Identifying key habitats to conserve the threatened brown bear in the Himalaya

Muhammad Ali Nawaz\textsuperscript{a,b,c,*}, Jodie Martin\textsuperscript{a,d,e}, Jon E. Swenson\textsuperscript{a,f}

\textsuperscript{a}Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, Post Box 5003, NO-1432 Ås, Norway
\textsuperscript{b}Department of Animal Sciences, Quaid-i-Azam University, Islamabad, Pakistan
\textsuperscript{c}Snow Leopard Trust, Pakistan Program, 17-Service Road North, F-8/3, Islamabad, Pakistan
\textsuperscript{d}Université Lyon 1, CNRS UMR5558, Laboratoire de Biométrie et Biologie Evolutive, F-69622 Villeurbanne, France
\textsuperscript{e}Centre for African Ecology, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Wits 2050, South Africa
\textsuperscript{f}Norwegian Institute for Nature Research, PO Box 5685 Sluppen, NO-7450 Trondheim, Norway

**A R T I C L E   I N F O**

Article history:
Received 30 July 2013
Received in revised form 16 December 2013
Accepted 22 December 2013

**Keywords:** Ecological Niche Factor Analysis
Habitat selection
Himalaya
Habitat suitability map
Pakistan
Ursus arctos

**A B S T R A C T**

The threatened Himalayan brown bear has a fragmented range in the Himalayas. However, its habitat has never been documented, which hinders conservation efforts. The Deosai Plateau in northern Pakistan has long been recognized as the core area for this subspecies in the country. To provide knowledge to help conserve the remnant populations in the Himalayan region, and especially in protected areas, we investigated habitat selection of brown bears and the influence of human presence on brown bear distribution in Deosai National Park, Pakistan.

We used an Ecological Niche Factor Analysis to assess brown bear habitat selection, using scats sampled along transect routes throughout the park as location data. Habitat use based on 137 observations of brown bears during monitoring confirmed that differential scat detectability did not bias our results. Only 65% of the park area had productive vegetation. Our analyses indicated that brown bears avoided higher elevations and steeper slopes and selected more productive parts of the park (marshy, grassy, and stony vegetation types). The marshy vegetation was the most preferred habitat, probably because it had the highest forage production and density of golden marmots. Brown bears tolerated human infrastructures, 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 unsuitable for brown bears.

The vegetation and habitat suitability maps also provide an objective criterion for evaluating present and future developments in the park. Until recently, communities seem to have used the park’s resources without significantly affecting the brown bear population. However, in recent years a large influx of nomadic communities with their livestock has become a challenge, which needs urgent attention to continue the present brown bear population recovery and to secure its habitat. We recommend monitoring the livestock and conducting a detailed inventory of the rangeland to understand grazing dynamics in the park and to maintain sustainable stocking rates.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Human persecution, increasing 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). Large carnivore conservation is particularly challenging, because these animals typically need large areas to meet their requirements, which necessitates landscape-level management. Protected areas can provide an important sanctuary for sensitive species, such as large carnivores, but they are often too small to ensure population viability (Newmark, 1995; Woodroffe and Ginsberg, 1998). Nevertheless, protected areas often constitute important, core habitats that better enable large carnivores to exist compared with mostly human-dominated landscapes (Schwartz et al., 2006). Zoning is an increasingly popular approach in wildlife conservation that results in distributing the resources within a protected area among various competing interests, such as human uses and wildlife

* Corresponding author at: Department of Animal Sciences, Quaid-i-Azam University, Islamabad, Pakistan. Tel.: +92 51 90643155.
E-mail address: ali.nawaz2@slf.org.pk (M.A. Nawaz).
(Hepcan, 2000; Kothari et al., 1996). However, reserving suitable areas for wildlife requires specialized knowledge, which is generally unavailable in many areas of the world and managers often select areas on an ad hoc basis, without a clear understanding of the ecological needs of the species they manage.

