

Feeding habitats of blue sheep (*Pseudois nayaur*) during winter and spring in Helan Mountains, China

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Abstract The feeding habitat selection of blue sheep (*Pseudois nayaur*) was studied by direct observation method in the Helan Mountains, China during winter (from November to December) and spring (from April to June) from 2003 to 2004. We established 25 line transects to collect information on feeding habitats used by blue sheep. Blue sheep in the study area preferred mountain savanna forests, a habitat dominated by *Ulmus glaucescens*, with medium tree density (<4 individuals / 400 m²), moderate tree height (4–6 m), higher shrub density (>5 individuals / 100 m²), higher shrub (>1.3 m), higher food abundance (>50 g), moderate distance to human disturbance (<500 m), and mild distance to bare rock (<2 m). Such habitats characterized by 12 ecological factors were preferred as feeding areas by blue sheep during winter. Similar to habitat selection by the species during winter, blue sheep also showed a preference for mountain savanna with tree dominated by *Ulmus glaucescens* and medium tree density (<4 individuals / 400 m²) during spring. Nevertheless, blue sheep preferred medium tree height (<6 m), moderate tree density (5–10 individuals / 100 m²), medium shrub height (1.3–1.7 m), higher food abundance (>100 g), moderate altitude (<2 000 m), moderate distance to water resource (<500 m), and medium hiding cover (50%–75%) during spring. Selection of the feeding habitats by sheep showed a significant difference in vegetation type, landform feature, dominant tree, tree height, shrub density, distance to the nearest shrub, food abundance, slope direction, slope degree, distance to water resource, and hiding cover between winter and spring. Results of principal components analysis indicated that the first principal component accounted for 24.493% of the total variance among feeding habitat variance during winter, with higher loadings for

vegetation type, dominant tree, tree height, distance to the nearest tree, shrub density, shrub height, altitude, distance to water resource, and distance to human disturbance. In spring, the first principal components explained 28.777% of the variance, with higher loadings for vegetation type, distance to the nearest tree, shrub height, distance to the nearest shrub, food abundance, altitude, and distance to human disturbance.

Keywords blue sheep, *Pseudois nayaur*, habitat selection, principal components analysis, Helan Mountains

1 Introduction

Animal foraging tactics include feeding time, food species, and feeding habitat selection (Nagy, 1987, 1994; Julien-Laferrière, 1999; Sun, 2001). Food resources vary in time and space (Jiang, 2004). The availability and quality of forage used by ungulates in the northern regions changes with seasons. Winter is considered to be a critical period of low availability and quality of vegetation, whereas spring is regarded as a period with gradually increasing vegetation resources to the higher points in the northern regions (Chen and Gao, 1992). Accordingly, ungulate foraging tactics will vary with food resources in order to compensate for increased energy demands in winter (Mautz, 1978; Parker and Robbins, 1984; Schmitz, 1991; Chen et al., 1999). Having grasped the mechanism of the shift in foraging tactics, especially feeding habitat selection, we can understand how animals can adapt to their surrounding environment (Jiang, 2004).

Blue sheep (*Pseudois nayaur*) is distributed widely across the Tibetan Plateau and the surrounding mountain areas. The animal is primarily found in the western portion of China, extending into Nepal, Bhutan, India, and Pakistan (Wang et al., 1998a). Blue sheep typically prefer plateau, alpine barren rock, and inter-valley grassland (Schaller, 1977).

Although some authors have reported the habitat selection by blue sheep distributing in different regions (Wilson, 1981; Harris and Miller, 1995; Oli, 1996; Namgail et al., 2004; Liu et al., 2005), they did not study the feeding habitat used by sheep in particular. It is unfortunate that these studies were restricted in some particular seasons (Harris and Miller, 1995; Namgail et al., 2004; Liu et al., 2005), in a few habitat variables (Wilson, 1981; Harris and Miller, 1995; Oli, 1996; Namgail et al., 2004), and in insufficient plots (Oli, 1996; Wilson, 1981; Harris and Miller, 1995). Due to the shift of food resources from winter to spring, we predict that winter foraging sites by blue sheep should show some differences from spring sites. The aim of this study was to describe the characteristics of feeding habitats, compare and analyze variation across two seasons at the feeding sites from November to December, 2003 and from April to June, 2004.

2 Study area

This study was carried out in the Helan Mountain region (38°21'–39°22' N, 105°44'–106°42' E) between the eastern Yinchuan Plain and the western Alashan Plateau, China. Elevation within the area used by sheep ranges from 2 000 m to 3 000 m. The Helan Mountain region is one of the central areas and eastern boundary of the blue sheep's distribution (Wang and Schaller, 1996). The climate is characterized by cool and dry conditions with an average annual temperature of -0.9°C . Annual rainfall averages 420 mm. The vegetation of Helan Mountain is typical for temperate arid and semiarid upland vegetation. There is a very clear vertical distribution of vegetation: 1 400–1 600 m, mountain grassland; 1 600–2 000 m, mountain savanna; 1 900–3 000 m, mountain conifer forest; 3 000–3 556 m, subalpine shrubland and meadow (Di, 1986).

