HABITAT SELECTION BY BROWN BEARS IN DEOSAI NATIONAL PARK, PAKISTAN, AND IMPLICATIONS FOR PARK MANAGEMENT

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Abstract

The Himalayan brown bear is a threatened species with a fragmented range in the Himalayas, yet its habit requirements are not known. We investigated habitat selection of brown bears and the impact of human disturbance factors in Deosai National Park, Pakistan.

An Ecological Niche Factor Analysis indicated that bears avoided higher elevations and steeper slopes, and showed a higher preference for more productive parts of the park (marshy, grassy, and stony vegetation types). Only 65% area of the park was vegetatively productive, with a standing crop of about 900 kg dry matter/km^2. The marshy vegetation was the most preferred habitat, probably due to its highest forage production and highest density of golden marmots. Brown bears tolerated human structures like roads and camps, but strongly avoided grazing areas with high livestock density. The habitat suitability map generally followed the biomass productivity patterns of the park. It indicated the central part as suitable, and classified half of the park, mainly peripheral areas, as not suitable for brown bears.

The vegetation and habitat suitability maps provide an objective criterion for evaluating present and future developments in the park. Until recently, the park seems to have sustained resource use by communities without significantly affecting the brown bear population or other park resources. However a large influx of livestock by nomad grazers in the last two years has become a major challenge, which needs urgent attention to continue the present brown bear population recover and to secure its habitat. We recommend monitoring of the livestock and a detailed inventory of the rangeland to understand grazing dynamics in the park and to maintain sustainable stocking rates.

Key words: ENFA, habitat selection, Himalaya, habitat suitability map, Pakistan, *Ursus arctos*

Introduction

Human persecution, increases in human populations and their activities, and habitat degradation and fragmentation have reduced populations of large carnivores in much of the world (Weber and Rabinowitz 1996; Woodroffe 2000). Protected areas can provide an important sanctuary for sensitive species, such as large carnivores, but they are often too small to provide for viable populations (Newmark 1995; Woodroffe and Ginsberg 1998). In addition, protected areas sometimes hold lower densities of important species for protection than adjacent areas used by humans (Rannestad et al. 2006) or may constitute a population sink, with the source being on the adjacent human-used lands (Swenson et al. 1986). Nevertheless, protected areas often constitute important, core habitats that allow large carnivores to better survive in mostly human-dominated landscapes (Schwartz et al. 2006). Even in protected areas, zoning is an increasingly popular approach. Zoning results in distributing the resources within a protected area among various competing interests, such as human uses and wildlife, in order to meet management goals (Hepcan 2000; Kothari et al. 1996). However reserving suitable areas for wildlife requires specialized knowledge, but managers often select areas on an ad hoc basis without a clear understanding of the ecological needs of species.

Brown bears (*Ursus arctos*) are highly endangered in Southern Asia, where mostly small, isolated populations exist in the remote and rugged mountainous areas (Servheen 1990). Similarly the Himalayan brown bear (*U. a. isabellinus*) is a highly threatened species with fragmented populations in Pakistan (Nawaz 2007). To date, almost no research has been conducted on the habitat requirements of brown bears in the Himalayan region.

When Deosai National Park (DNP) was created in northern Pakistan in 1993, a zoning plan was introduced to accommodate the resource needs of local communities and nomad grazers (HWF 1999). Although people were allowed to use resources in consumptive zones, a "core area" was designated for brown bears, which was managed as a restricted area, where public entry was not allowed. This was done because the conservation of the remnant bear population was one of the goals of the park when it was created (HWF 1999). The ecological needs of brown bears were not known at that time, therefore the demarcation of the core area was based on sightings of brown bears and subjective assessments. The brown bear population in the park is growing (Paper III), which suggests that the management has been positive for the bears. Nevertheless, livestock numbers in the park are also increasing. There have been unsuccessful attempts by the livestock herders to encroach into the core area, and new developments have been proposed for the park, including new roads, hotels, sport facilities, etc. A better understanding of the park resources and how bears respond to human activities is required to understand how these issues might affect the bear population. It is therefore very important for management of the park; a) to understand habitat preferences of brown bears, and b) to assess park resources (particularly pastures) and its spatial distribution in relation to bears. This study aims to address these questions.

Materials and Methods

Study area

DNP, about 1800 km^2, occupies part of an alpine plateau in the western Himalayas, and is managed administratively by the Northern Areas Forest and Wildlife Department, Northern Areas, Pakistan. It is a typical high-altitude ecosystem, with mean daily temperatures ranging from –20°C to 12 °C, and annual precipitation varying between 510 mm and 750 mm. It is above the tree line and vegetation is predominately herbaceous perennials, grasses and sedges.

The grazing ranges of the park are an essential resource for wildlife, particularly brown bears (Nawaz 2007). These rangelands also contribute substantially to the livelihood of local communities and nomadic groups (*Bakarwals* or *Gujjars*). About 9,000 livestock, mainly goats and sheeps, grazed within the DNP in 2004. According to the zoning plan, the south-eastern part of the park, covering about half of its area, was designated as the core area for brown bears, whereas local communities and Gujjars were allowed to continue grazing ranges in rest of the park.

Data collection

The locations of brown bear feces (hereafter referred to as sign) were used to indicate areas used by bears. We divided the study area into five blocks, and each block was searched for sign every year in order to cover most of DNP (see details in Bellemain et al. 2007). In addition to this planned collection, the DNP field staff recorded sign during their normal patrolling of the park. A total of 450 occurrences of sign were documented between 2003-2006.

Vegetation classification

We used the 28 July 1998 LANDSAT Thematic Mapper (TM) satellite image for habitat classification. A subset of the study area was made after geocorrection of the image. The image comes with seven bands (1: visible blue, 2: visible green, 3: visible red, 4: near infra red, 5:

middle infra red, 6: thermal infra red, 7: short wave infra red). The false color composites of 7, 4, 3 and 4, 3, 2 (in red, green, and blue) were useful in discriminating vegetation types in DNP.