Brown bears (Ursus arctos) are endangered in Southern Asia, where mostly small, isolated populations exist in remote and rugged mountainous areas (Servheen, 1990). Although brown bears are generally well studied in North America and Europe, very little is known about their status and requirements for survival in Asia (Servheen et al., 1999), which hinders conservation efforts. The Himalayan brown bear (U. a. isabellinus) is a subspecies that represents an ancient lineage of the brown bear (Galbreath et al., 2007) and is distributed over the Great Himalaya region. This subspecies is threatened and its population is fragmented in Pakistan (Nawaz, 2007; Sathyakumar, 2001; Aryal et al., 2012). To date, almost no research has been conducted on the habitat requirements of brown bears in the Himalayan region, where they occur at low densities, usually in alpine meadows above timberline, between 3000 and 5500 m a.s.l. (Sathyakumar, 2001; Aryal et al., 2012). Most brown bears in Pakistan occur on the Deosai Plateau (Rasool, 1991; Roberts, 1997; Nawaz, 2007), but there were only about 20 individuals (Nawaz et al., 2008). This raised concerns for their survival and lead to the declaration of the area as a national park in 1993.

One of the goals of the Deosai National Park (DNP) was the conservation of the remnant bear population (HWF, 1999). A zoning plan was created to accommodate the resource needs of local and nomadic herding communities (HWF, 1999). Although people were allowed to use resources in consumptive zones, a “core area” was designated for brown bears, where public entry was prohibited. The ecological needs of brown bears were unknown at that time, so the demarcation of the core area was based on sightings of brown bears and subjective assessments. These conservation efforts seem to have been successful, because the brown bear population in the park grew by about 5% annually between 1993 and 2006 (Nawaz et al., 2008). Nevertheless, livestock numbers in the park also are increasing and there have been unsuccessful attempts by the livestock herders to encroach into the core area. However, new developments have been proposed for the park, including new roads, hotels, and sport facilities. Brown bears will not necessarily avoid livestock, as depredation losses on unguarded livestock can be high (Sager et al., 1997), but brown bears do avoid human activities, settlements, and tourist developments at several levels of spatial scale (Nellemann et al., 2007; Martin et al., 2010). A better understanding of the park resources and how brown bears respond to human activities is required to understand how these issues might affect the bear population and also would provide important information to assist in the successful conservation of the remnant populations throughout the Himalayan region.

Our goal was to document the Himalayan brown bear’s spatial ecology and use this knowledge to help improve park conservation efforts. Our objectives were to (1) assess habitat selection of brown bears, (2) assess the influence of human presence on bear distribution, and (3) provide a habitat suitability map for the brown bear as a tool for further conservation actions within this park.

2. Materials and methods

2.1. Study area

DNP occupies about 1800 km² of an alpine plateau in the western Himalaya and is managed administratively by the Gilgit-Baltistan Forest and Wildlife Department, Gilgit-Baltistan, 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 and 750 mm. The vegetation is predominantly herbaceous perennials, grasses, and sedges.

The alpine pastures 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 (Gujjars). About 9000 livestock, mainly goats and sheep, grazed within the DNP in 2004. According to the zoning plan (HWF, 1999), the southeastern half of the park was designated as the core area for brown bears; local communities and Gujjars were allowed to graze alpine grasslands in the rest of the park.

2.2. Data collection

The locations of brown bear feces (hereafter referred to as sign) were used to indicate areas of use. Other brown bear sign (e.g., hairs, tracks) were not easy to find along the transect routes. We therefore only used scats as location of brown bear presence. We believe scats were representative of important habitats used by brown bears in the study area, because brown bears are not known to defecate in particular areas, except for concentrations at bed sites (Menges, 2011), which could bias our results. Therefore, they were adequate for assessing habitat suitability at the population level. Feces are commonly used in wildlife investigations to estimate abundance, species richness, and detection of prey in the diet (Wilson and Delahay, 2001; Bellemain et al., 2007), and recent advancement in molecular tools has enhanced precision and efficiency in these techniques (Valentini et al., 2009; Shehzad et al., 2012). Particularly for detection of carnivores at large spatial scales, sign surveys are known to be the most efficient methods both in economic and logistic terms (Barea-Azcon et al., 2007). However factors like seasonality and habitat type may influence detection and count of feces (Wilson and Delahay, 2001).

We divided DNP into five blocks, delineated by major rivers, and each block was searched for brown bear feces. Transects, 40 m wide and 40–60 km long, were placed in each block, and walked by a team of 2–3 people. The transect routes were located throughout most of the block, and included all elevation ranges and habitat types. Transect routes resembled a loop, starting from the central road, progressing towards the periphery of the park, and ended at the starting point. Each transect was completed in 2–3 days, with night stays made in portable tents. Sampling was done in September–October each year, towards end of the summer season, and scats of all age classes included. Age of scats was categorized into six classes, based on freshness (see details in Bellemain et al., 2007), however all age classes were included in collection to cover the entire summer season. Scats detectability was similar in each vegetation type, as the vegetation in the study area is not dense or tall enough to induce variability in detection rates.