3 Methods

3.1 Habitat characteristics

We established 25 line transects in Maliankou, Xiaokouzi, Suyukou, Dashuigou, Rujigou, Gulaben, Fanjiayingzi, and Zhenmuguan, respectively during winter (from November to December) in 2003 and spring (from April to June) in 2004 (Encyclopedist Committee of Ningxia, 1998). Those transects traversed the whole study area and covered all the vegetation types. Transects ranged in length from 2.4 km to 42.5 km for a total of 243.8 km and 235.5 km, respectively during winter and spring.

Recent estimation on the population size of blue sheep has increased to over around 10 000 individuals in the Helan Mountain region (Liu et al., 2004a). Characteristics of feeding habitats used by blue sheep were recorded by direct observation. When we saw sheep feeding and located sheep

herds, we waited until the herd had fed and gradually moved away. Then we visited the feeding area to determine characteristics of feeding habitat. We sampled a 10 m \times 10 m, and 5 m \times 5 m plots at the center of each forage sites, and then we sampled five 1 m \times 1 m plots at the center of each 5 m \times 5 m plots and the four corners of the plots respectively. From winter 2003 to spring 2004, we measured 188 and 104 feeding sites. At each feeding site we recorded vegetation type, landform feature, dominant tree, tree density, tree height, distance to the nearest tree, shrub density, shrub height, distance to the nearest shrub, food abundance, slope direction, slope degree, latitude, distance to water resource, distance to human disturbance, distance to bare rock, and hiding cover (Oli, 1996; Teng et al., 2004; Liu et al., 2004b, 2005). On these transects we randomly selected 50 and 48 locations every 2 000 m respectively during winter and spring and measured the concerned variables as for feeding sites.

3.2 Data analysis

A chi-square goodness-of-fit test was employed to examine whether the variables of feeding habitat differed from those of the expected habitat. Bonferroni confidence intervals were calculated to determine which variables were preferred or avoided (Marcum and Loftsgaarden, 1980). If the sheep selected one variable, Bonferroni confidence interval was calculated by the following formula:

$$(p_i - r_i) \pm Z_{1-\alpha/2k} \times \sqrt{p_i(1-p_i)/n_i + r_i(1-r_i)/m_i}$$

where, n_i was the number of random plots in category i , and p_i was the proportional usage of these plots that fall in category i ; m_i was the total number of plots used by sheep, r_i was the proportion of plots used by sheep that fall in category i ; $Z_{1-\alpha/2k}$ was the upper standard normal table value corresponding to a probability tail area of $1-\alpha/2k$; α was the level of significance; k was the number of categories tested.

If the confidence intervals included 0, then it was used in proportion to its availability. If 0 was not in the interval and both end points of the interval were positive, it was truly used less than expected, and it was "avoided" by sheep. If 0 was not in the interval and both end points of the interval were negative, it was selected more than expected and it was "preferred".

We used chi-square test to determine the differences in vegetation type, landform feature, dominant tree, and slope direction between winter and spring. A non-parametric Mann-Whitney U test was also used to test seasonal differences in tree density, tree height, distance to the nearest tree, shrub density, shrub height, distance to the nearest shrub, food abundance, slope degree, latitude, distance to water resource, distance to human disturbance, distance to bare rock. The data of 17 variables were subjected to principal component analysis (PCA) for identifying the importance of habitat variables used by blue sheep.

4 Results

4.1 Characteristics of feeding habitat used by blue sheep in winter

In winter, blue sheep preferred mountain savanna and habitat dominated with *Ulmus glaucescens*. Sheep selected feeding sites with more tree species and avoided sites with less trees (Table 1). Trees with medium height (4–6 m) were selected as feeding sites. Sheep tended to use feeding habitats with more shrub species and higher shrubs and avoid habitats with less and lower shrubs. Feeding habitats associated with more food resource, closer to human disturbance, and closer to bare rock were preferred by sheep. There was no significant difference in landform feature ($\chi^2 = 4.08$, $df = 4$, $P > 0.05$), distance to the nearest tree ($\chi^2 = 4.37$, $df = 2$, $P > 0.05$), slope direction ($\chi^2 = 2.91$, $df = 2$, $P > 0.05$), slope degree ($\chi^2 = 3.52$, $df = 2$, $P > 0.05$) and hiding cover ($\chi^2 = 6.74$, $df = 3$, $P > 0.05$) between feeding habitats and randomly selected sites.

4.2 Characteristics of feeding habitat by blue sheep in spring

In spring, blue sheep showed a strong preference for mountain savanna and sites dominated with *Ulmus glaucescens* (Table 2). Feeding habitats with less tree species and lower trees were preferred by sheep. Sheep selected feeding sites with medium shrub density (5–10 individuals) and shrub height (1.3–1.7 m). Blue sheep preferred more food resource, lower altitude, closer to water resource, and higher hiding cover as feeding sites in spring. Landform feature, ($\chi^2 = 8.69$, $df = 4$, $P > 0.05$), distance to the nearest tree ($\chi^2 = 2.60$, $df = 2$, $P > 0.05$), slope direction ($\chi^2 = 3.57$, $df = 2$, $P > 0.05$), slope degree ($\chi^2 = 4.37$, $df = 2$, $P > 0.05$), distance to human disturbance ($\chi^2 = 4.19$, $df = 2$, $P > 0.05$), and distance to bare rock ($\chi^2 = 3.69$, $df = 2$, $P > 0.05$) were similar between feeding sites and random plots.