We used a combination of supervised and unsupervised classification tools and ground control points in the ERDAS Imagine Program (Leica Geosystems, Inc.), to classify DNP into six classes; marshy, grassy, stony, rocky, water and snow (Table 1). The cloud-covered areas in the 28 July 1998 LANDSAT image, about 8%, were replaced by 30 September 2001 LANDSAT Enhanced Thematic Mapper (ETM) image.

Standing biomass assessment

To obtain an index of forage production, from standing crop (Soest 1994; Vallentine 1990), we randomly established 5 quadrats (0.5 x 0.5 m) in marshy areas, 5 in grassy and 6 in stony areas (both 1.5 x 1.5 m). All edible parts (twigs, leaves, etc) from shrubs and whole plants of herbs and grasses were clipped and stored for dry matter (DM) biomass analysis. Sampling was done in August (mid growing season) in low grazing area. We collected only palatable species, supposed to be eaten by bears and livestock. The collected samples were weighed and oven-dried for 24 hrs at 70°C in a fan-forced oven. Dry matter weight was then calculated, and biomass production per unit area was calculated.

Data preparation

We projected the map of the DNP on the UTM (WGS 84, 43N) coordinate system. Raster maps of 11 ecogeographical variables (EGV) (Table 2) were prepared in Arc GIS (ESRI Inc., 2006). Resource units (RU) were defined as 200 x 200 m pixels of raster maps (Manly et al. 2002).

We acquired elevation data from the Shuttle Radar Topography Mission (SRTM) (http://www2.jpl.nasa.gov/srtm/). For DNP, two SRTM images (N34E075, N35E075) were required, which we joined to make a subset for the study area (Fig. 1a). The areas of missing data ("voids") in the SRTM images were replaced with information from topographical maps of the Survey of Pakistan, using ERDAS Imagine Program (Leica Geosystems, Inc.). Streams were digitized from the 30 September 2001 LANDSAT image. Roads were digitized from topographical maps of the Survey of Pakistan, and were categorized as main and small roads, depending on their size and traffic volume. There was a single main road, crossing DNP in the middle, and connecting the two main towns of the area; Skardu on the east and Astore towards the southwest. This road receives public transport travelling between these towns and other villages on the way. Also tourists coming to DNP or travelling in Baltistan use this road. There were two minor roads that connect Matyal Village and the Gultari/Minimerg Valley to this main road. These are smaller roads with considerably low traffic volume, because these are generally used by vehicles bringing supplies to these villages or transporting agricultural products.

Locations of camps belonging to nomad and local livestock herders and seasonal hotels were recorded with a GPS receiver. During the vegetation surveys in 2002-2003, livestock grazing pressure in Deosai was documented from the proportion of plants grazed in quadrats and the park area was divided into three grazing impact zones; high, medium, low (Nawaz et al. 2006). We calculated topographic ruggedness index by using the TRI Arc Macro Language (AML) code in Arc/Info Workstation (Arc 9.2 ESRI 1982-2006). The TRI is a measurement developed by Riley et al. (1999) to express the amount of elevation difference between adjacent cells of a digital elevation grid. The TRI has been used to explain habitat selection of large mammals (Nellemann and Cameron 1996; Nellemann and Reynolds 1997; Vistnes and Nellemann 2001) including brown bear (Nellemann et al. 2007). In the present study TRI and the slope map were quite identical in pattern and also highly correlated (r: 0.87), we therefore did not use TRI in further analysis.

Data analysis

We performed Principal Component Analysis (PCA) involving 11 EGVs (Table 2) to determine the spatial relationship among landscape components. We investigated spatial pattern at locations of bear sign by calculating mean center, directional distribution, and average nearest-neighbor distance (O'Sullivan and Unwin 2003). The ratio between the observed and expected mean nearest-neighbor distances indicates tendency towards clustering if the value is <1; a larger value means that events are evenly spaced. We summarized counts of bear sign in a grid of 4x4 km, investigated spatial autocorrelation at this scale by computing Moran's I, and calculated relative density of sign using kriging interpolation (O'Sullivan and Unwin, 2003). These statistics helped determining whether bear movement in the landscape was random or concentrated in particular areas.

We used Ecological Niche Factor Analysis (ENFA) to investigate habitat preferences of the brown bear in DNP. ENFA, developed by Hirzel et. al. (2002), is based on Hutchinson's (1957) concept of niche, defined as a hypervolume in the multidimensional space of habitat characteristics. It is a multivariate method that first extracts one axis of marginality and then several axes of specialization. The marginality axis measures the difference between the conditions used on average by the species and the mean available habitat. The coefficients of the marginality factor determine magnitude and direction (preference, avoidance) for each EGV. The specialization factor is calculated as the ratio of the global variation in an EGV to the variation in the part utilized by the focal species. It is a measure of the width of the niche within available habitat. The higher absolute coefficients (sign is arbitrary) indicate a restricted range of focal species for that EGV (Hirzel et. al. 2002, Basille et.al., In press). The biplot of an ENFA is a useful visualization of the ecological niche of a species. It projects used and available resource units in the ecological space on the plane defined by the marginality axis and one specialization axis. All EGVs are projected by arrows on this plot, and their length and direction express their influence on the position and volume of the ecological niche (Basille et.al., In press).

We used locations of bear sign as the response variable, and normalized some EGVs by square-root transformation. All analyses were carried out with the Adehabitat package (Calenge 2006) in R-software (R Development Core Team, 2006). A randomization test was performed to test the significance of marginality and the first eigenvalue of specialization. One thousand sets of 450 localizations were distributed randomly over the study area. Marginality and specialization were computed for each set of random locations and compared with actual values (Manly 1997, Basille et al. in press).

