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ORIGINAL ARTICLE

Abundance, distribution and conservation status of Siberian ibex, Marco Polo and Blue sheep in Karakoram-Pamir mountain area

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Abstract This study was carried out to investigate abundance, distribution, structure and conservation status of three major ungulate species viz., *Capra sibirica*, *Pseudois nayaur* and *Ovis ammon polii*, in the Karakoram-Pamir mountain area between China and Pakistan. Results showed that the entire study area had a scattered but worthwhile population of Siberian ibex, Blue sheep and Marco Polo sheep, except Khunjerab Pass, Koksil-Pateshek and Barkhun areas of Khunjerab National Park (KNP). Large groups of Blue sheep were sighted in Shimshal and Barkhun valleys (KNP) but it did not show up in the Muztagh part of Taxkorgan Nature Reserve (TNR) in China. Despite scarcity of natural vegetation and extreme climate, estimated abundance of ibex and Marco Polo sheep was not different from that in Protected Areas of Nepal, China, and India, except for Blue sheep. Marco Polo sheep, Blue sheep and Snow leopard roam across international borders among China, Pakistan and other adjacent countries. Illegal hunting and poaching, removal of natural vegetation for fodder and firewood, and over grazing of pastures by livestock were main habitat issues whereas, border fencing for security reasons, has been a major impediment restricting free movement of the wildlife across international borders. A science based conservation and development strategy is proposed to restore viable wildlife

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populations and maintain ecological flows of Karakoram Pamir Mountains to benefit both the wild species and the local human communities.

1. Introduction

The Karakoram Mountain Range spreading over 650 km from the extreme north of Pakistan with off shoots into Chinese Pamir in the northwest up to Ladakh range of India is one of the three important mountain ranges of Pakistan, others being Himalaya and Hindu Kush, all believed to terminate in the Chinese Pamir (Khan, 2011). Huge mountains with snow covered peaks, ravines, valleys and streams with dry alpine scrub vegetation represent a predominantly cold arid and montane climate. It is one of the most important hubs of biological diversity in Pakistan with some of the species being endemic, endangered and globally significant. Gilgit–Baltistan, where three great mountain ranges, viz., Karakoram, Hindu Kush and Himalayas, meet, is believed to harbor at least nine large mammal species, including snow leopard (*Panthera uncia*), Himalayan brown bear (*Ursus arctos isabelinus*), black bear (*Ursus thibetanus*), Astore markhor (*Capra falconeri falconeri*), Blue sheep (*Pseudois nayaur*), Ladakh urial (*Ovis vignei*), Marco Polo sheep (*Ovis ammon polii*), musk deer (Moschus chrysogaster), and *Siberian ibex* (Capra sibirica) (Roberts, 1999; Rasheed, 2007; Schaller, 2007; Khan et al., 2014a,b). The floral diversity is believed to have penetrated mainly from Palearctic, Pamir-Tian Shan and Tibetan phytogeographic realms (Khan, 1996).

Taxkorgan in (China) and the adjacent Khunjerab National Park (Pakistan) constitute one of the most important wildlife areas in the mountains of Asia. Important populations of large ungulates and carnivores, notably Marco Polo sheep and snow leopard (Schaller et al., 1987) provide the foundation for an international protected area in the region (Schaller, 2007). The two ecologically contiguous areas were known to have thousands of Marco Polo sheep and ibex till the mid-nineties (Roberts, 1999) and were inhibited by Kirgiz, Tajik, and Brosho folks carving out a living from pastoral animals husbandry, utilizing sub-alpine and alpine pastures in a complex pastoral herding system (Knudsen, 1999; Ablimit et al., 2011; Khan et al., 2014a,b).

Ungulates such as Blue sheep, Siberian ibex *and* Marco Polo sheep provide almost 50–60% of the biomass consumed by large sympatric carnivores, such as, snow leopard, wolf, brown bear and lynx (Johnsingh, 1992; Oli, 1994) hence their conservation is essential for sustaining populations of large predators in the mountain ecosystem (Karanth and Sunquist, 1995) but the numbers of Marco Polo sheep have decreased fast due to poaching and illegal hunting in China, Pakistan and other neighboring countries (Schaller and Kang, 2008).

Ibex and Blue sheep prefer rugged terrain to escape predators but sometimes distribution of one species may affect distribution of the other. Normally Blue sheep avoids low areas (< 4000 m) and ibex snow free areas (Namgail, 2006) but grazing by domestic herbivores on shared habitats causes food competition and reduces forage availability for wild herbivores (Bagchi et al., 2003). Resource selection studies are widely used for assessing habitat suitability for wild animals (Manley et al., 2002; Krebs et al., 2007) which incorporate spatial behavior of prey species depending on habitat type (Gilpin and Soule, 1986), proximity to human settlements and other environmental and socio-economic factors, and helps in identifying and protect critical habitats of prey species while assisting herders manage their livestock from depredation near the habitats preferred by prey species.

The Karakoram-Pamir landscape is a combination of several agro-ecological units, with one merging into another, representing some of the unique ecosystems in the region. Being highly rugged, remote and challenging it is yet to be explored in terms of biodiversity (Xu et al., 2009). The protected populations of wild ungulates and carnivores, sharing resources with livestock and herders mostly on barren habitats offer favorable conditions to investigate ungulate dynamics and their interaction with carnivores and livestock. Using fixed point direct counting methods (Aryal et al., 2010) this study aimed to generate reliable information on ungulate ecology and abundance in Karakoram-Pamir mountain area.