4.3 Comparison of feeding habitats between winter and spring

The chi-square goodness-of-fit test indicated significant differences in vegetation type ($\chi^2 = 18.10$, $df = 3$, $P < 0.01$), landform feature ($\chi^2 = 33.36$, $df = 4$, $P < 0.01$), dominant tree ($\chi^2 = 19.15$, $df = 6$, $P < 0.01$), and slope direction ($\chi^2 = 6.51$, $df = 2$, $P < 0.05$) between winter and spring. There were significant differences in tree density, tree height, shrub density, distance to the nearest shrub, food abundance, slope degree, distance to water resource, distance to human disturbance, and hiding cover between winter and spring (Mann-Whitney U test, $P < 0.05$). During winter, feeding habitats were associated with more and higher trees than those during spring. For blue sheep, winter feeding sites had more shrubs and closer to the nearest shrubs than those in spring.

In spring, blue sheep tended to use feeding habitats with more abundant food resource, steeper slope, closer to water resource, farther distance to human disturbance, and higher hiding cover than those in winter (Table 3).

4.4 Principal component analysis on feeding habitats in winter and spring

Principal component analysis showed that the first 4 principal components explained 69.424% of the total variance among all feeding habitat variables during winter. The first principal component was positively related to vegetation type, landform feature, dominant tree, distance to the nearest tree, shrub density, altitude, distance to water resource, distance to human disturbance, distance to bare rock, and hiding cover. The first principal component was negatively correlated with tree density, tree height, canopy cover of shrub, shrub height, distance to the nearest shrub, food abundance, slope direction, and slope degree. The first principal component accounted for 24.493% of the variance, with high loadings for vegetation type, dominant tree, tree height, distance to the nearest tree, shrub density, shrub height, latitude, distance to water resource, and distance to human disturbance (Table 4).

In spring, the first 4 principal components explained 71.306% of the total variance. The first principal component was positively related to vegetation type, landform feature, dominant tree, distance to the nearest tree, distance to the nearest shrub, slope degree, altitude, distance to water resource, distance to human disturbance, distance to bare rock, and hiding cover. The first component was negatively correlated with tree density, tree height, shrub density, shrub height, food abundance, and slope direction. The first principal component explained 28.777% of the variance, with high loadings for vegetation type, distance to the nearest tree, shrub height, distance to the nearest shrub, food abundance, altitude, and distance to human disturbance (Table 4).

5 Discussion

In Helan Mountains blue sheep showed no significant selection in landform feature, distance to the nearest tree, slope direction, and slope degree whether during winter or spring ($P > 0.05$). However, sheep preferred mountain savanna dominated by *Ulmus glaucescens*, more abundant food resources, fewer trees, and lower trees (Table 1, 2). There was no difference in tree height, distance to the nearest tree, shrub height, latitude, and distance to bare rock. We found significant difference in other habitat variables between winter and spring (Table 3). These coincide with our prediction that blue sheep selected different feeding habitats when the availability and quality of forage changes with seasons.

Some studies on habitat selection of blue sheep from different localities indicated that sheep preferred grassland or scrub habitat, and moderately steep slopes with elevation above 4 200 m on southerly aspects. The sheep maintained

Table 1 Utilization and selection of 12 ecological factors in feeding habitat used by blue sheep during winter

