub, dry evergreen scrub, Himalayan moist temperate, agriculture and miscellaneous. These classes were ordered and ranked starting from open to closed vegetation types. The openness rank for each of the 12 vegetation categories were Snow - 1, Barren land - 2, Moist alpine pasture - 3, Wet grasslands - 4, Dry alpine scrub - 5, *Rhododendron* - 6, Sub alpine - 7, Dry deciduous scrub - 8, Dry evergreen scrub - 9, Himalayan moist temperate - 10, Agriculture - 11 and Miscellaneous - 12. These ranks were then standardized using standard normal transformation to be used as a continuous variable in the study. Digital Elevation Model (ASTER 30 m DEM) was acquired from Ecological Mapping Atlas of Askot Landscape, Uttarakhand, India (WII-BCRLIP 2015). Raster layers of the aspect, slope and terrain ruggedness index (TRI) were derived from DEM. We considered steep cliffs as escape terrain for blue sheep based on the terrain of the study area. To generate an escape terrain layer, slope was classified into two classes (0–45 and 45–80 degrees) and slopes above 45 degrees were considered steep cliffs (Namgail et al. 2004; Ahmad et al. 2016). Euclidean distances from the steep cliffs (slopes > 45 degrees) were calculated at 100 m intervals (maximum distance 2 km) to generate a distance from escape terrain (DET) raster layer. This was done as blue sheep sighting from nearest escape terrain varied from 100–2000 m during the study. Based on the average daily movement distance of blue sheep, we used DET intervals of 100 m from the steep cliffs so that the results are not skewed towards a particular DET category. From point locations (direct and indirect) of blue sheep and livestock collected during the field study, we extracted the raster values of the topographic layers (Vegetation type, DEM, slope, aspect, TRI and DET). These variables are known to influence resource selection in these species (Namgail 2001; Suryawanshi et al. 2009; Johnsingh and Manjrekar 2015). All geospatial analysis was done in GIS domain (Arc GIS 9.3, Esri Inc 2008) and all raster layers were resampled to a resolution of 30 m.

Resource selection probability

Presence-only data are a set of point locations $y = \{y_1 \dots y_n\}$ in a continuous space A, where the locations (y_i) are recorded as presences. Analysis of y is done as a point process, jointly modelling the number of presence points, n, and their locations (y_i). A map of values in the space A for each k explanatory variables that were observed (values of these variables at y_i) are denoted as $x = (x_{i1} \dots x_{ik})$. Here, intensity at point y_i (λ_i = expected number of presence points per unit area) is modelled as a log-linear function of covariates (k). The parameters of the model are stored in the vector $\beta = \{\beta_0, \beta_1 \dots \beta_k\}$ (Cressie 1993).

(1) $\log(\lambda_i) = \beta_0 + \sum_{j=1}^{k} x_{ij}\beta_j$.
where λ_i = intensity at point y_i
x = values of covariates
β = coefficient

Spatial locations of presence points (direct and indirect) of blue sheep and livestock and a background sample of random points (availability locations) were taken for point process analysis. The number of random points were chosen in point process framework using likelihood convergence method. Thus, 1000 random points were found suitable for our study area of ~950 km^2 at an intensity of one point per km^2. The 1000 random points were generated across the study area and labelled as zeroes to account for pseudo-absences. An intensity of random points of one point per km^2 was considered for analysis to accommodate the comparable effort across point intensity for both species and avoid pseudo replication. We evaluated spatial independence within our observation points through Moran's I test (Moran

1950) for spatial autocorrelation. The results indicated a somewhat clustered pattern of our observation points, which may be due to random chance (Moran's Index = 0.03). Raster values of the topographic variables were extracted for both the presence and pseudo-absence locations. A binomial point process model was fitted to the binary data using the covariates at all of the used and available locations. The beta values for each covariate were estimated using the framework with a generalized linear model (GLM). The models were evaluated through Receiver Operating Characteristic (ROC) curve values, along with information theoretic approaches like Akaike Information Criterion (AIC) (Akaike 1974) and Bayesian Information Criteria (BIC) (Schwarz 1978). ROC was calculated using the package "pROC" in the R 3.5 (R core team 2017). We did not separate the training and test data as our sample size was small, but validation was done comparing with the whole dataset. Models with lowest AIC values were considered best fit models. However, the AIC values of the best fit models for both blue sheep and livestock had differences of less than two to determine the best model among them. For best model selection we used BIC values as they are better in situations where false positives are more misleading than false negatives. As we are more interested in minimizing the false positives in this case, BIC values provide better insights than AIC. The significant variables of the best fit model were used to generate maps of the predicted intensity of resource selection probability for both blue sheep and livestock. The intensity maps were generated using the map equation