Habitat suitability mapping

We used Mahalanobis distance statistics (Clark et al. 1993) to compute a habitat suitability map. It is a measure of dissimilarity between the average habitat characteristics at each resource unit (pixel) and the mean of habitat characteristics estimated from animal locations. Thus smaller distances represent better habitat. Assuming multivariate normality, squared Mahalanobis distances have a Chi-square distribution with n-1 degrees of freedom (n = number of EGVs). The Adehabitat package in R (Calenge 2006) allows computing a map with continuous gradient of suitability (pixels represented by p-values ranging 0-1) from squared Mahalanobis distances. This gradient of suitability coveys more information, yet for managers it is more convenient to work with few classes (suitable, unsuitable, etc). Hirzel el. al. (2006) noted that a continuous scale is often misleading, because in a real environment the suitability index may not be linearly proportional to the probability of use; real curves may have staircase or exponential shapes. They suggested computing a curve of the ratio of expected-to-predicted frequencies of evaluations points. This curve provides insight into accuracy of the habitat suitability map, and also provides an objective criterion for choosing thresholds for reclassifying suitability maps into few classes.

We used all EGVs in Table 2, except slope, because it was correlated with elevation (r = 0.51). We divided the habitat suitability map into 10 classes (with 0.1 intervals), and calculated predicted-to-expected ratios (F_i) for each class (Hirzel et al. 2006):

$F_i = \dfrac{p_i}{E_i}$, where p_i is the predicted frequency of evaluation points in class i, and E_i is the expected frequency as expressed as relative area covered by each class.

We plotted F_i against class intervals (Hirzel et al. 2006) and reclassified the suitability map into three classes (poor, suitable, and high quality) by choosing threshold points from the F_i

curve. F_i = 1 indicates a random model when presences are equal to expected by chance. We choose this point as the boundary between poor ($F_i \leq 1$) and suitable ($F_i > 1$) habitats (Hirzel et al. 2006). The second boundary for a high quality habitat was selected at $F_i \geq 2$, when the curve became steeper after a plateau.

The predictive power of the habitat suitability map was evaluated by the Boyce Index (Boyce et al. 2002; Hirzel et al. 2006), calculated as Spearman rank correlation coefficient between F_i and i. The positive values in the Boyce Index (range: -1 to 1) indicate good prediction power of the habitat suitability map, zero means a random model, and negative values indicate an incorrect model.

Results

Description of the landscape

The 15% of the DNP was classified as marshy, 27% as grassy, 23% stony, 30% rocky, 5% permanent snow and 1% water (Table 1, Fig. 1b). The standing plant biomass of the park occurred on marshy, grassy and stony areas, with 35% of the area (rock, snow, water) being vegetatively unproductive. The average standing biomass of the park was 900 kg DM/km^2. Marshy areas contributed 56% of the total biomass, followed by grassy areas with 34%.

The central part of the DNP is relatively flat (0-10° slope) at elevations between 3400-4000 m, whereas the peripheral areas are steeper (up to 50° slope), with elevations up to 5300 m. The first Principal Component (PC) explained 30% of the variation in the data, and showed that elevation, slope and rocky areas were highly correlated (Fig 2). This component can be considered as a *productivity component,* as it contrasts between productive areas (marshy, grassy and stony vegetation types) and unproductive parts of the park. It indicated that productive areas were associated with lower elevations and occupied flatter terrain. This means that the central part of the park is productive, whereas the peripheral parts are predominantly rock and snow. The second PC, which explained 14% of the variation, showed that camps were associated with roads and that both were closer to rivers. The higher levels of grazing impact also were related to roads and camps. In the first PC, roads and camps were linked with lower elevations, which means that human structures are situated in the productive part of the park. In the second PC, marshy vegetation also was associated more with stony vegetation than grassy vegetation areas.

Spatial pattern of bear sign

The mean center of the bear sign locations (X: 539034, Y: 3871490) was located in center of the park (Fig. 1c). Average nearest-neighbor distance (1.68) suggested dispersion in the data ($P< 0.01$), and directional distribution showed an east-world trend in the data (rotation of long axis: 78.35°). In contrast to the pattern depicted by individual locations, counts of sign in 4x4 km grid cells indicated strong autocorrelation (Moran's I: 0.09) and a tendency for clustering. This suggested that the bear use of the landscape was not random, and bear sign was concentrated in the central parts of the park (Fig. 1c). The "Black Hole" and "Bowl" areas, in the central part of the park, had the highest density of sign (> 20 per grid cell), which is in agreement with the highest density of brown bears in this area (Paper III).

Habitat selection

Bear use of habitat differed significantly from random, as indicated by randomization tests carried out on marginality and the first axis of specialization ($P< 0.001$, for both tests). The global marginality was 2.435, signifying that the niche of the brown bear was different from the mean of available conditions (Fig. 3). Elevation and slope had the largest coefficients for marginality, indicating strong avoidance of higher elevations and steeper slopes (Table 3). Bears preferred marshy, stony and grassy vegetation types, and avoided rocky areas. Interpretation of EGVs that were measured as distances from objects (like distance to streams, roads, camps) is tricky, because negative coefficients of the marginality factor for these EGVs would mean the occurrence of bears was in the proximity of these objects. Large negative coefficients for human disturbance factors (distances to roads and camps) therefore suggested that bears were tolerant to these structures. The marginality factor also indicated that the bears occupied the proximity of streams. There was a negative relationship between the level of grazing impact and the bears' habitat use.

The specialization factor implied that the ecological niche of brown bears in Deosai was much narrower than the available variation in habitat components. Elevation, slope and grazing impact were the most prominent variables affecting this factor. As these variables also had negative coefficients on the marginality axis, the higher values on the specialization axis suggested a mean shift towards lower values. Thus, bears utilized narrower ranges of available variation in these variables towards their lower range. For example, the slope of the study area ranged between 0°-50°, yet the majority of the bear sign (89%) was located in areas with <15° slope (which covered 64% of the total slope surface).