Variables	Category	Actual proportion used (p) $n = 188$	Expected proportion used (r) $n = 50$	Bonferroni interval for $p_i - r_i$	Preference
Vegetation type	Mountain grassland	0.207	0.120	$-0.223 \leq p_i - r_i \leq 0.049$	0
	Mountain savanna	0.649	0.340	$-0.497 \leq p_i - r_i \leq -0.120$	+
	Mountain conifer forest	0.107	0.480	$0.187 \leq p_i - r_i \leq 0.558$	-
	Subalpine shrubland and Meadow	0.037	0.060	$-0.067 \leq p_i - r_i \leq 0.113$	0
$\chi^2 = 32.13, df = 3, P < 0.01$					
Dominant tree	<i>Ulmus glaucescens</i>	0.559	0.260	$-0.492 \leq p_i - r_i \leq -0.105$	+
	<i>Populus davidiana</i>	0.011	0.120	$-0.016 \leq p_i - r_i \leq 0.234$	0
	<i>Juniperus rigida</i>	0.037	0.140	$-0.034 \leq p_i - r_i \leq 0.240$	0
	<i>Pinus tabulaeformis</i>	0.021	0.140	$-0.016 \leq p_i - r_i \leq 0.254$	0
	<i>Picea crassifolia</i>	0.021	0.120	$-0.028 \leq p_i - r_i \leq 0.226$	0
	Mixture	0.112	0.080	$-0.152 \leq p_i - r_i \leq 0.088$	0
	No tree	0.239	0.140	$-0.255 \leq p_i - r_i \leq 0.057$	0
$\chi^2 = 39.21, df = 6, P < 0.01$					
Tree density	<2 individuals / 400 m ²	0.324	0.140	$-0.327 \leq p_i - r_i \leq -0.040$	+
	2–4 individuals / 400 m ²	0.532	0.220	$-0.477 \leq p_i - r_i \leq -0.146$	+
	>4 individuals / 400 m ²	0.144	0.640	$0.321 \leq p_i - r_i \leq 0.670$	-
$\chi^2 = 53.44, df = 2, P < 0.01$					
Tree height	<4 m	0.351	0.240	$-0.278 \leq p_i - r_i \leq 0.056$	0
	4–6 m	0.564	0.300	$-0.638 \leq p_i - r_i \leq -0.429$	+
	>6 m	0.085	0.460	$0.198 \leq p_i - r_i \leq 0.551$	-
$\chi^2 = 29.47, df = 2, P < 0.01$					
Shrub density	<5 individuals / 100 m ²	0.165	0.680	$0.343 \leq p_i - r_i \leq 0.686$	-
	5–10 individuals / 100 m ²	0.505	0.280	$-0.400 \leq p_i - r_i \leq -0.049$	+
	>10 individuals / 100 m ²	0.330	0.040	$-0.395 \leq p_i - r_i \leq -0.184$	+
$\chi^2 = 133.67, df = 2, P < 0.01$					
Shrub height	<1.3 m	0.282	0.740	$0.289 \leq p_i - r_i \leq 0.626$	-
	1.3–1.7 m	0.537	0.220	$-0.482 \leq p_i - r_i \leq -0.151$	+
	>1.7 m	0.181	0.040	$-0.241 \leq p_i - r_i \leq -0.050$	+
$\chi^2 = 61.82, df = 2, P < 0.01$					
Distance to the nearest shrub	<0.5 m	0.245	0.220	$-0.184 \leq p_i - r_i \leq 0.134$	0
	0.5–1.5 m	0.665	0.520	$-0.333 \leq p_i - r_i \leq 0.043$	0
	>1.5 m	0.090	0.260	$0.012 \leq p_i - r_i \leq 0.327$	-
$\chi^2 = 7.70, df = 2, P < 0.05$					
Food abundance	<50 g	0.170	0.940	$0.666 \leq p_i - r_i \leq 0.874$	-
	50–100 g	0.537	0.060	$-0.595 \leq p_i - r_i \leq -0.358$	+
	>100 g	0.293	0.000	$-0.372 \leq p_i - r_i \leq -0.213$	+
$\chi^2 = 221.14, df = 2, P < 0.01$					
Altitude	>1 600 m	0.202	0.120	$-0.218 \leq p_i - r_i \leq 0.054$	0
	1 600–2 000 m	0.649	0.460	$-0.385 \leq p_i - r_i \leq 0.007$	0
	2 000–3 000 m	0.112	0.360	$0.068 \leq p_i - r_i \leq 0.427$	-
	>3 000 m	0.037	0.060	$-0.067 \leq p_i - r_i \leq 0.113$	0
$\chi^2 = 15.67, df = 3, P < 0.01$					
Distance to water resource	<500 m	0.303	0.220	$-0.245 \leq p_i - r_i \leq 0.079$	0
	500–1 000 m	0.399	0.240	$-0.327 \leq p_i - r_i \leq 0.009$	0
	>1 000 m	0.298	0.540	$0.054 \leq p_i - r_i \leq 0.429$	-
$\chi^2 = 12.26, df = 2, P < 0.01$					
Distance to human disturbance	<500 m	0.601	0.260	$-0.512 \leq p_i - r_i \leq -0.169$	+
	500–1 000 m	0.128	0.260	$-0.028 \leq p_i - r_i \leq 0.292$	0
	>1 000 m	0.271	0.480	$0.022 \leq p_i - r_i \leq 0.395$	-
$\chi^2 = 30.26, df = 2, P < 0.01$					
Distance to bare rock	<2 m	0.500	0.140	$-0.506 \leq p_i - r_i \leq -0.213$	+
	2–5 m	0.245	0.360	$-0.064 \leq p_i - r_i \leq 0.294$	0
	>5 m	0.255	0.500	$0.058 \leq p_i - r_i \leq 0.431$	-
$\chi^2 = 54.13, df = 2, P < 0.01$					

Table 2 Utilization and selection of 11 ecological factors in feeding habitat used by blue sheep during spring