(2) $Output = Beta_1*Raster_1 + Beta_2*Raster_2 \ldots + Beta_n*Raster_n$

in the GIS domain with the coefficient values of the most significant variables of the best fit models for respective species.

After the intensity raster layers were generated, we extracted the intensity values for the training locations and applied a threshold based on the minimum intensity value, then divided the layers of the respective species into five intensity classes: very low, low, moderate, high and very high. Area for predicted presence was calculated using moderate, high and very high classes. We first ran separate analyses with direct and indirect evidence presence points, which revealed insignificant differences in values to be considered for separate interpretation (Table S1). We used both evidences combined for analysis to increase the spatial coverage of the dataset and incline towards more accurate results by increasing the number of unique observations. This did not alter the model for interpretation. All analyses for resource selection was done using the "Raster" (Hijmans 2016) and "spatstat" (Baddeley and Turner 2005) packages in R 3.5 (R core team 2017) and ArcGIS 9.3 (Esri Inc 2008).

Since the covariate vegetation type was used as a continuous variable for vegetation openness in the point process model, we conducted a post hoc test to validate the results. We conducted Design I of Manly's Resource Selection Function (Manly et al. 2002) to estimate resource selection via the habitat use vs availability framework for blue sheep and livestock. Design I was used as it does not need to identify individual animals and the resource units are assumed to be sampled for the entire study area. We compared the number of individuals in each vegetation type to the relative availability of the respective vegetation type in the study area. Habitat use vs the proportion of available habitat was calculated using the package "adeHabitatHS" in R 3.5 (Calenge 2016). Used habitats were considered as the areas, which were selected and received some investment by an animal. The proportion of available habitat was the quantity of the particular vegetation type accessible to the species in the entire study area (Manly et al. 2002). Therefore, available resources were considered as the areas that the study species may select (Lele et al. 2013). The percentage use for each category was then compared to its respective availability to evaluate resource selection. We used the commonly employed ratio of percentage use divided by percentage available, which is referred to as the forage ratio or selectivity index (Savage 1931, Manly 1974) as the resource selection index (wi).

(3) $wi = oi / \tilde{\pi}i$

where oi = sample proportion of used units in category i
$\tilde{\pi}i$ = sample proportion of available units in category i

A resource item for a species could be highly favoured but difficult to access, and hence, less utilized. Conversely, less favoured resources might comprise a large portion of resources used out of necessity if they are the only ones available to the species (Manly et al. 2002). The selection index mainly indicates a high preference for a particular habitat unit that is highly used.

RESULTS

In this study, 63% of the entire study area was sampled intensively, and the rest of inaccessible for sampling. A total of 87 presence points (51 direct, 36 indirect) for blue sheep (Fig. S5) and 327 presence points (97 direct, 230 indirect) for livestock (Fig. S6) were obtained. The survey effort consisted of a total of 40 sampling points with 520 point count replicates for 5200 minutes (single season) along with 149 km of trail walk for 4172 minutes per season (three seasons) and 304 pellet plots of 315 m^2 each (single season).

Factors influencing resource selection

Best models with AIC differences of two or less were considered to explain variability in the data. In the case of blue sheep factors influencing resource selection, the best models were generated using vegetation openness and DET as predictor variables (Fig. 2, Table 1). Slope and TRI had the least influence and was omitted from subsequent equations. Vegetation openness showed a negative relationship with blue sheep presence (coefficient = -0.35, $p < 0.01$), showing preference towards open vegetation types, including alpine grasslands, barren and snow covered areas. The post hoc test complimented this result (Fig. S2, Table 3), revealing that blue sheep mostly preferred alpine meadows that were used more frequently than they were available. Escape terrain had a strong positive relation with blue sheep presence (coefficient = 0.45, $p < 0.001$) showing preference of blue sheep towards less steep cliffs. Though aspect and elevation had low significance levels, the variables supported the ecological relationships with the significant covariates. In the case of livestock, resource selection was best modelled using vegetation type (coefficient = -0.36, $p < 0.001$) and elevation (coefficient = -1.31, $p < 0.001$) as variables. Slope and aspect, the least significant variables, were omitted. Both elevation and vegetation openness showed a negative relationships (Fig. 3, Table 2) with livestock presence, showing preference for open vegetation at lower altitudes. The post hoc test for livestock also complimented these results (Fig. S3, Table 3), showing that alpine meadows were their most preferred habitat type.