Habitat suitability map

The habitat suitability map, based on Mahalanobis distance (Fig. 1d), indicated that the DNP offers a range of bad to excellent habitat to brown bears. F_i values ranged between 0.4-2.5 (Fig. 4), and the Boyce Index (Spear man r: 0.98, P < 0.01) indicated good prediction power of the suitability map. About 49% of the area was classified as poor habitat, 39% was suitable, and 12% of the area constituted high quality habitat. The suitability map generally followed the productivity contour of the park, although the northeastern part of the park, with good productivity, received a low suitability value. This was probably due to the high grazing pressure there. The central part of the park was mapped as the most suitable for brown bears, with the peripheral parts as least suitable.

Discussion

The brown bear is omnivorous and, although feeding habits are complex, plant base classification provides a useful means for describing bear habitat, as in other mammals (Craighead et al. 1995; Morrison et al. 2006). However, habitat and ecological niche are by definition multivariate concepts (Hutchinson 1987; Hirzel et. al. 2002). Multivariate methods as ENFA or Mahalanobis distances allow including several variables (elevation, slope, human disturbance, vegetation type) simultaneously in analyses and therefore provide a comprehensive understanding of the habitat selection.

Himalayan brown bears are known to occupy higher elevations, for example in the Karakoram Range they occupy areas >5000 m. The avoidance of high elevations (>4500 m) in Deosai is probably because these areas are just rock and ice. Similarly, brown bear habitat in Neelam and Gurez valleys (Nawaz 2007) is much steeper than in DNP, but those slopes are covered with forest. Habitat selection by brown bears in DNP therefore is related primarily to biomass production, which we indexed by measuring standing crop. Thus almost all Himalayan alpine meadows can be considered as suitable, or potentially suitable, habitat for bears, except for the rock- and ice-dominated areas.

Marshy vegetation was the most selected habitat, probably because it had the highest vegetative productivity. Moreover, the abundance of golden marmot (*Marmota marmota*), which is the main meat source for brown bears, is also related to vegetation types. Indeed, they occur with higher density in marshy areas (1.4 times higher density than in grassy and stony vegetation, Paper V). Diet analyses (Paper V) indicated that brown bears in Deosai consume a wide range of plant species, with a higher preference for graminoids, which is a dominant plant group in marshy areas. The higher preference for stony vegetation than grassy vegetation is counter-institutive, because the grassy vegetation habitat type was more productive vegetatively. However, stony areas have a marmot density similar to grassy areas (18 and 20 colonies per km^2, respectively, Paper V), and stony areas were more closely associated with marshes (r: 0.327) than grassy areas (r: 0.016). The majority of the known brown bear bedding sites are located on stony slopes at the banks of marshes. These locations also provided a good visibility of a broader landscape, which may explain the higher density of sign (scats) there.

The selection of areas close to roads and camps could be a byproduct of the proximity of these structures to productive habitats (marshy, stony, and grassy vegetations). The ENFA therefore suggests that brown bears tolerate human presence, when it was within a suitable habitat. The continuous monitoring in the park since 1993 has reduced poaching and ensured that people living in camps (livestock herders) or visitors do not harass bears. Elusive species can occupy areas close to human presence (Zimmermann 2004) if they do not associate human activity with threat. An activity pattern study (Nawaz and Kok 2004) and diet analyses (Paper V) showed that fish was not a substantial component of the brown bear's diet in DNP. The presence of bears near streams, as indicated by ENFA, is probably due to the positive correlation between streams and productive habitats (r: -0.313 between marshes and distance to streams).

The habitat suitability map depicted the central part of the park on either side of the central river (Barapani) as equally suitable for bears. The vegetation map also confirmed that both areas were almost equally productive. However the density of bear sign was relatively higher on the eastern side of the Barapani River, particularly in the Black Hole and Bowls (Fig. 1). We propose three possible reasons; 1) proximity of this eastern area to highly rugged terrain, which, although unproductive, provides escape terrain in case of danger or disturbance, 2) there are no human structures (road, camp, grazing) at all in this area, and/or 3) this area has been managed as a restricted area for the public since the inception of the park and human presence is therefore very low.

The vegetation and habitat suitability maps are the useful outcomes of this study, which can be used as decision making instrument for evaluating future developments within the park. Using these tools, we also can evaluate the effectiveness of the original zoning plan of the park. The core area for bears in the original zoning plan (HWF 1999), covering about half of the park, encompasses 50% poor, 34 suitable and 14% high quality habitat. A major part of the core area (68%) has productive vegetation types, and appears to be adequate for the requirements of the present brown bear population. However, a moderate level of grazing and the presence of camps in the western part of the core area, suggests that a gradual encroachment of human activities is occurring. This needs to be addressed to secure the quality of bear habitat in the DNP.

Conclusion and implications

Resource selection is related to reproductive success in animals (McLoughlin et al. 2006), therefore an analysis of habitat helps identifying resources critical for survival and reproduction of a species. The brown bear population in DNP has a very low reproductive capacity (Paper III), which complicates its conservation efforts. A time budget study indicated that brown bears in Deosai spend most of a day foraging (67%), mainly grazing (96%) and the rest in capturing rodents (Nawaz and Kok 2004). A diet analysis (Paper V) also showed that vegetation dominated the diet. These observations support the findings of the ENFA that the relatively dense vegetation of marshes was the most preferred habitat, and probably explains the low reproductive rates in the population, because reproductive success is related to the amount of meat in the diet in bears (Bunnell and Tait 1981; Hilderbrand et al. 1999). It also highlights the importance of marshy areas, particularly of Black Hole and Bowls (Fig. 1), as critical habitats for bears.