Variables	Category	Actual proportion used (p) $n = 104$	Expected proportion used (r) $n = 48$	Bonferroni interval for $p_i - r_i$	Preference
Vegetation type	Mountain grassland	0.115	0.125	$-0.132 \leq p_i - r_i \leq 0.152$	0
	Mountain savanna	0.798	0.375	$-0.623 \leq p_i - r_i \leq -0.222$	+
	Mountain conifer forest	0.048	0.438	$0.203 \leq p_i - r_i \leq 0.576$	-
	Subalpine shrubland and Meadow	0.039	0.062	$-0.075 \leq p_i - r_i \leq 0.123$	0
$\chi^2 = 40.02, df = 3, P < 0.01$					
Dominant tree	<i>Ulmus glaucescens</i>	0.600	0.292	$-0.527 \leq p_i - r_i \leq -0.088$	+
	<i>Populus davidiana</i>	0.010	0.042	$-0.050 \leq p_i - r_i \leq 0.114$	0
	<i>Juniperus rigida</i>	0.019	0.083	$-0.049 \leq p_i - r_i \leq 0.177$	0
	<i>Pinus tabulaeformis</i>	0.021	0.140	$-0.021 \leq p_i - r_i \leq 0.259$	0
	<i>Picea crassifolia</i>	0.010	0.146	$-0.004 \leq p_i - r_i \leq 0.276$	0
	Mixture	0.039	0.063	$-0.083 \leq p_i - r_i \leq 0.131$	0
	No tree	0.308	0.271	$-0.249 \leq p_i - r_i \leq 0.175$	0
$\chi^2 = 30.75, df = 6, P < 0.01$					
Tree density	< 2 individuals /400 m ²	0.462	0.313	$-0.347 \leq p_i - r_i \leq -0.049$	+
	2–4 individuals /400 m ²	0.404	0.333	$-0.271 \leq p_i - r_i \leq -0.129$	+
	> 4 individuals /400 m ²	0.134	0.354	$0.036 \leq p_i - r_i \leq 0.404$	-
$\chi^2 = 10.69, df = 2, P < 0.01$					
Tree height	< 4 m	0.385	0.354	$-0.232 \leq p_i - r_i \leq -0.170$	+
	4 m–6 m	0.577	0.313	$-0.462 \leq p_i - r_i \leq -0.065$	+
	> 6 m	0.038	0.333	$0.125 \leq p_i - r_i \leq 0.464$	-
$\chi^2 = 23.36, df = 2, P < 0.01$					
Shrub density	< 5 individuals /100 m ²	0.212	0.500	$0.089 \leq p_i - r_i \leq 0.486$	-
	5–10 individuals /100 m ²	0.654	0.417	$-0.441 \leq p_i - r_i \leq -0.032$	+
	> 10 individuals /100 m ²	0.134	0.083	$-0.175 \leq p_i - r_i \leq 0.073$	0
$\chi^2 = 15.93, df = 2, P < 0.01$					
Shrub height	< 1.3 m	0.212	0.688	$0.288 \leq p_i - r_i \leq 0.663$	-
	1.3–1.7 m	0.644	0.250	$-0.581 \leq p_i - r_i \leq -0.206$	+
	> 1.7 m	0.144	0.062	$-0.199 \leq p_i - r_i \leq 0.035$	0
$\chi^2 = 50.82, df = 2, P < 0.01$					
Distance to the nearest shrub	< 0.5 m	0.154	0.125	$-0.171 \leq p_i - r_i \leq 0.113$	0
	0.5–1.5 m	0.740	0.583	$-0.356 \leq p_i - r_i \leq 0.042$	0
	> 1.5 m	0.105	0.292	$0.013 \leq p_i - r_i \leq 0.360$	-
$\chi^2 = 8.10, df = 2, P < 0.05$					
Food abundance	< 50 g	0.019	0.437	$0.243 \leq p_i - r_i \leq 0.592$	-
	50–100 g	0.096	0.125	$-0.104 \leq p_i - r_i \leq 0.162$	0
	> 100 g	0.885	0.438	$-0.634 \leq p_i - r_i \leq -0.259$	+
$\chi^2 = 41.41, df = 2, P < 0.01$					
Altitude	> 1 600 m	0.115	0.125	$-0.132 \leq p_i - r_i \leq -0.152$	+
	1 600–2 000 m	0.798	0.375	$-0.623 \leq p_i - r_i \leq -0.222$	+
	2 000–3 000 m	0.048	0.438	$0.203 \leq p_i - r_i \leq 0.576$	-
	> 3 000 m	0.039	0.062	$-0.076 \leq p_i - r_i \leq 0.122$	0
$\chi^2 = 40.02, df = 3, P < 0.01$					
Distance to water resource	< 500 m	0.606	0.104	$-0.658 \leq p_i - r_i \leq -0.345$	+
	500–1 000 m	0.337	0.292	$-0.237 \leq p_i - r_i \leq 0.147$	0
	> 1 000 m	0.057	0.604	$0.369 \leq p_i - r_i \leq 0.725$	-
$\chi^2 = 140.42, df = 2, P < 0.01$					
Hiding cover	> 25%	0.010	0.083	$-0.029 \leq p_i - r_i \leq 0.175$	0
	25%–50%	0.067	0.229	$-0.001 \leq p_i - r_i \leq 0.325$	0
	50%–75%	0.327	0.125	$-0.367 \leq p_i - r_i \leq -0.036$	+
	> 75%	0.596	0.563	$-0.248 \leq p_i - r_i \leq 0.182$	0
$\chi^2 = 24.34, df = 3, P < 0.01$					

Table 3 Characteristics of 13 ecological factors at feeding habitat used by blue sheep during winter and spring in Helan Mountain