Resource selection probability

An intensity map of resource selection probability for blue sheep (Fig. 4a) showed its predicted presence in areas with open vegetation representing the alpine grasslands. Their presence was predicted in a suitable area of 659.18 km^2 which was 69% of the total study area. Their selection probability was in areas towards the alpine grasslands and valley floors on the southern aspect keeping a distance of 600–1000 m from the cliffs. There was no significant difference between the intensity maps of blue sheep generated separately with direct and indirect evidence (Fig. S1 a b c). Livestock, accompanied by humans, also showed presence probability (Fig. 4b) in areas with open vegetation but at lower altitudes with moderate terrain ruggedness away from cliffs, mainly on the valley floors. Their presence was predicted in an area of 545.97 km^2 which was ~57% of the total study area. An overlap map of livestock intensity areas with blue sheep intensity areas showed an overlap area of 259.37 km^2 which was ~39% of blue sheep resource selection probability area (Fig. 5).

DISCUSSION

Wild ungulates tend to avoid competition through differential resource selection patterns. The basis of this differential selection may be habitat, diet

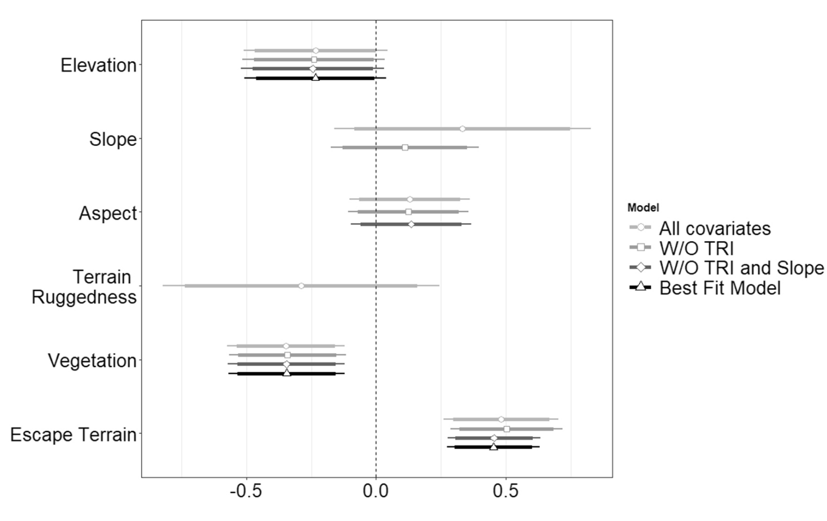

Fig. 2. Coefficient plot of covariates used in the point process model of blue sheep.

or anti-predator strategies (Namgail et al. 2007). In most applications for estimating resource selection function, only relative probabilities rather than absolute probabilities can be used. This study reveals that vegetation openness is an important variable for predicting the resource selection by both blue sheep and livestock. Our results reflected the openness value of the selected vegetation categories. We inferred that blue sheep have a preference towards alpine grasslands (moist and dry) and barren and snow covered areas in our study. The negative relation indicated a preference for open alpine areas with herbaceous vegetation type,

Table 1. Coefficients and *p* values of point process models with different combinations of covariates for blue sheep