The brown bear is the flagship species of DNP and its protection was the core reason behind the park's establishment (HWF 1999). The habitat requirements of the brown bear should remain the key element in the management strategy for the park resources. The habitat suitability map indicated that brown bear habitat, which occupied the central part of the park, is rather contiguous and not fragmented. This central part of the park has been attractive for many development interventions in past. For example, proposals to establish a polo ground and constructing a new road (passing through the high bear density area) to access Karabosh Village probably would be detrimental for the bears.

DNP was established using the community participation approach (HWF 1999), which aimed to engage communities in conservation efforts by recognizing their rights within the park and also sharing park benefits (revenues, etc) with them. Therefore securing the livelihoods of the local communities, which is largely dependant on grazing, without compromising ecological integrity is the second important element of the park management. Until now the park seems to have been successful on both fronts, because the brown bear population is increasing while the communities are grazing within the park (Paper III).

Among the human disturbance factors, grazing pressure was the strongest factor affecting habitat suitability of the park. The park' range seems to have been able to sustain the level of grazing pressure in the past, because only 19% area was indexed as heavily impacted and avoided by bears. However livestock numbers have increased alarmingly in the last two years, particularly due to an influx of Gujjars. About 8000-9000 livestock were brought in by Gujjars in 2007, compared with approximately 5000 in 2003. The primary reason for this unprecedented increase in numbers was the careless sale of grazing permits by the Northern Areas Forest and Wildlife Department. Though a detailed inventory of the rangeland would be required to understand grazing dynamics of the park and to determine impacts on species diversity in high grazing areas, it is obvious that, with only 65% of the area being vegetatively productive, DNP cannot support this large stock without impacting brown bears and other important resources of the park.

Because poaching and other threats are under better control (Paper III), we see range and livestock management as the key management problem for future; this challenge can put the success of park management and population recovery of brown bears at risk. The expansion in livestock numbers will likely result in an expansion in their range, and may boost management challenges by increasing human-bear conflicts. Brown bears seldom attack humans and attacks on property also have been rare in past, probably due to their low density and a general segregation between areas of high bear density and high grazing density. Increased human encroachment into the core area of the growing bear population can potentially spawn more conflicts.

The third important mandate of the park is recreation and education. The ENFA indicated that bears are tolerant to the present level of activity on roads. Therefore promotion of carefully managed tourism should be acceptable. However intensive nodes of tourist-related structures like hotels or camping facilities should be limited to the peripheral areas (Ali Malik Top and Sheosar Lake). Limited guided tours into the bear core areas like “Bowls” (area along the left bank of Barapani River) should also be considered, if they are strictly managed by the staff of the wildlife department. It should promote awareness and education among visitors, which hopefully would promote conservation efforts.

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Table 1: Vegetation classes in Deosai National Park, Northern Areas, Pakistan, their spatial extent, and biomass production.

Vegetation type	Description	Area (km^2)	Biomass (kg dry matter/km^2)
Marshy vegetation	Prevalent in low-lying areas and depressions. It is dominated by various species of *Poa* and *Carex*, and *Aconitum violeceum*. Other common species of this habitat are *Veronica anagalis-aquatica, Rhodiola heterodonta, R. tibetica, Euphrasia densiflora, Lamatogonium coeruleum, Pedicularis pyramidata, Aconitum heterophyllum, Thalictrum alpinum, Primula macrophylla, Saxifraga flagellanis sub sp. stenophylla, Minuartia biflora,* and *Sausseria atkinsonii*.	262	3919.0
Grassy vegetation	Generally associated with flat or undulating areas, dominated by *Poa* species. Other associated herbs include *Bistorta affinis, Leontopodium leontopodinum, Oxytropis cashmiriana,* and shrubs include *Tanacetum falconeri, Potentilla grandiloba, Artemesia* spp., *Aster falconeri*, etc.	475	1306.6
Stony vegetation	The substrate is stony, dominated by herbs like *Saxifraga flagelaris*, *Oxytropis cashmiriana, Oxyria digyna, Lagotis kachmiriana, Aconogonon rumicifolium*, and shrubs like *Sausserea falconeri, Senecio analogus,* and *Androsace baltistanica*.	413	446.0
Rocky	Rocky or gravel areas that are generally devoid of vegetation or have a sparse cover of plants such as *Sorosaris dysaie, Saussuria gnaphalodes* and *Saxifraga jacquemontiana*, *Aster flaccida*, *Rhodiola wallichiana,* and *Primula macrophylla*.	526	0
Water	Lakes and streams	12	0
Snow	Areas of permanent snow	81	0

Table 2: Ecogeographical variables (EGVs) used in the Ecological Niche Factor Analysis of brown bear habitat and Mahalanobis distance suitability map in Deosai National Park, Northern Areas, Pakistan. Each variable was represented by a raster map of 200 m pixel size, called a Resource Unit (RU).

EGV	Code	Description
Marshy vegetation	marsh	Proportion of marshy vegetation in each RU
Grassy vegetation	grass	Proportion of grassy vegetation in each RU
Stony vegetation	stone	Proportion of stony vegetation in each RU
Rock	rock	Proportion of rocky vegetation and permanent snow in each RU
Elevation	elevation	Digital elevation data from Shuttle Radar Topography Mission (SRTM)
Slope	slope	Slope in degrees calculated by Spatial Analyst extension in Arc GIS.
Distance to stream	river	Linear distance from streams calculated by Spatial Analyst extension in Arc GIS.
Grazing impact	grazing	Livestock grazing pressure in DNP; 1: low, 2: medium, 3: high
Distance to main road	mroad	Linear distance calculated by Spatial Analyst extension in Arc GIS. Classified as; 1: 0-500m, 2: 500-1000 m, 3: 1000-2000 m, 4: 2000-3000 m, 5: 4000-5000 m, 6: > 5000m
Distance to small road	sroad	Same as above
Distance to camps	camp	Same as above

Table 3: Results of the Ecological Niche Factor Analysis of brown bear habitat in Deosai National Park, Northern Areas, Pakistan, with locations of bear scats as the response variable. Positive values on the marginality factor indicate preference, and negative values mean avoidance.