2. Materials and methods

2.1. Study area

Karakoram-Pamir Landscape (KPL) shared between China and Pakistan, constituting one of the most important wildlife habitats in the mountains of Asia and harboring significant populations of large ungulates and carnivores, particularly Marco Polo sheep, snow leopard and Blue sheep (Schaller and Kang, 2008) was the broader study area. However, considering the vast geographical spread and remoteness, the study area was divided into intensive and extensive research areas. The Khunjerab National Park (KNP) covering some 4455 km^2 in the Pakistan's Karakoram was chosen for intensive research, whereas the Taxkorgan Nature Reserve (TNR) encompassing 15,863 km^2 in the China's Quorum and Pamir mountains was explored using extensive extrapolation techniques, together covering about 20,000 km^2 of the trans-boundary protected areas in the Sino-Pak border region. Seven major buffer zone valleys were accessed for data collection on social, economic and ecological parameters (Fig. 1).

KNP, established in 1975 to protect Marco Polo sheep (*O. a. polii*) and snow leopard in their natural habitats, is located in the extreme north of Pakistan (74° 52′ 33.21″–76° 02′ 26.96″ E; 36° 56′ 11.63″–36° 13′ 24.04″ N) with altitudes ranging from 2439 m to 4878 m above mean sea level (Khan et al., 2011). It lies in the alpine zone with comparatively harsh winters but mild autumn and pleasant summers. Maximum temperature in May goes up to 27 °C and falls below 0 °C in October. Higher precipitation is received in April and May (18–40 mm) followed by a second

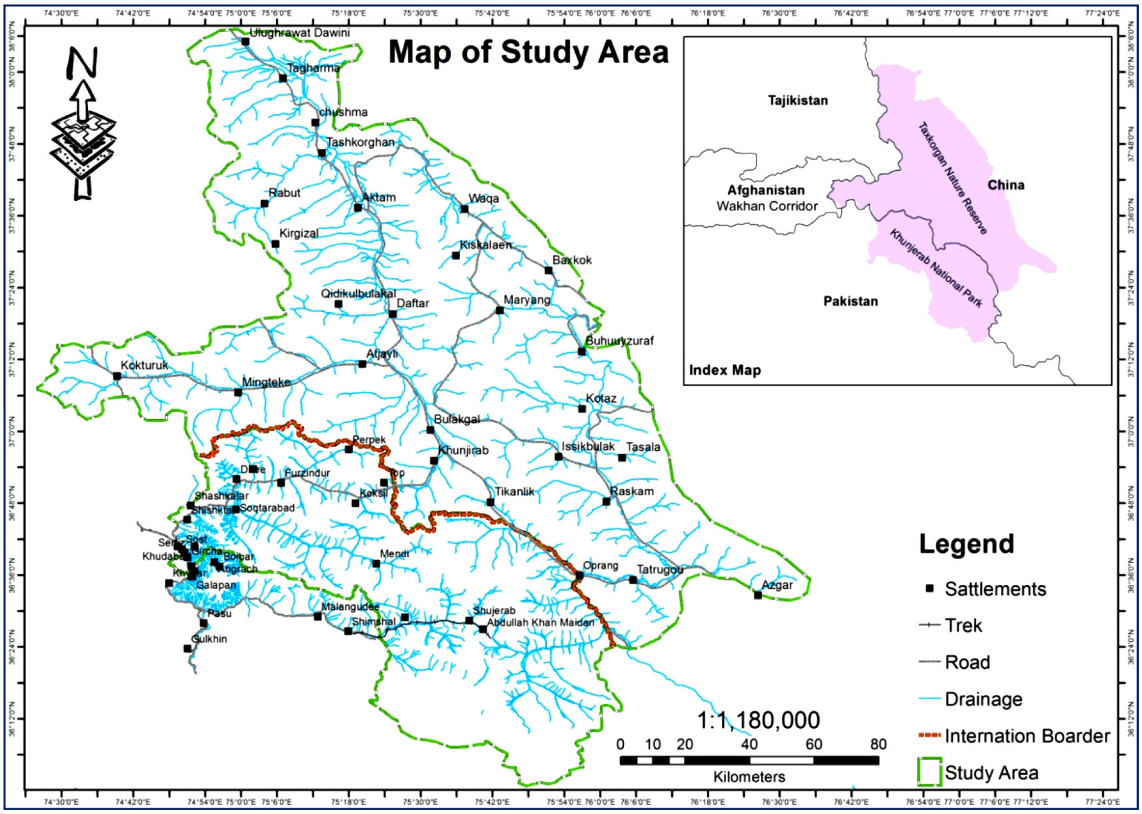

Figure 1 Map of Karakoram Pamir trans-boundary area between China and Pakistan.

peak in August (10–26 mm), while June, October and November are the driest months (< 10 mm). KNP is one of the key biodiversity hotspots in the cold desert eco-region of Pakistan. It harbors 24 orders, 54 families, 113 genera and 160 species of wild vertebrates, including 11 fish, 2 amphibian, 8 reptiles, 103 birds and 36 mammalian species. Out of the total, 24 species have been listed in the IUCN Red data book and CITES appendices as endangered, vulnerable and low risk species (Ablimit et al., 2010). Marco Polo sheep, Blue sheep, Siberian ibex, Snow leopard, Brown bear, wolf, Golden marmot, lynx, red fox and cape hare are the key mammal species (Rasool, 1990). Flora includes *Artemisia*., *Juniperus*., *Rosa*, *Hippophae*, *Salix*, *Betula*, *Populus*, *Primula and Potentilla* lying mostly along stream beds and flat soil patches (Khan, 1996; Khan et al., 2011).The Park and its peripheries are inhabited by a human population of some 5000 Tajik and Brusho ethnic groups, holding about 7000 livestock heads (Khan et al., 2011, 2014a,b).