Variables	Winter (mean \pm SE)	Spring (mean \pm SE)	Z	P
Tree density / (individuals 400 m ⁻²)	2.69 \pm 0.19	1.86 \pm 0.21	-3.351	0.001
Tree height /m	3.99 \pm 0.19	3.47 \pm 0.25	-2.104	0.035
Distance to the nearest tree /m	30.30 \pm 6.85	15.28 \pm 2.33	-0.107	0.915
Shrub density / (individuals 100 m ⁻²)	8.98 \pm 0.39	6.52 \pm 0.30	-3.601	0.000
Shrub height /m	1.42 \pm 0.30	1.41 \pm 0.04	-0.396	0.692
Distance to the nearest shrub /m	0.92 \pm 0.09	1.25 \pm 0.19	-1.976	0.048
Food abundance /g	85.89 \pm 2.71	443.46 \pm 20.65	-12.186	0.000
Slope degree /°	42.04 \pm 1.25	36.25 \pm 1.61	-2.895	0.004
Altitude /m	1 783.09 \pm 28.93	1 787.08 \pm 35.12	-0.876	0.381
Distance to water resource /m	904.49 \pm 54.93	486.10 \pm 31.01	-5.501	0.000
Distance to human disturbance /m	998.13 \pm 102.45	1 402.21 \pm 165.14	-4.073	0.000
Distance to bare rock /m	5.35 \pm 0.60	6.95 \pm 0.94	-0.419	0.675
Hiding cover /%	82.21 \pm 1.24	76.82 \pm 1.61	-3.419	0.001

Table 4 Principal component analysis (PCA) on feeding habitat during winter and spring in Helan Mountains

Variables	Winter				Spring			
	1(24.493)*	2(46.042)	3(60.416)	4(69.424)	1(28.777)	2(49.178)	3(63.271)	4(71.306)
Vegetation type	0.510	0.678	0.171	-0.228	0.589	0.526	0.397	0.181
Landform feature	0.039	0.392	-0.793	0.062	0.463	0.046	-0.794	-0.047
Dominant tree	0.508	-0.201	-0.185	0.662	0.492	-0.607	0.020	0.467
Tree density / (individuals 400 m ⁻²)	-0.403	0.631	0.331	-0.034	-0.195	0.809	0.006	0.075
Tree height /m	-0.523	0.546	0.311	-0.428	-0.400	0.826	-0.038	-0.298
Distance to the nearest tree /m	0.919	0.080	0.061	0.038	0.665	-0.602	-0.077	0.170
Shrub density / (individuals 100 m ⁻²)	0.623	-0.495	-0.192	-0.174	-0.425	-0.433	-0.040	0.304
Shrub height /m	-0.633	0.077	-0.035	0.021	-0.788	-0.106	-0.050	0.166
Distance to the nearest shrub /m	-0.127	0.414	0.518	0.428	0.761	0.144	0.297	-0.073
Food abundance /g	-0.069	-0.772	-0.037	-0.106	-0.682	-0.157	0.269	0.292
Slope direction /°	-0.158	0.259	-0.091	0.433	-0.103	0.164	0.039	0.503
Slope degree /°	-0.045	0.433	-0.793	0.063	0.425	0.086	-0.845	0.045
Altitude /m	0.751	0.564	0.145	-0.158	0.774	0.426	0.336	0.168
Distance to water resource /m	0.583	0.526	-0.040	-0.149	0.387	0.425	-0.088	0.443
Distance to human disturbance /m	0.736	0.110	0.224	-0.031	0.759	0.076	0.106	-0.185
Distance to bare rock /m	0.139	-0.267	0.707	0.380	0.149	-0.310	0.767	-0.162
Hiding cover /%	0.252	-0.597	0.154	-0.493	0.249	-0.616	0.019	-0.490

*: Cumulative proportion of variance explained /%

proximity to cliffs or bare rock (Wilson, 1981; Harris and Miller, 1995; Oli, 1996; Namgail et al., 2004). Similar results were obtained in this study but blue sheep from the present study showed no significant difference in slope direction and degree between winter and spring (Table 1). Furthermore, sheep preferred mountain savanna, a habitat dominated with *Ulmus glaucescens* within the elevation range of 1 600–2 200 m as foraging sites in the study region. The difference may be explained by the unique geographical location of the Helan Mountain, with associated ecological adaptation of the blue sheep.

The Helan Mountain region is situated within the boundary of three deserts in the northern Ningxia Hui Autonomous Region and the boundary between temperate grassland and desert (Di, 1987; Tian, 1996). The Helan Mountain region is surrounded by Yinchuan City, deserts, and the Yellow River (Liu et al., 2000). Blue sheep population from this region

is believed to be an isolated geographical population, and this situation lasted much longer (Wang and Schaller, 1996). Therefore, sheep might have created the genetic adaptation suited to the special geography and climate of Helan Mountains. In the Helan Mountains, blue sheep inhabits the various habitats, including mountain grassland, mountain savanna, mountain conifer forest, and sub-alpine shrubland and meadow (Wang et al., 1998b). The habitats of the sheep from other localities in China are composed of relatively simple vegetation (Schaller, 1977; Northwest Institute of Plateau Biology, 1989; Hu, 1994). Elevation used by sheep in the study area ranges from 1 500 to 3 000 m (Wang et al, 1998a, 1998b), whereas altitude in other distribution region is above 3 000 m (Schaller, 1977; Northwest institute of plateau biology, 1989). Blue sheep in the study area have smaller body size and lighter hair than those from other distribution region (Wang et al., 1999).