EGV	Marginality	Specialization 1	Specialization 2
Marshy vegetation	0.270	0.155	0.186
Grassy vegetation	0.087	0.062	0.036
Stony vegetation	0.277	0.096	0.108
Rock	-0.294	0.037	0.204
Elevation	-0.531	0.519	0.451
Slope	-0.490	0.446	0.078
Distance to stream	-0.272	0.067	0.048
Grazing impact	-0.157	0.529	0.264
Distance to main road	-0.283	0.184	0.231
Distance to small road	-0.071	0.369	0.147
Distance to camps	-0.225	0.199	0.745

Figure Captions:

Fig. 1. (a) A digital elevation model showing elevation range (3400-5387 m) in DNP. The 3-D view was produced by overlaying elevation layer on a hill shade map for better presentation of the geomorphology of the area. **(b)** Vegetation map, differentiating vegetation types in DNP. Black, dark gray, medium gray and light gray areas represent marshy, grassy, stony and rocky vegetation types, respectively. Water and permanent snow areas are shown as white. **(c)** Relative density of bear sign in DNP, darker gray shades showing higher densities. Gray surface was calculated by kriging interpolation using counts of bear sign in 4x4 km grids. Mean center (black point) and directional distribution as standard deviation ellipses are shown. **(d)** Habitat suitability map for brown bears in DNP. The probability distribution is based on Mahalanobis distances between the available resources and the mean of habitat characteristics used by brown bears.

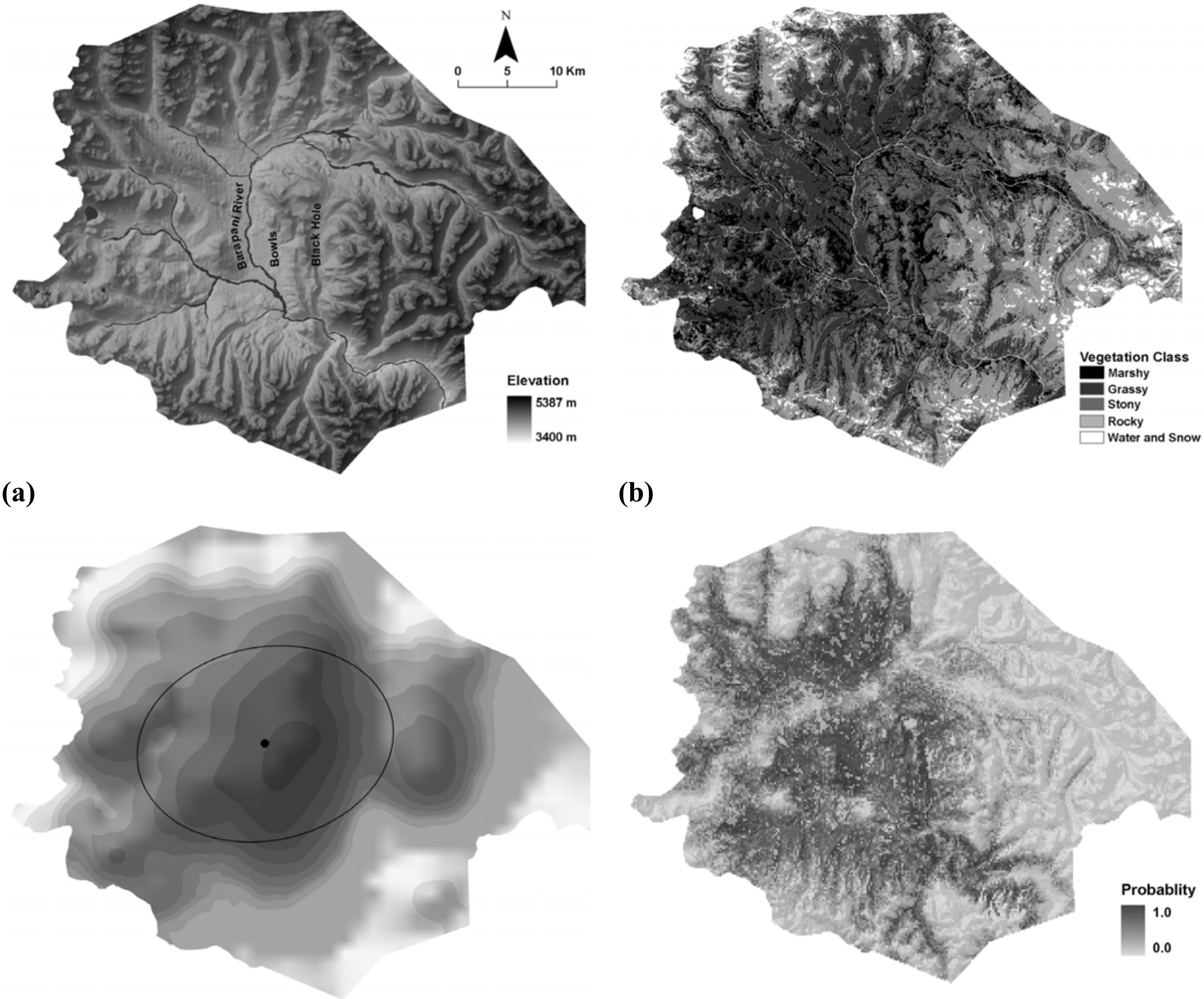
Fig. 2. Loading plot of the first two Principal Components, depicting the relationships among 11 ecogeographical variables in Deosai National Park, Northern Areas, Pakistan. "barplot" of the eigenvalues. A barplot of the eigenvalues is shown as a small insert on top-right coner.

Fig. 3. Biplot of the Ecological Niche Factor Analysis of brown bear habitat in Deosai National Park, Northern Areas, Pakistan. The light gray area represents the available habitat and the dark area corresponds to the ecological niche of the brown bear (used area). The plane consists of marginality on the X axis and the first specialization on the Y axis. Ecogeographical variables are projected by arrows. The white dot corresponds to the barycentre of the niche. The distance between this point and the barycentre of available conditions (intersection of the two axes) represents the marginality of the niche within

available habitat.