TNR, IUCN management category IV protected area, established in 1984, is situated in the south-west corner of the Xinjiang Uygur Autonomous Region, at the juncture of the China, Pakistan, Afghanistan and Tajikistan borders (35°40′N–37°25′NL, 74°30′E-76°50′E) between below 3000 m to 8611 m asl at the summit of K2 peak. The south-western boundary follows the Pakistan border from the vicinity of Kilik Pass south-eastward to just beyond K2. TNR is ecologically contiguous to KNP of Pakistan. The reserve is mountainous, about half of it is above 4500 m asl, including the northern flanks of the Karakoram, the western edge of the Kunlun Shan and the eastern rim of the Pamir Mountains. Conditions are cool and dry with annual precipitation of less than 75 mm. Most of the terrain is too high or arid to support much vegetation. Below 3000–3200 m asl there are usually cliffs, screes, sand and silt; a desert that is so dry that few plants survive except along streams. Native trees, like, willow (*Salix*), tamarisk (*Tamarix*), popular (*Populus*) and birch (*Betula*) are found in low-lying valleys, a few being as tall as 10 m, greatly modified by human and livestock use. Some 7750 Kirgiz and Tajik people, holding some 70,000 heads of livestock (80% sheep and goats), live and use the reserve seasonally. Where land is flat and irrigation possible, barley and a few other crops are grown. Three wild ungulate species viz., Marco Polo sheep, Siberian ibex, and Blue sheep inhabit the reserve; a fourth, wild ass (*Equus hemionus*), once occurred along the upper Yarkant and Oprang River, but has never been sighted since 1950s. Among carnivores, brown bear, wolf and snow leopard survive in the area (Schaller et al., 1987, 1988).

2.2. Survey

Considering the rugged mountain terrain, the entire study area was divided into intensive (KNP) and extensive (TNR) research areas. Using Fixed-Point Direct Count Method, wildlife counts were made from high vantage points fixed along ridgelines, randomly selected from seven different study zones of the entire study area, identified on the basis of previous knowledge about species occurrence (Schaller, 2007; Ablimit et al., 2011), during dawn and dusk when ungulates were comparatively more active for feeding and drinking (Aryal et al., 2010) in late spring (April–May) and early winter (November–December) during 2010 and 2011. The vantage points were designed to cover the total area scanning all possible microhabitats for counts. High power binoculars (10 × 50 (6.50) PENTAX XCF; Pentax Co., Philippine) and Spotting scopes (80 mm SWAROVSKI HABICHT ST 80) were used to count animal in herds. Hand GPS (Garmin GPSmap 76Csx) was used to record geo-references and elevation of each site. A compass was used to measure the angle and distance to herds was approximated with naked eye between 200–500 m. Observed herds were classified by sex (male and female) and age classes were determined by experts (local ex hunters engaged in survey team) as [(trophy age male (⩾7 years old), adult (2–6 years old), yearling (⩽1 year old) and kid or lamb (⩽6 month old)] as suggested by Wegge (1997) and Aryal et al. (2010). To minimize repeated counts, distinguishing features i.e., broken or additional horn of one or more individuals in a herd were noted where possible; however, it was often difficult to identify the animal individually. Age and sex composition were used to differentiate among herds seen in two adjacent areas (Oli et al., 1993).

Potential habitats for all the three prey species were determined using habitat suitability index (HIS) in MaxEnt (Maximum Entropy) modeling technique following ENFA principles based on the niche concept (Hirzel and Arlettaz, 2003), which is implemented in a multivariate statistical framework (Hirzel et al., 2006). MaxEnt determines habitat suitability by describing the eco-geographical variables (EGVs) and compares these for sighting data with all other locations of the study area (Hirzel et al., 2002). Although several approaches have been used for modeling species distribution but a careful review of relevant reported research depicted MaxEnt as superior in performance (Sérgio et al., 2007; Phillips et al., 2006) than others (ENFA and GARP methods) even for small sample size (Phillips et al., 2006). Hence, MaxEnt was adopted in this research.

We imported data about actual sightings of prey species (ibex, Blue sheep and Marco Polo sheep) and vantage point coordinates into the GIS database of the study area (GIS ArcMap 10 ESRI) and generated values for the habitat variables. such as Landcover (Definiens recognition 2007), Normal Differential Vegetation Index (ERDAS Imagine 9.2), climate data for Mean minimum and maximum temperature and precipitation (WORLDCLIM), Digital Elevation Model (Aster 30 m; NASA Geo-portal), Distance to nearest cliff (escape terrain), aspect and slope for the study areas (Kushwaha et al., 2004; Whittaker and Lindzey, 2004; Arshad, 2011).

Using stratified random sampling; values for different Eco Geographical Variables (EGVs) representing all classes proportionately to area and distribution were extracted in GIS ArcMap 10 from a total of 12,727 points (KNP = 4966 and TNR = 7761) generated for the entire study area (KP TBA). The values of ROC/AUC were used to evaluate performance and fitness of the model (Maxent) to our data. HSI values ranging between 0 and 1 were used to classify habitat suitability for each species as highly suitable (> 0.7), moderately suitable (0.5–0.7) and least suitable (< 0.5). Kappa statistics was used to assess whether the prediction is better than random prediction. Jackknife gains for the training and test values were used to test relation of different eco-geographical variables with the species distribution and response curves were compared for the species association with each EGV in the environment (Phillips et al., 2006; Negga, 2007; Arshad, 2011).