2.3. Vegetation classification

We used the 28 July 1998 LANDSAT Thematic Mapper (TM) satellite image (Scene ID: L75149036009820910) for habitat classification. There is snow cover in Deosai from October to May/June and cloud cover is dense and frequent. Although more recent images were available, the 28 July 1998 LANDSAT gave the best unobstructed view of the vegetation. 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 vegetation, grassy vegetation, stony vegetation, rocky, water, and snow (Table 1). The cloud-covered areas in the 28 July 1998 LANDSAT image, about 8%, were replaced using the 30 September 2001 LANDSAT Enhanced Thematic Mapper (ETM) image (Scene ID: p149r036_7120010930).
Vegetation type | Description | Area (km²)
--- | --- | ---
Marshy vegetation | Prevalent in low-lying areas and depressions. It is dominated by various species of *Pog* and *Carex*, and *Aconitum violeceum*. Other common species of this habitat are *Heracleum condicans*, *Cerastium pusillum*, *Veronica anagalis-aquatica*, *Rhodiola heterodonta*, *R. tibetica*, *Euphrasia densiflora*, *Lamutogonion coeruleum*, *Pedicularis pyramidalis*, *Aconitum heterophyllum*, *Thalictrum alpinum*, *Primula macrophylla*, *Saxifraga flagellaria* sub sp. *stenophylla*, *Minautria biflora*, and *Saussuria atkinsonii* | 262
Grassy vegetation | Generally associated with flat or undulating areas, dominated by *Pog* species. Other associated herbs include *Bistorta affinis*, *Aegrotis vinealis*, *Aconogonon rumin很差*, *Rumex nepalensis*, *Galium boreale*, *Leontopodium leontopodimum*, *Oxypotis cashmiriana*, and shrubs include *Tanacetum falconeri*, *Potentilla grandiloba*, *Artemisia spp.*, and *Aster falconeri* | 475
Stony vegetation | The substratum is stony, dominated by herbs like *Saxifraga flagellaria*, *Oxypotis cashmiriana*, *Oxypotis digyna*, *Logotis kachmiriana*, *Aconogonon rumin很差*, *Cerastium cerastoides*, and shrubs like *Saussurea falconeri*, *Senecio analogus*, and *Androsace balantisana* | 413
Rocky | Rocky or gravel areas that are generally devoid of vegetation or have a sparse cover of plants such as *Sorosaria dysa*, *Sausswia gnaphalodes*, *Elymus longi-aristatus*, and *Saxifraga jacquemontiana*, *Aster flaccida*, *Rhodola violaciflora*, and *Primula macrophylla* | 526
Water | Lakes and streams | 12
Snow | Areas of permanent snow | 81

### 2.4. Data preparation

We projected the map of the DNP onto the UTM (WGS 84, Zone 42N) coordinate system. Raster maps of 11 ecogeographic variables (EGV) ([Table 2](#)) were prepared in Arc GIS (ESRI Inc., 2006). Resource units (RU) were defined as 200 × 200 m pixels of raster maps ([Manly et al., 2002](#)).

We acquired elevation data from the Shuttle Radar Topography Mission (SRTM) ([http://www.srtm.usda.gov](http://www.srtm.usda.gov/)). The areas of missing data (“voids”) in the SRTM images were replaced with information from topographic 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 topographic 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 and Astore), which receives public transport and tourists. Two minor roads connect Mattyal Village and the Gultari/Minimerg Valley to this main road, but with considerably lower traffic volume.

Locations of camps belonging to nomadic and local livestock herders and seasonal hotels were recorded with a GPS receiver. During the vegetation surveys in 2002–2003 ([Nawaz et al., 2006](#)), grazing, browsing, and harvesting indices for each species in a quadrant was recorded using a semi-quantitative scale, ranging from 1 (no to slightly impact), 2 (medium impact), to 3 (heavily grazed, browsing, and harvesting). Based on this index, the park area was divided into three grazing impact zones; low, medium, and high. To provide information on the spatial structure of these EGV within the study area, we performed a Principal Component Analysis (PCA; [Table 2](#)). This analysis provided a summary of their spatial structure and determined the spatial relationships among these landscape components.