Predictors for Blue Sheep	Model 1	Model 2	Model 3	Model 4	Model 5
(Intercept)	-2.58 ***	-2.56 ***	-2.57 ***	-2.56 ***	-2.54 ***
SE	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Slope	0.33	0.11			
SE	(0.25)	(0.15)			
Aspect	0.13	0.12	0.13		
SE	(0.12)	(0.12)	(0.12)		
Terrain Ruggedness	-0.29				
SE	(0.27)				
Vegetation Openness	-0.35 **	-0.34 **	-0.35 **	-0.34 **	-0.43 ***
SE	(0.12)	(0.11)	(0.11)	(0.11)	(0.10)
Elevation	-0.23	-0.24	-0.24	-0.23	
SE	(0.14)	(0.14)	(0.14)	(0.14)	
Escape Terrain	0.48 ***	0.50 ***	0.45 ***	0.45 ***	0.47 ***
SE	(0.11)	(0.11)	(0.09)	(0.09)	(0.09)
N	990	990	990	990	991
AIC	550.47	549.70	548.28	547.59	549.09
BIC	584.75	579.09	572.77	567.18	563.79
Pseudo R^2	0.11	0.10	0.10	0.10	0.09
ROC	0.716	0.715	0.715	0.717	0.701

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 2. Coefficients and *p* values of point process models with different combinations of covariates for livestock

Predictors for Livestock	Model 1	Model 2	Model 3	Model 4
(Intercept)	-1.57 ***	-1.57 ***	-1.56 ***	-1.53 ***
SE	(0.10)	(0.10)	(0.10)	(0.10)
Slope	0.08			
SE	(0.16)			
Aspect	0.10	0.10		
SE	(0.08)	(0.08)		
Terrain Ruggedness	-0.30	-0.23 *	-0.23 *	
SE	(0.17)	(0.10)	(0.10)	
Vegetation Openness	-0.36 ***	-0.36 ***	-0.36 ***	-0.36 ***
SE	(0.07)	(0.07)	(0.07)	(0.07)
Elevation	-1.33 ***	-1.33 ***	-1.31 ***	-1.29 ***
SE	(0.11)	(0.11)	(0.10)	(0.10)
Escape Terrain	0.45 ***	0.44 ***	0.44 ***	0.55 ***
SE	(0.09)	(0.09)	(0.09)	(0.07)
N	1234	1234	1234	1234
AIC	1059.65	1057.90	1057.49	1060.42
BIC	1095.48	1088.61	1083.08	1080.89
Pseudo R^2	0.39	0.39	0.39	0.39
ROC	0.843	0.842	0.842	0.841

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

which coincides with the diet and foraging patterns of both species. In summers, both species are hugely dependent on alpine grasses and other associated plant species that mainly grow on the warmer aspects (Kala et al. 2002). The analysis reveals that, though blue sheep continue to use the same area after migratory livestock arrive, they separated, selecting different variables or resources based on topographic features. Blue sheep selected warmer aspects in moderately rugged terrains to forage on the grasses, and also showed a preference to remain a moderate distance from the escape terrain. The preference to remain towards the cliffs is an artefact of a behavioural trait (Namgail et al. 2009; Johnsingh and Manjerakar 2015). According to our results, they prefer to remain 600–1000 m from the cliffs to exploit the alpine meadows. Since the summer monsoon season is the main foraging season for blue sheep, it is most likely to prefer the lesser rugged habitat patches other than the steep cliffs. It was also suggested in Namgail (2001) and Namgail et al. (2004) that there is less forage available in the cliffs, so blue sheep have to move out of such escape terrain to feed on the grasses, thus compromising their safety. The above mentioned studies showed that blue sheep in a Trans Himalayan landscape tend to remain closer to the cliffs (within 250 m). Escape terrain, like the other covariates, is a function of topography, which varies across different Himalayan zones. In a greater Himalayan landscape, the better foraging sites are the places with alpine grasses, which are quite far from the steep cliffs. Thus, blue sheep need to balance food acquisition and predator avoidance while feeding outside the escape terrain. We analysed the relation of DET with our direct and indirect evidences and found that most observations were within a distance of 1000 m and 600 m from the cliffs, respectively (Fig. S4). Use of an escape