2.3. 3Analysis

MINITAB version 15.0 was used for statistical analysis of the data. Species abundance in terms of density was acquired using species numbers and an estimate of the area offering suitable habitat only (*calculated in MaxEnt*) for each study zone. Estimated specific densities and average live weights were then used to estimate biomass for the entire study area. For this purpose, corrected ungulate densities for the three species, viz., Siberian ibex, Blue sheep and Marco Polo sheep, were multiplied with their average live weights (kg) and total biomass was obtained (Oli, 1994; Wegge, 1997). Mann–Whitney U test was applied to compare reliability of sample means between different survey timings (years). Independent two-sample t-test was used to test significant difference between two population means. Specific density estimates for all potential habitats were then used to calculate prey biomass availability (Wang, 2008).

3. Results

3.1. Distribution and status

A total of seven catchments and sub-catchments (study zones) covering 1,895.20 km^2 mostly inside the protected areas (KNP and TNR) were surveyed for Siberian ibex, Blue sheep and Marco Polo sheep during winter (December) 2010, spring (April–May) and winter (Dec) 2011. Results revealed a wider distribution of ibex and limited distribution of Marco Polo and Blue sheep in the study areas, and Blue sheep did not show up in TNR during the winter survey. A total of 1682 animals were sighted from 76 vantage points surveyed. Ibex was maximum with a total count of 899 (53.44%, n = 1682) followed by Marco Polo sheep716 (42.60%, n = 1682) and Blue sheep 67 (3.98%) (Table 1).

Siberian ibex was widely distributed throughout the study area with highest population seen in Shimshal (28.25%) followed by Koksil-Patikeshek (24.03%), Taxkorgan-Muztagh (23.80%), Dhee (10.12%), Qarchanai (10.01%) and Barkhon (2.78%). Minimum number of ibex was seen at Khunjerab Pass counting only 1.0% of the total population. Trophy size males (⩾7 years old) were seen in Qarchanai (14/90), Dhee (15/91), Shimshal (38/254) and Muztagh Taxkorgan (23/214). Herds observed at Khunjerab Pass, Koksil-Patikeshek and Barkhon were mostly adult and sub adult males with females, kids and yearlings. Despite second highest total population, trophy size males were absent in Koksil-Patikeshek. Blue sheep apparently seemed confined to Barkhon (4.48%) and Shimshal (95.52%) valleys. However, a few herds (8–15 animals each) were seen in Soqtarabad outside the KNP. We could not see any sheep in Muztagh Taxkorgan during the winter survey 2009. We counted 619 Marco Polo sheep in Muztagh area of TNR and 97 in Qarchanai valley of KNP during winter and summer surveys.

3.2. Population density and biomass

The mean annual populations of ibex, Marco Polo and Blue sheep in all potential habitats were estimated to be 491, 33 and 667, respectively. The estimated average annual densities stood at 0.259 ibex, 0.017 Blue sheep and 0.325 Marco Polo

Table 1 Distribution, total count and herd structure of key ungulates in Karakoram-Pamir (2010–2011).

Species	Study zone/micro habitats	Population structure						
		Male	Female	Yearling	Kid	Total	Trophy size	% of total
Siberian ibex	Khunjerab Pass	4	2	2	1	9	0	1.00
	Koksil-Patikeshek	79	88	32	22	216	0	24.03
	Barkhon	3	16	6	0	25	0	2.78
	Qarchanai	29	32	19	11	90	14	10.01
	Dhee	22	39	24	6	91	15	10.12
	Shimshal	71	92	35	40	254	38	28.25
	Taxkorgan (Muztagh)	89	76	28	21	214	23	23.80
	Sub-total	297	345	146	101	899	90	100.00
Blue sheep	Shimshal	20	25	17	5	64	10	95.52
	Barkhon	3	0	0	0	3	0	04.48
	Sub-total	23	25	17	5	67	10	100.00
Marco Polo sheep	Qarchanai	10	13	15	0	97	0	13.54
	Taxkorgan (Muztagh)	398	175	46	46	619	136	86.45
	Sub-total	408	188	61	46	716	136	100.00
Grand total		728	558	224	152	1682	236	100.00

Table 2 Distribution, specific density (animals' km^{-2}) and estimated biomass (kg km^{-2}) of ibex, Blue sheep (BS) and Marco Polo sheep (BPS) in Karakoram Pamir mountain area.

Study zone	Area (Km^2)	Species						Biomass			Total biomass (kg km^{-2})
		Ibex		Blue sheep		Marco Polo sheep		Ibex	BS	MPS	
		#	Density	#	Density	#	Density				
Khunjerab Pass	72.16	3	0.042	0	0	0	0	2.851	0	0	2.851
Koksil-Patikeshek	100.68	72	0.715	0	0	0	0	49.045	0	0	49.045
Barkhon	248.06	15	0.060	1	0	0	0	4.147	0.29	0	4.366
Qarchanai	163.64	30	0.183	0	0	48.5	0.296	12.573	0	36.331	48.904
Dhee	80.07	30.33	0.379	0	0	0	0	25.978	0	0	25.978
Shimshal	522.09	127	0.243	32	0.061	0	0	16.682	3.36	0	20.018
Taxkorgan (Muztagh)	708.5	214	0.302	0	0	619	0.874	20.714	0	107.095	127.81

Note: average live weight: ibex 68.58 kg, Blue sheep 54.42 kg, Marco Polo sheep 122.58 kg (Roberts, 1999).

sheep km^{-2} (Table 2). The method used to estimate number of animals excluded repeated counts, but did not take into account the animals that were missed during the census. Therefore, actual number of animals counted is likely to be closer to the maximum estimate (Oli, 1994).