### 2.5. Data analyses

The multivariate methods we used ([Ecological Niche Factor Analysis – ENFA](#) and Mahalanobis distances, see below) provide a comprehensive understanding of the habitat selection by allowing the analysis of several variables (elevation, slope, human disturbance, vegetation type) simultaneously. These methods are more robust for investigating habitat selection when little is known about the studied system, as they do not require independence of the explanatory variables (contrary to generalized linear models) and therefore prior assumptions about which variables may be important for the species ([Hirzel et al., 2002](#)). In addition, these methods do not require absence data ([Hirzel et al., 2002](#)) and were therefore more appropriate for our study system. Indeed, when the studied population is small and the density is low, it can be difficult to assess true absence of individuals. The absence of scats in a particular area may either indicate that the habitat is not suitable for the species, but also that this area/habitat has not yet been colonized.

We used ENFA ([Hirzel et al., 2002](#)) to investigate habitat selection by the brown bears in DNP. It is based on Hutchinson’s ([1957](#)) concept of niche, defined as a hypervolume in the multidimensional space of habitat characteristics. It 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 (selection, 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 the 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., 2008](#)). 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. The arrows represent the projection of all EGVs on each axis of the factorial plane. For the marginality axis, their direction and length express their influence on the position of the ecological niche. For the specialization axis, the direction of the arrow is not informative, only the length has a biological meaning. The longest arrows along an axis (marginality or specialization) represent the most influential variables for the corresponding axis.

We used locations of bear sign as the response variable, and normalized some EGVs by square-root transformation. A randomization test was performed to evaluate the significance of marginality and the first eigenvalue of specialization. To test the null hypothesis of random habitat selection by the brown bears, 1000 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 values computed on actual locations of brown bears ([Manly, 1997](#); [Basille et al., 2008](#)). All analyses were carried out with the Adahabitat package ([Calenge, 2006](#)) in R-software ([R Development Core Team, 2005](#)).

In order to determine if the spatial distribution of scats reflected the distribution of brown bears DNP, we used sighting data to estimate the selection probability ([Manly et al., 2002](#)) of

---

**Table 1** Vegetation classes in Deosai National Park, Gilgit-Baltistan, Pakistan, their spatial extent, and estimates of standing crop of vegetation. Species preferred by brown bears ([Nawaz, 2008](#)) are underlined.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshy</td>
<td>Prevalent in low-lying areas and depressions.</td>
<td>262</td>
</tr>
<tr>
<td>Grassy</td>
<td>Generally associated with flat or undulating areas.</td>
<td>475</td>
</tr>
<tr>
<td>Stony</td>
<td>The substratum is stony, dominated by herbs like <em>Saxifraga flagellaria</em>,</td>
<td>413</td>
</tr>
<tr>
<td>Rocky</td>
<td>Rocky or gravel areas that are generally devoid of vegetation or</td>
<td>526</td>
</tr>
<tr>
<td>Water</td>
<td>Lakes and streams</td>
<td>12</td>
</tr>
<tr>
<td>Snow</td>
<td>Areas of permanent snow</td>
<td>81</td>
</tr>
</tbody>
</table>
each vegetation class by the bears. We analyzed observations collected opportunistically by the park staff during routine monitoring of the brown bear population on this open, treeless plateau during summer (June–October) from 2003 to 2006. The selection ratio, defined as relative probability of selection for category $i$, was estimated by following equation (Manly et al., 2002):

$$w_i = o_i / \pi_i$$

where $w_i$ is selection ratio, $\pi_i$ is proportion of available resource units in category $i$, $o_i$ and proportion of used resource units in category $i$. The $w_i$ above 1 indicates preference, and values less than 1 indicate avoidance. The selection ratio was standardized ($B_i$) so that they add to 1. $B_i$ is the probability of selection a category $i$ resource unit, provided that all types of resource units are equally available (Manly et al., 2002).

### Table 2

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

Fig. 1. (a) A digital elevation model showing elevation range (3400–5387 m) in DNP. The 3-D view was produced by overlaying an elevation layer on a hill shade map for better presentation of the geomorphology of the area. (b) Vegetation map, differentiating vegetation types in DNP. (c) 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, Gilgit-Baltistan, Pakistan. A barplot of the eigenvalues is shown as a small insert in the top-right corner.