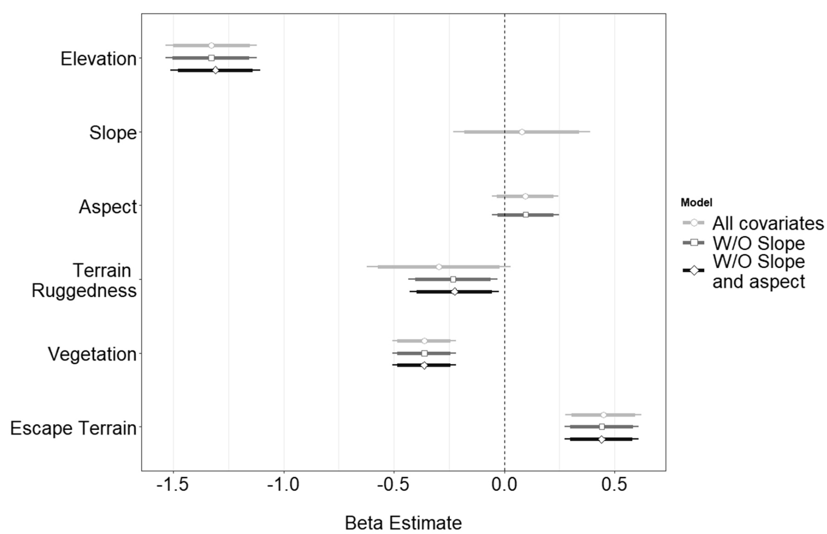

Fig. 3. Coefficient plot of covariates used in the point process model of livestock.

Table 3. Selection index (Wi values) of use vs availability for blue sheep and livestock

Habitat Type	Blue sheep Wi	SE	Livestock Wi	SE
Moist Alpine	1.813***	0.116	2.263***	0.012
Barren	0.736**	0.068	0.701*	0.007
Dry Alpine Scrub	2.254	1.001	4.246	0.140
Dry Evergreen Scrub	0.000	0.000	0.000	0.000
Agriculture	0.000	0.000	0.000	0.000
Wet Grassland	2.336***	0.280	2.465***	0.029
Sub Alpine	0.000	0.000	7.430	0.330
Himalayan Moist Temperate	0.000	0.000	0.000	0.000
Rhododendron	1.711	0.760	4.297	0.122
Dry Deciduous Scrub	0.000	0.000	0.000	0.000
Snow	0.450**	0.058	0.000	0.000

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

terrain during foraging seasons is a strategy to exploit resources and avoid predation. A study by Wegge (1979) reported blue sheep feeding in open habitats and resting in rugged terrains. Due to presence of livestock, blue sheep avoid close proximity to the optimal patches, resulting in selecting an optimal DET. We found this threshold distance to be 600–1000 m from the cliffs. This also explains the negative relation with elevation (Fig. 2), as blue sheep are found to prefer areas closer to the alpine meadows in the summer-monsoon season. Previous studies on blue sheep tied with our results led us to infer a probable shift in habitat preference from known preferred habitats of the species. It might seem from the results that blue sheep have a selective advantage for feeding on resources of their choice because of their ecology in rugged terrains. Advantage with the topographical factors for blue sheep allows the species to use some habitat and utilize those resources that otherwise would not have been possible due to presence of livestock.

Livestock, accompanied by pastoralists, preferred areas at lower elevations than blue sheep, with moderately rugged terrain, mainly on the valley floors. These are areas convenient for pastoralists to establish campsites and are feasible for grazing. Presence probability of livestock overlapped with ~39% of the high intensity area for predicted blue sheep presence (Fig. 5). These highly suitable areas were along the valley floors and low altitude alpine patches interspersed with Krummholz zones and grassy slopes, the optimal areas preferred by pastoralists because they have nutritious grasses for their livestock. This makes the resource selection probability area greater for livestock than ungulates. This supports our results that blue sheep are shifting to a rugged topography at a threshold distance to their escape terrain, although there is a chance of selecting the optimal areas.