The estimated specific density when compared for study zones was highest for Muztagh-Taxkorgan (D = 1.17 animals km^{-2}) followed by Koksil-Patikeshek (D = 0.715 animals km^{-2}), Qarchanai (D = 0.48 animals km^{-2}), Dhee (D = 0.379 animals km^{-2}) and Shimshal (D = 0.305 animals km^{-2}). It was minimum for Khunjerab Pass (D = 0.042 animals km^{-2}) and Barkon (D = 0.064 animals km^{-2}) areas in KNP. Koksil-Patikeshek had highest density values for ibex (D = 0.715 animals km^{-2}), whereas Muztagh had highest values for Marco Polo sheep (D = 0.874 animals km^{-2}) and Shimshal had maximum value of density for Blue sheep (D = 0.063 animals km^{-2}).

Analysis of variance (ANOVA) revealed that the estimated densities for ibex, Blue sheep and Marco Polo sheep varied significantly across different study zones. Results of the two-sample test showed greater density for ibex than Blue sheep (t = 2.52, df = 5 P = 0.026) and Marco Polo sheep (t = 1.94, df = 7, P = 0.046) but a non-significant result for densities of Blue and Marco Polo sheep (t = 0.76, df = 5, P = 0.479). Prey biomass estimated, using prey densities and average live weight of the animals, suggested that the study area harbored a lowest ungulate biomass of 278.97 kg km^{-2}. Marco Polo sheep had the highest biomass (143.42 kg km-2, 51.41%) while ibex contributed 131.99 kg km^{-2} (47.31%) and Blue sheep contributed only 1.30 kg km^{-2} (1.31%) out of the total biomass available.

3.3. Potential habitats

The species distribution maps for ibex, Blue sheep and Marco Polo sheep for intensive research area (KNP) produced varying results (Fig. 2). High and moderate suitability habitat patches scattered widely across KNP show small isolated suitable habitats for ibex (Fig. 2a). High and moderate habitats for Blue sheep are distributed along southwestern and northeastern flanks (Fig. 2b) whereas, northwestern edges (Fig. 2c) like Qarchanai and Kilik–Mintaka have the only suitable habitats for Marco Polo sheep.

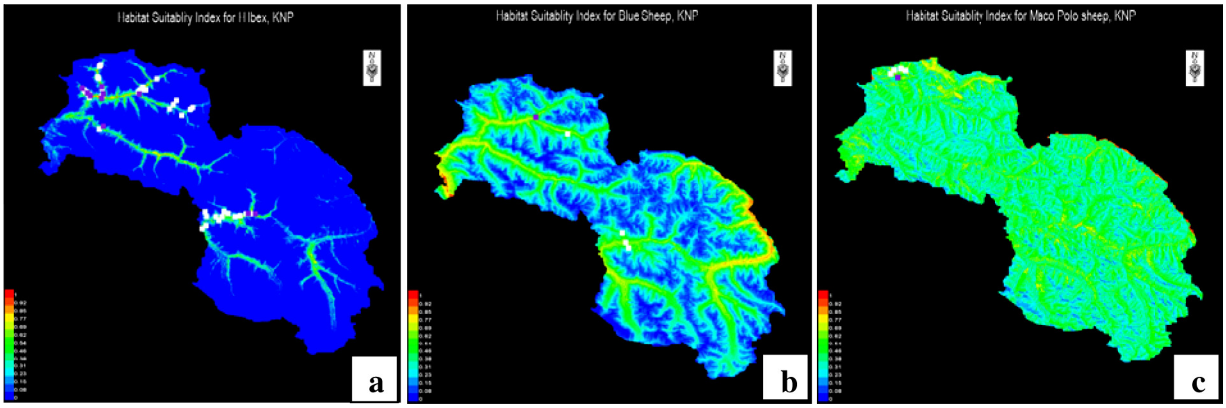

Figure 2 MaxEnt generated habitat suitability maps for Khunjerab National Park using Habitat Suitability Index (HSI) calculated between 0 and 1 for (a) Siberian ibex, (b) Blue sheep and (c) Marco Polo sheep, based on their actual sightings. Red colors show high suitability, yellow moderate and blue low suitability habitat.

Although ibex seems widely distributed throughout TNR however its concentration is comparatively higher on the southern flanks (along the border with KNP), southeastern (further toward Shimshal) and southwestern mountains. Small patches also appear in the northern parts of TNR. Maps show suitable habitats for ibex mostly in south (east and west) and northern slopes. Habitat requirements of Blue sheep and ibex seemed occupying southern parts of the study area. Fig. 3b also showed some moderately suitable habitats (yellow spots) for the sheep in northeastern and northwestern parts of the TNR.

The Receiver Operating Characteristics (ROC) curves indicate a training Area Under Curve (AUC) of 0.984 for ibex, 0.863 for Blue sheep and 0.934 for Marco Polo sheep showing high accuracy of the MaxEnt model distribution (Metz, 1978). Slightly lower AUC values for Blue sheep could possibly be attributed to fewer actual sightings from the field. AUC test gains for all the target species however showed values higher than 0.940 (Fig. 4a–c) proving optimum reliability of the model used.