Fig. 3. Biplot of the Ecological Niche Factor Analysis of brown bear habitat in Deosai National Park, Gilgit-Baltistan, 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. Slope and elevation explained most of niche marginality, but also explained most of the niche specialization along with grazing and small roads. 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 the available habitat.
2.6. 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 degrees of freedom (n = number of EGVs). The Adehabitat package in R (Calenge, 2006) allows computing a map with a continuous gradient of suitability (pixels represented by p-values ranging 0–1) from squared Mahalanobis distances. This gradient of suitability conveys more information, yet for managers it is more convenient to work with few classes (e.g., suitable, unsuitable). Hirzel et 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 the 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, 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):

$$F_i = \frac{p_i}{E_i},$$

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 $E_i$ 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 boundary between suitable and high-quality habitat was selected at $F_i \geq 2$, where 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), which ranges from –1 to 1 and was calculated as the Spearman rank correlation coefficient between $F_i$ and $i$. Positive values of the Boyce Index indicate good prediction power of the habitat suitability map, zero indicates a random model, and negative values indicate an incorrect model.

3. Results

3.1. Description of the landscape

The DNP was 15% marshy, 27% grassy, 23% stony, 30% rocky, 5% permanent snow, and 1% water (Table 1, Fig. 1b). The central part of the DNP is relatively flat (0–10° slope) at elevations between 3400 and 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 positively correlated, whereas they were negatively correlated with marshy and stony areas (Fig. 2). This component can be considered as a productivity component, as it contrasts between unproductive and productive areas (marshy, grassy and stony vegetation types). It indicated that productive areas were associated with lower elevations and occupied flatter terrain. 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 were also related to roads and camps. In the first PC, long distances to roads and camps were linked with high elevations (arrows on the right side of the axis), which means that human infrastructure is situated in the productive part of the park.

3.2. Habitat selection

A total of 450 occurrences of sign documented during 2003–2006 were used in ENFA. Brown 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). Brown bears selected marshy, stony, and grassy vegetation types, and avoided rocky areas. Large negative coefficients for human presence factors (distances to main roads and camps) suggested that brown bears were tolerant of these infrastructures. The marginality factor also indicated that the brown bears occupied areas in proximity of streams. There was a negative relationship between the grazing impact and the brown bears’ habitat use.

The specialization factor (niche width) 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 niche width. Thus, brown bears utilized a narrow range of available variation in these variables and at low elevation, on gentle slopes, and where the grazing impact is lower (Fig. 3). For example, the slope of the study area ranged between 0° and 50°, yet the majority of

### Table 3

Results of the Ecological Niche Factor Analysis of brown bear habitat in Deosai National Park, Gilgit-Baltistan, Pakistan, with locations of brown bear scats as the response variable. Positive values on the marginality factor indicate selection, and negative values mean avoidance.

<table>
<thead>
<tr>
<th>EGV</th>
<th>Marginality</th>
<th>Specialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshy vegetation</td>
<td>0.270</td>
<td>0.155</td>
</tr>
<tr>
<td>Grassy vegetation</td>
<td>0.067</td>
<td>0.062</td>
</tr>
<tr>
<td>Stony vegetation</td>
<td>0.277</td>
<td>0.096</td>
</tr>
<tr>
<td>Rock</td>
<td>–0.294</td>
<td>0.037</td>
</tr>
<tr>
<td>Elevation</td>
<td>–0.531</td>
<td>0.519</td>
</tr>
<tr>
<td>Slope</td>
<td>–0.490</td>
<td>0.446</td>
</tr>
<tr>
<td>Distance to stream</td>
<td>–0.272</td>
<td>0.087</td>
</tr>
<tr>
<td>Grazing impact</td>
<td>–0.157</td>
<td>0.529</td>
</tr>
<tr>
<td>Distance to main road</td>
<td>–0.283</td>
<td>0.184</td>
</tr>
<tr>
<td>Distance to small road</td>
<td>–0.071</td>
<td>0.369</td>
</tr>
<tr>
<td>Distance to camps</td>
<td>–0.225</td>
<td>0.199</td>
</tr>
</tbody>
</table>

### Table 4

Relative probabilities of selection of vegetation types by brown bears, estimated based on 137 sightings in Deosai National Park, Gilgit-Baltistan, Pakistan.