Fig. 4. A plot of predicted-to-expected ratios (F_i) of evaluation points against 10 habitat suitability classes. The F_i curve shows a monotonic increase, suggesting good prediction power of the suitability map. The solid horizontal line (F_i = 1) is the curve of a completely random model, which makes boundary between poor ($F_i \leq 1$) and suitable (F_i > 1) habitats.

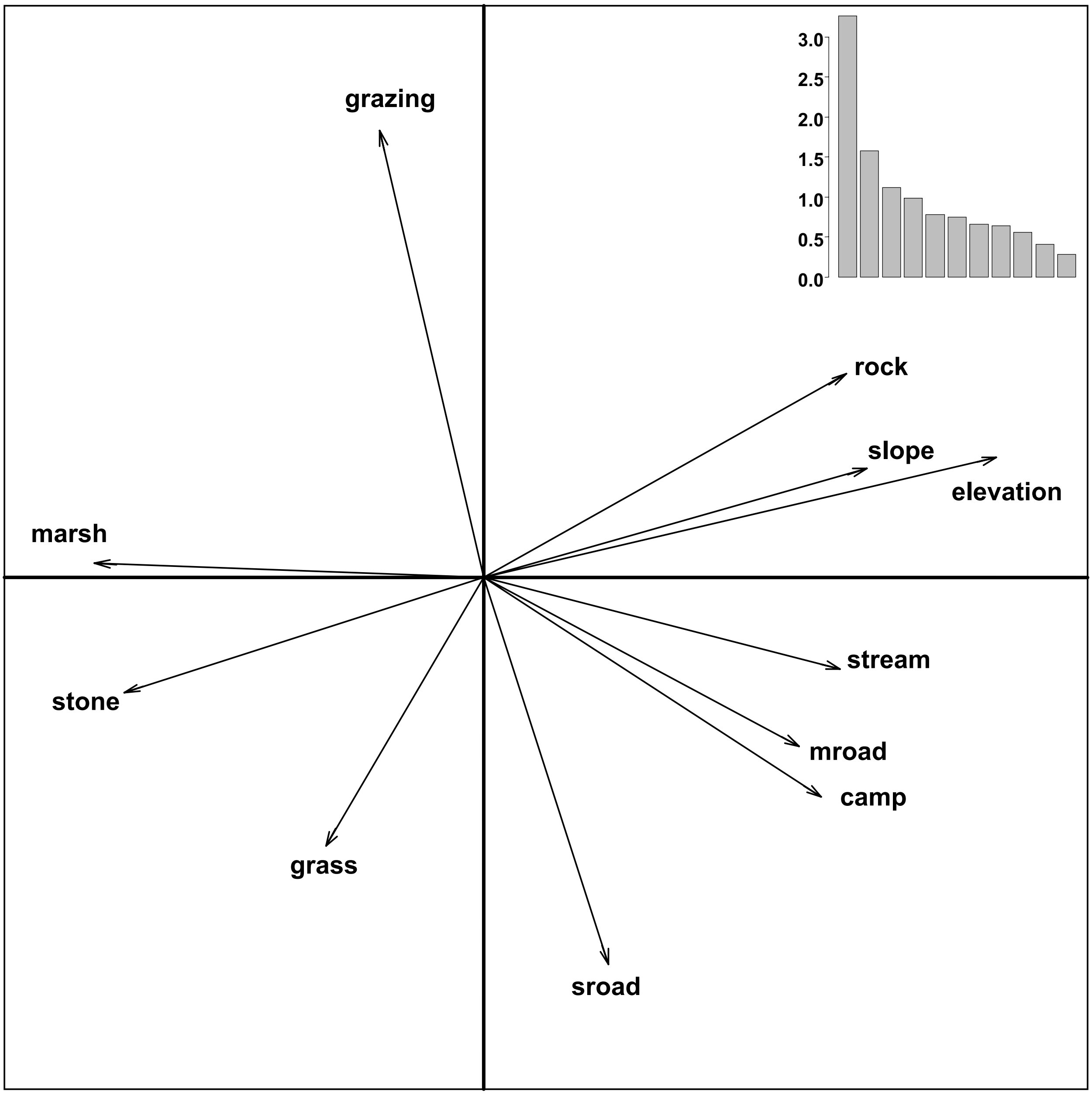
Fig. 1.



N
0
5
10 Km
Barapani River
Bowls
Black Hole
Elevation
5387 m
3400 m
Vegetation Class
Marshy
Grassy
Stony
Rocky
Water and Snow
Probablity
1.0
0.0

(a) (b) (c) (d)

Fig. 2.



3.0
2.5
2.0
1.5
1.0
0.5
0.0
grazing
rock
slope
elevation
marsh
stream
stone
mroad
camp
grass
sroad

Fig. 3.