Kappa statistics showed a prediction better than expected by random (AUC = 0.5) in all cases (Table 3).

Jackknife test of variable importance for ibex showed the highest training gain for precipitation in both when used alone and omitted from the model reflecting that precipitation had effect on the goat's preference for suitable habitats (Fig. 5a). For Blue sheep, Jackknife gain was the highest for minimum temperature when computed in isolation contrary to land cover having most useful information when omitted from the model (Fig. 5b). Marco Polo sheep attained highest value for NDVI (vegetation) when compared alone whereas; it got the lowest value for maximum temperature when it was compared with all variables (Fig. 5c).

4. Discussion

The study area harbors Siberian ibex, Blue sheep and Marco Polo sheep coexisting with a guild of sympatric carnivores, i.e., snow leopard, wolf, brown bear and lynx. Results showed that distribution, abundance and population structure of ungulates varied from place to place. Average ungulate population for the last three seasonal surveys showed the highest numbers for Marco Polo sheep followed by ibex and Blue

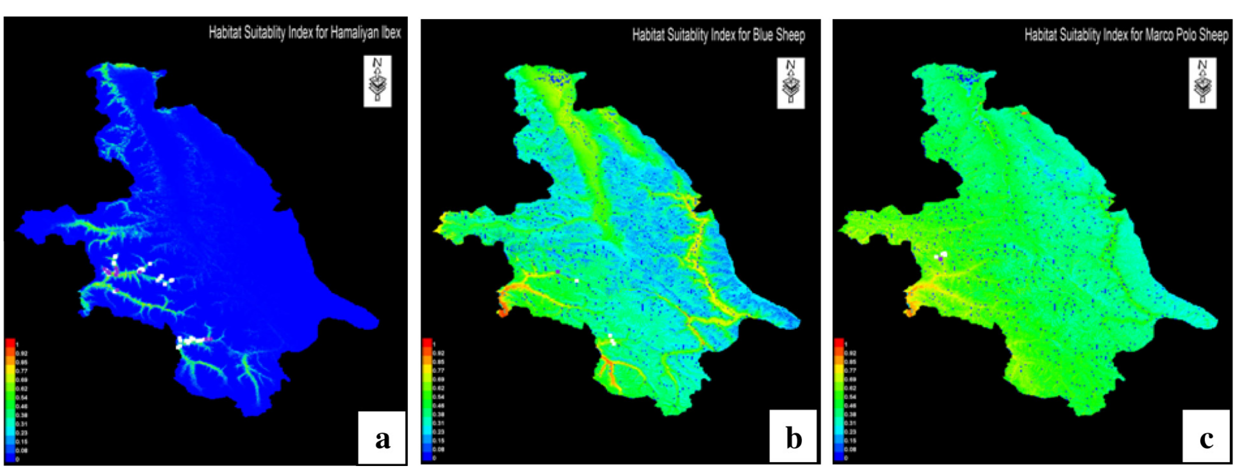

Figure 3 MaxEnt generated habitat suitability maps for Taxkorgan Nature Reserve, using Habitat Suitability Index (HSI) calculated between 0 and 1 for ibex (3a), Blue sheep (3b) and Marco Polo sheep (3c) based on their actual sightings. Red colors show high suitability, yellow moderate and blue low suitability habitat.

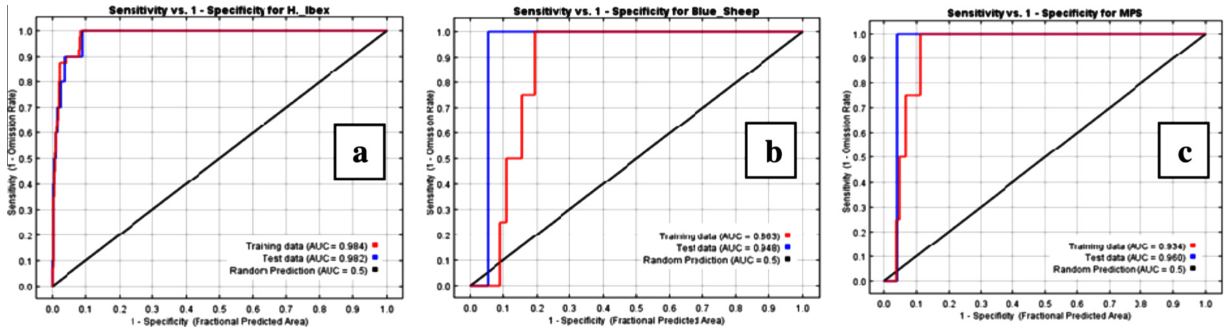

Figure 4 MaxEnt generated values for ROCs indicating AUC (reliability of the model) for (4a) Siberian ibex, (4b) Blue sheep and (4c) Marco Polo sheep.