Our analysis suggests that, to avoid pastoralist occupied areas, blue sheep select resources in more rugged areas that are less disturbed and inaccessible to humans. Whether the selected areas are really sub-optimal foraging sights for the wild ungulates is difficult to predict. Moreover, RSF maps that predict high probability of use for certain areas do not necessarily define them as optimal habitats. This is because there is not much information on these areas, because they are inaccessible. Nevertheless, we can suggest from our results a definite segregation of resource selection patterns, with blue sheep taking refuge in topographic covariates instead of coveting nutritious factors. In

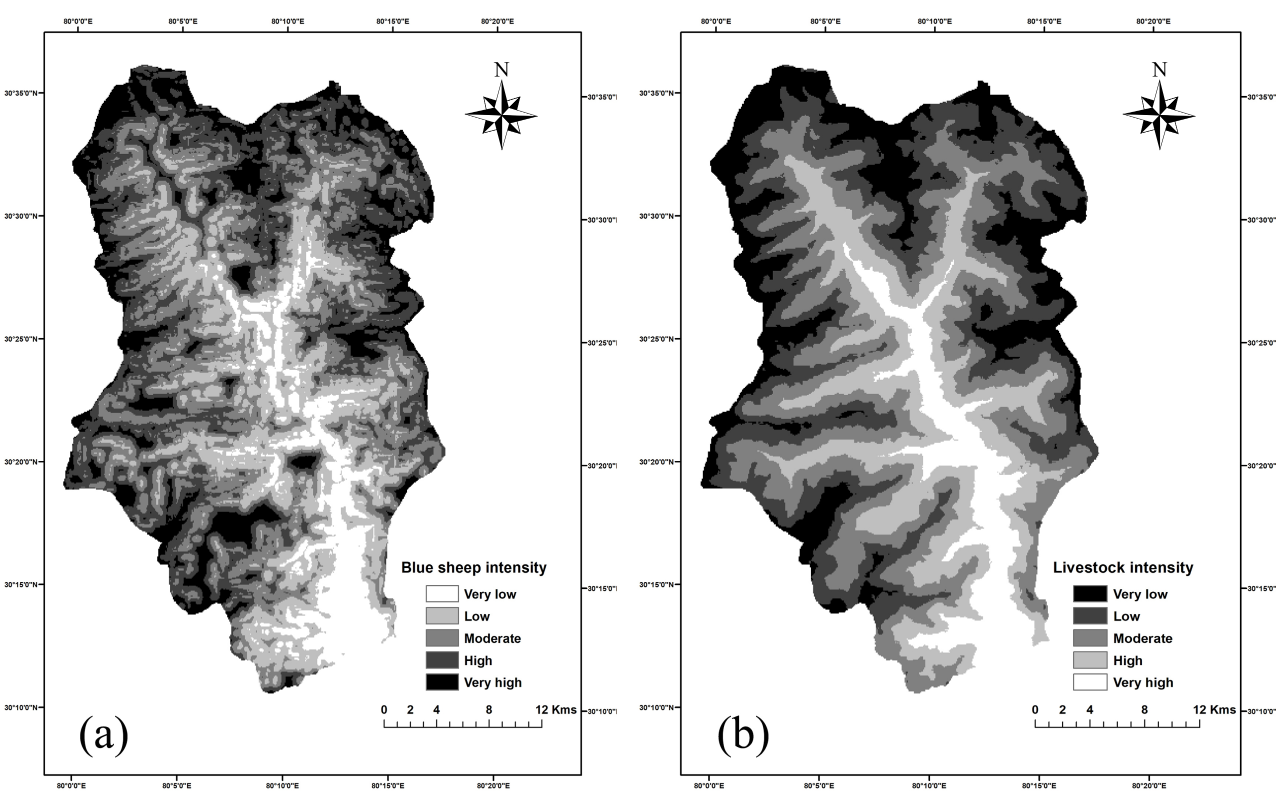

Fig. 4. Map showing intensity of resource selection probability of (a) Blue sheep (Output = 0.47 * Distance to escape terrain raster layer – 0.43 * Vegetation type raster layer) and (b) Livestock (Output = 0.55 * Distance to escape terrain raster layer – 1.29 * Elevation raster layer – 0.36 * Vegetation type raster layer).