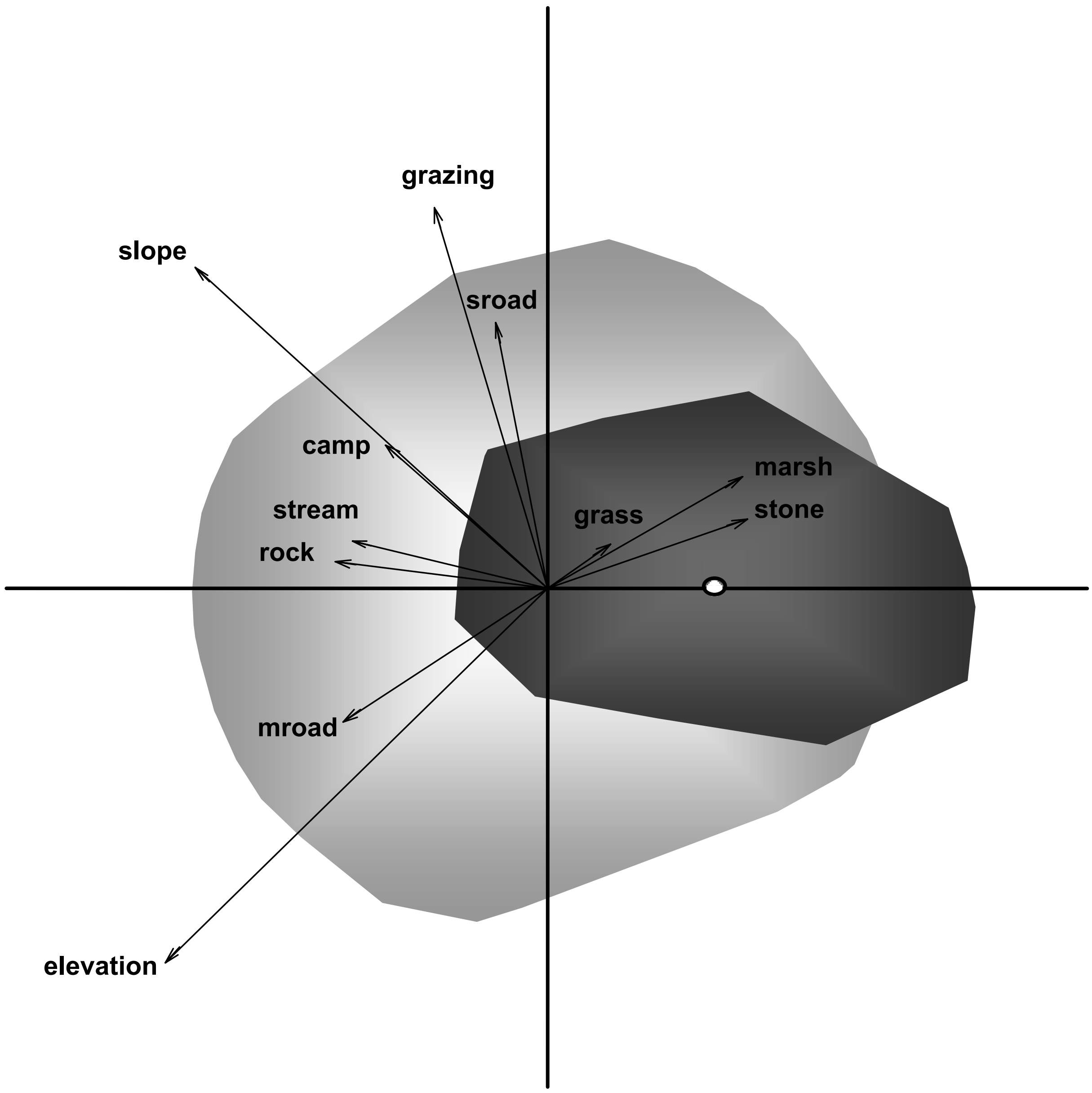
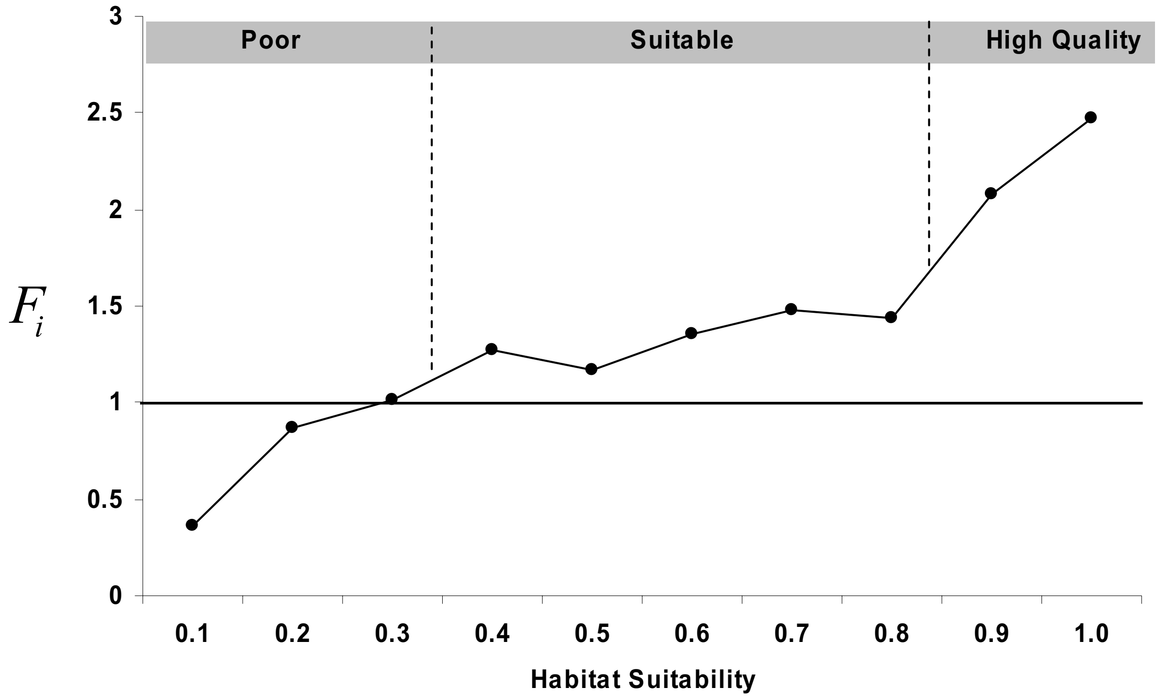

grazing
slope
sroad
camp
marsh
stream
grass
stone
rock
mroad
elevation

Fig. 4.



Poor
Suitable
High Quality
3
2.5
2
1.5
1
0.5
0
F_i
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Habitat Suitability

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