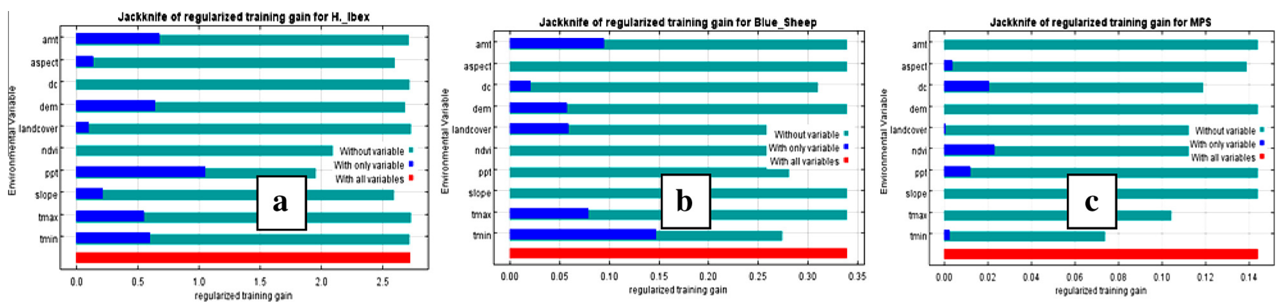

Figure 5 MaxEnt generated values of Jackknife regularized training gain for (5a) Siberian ibex, (5b) Blue sheep and (5c) Marco Polo sheep.

Table 3 ROC curve and KAPA statistics for species using training and test data.

Category	ROC	KAPPA
Test data	0.948 (*Pseudois nayaur*)	0.896
	0.982 (*Capra sibirica*)	0.964
	0.96 (*Ovis ammon polii*)	0.92
Training data	0.863 (*Pseudois nayaur*)	0.726
	0.984 (*Capra sibirica*)	0.968
	0.934 (*Ovis ammon polii*)	0.868

sheep. Ibex had higher density as compared to Marco Polo and Blue sheep. Low abundance of three ungulates in the study area was probably due to peculiar barren habitats, offering less food and excessive poaching for meat and trophies (Wegge, 1988; Schaller et al., 1987; Shafique and Ali, 1998). Slightly larger herds in Shimshal and Koksil-Patikeshek compared to Khunjerab Pass might be due to better forage and lower disturbance in Shimshal Pamir pastures. Absence of trophy size males (>7 years old) in a large herd of 216 ibex seen in Koksil-Patikeshek inside the Park could possibly be a result of male segregation from females after the rut season (Ruckstuhl and Neuhaus, 2002). Once occurring in hundreds in KNP it was ruthlessly killed for food during the construction of KKH in late 1960s and early 1970s and its numbers drastically declined (Schaller, 2007). Rasool (1990) counted 300 animals in 1974, 100 in 1980 and 20 in 1988 in Khunjerab Pass area. Similarly, Khan (1996) counted 52 animals in Qarchanai valley in 1989. Marco Polo sheep now visits Qarchanai valley for lambing (Jackson, 2002) from May till September, and that is how it was seen here during summer only. However, its numbers have recently increased on the Chinese side probably due to better protection by Chinese authorities (Schaller and Kang, 2008).

The ungulate biomass recorded from the study area was lower (278.97 kg km^{-2}) than that reported for other Protected areas of Asia. The lowest biomass (378 kg km^{-2}) was previously reported for Jigme Singye Wangchuk National Park, Bhutan (Wang, 2008). Low ungulate densities (Schaller et al., 1987, 1988; Schaller and Kang, 2008) might be one of the reasons for lower number of carnivores in the Karakoram Pamir trans-border area. Using Jackson and Hunter's (1996) estimation for food requirements of the adult snow leopards (1.3–2.0 kg day^{-1}) about 600–900 kg of biomass is required to support an adult snow leopard for one year and about 20–30 sheep/goats annually. The available biomass can hardly support 3–4 snow leopards per 100 km^2 for one year, meaning that the rest of the biomass required by other snow leopards (if number >4) and other carnivores is met from the domestic stock being grazed in the study area (Khan, 1996). When compared with earlier findings of Schaller et al. (1987) and Schaller and Kang (2008), though patchy and scattered but the historical abundance of major ungulate species Ibex, Blue sheep and Marco Polo sheep was slightly higher in Taxkorgan than the current level of densities in TNR and KNP (Table 4).

The MaxEnt modeling showed a larger variation in the distribution of species across the study area depending mostly upon prevailing climatic and peculiar eco-geographical conditions. Habitat suitability (HS) maps are almost in line with

Table 4 Historical distribution, densities (km^{-2}) and biomass ($kg\ km^{-2}$) of three ungulate species in Taxkorgan Nature Reserve, China.

Study Zone	Area (km^{-2})	Population						Estimated biomass			Total
		Ibex		Blue sheep		Marco Polo sheep		Ibex	Blue sheep	Marco Polo sheep	
		#	Density	#	Density	#	Density				
Mingteke	850	13	0.02	0.00	0.00	48.00	0.06	1.05	0.00	6.94	7.99
Khunjrab	140	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mazar	185	100	0.54	0.00	0.00	0.00	0.00	37.07	0.00	0.00	37.07
Raskam	150	0	0.00	31.00	0.21	0.00	0.00	0.00	11.25	0.00	11.25
Mariang	120	33	0.28	265.00	2.21	0.00	0.00	18.86	120.18	0.00	139.04
Datung	140	196	1.40	0.00	0.00	0.00	0.00	96.01	0.00	0.00	96.01
Kukshilik	75	177	2.36	0.00	0.00	0.00	0.00	161.8	0.00	0.00	161.85
Total	1660	519	0.31	296.0	0.18	48.00	0.03	21.4	9.70	5896.80	453.20

Source: Schaller et al., 1987.

recent findings of this study and the available literature from Khan et al. (2011), Roberts (1999), Khan (1996), Rasool (1990), Schaller and Kang (2008) and Ablimit et al. (2011) in literature.