Snow leopard (*Uncia uncia*) and wolf (*Canis lupus*) are very important predators of blue sheep in the Tibetan Plateau (Schaller et al., 1988; Oli, 1994; Shrestha, 1997; Liu et al., 2003). Blue sheep select steep terrain near bare rock or cliffs to avoid predation by snow leopards (Wilson, 1981; Harris and Miller, 1995; Oli, 1996; Namgail et al., 2004). However, some carnivores, such as the snow leopard, wolf, and lynx (*Lynx lynx*) have disappeared since the 1980s in the Helan Mountains, China (Wang and Schaller, 1996). In winter, sheep still preferred foraging sites near bare rock in the study area (Table 1), which is not for avoiding predators apparently. Liu et al. (2005) suggested that bare rock can protect sheep from the cold wind, and have a thermal benefit to reduce the energy loss.

In the northern region, low temperature and high wind may increase energy demands of herbivores in winter. To maintain and reduce energy demands for survival, herbivores select their habitat strictly (McCorquodale, 2003), which is related to food availability (Frankin et al., 1975). In winter, blue sheep tended to use the areas closer to human disturbance as foraging sites (Table 1), whereas no such selection was observed in spring. There was significant difference in this variable between winter and spring (Table 3). Due to heavy snow in winter, the number of visitors apparently decreased. Furthermore, sheep had to feed in the areas closer to rangers' station, even vegetation remains as a result of absence of food resource. Therefore, it was not surprising that the sheep preferred foraging habitats close to human disturbance. Liu et al. (2005) found no significant difference in bed-site selection by sheep during winter. This result can be attributed to the above mentioned reasons. When vegetation resources and visitors began to increase gradually, sheep preferred feeding sites away from human disturbance (Table 3).

Blue sheep selected more trees and shrubs as foraging sites in winter than in spring (Table 3). This is explained more easily for obtaining more food. Food resources dropped dramatically to the lowest point in the northern regions during winter, so sheep also feed on the fallen leaves of trees and shrubs. We usually found sheep removing the snow cover to obtain fallen leaves during field observation. There are more fallen leaves available in the areas with more trees and shrubs, therefore the sheep selected such sites.

Water is one of the requirements in animal habitat selection (Ma and Jia, 1990). Blue sheep in the study area avoided feeding sites farther from water resource whether during winter or spring. In spring, the sheep selected sites closer to water. It could be explained by the fact that snow cover usually satisfies sheep's need for water resource, which was further supported by the results from other northern regions (Chang and Xiao, 1988; Zhang and Xiao, 1990). Field observation suggested that the sheep obtained water by licking snow. However, water is an important limiting factor for red deer (*Cervus elaphus alxaicus*) in habitat selection during winter (Liu et al., 2004b). The frequent use of habitat closer to water resource by red deer appears to be associated with

little snow cover in mountain grassland. Mountain savanna preferred by blue sheep ranges from 1 600 to 2 000 m, while mountain grassland ranges from 1 400 to 1 600 m (Di, 1987). The snow cover on north aspects could supply available water for sheep during winter. In spring, some studies suggested that forage species fed by ungulates may supply water (Zeng et al., 2001; Teng et al., 2004). Owing to the desert and semi-desert vegetation in Helan Mountain, the sheep prefer feeding sites closer to water resource.