greater Himalaya, both blue sheep and the pastoralists exploit the seasonal abundance of grazing resources that are available in marginal environments. Nutritional quality of forage during the summer is suggested to be a mediator of both blue sheep and livestock survival during the remainder of the year (Cincotta et al. 1991). Competition is expected among sympatric ungulates when shared resources are in short supply (Pianka and Huey 1978). As alpine meadows are less abundant, exploitative competition is likely to occur. We propose that, through the pattern of resource selection, blue sheep avoid optimal pastures, which can alter their foraging and dietary pattern. Suryawanshi et al. (2009) showed this avoidance through diet estimation and foraging availability of blue sheep in Trans-Himalaya. Livestock has a competitive advantage due to the presence of humans who lead them to optimal grazing pastures. They remove large amounts of forage from pastures, reducing its availability for wild ungulates (Bagchi et al. 2004; Suryawanshi et al. 2009), thus imposing resource limitations. This might lead to their exclusion from better habitat patches, in turn affecting their ecology. Our results suggest that blue sheep might prefer the resources in the optimal patches used by livestock as these patches have high nutritional content and require less energy expenditure. Our model predicts that blue sheep will avoid optimal grazing areas in the presence of livestock, suggesting a segregation of resource selection patterns.

The advantage of using the point process in this

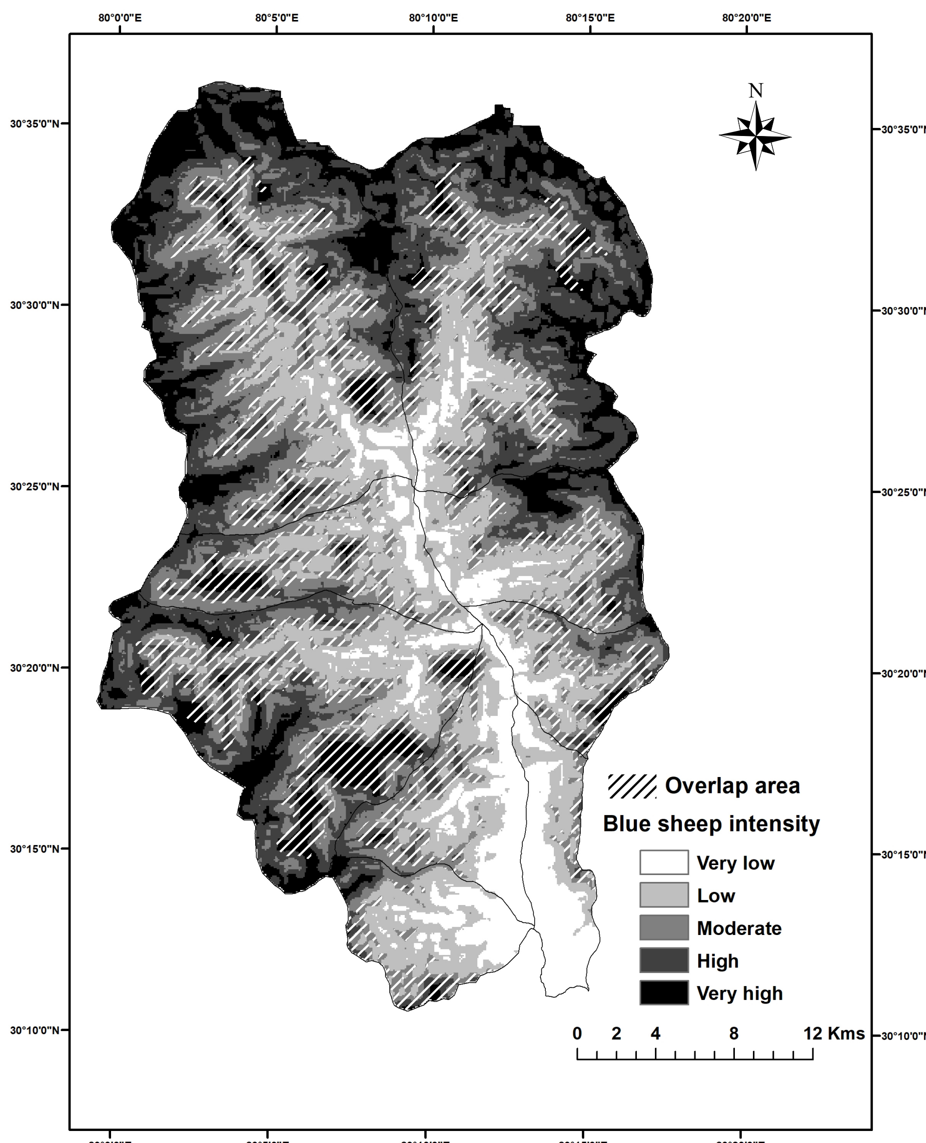

Fig. 5. Map showing overlap of resource selection intensity between livestock and blue sheep.