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Brown bear sightings</th>
<th>Proportion of use $o$</th>
<th>Proportion of vegetation type $\pi$</th>
<th>Selection ratio $w$</th>
<th>Standardized index $B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshy</td>
<td>38</td>
<td>0.28</td>
<td>0.16</td>
<td>1.774</td>
<td>0.396</td>
</tr>
<tr>
<td>Grassy</td>
<td>41</td>
<td>0.30</td>
<td>0.28</td>
<td>1.056</td>
<td>0.236</td>
</tr>
<tr>
<td>Stony</td>
<td>48</td>
<td>0.35</td>
<td>0.25</td>
<td>1.422</td>
<td>0.317</td>
</tr>
<tr>
<td>Rocky</td>
<td>10</td>
<td>0.07</td>
<td>0.31</td>
<td>0.233</td>
<td>0.052</td>
</tr>
</tbody>
</table>
the brown bear sign (89%) was located in areas with <15° slope, which covered 64% of the total slope surface.

We also estimated habitat selection ratios, based on 137 observations of brown bears on this treeless alpine plateau. The results indicated preference for marshy, grassy, and stony vegetation types and avoidance of rocky areas (Table 4). The standardized index showed highest probability of selection for marshy vegetation, followed by the stony and grassy types. This result agrees with the findings of ENFA, thus indicating that the selection pattern documented using an analysis of scat data was not a consequence of differential detectability of scats among the four vegetation types.

3.3. Habitat suitability map

The habitat suitability map, based on Mahalanobis distance (Fig. 1c), indicated that brown bear habitat was not uniformly distributed in DNP. $F_r$ values ranged between 0.4 and 2.5 (See Fig. A1), and the Boyce Index ($\text{Spearman} r = 0.98, P < 0.01$) indicated good predictive power of the suitability map. About 51% of the area was classified as suitable, and 12% of that was relatively high-quality habitat. The suitability map generally followed the productivity pattern 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.

4. Discussion

Himalayan brown bears are known to occupy high elevations (e.g. they occupy areas >5000 m a.s.l. in the Karakoram Range, Nawaz, 2007). Their avoidance of high elevations (>4500 m) in DNP was probably because these areas are dominated by rock and ice and thus do not provide food resources for brown bears. The average vegetation biomass of the park is 900 kg DM/km² and it occurs on marshy, grassy, and stony areas (Nawaz, 2008). Habitat selection by brown bears in DNP therefore seemed to be related primarily to vegetative biomass production. The general abundance and spatio-temporal availability of food resources are known to be of high relevance for habitat use in brown bears (Ferguson and McLoughlin, 2000; McLoughlin and Ferguson, 2000; McLoughlin et al., 2000). A positive relationship between diet of bears and their reproductive performance has been documented in a wide range of studies (e.g., Hilderbrand et al., 1999), and in North America, >90% of the variation in age of first reproduction was explained by vegetational productivity (Ferguson and McLoughlin, 2000).

In Himalaya, Karakoram and Pamir mountain ranges of south and central Asia, brown bears seem to prefer alpine meadows. However, in other alpine landscapes (e.g. in Western Europe), brown bears generally avoid high-elevation meadows, because the food resources are scarce compared to forested areas at lower elevation (Katajisto, 2006; Güthlin et al., 2011; Martin et al., 2012). In these regions, they show tradeoffs between resource-rich areas and proximity to human infrastructures that both occur at medium or low elevation. In DNP, forested areas are non-existent and marshy vegetation is the most selected habitat, probably because it had the highest vegetative productivity (Marshy areas contribute 56% of the total vegetative biomass in DNP, Nawaz, 2008). Indeed, brown bears in DNP consume a wide range of plant species (Nawaz, 2008; Valentini et al., 2009), with a higher preference for graminoids, a dominant plant group in marshy areas. Moreover, the density of golden marmots (Marmota caudata), which is the main source of protein for brown bears there (Nawaz, 2008), is 1.4 times higher in marshy areas compared to grassy and stony vegetation in DNP (Nawaz, 2008).