Schaller et al. (1987) and Ablimit et al. (2010) found the sheep fairly abundant in Mariang in the northern part of TNR. Historically, Marco Polo sheep inhabits Tajikistan, Wakhan (Afghanistan) and Kilik–Mintaka (Misgar) and Qarchanai areas of KNP in Pakistan where sheep moves seasonally across international borders between Pakistan, China and Tajikistan (Schaller and Kang, 2008). Its suitable habitats (red-yellow area in Fig. 3c) are mostly along the southeastern flanks of the study area, nearer to Pakistan's Mintaka and Afghanistan's Wakhan Corridor. Similarly, Schaller (2007) found the highest concentration of sheep in Pixilang, southern part of the study area. All countries except Pakistan have moderately large Marco Polo sheep populations, making it possible through effective management on a long-term basis (Schaller and Kang, 2008). Marco Polo sheep, once occurring in hundreds (Rasool, 1990) had fallen to 74 animals in 2008, 59 in 2010 and 38 in 2011 (in Qarchanai area), and were mostly sub adult males, females and newly born lambs. We did not find any Marco polo sheep at Khunjerab Pass during the last six years. The sheep had been ruthlessly killed for food during the construction of the Karakoram Highway in the late 1960s and early 1970s, resulting in a drastic decline in its population (Schaller et al., 1987) and hunting mostly of large males still continues without any restriction in the Kilik–Mintaka areas.

Marco Polo sheep had been entering Pakistan from China via Kilik, Mintaka, Khunjerab and Qarchanai passes but now the sheep is confined to only a limited lambing habitat in Wuluqdur across Qarchanai pass in KNP (Khan and Ali, 2009). Although Khunjerab Pass holds some 50 km^2 of good habitat but the Karakoram Highway, with all its roaring traffic, deployed forces and other anthropogenic activities coupled with the border fence stretched partially across the valley along Pakistan-China border have greatly reduced the free movement of the sheep, which if not restored may have disastrous implications on genetic diversity of the species, reducing its genetic vigor to withstand the harsh climatic and poor forage conditions peculiar to its only lambing habitat in the study area.

Similarly ibex and Blue sheep, once reportedly ubiquitous in the KPL, now survive in scattered isolated patches both in KNP and TNR. Blue sheep's current distribution in KNP is confined to Shimshal and Barkhun valleys, contrary to its sighting at Khunjerab Pass in the recent past. Although ibex is still widely distributed and along with Blue sheep offer maximum biomass to the predators, their remnant populations are under severe pressure of hunting and habitat degradation from overstocking and removal of vegetation for household energy throughout the study area. Retaliatory killing of top predators against predation on domestic stock is another issue that badly affects the prey-predator balance resulting in overstocking sometimes as large carnivores play a major role in shaping prey communities in tropical environments (Terborgh, 1990; Karanth and Sunquist, 1995; Rabinowitz, 1989).

Further the deductive modeling of species distribution for Habitat Suitability Index (HSI) in MaxEnt modeling technique showed a strong relationship of the target species with different eco-geographical variables (EGV). For instance, ibex distribution in the study area is strongly associated with climate variables like minimum temperature (42%) and precipitation (37.8%) but showing non-significant relation with altitude, slope, aspect, land cover, escape distance and vegetation. Similarly habitat preference of Blue sheep seemed strongly influenced by the prevailing climatic conditions, like minimum temperature (54.6%), precipitation (11.1%) and land cover (snow 26.4%). Marco Polo sheep distribution is again significantly associated with minimum temperature (24.3%), escape distance (20.5%), precipitation (18.6%), maximum temperature (13.8%) and NDVI (12.4%). Other factors have comparatively non-significant contributions toward habitat suitability index for the sheep. The results are in line with study findings from Negga (2007), Phillips et al. (2006) and Arshad (2011).

The study shows that the peculiar harsh climatic conditions with temperatures, below the freezing point, are the major factor influencing species distribution and habitat suitability for ungulates in the study area. One of the many reasons for such a vivid association is the barren high altitude coupled with unforgiving ruggedness of the terrain where forage availability is highly subject to snow cover, and particularly where the palatable vegetation appears with gradual melting of snow upward attracting the herbivores and ultimately influence their distribution (Namgail, 2006). Moreover, variation in percent contribution of climatic and environmental variables toward HSI might be due to species specific thermo-regulatory requirements and varying foraging behaviors as sheep are more sensitive to heat than goats and browse higher than goats which graze in usual circumstances. Our findings are mostly in line with Wegge (1988), Schaller et al. (1987), Khan (1996), Ruckstuhl and Neuhaus (2002), Namgail (2006) and Schaller (2007). Marco Polo sheep is not a resident species of Pakistan but females and sub-adult males visit Qarchanai valley (KNP) in late May for lambing and return to greater Pamir by the mid of September for wintering (Schaller and Kang, 2008).

5. Conclusion

The Karakoram Pamir mountain area, represented by KNP and TNR harbor seven large mammalian species, where the specific densities of three target ungulate species is at par with their densities in the regional PAs. Considering low wild prey base in the KPMA, all conservation efforts should aim to increase the numbers of the prey species to make their populations viable in longer run. Further, in a predator guild of sympatric carnivores with lower wild prey base and overstocked pastures like in KPMA, the wise and carefully worked out multipronged management strategy including research based management, habitat improvement, animal husbandry, wildlife management and community based conservation programs with avenues for economic development and benefit sharing will be helpful to restore species and their habitats (Jackson et al., 1996; Khan et al., 2012a,b, 2014a,b).

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