study is the choice of background points or pseudo-absences according to the objective of the study. In the RSF designs explained by Manly et al. (2002), available resource units were sampled for the entire study area or unused resource units were considered as available units. The point process framework provides a platform to systematically select our background or available points in accordance with the species presence points. This gives more specificity to the intensity prediction. Another advantage of this method is its relation to the common approaches for RSF estimation. These models are a generalization of the frequently-used weighted distribution models, like GLM and MaxEnt (Johnson et al. 2013; Renner et al. 2015). This can be readily implemented by animal ecologists inferring about relative patterns in species abundances taking sampling biases into account. Earlier studies (Bagchi et al. 2004; Namgail et al. 2007; Suryawanshi et al. 2009) mainly explained resource selection through dietary patterns. Other habitat association studies (Namgail et al. 2007; Shrestha and Wegge 2008) explained RSF through GLMs with the entire study area as available habitat. Our study focuses on the spatial basis of selection probability. We used background points to provide a more accurate association with the habitat variables and the species presence points rather than a generalized proportional probability layer. We used the point process framework to model the resource selection probability of blue sheep and livestock via intensity functions. Instead of a probability, we estimated the expected abundance of species presence throughout the study area, using intensity as a function of the covariates (Renner et al. 2015). This is the first study in which the point process model is used to model the resource selection function of terrestrial mammal species without radio-telemetry data.

CONCLUSIONS

The main aim of studying mountain ecosystems is to inform better management decisions for practitioners and managers. These insights include spatial layers relating to the ecology of the species. Resource selection patterns can be used to infer the relationship between an animal's space use and its environmental niche. A sound knowledge of spatial factors facilitates prioritization for management strategies. Our study will help inform monitoring and planning efforts focusing on identifying and protecting important habitat resources in the Himalayan region. Our spatial information represented in the resource selection and overlap maps can serve as a tool for directing efforts towards planning managed pastoral practices in the Johar Valley. Managed pastoral practices can include exclusion of particular pastures from the priority areas for livestock grazing and cohesion of pastoralist groups for sharing of pastures instead of individual pastures. Our predictive maps, when applied appropriately, can also help identify areas across Himalayan landscapes with a high potential of being good blue sheep habitat. Identification of such areas will assist with large-scale land-use planning, management and recovery efforts for threatened species (Boyce and McDonald 1999; Boyce and Waller 2003). The RSF coefficients and predictive maps from the study can also serve to generate hypotheses for future research and direct population inventories across areas where relatively little is known about the distribution of blue sheep or other species. We recommend that these models and maps, and results from similar applications, be used as baseline information for future research. According to Mladenoff et al. (1999), observations from further research and inventory efforts can be used in an integrative fashion to assess and update RSF and resulting maps. According to our conclusion, we suggest that land managers use distribution maps and treat the overlapped areas as conservation priority areas. We posit that conservation of threatened and important prey species in Himalayan rangelands depends on managed pastoral practices and community participation. Those areas can be dealt with by the management for managed pastoral practices and inclusion of pastoralist communities to maintain a biodiversity information flow and help in conservation of wildlife. Our study provides helpful insights for managing rangelands at a landscape scale, which can be tied with microhabitat level dietary patterns, yielding a more all-encompassing approach to proper conservation measures in the future.

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final version of this manuscript.

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Availability of data and materials: Data used for the analysis has been uploaded to the Dyrad data repository (https://datadyrad.org). doi:/10.5061/dryad.nk98sf7qm.

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Supplementary materials

Fig. S1. Intensity map of blue sheep resource selection probability of (a) Combined (b) Direct and (c) Indirect evidences. (download)

Fig. S2. Resource selection and utilization of blue sheep with respect to available habitat. (download)

Fig. S3. Resource selection and utilization of livestock with respect to available habitat. (download)

Fig. S4. Relation between distance to escape terrain and probability of blue sheep occurrence. (download)

Fig. S5. Observation points of blue sheep recorded in Johar Valley. (download)

Fig. S6. Observation points of livestock recorded in Johar Valley. (download)

Table S1. Coefficient and *p* values of blue sheep direct, indirect and combined observations. (download)