The selection of areas close to roads and camps by bears could be a byproduct of their proximity to productive habitats (especially marshy vegetation, Fig. 2). Similar to other brown bears populations in alpine landscapes, this may reflect tradeoffs between resource-rich areas and human presence. 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 brown bears. Elusive species can occupy areas close to human presence (Zimmermann, 2004) if they do not associate human activity with threat. However, this also highlights the importance of not rewarding brown bears with food in camps and along roads by keeping proper storage of food items in parks.

The habitat suitability map depicted the central part of the park on either side of the central river (Barapani) as equally suitable for brown bears, probably because they were equally productive. However, the density of brown bear signs 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) the proximity of this eastern area to highly rugged terrain, which provides escape terrain in case of danger or disturbance, (2) there is no human infrastructure 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. This area might therefore represent a refuge for the brown bears (e.g. for denning, for females with young cubs) that could be easily accessed from the eastern side of the Barapani River.

The brown bears use DNP during June to October, and depending on snow conditions, they move down to the lower valleys in October, where they stay until May or early June. Our results therefore present habitat selection during the summer season. The study needs to be extended to other seasons in order to gain a year-round pattern and more comprehensive view of habitat use by bears in Himalaya.

5. Conclusion and implications

Our results provide important information for the conservation of alpine populations of the brown bears throughout the Himalayas. The population in DNP is the only population of this subspecies with an estimated reproductive rate; it is the lowest documented for brown bears (Nawaz et al., 2008). Reproductive success is related to resource selection (McLoughlin et al., 2006) and the amount of meat in the diet of brown bears is highly influential (Bunnell and Tait, 1981; Hilderbrand et al., 1999). Brown bears in DNP grazed during 96% of their foraging time (Nawaz and Kok, 2004), the rest of the time being spent capturing rodents (Woods et al., 1997 recorded seven rodent species from DNP), which probably explains the low reproductive rate in the population. Our results showed that marshy, stony and grassy were preferred habitats, probably because of the relatively dense vegetation and higher density of golden marmots. This highlights the importance of these areas and should be considered as critical habitats for the conservation of brown bears in such landscapes.

The vegetation and habitat suitability maps are also useful as decision-making instrument for evaluating future developments within the park and predicting future expansion of brown bears. The core area for brown bears in the original zoning plan (HWF, 1999), covering about half of the park, encompasses 50% poor, 34% suitable, and 14% high-quality habitat. Most of the core area (68%) has productive vegetation types, and appears to be adequate for the requirements of the present brown bear population during summer. DNP, like the majority of other protected areas (Newmark, 1995; Woodroffe and Ginsberg, 1998), is too small to ensure population viability for a species. The functional size of the protected area gets further reduced when only half of the park appears to be suitable. Given the low density and low reproductive rate of
the population (both probably due to low resource productivities), the gradual encroachment of human activities that is occurring in DNP must be stopped to secure the quality of brown bear habitat and contribute to population viability.

Grazing pressure was a factor that negatively affected habitat suitability for brown bears. Although the past levels of grazing pressure seem to have been sustainable, livestock numbers have increased greatly in recent years, particularly due to an influx of nomadic Gujjars. About 8000–9000 head of livestock were brought to DNP in 2007, compared with approximately 5000 in 2003. With only 65% of the area containing productive vegetation, DNP therefore cannot support this large amount of livestock without impacting brown bears. Moreover, although Eurasian brown bears seldom attack humans (Swenson et al., 1999) and attacks on property have been rare in DNP in the past, increased human encroachment into the core area of the growing brown bear population may potentially spawn more conflicts.

Our results also showed that brown bears were tolerant of the present level of activity on roads. Promotion of carefully managed tourism should therefore be acceptable and should even promote awareness and education among visitors, which hopefully would promote conservation efforts. However intensive nodes of tourist-related structures, like hotels or camping facilities, should be limited to the peripheral areas, preferably outside the park, because brown bears avoid them elsewhere (Nellemann et al., 2007).

Acknowledgements

Øystein Dick provided access to the geometric lab and helped classifying satellite image. Owe Løfman helped with GIS applications. Noor Kamal Khan, Ghulam Mehdi, Ghulam Murtaza, Muhammad Yunus and other staff of the Gilgit-Baltistan Parks and Wildlife Department and the Himalayan Wildlife Foundation assisted in field data collection. MAN was supported by PhD scholarship from the Norwegian government. We are thankful to all.

Appendix A

See Fig. A1.

References