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References

- Chang H, Xiao Q Z (1988). Selection of winter habitat of red deer in Dailing region. *Acta Theriol. Sinica*, 8(2): 81–88 (in Chinese)
- Chen H P, Gao Z X (1992). *Animals Ecology*. Harbin: Northeast Forestry University Press (in Chinese)
- Chen H P, Li F, Luo L Y, Wang H, Ma J Z, Li F (1999). Winter bed-site selection by red deer *Cervus elaphus xanthopygus* and roe deer *Capreolus capreolus bedfordi* in forests of northeastern China. *Acta Theriol.*, 44: 195–206
- Di W Z (1987). *Plantae Vasculares Helan Mountain*. Xi'an: Northwestern University Press, 20–22 (in Chinese)
- Encyclopedist Committee of Ningxia, *Encyclopaedia of Ningxia* (1998). Yinchuan: Ningxia People's Publishing House, 34 (in Chinese)
- Frankin W L, Mossman A S, Dole M (1975). Social organization and home range of Roosevelt elk. *J. Mammal*, 56: 102–118
- Harris R B, Miller D J (1995). Overlap in summer habitats and diets of Tibetan Plateau ungulates. *Mammalia*, 59: 197–212
- Hu J C (1994). *The Rare Mammals of Sichuan Province*. Chengdu: Sichuan Science and Technology Press (in Chinese)
- Jiang Z G (2004). *Principles of Animal Behavior and Techniques of Species Conservation*. Beijing: Science Press (in Chinese)
- Julien-Laferrière D (1999). Foraging strategies and food partitioning in the neotropical frugivorous mammals *Caluromys philander* and *potos flavus*. *J. Zool. Lond.*, 247: 7–80
- Liu C G., Zheng S W, Ren J R (2003). Research foods and foods source about snow Leopard (*Panthera uncia*). *J. Shaanxi Normal University (Natural Science Edition)*, 31: 154–159 (in Chinese)
- Liu Z S, Cao L R, Wang X M (2004). Management and conservation of Blue sheep population in Helan Mountain. *Chinese Wildlife*, 25(1): 56 (in Chinese)
- Liu Z S, Cao L R., Wang X M, Li T, Li Z G (2005). Winter bed-site selection by blue sheep (*Pseudois nayaur*) in Helan Mountains Ningxia, China. *Acta Theriol. Sinica*, 25(1): 1–8 (in Chinese)
- Liu Z S, Cao L R, Zhai H, Hu T H, Wang X M (2004). Winter habitat selection by red deer (*Cervus elaphus alxaicus*) in Helan Mountain, China. *Zool. Res.*, 25(5): 403–409 (in Chinese)
- Liu Z X, Sheng H L, Li Y G, Wang S D, Zhao D H, Du H P (2000). The current status and conservation of the isolated population of alpine musk deer (*Moschus chrysogaster*) in Helan Mountain. *Acta Ecologica Sinica*, 20(3): 463–467 (in Chinese)
- Ma J Z, Jia J B (1990). *Wildlife Management*. Harbin: Northeast Forestry University Press, 25 (in Chinese)
- Marcum C L, Loftsgaarden D O (1980). A nonmapping technique for studying habitat preferences. *J. Wildl. Manage.*, 44: 963–968
- Mautz W W (1978). Sledding on a bushy hillside: The fat cycle in deer. *Wildl. Soc. Bull.*, 6: 88–90

- McCorquodale S M (2003). Sex-specific movements and habitat use by elk in the cascade range of Washington. *J. Wildl. Manage.*, 67(4): 729–741
- Nagy K A (1987). Field metabolic rate and food requirement scaling in mammals and birds. *Ecol. Monogr.*, 57: 111–128
- Nagy K A (1994). Field bioenergetics of mammals: what determinates field metabolic rates? *Aust. J. Zool.*, 42: 43–53
- Namgail T, Fox J L, Bhatnagar Y V (2004). Habitat segregation between sympatric Tibetan argali *Ovis ammon hodgsoni* and blue sheep *Pseudois nayaur* in the Indian Trans-Himalaya. *J. Zool. Land.*, 262: 57–63
- Northwest Institute of Plateau Biology, CAS (1989). The economic animals of Qinghai Province. Xining: Qinghai People's Publishing House (in Chinese)
- Oli M K (1994). Snow leopards and blue sheep in Nepal: densities and predator: prey ratio. *J. Mammal.*, 75(4): 998–1004
- Oli M K (1996). Seasonal patterns in habitat use of blue sheep *Pseudois nayaur* (Artiodactyla, Bovidae) in Nepal. *Mammalia*, 60(2): 187–193
- Parker K L, Robbins C T (1984). Thermoregulation in mule deer and elk. *Can. J. Zool.*, 62: 1409–1422
- Schaller G B (1997). Mountain Monarchs: Wild Sheep and Goats of the Himalaya. Chicago: University of Chicago Press
- Schaller G B, Ren J R, Qiu M J (1988). Status of the snow leopard *Panthera uncia* in Qinghai and Gansu Provinces, China. *Biol. Conserv.*, 45: 179–194
- Schmitz O J (1991). Thermal constrains and optimization of winter feeding and habitat choice in white-tailed deer. *Holarct. Ecol.*, 14: 104–111
- Shrestha T K (1997). Mammals of Nepal. Kathmandu: P. K. Printers
- Sun R Y (2001). The Principles of Animal Ecology. 3rd ed. Beijing: Beijing Normal University Press (in Chinese)
- Teng L W, Liu Z S, Song Y L, Zeng Z G (2004). Forage and bed sites characteristics of Indian muntjac (*Muntiacus muntjak*) in Hainan Island, China. *Ecological Research*, 19(6): 675–681
- Tian L S (1996). Vegetation of East Slope in Helan Mountain. Huhehaote: Inner Mongolia University Press (in Chinese)
- Wang X M, Li M, Tang S X, Liu Z X (1998a). A preliminary study of some characters of blue sheep population ecology in spring. *Acta Theriol. Sinica*, 18(1): 27–33 (in Chinese)
- Wang X M, Li M, Tang S X, Liu Z X, Li Y G (1999). The study of resource and conservation of artiodactyls in Helan Mountain. *Chinese J. Zool.*, 34(5): 26–29 (in Chinese)
- Wang X M, Liu Z X, Xu H F, Li M, Li Y G (1998b). The blue sheep population ecology and its conservation in Helan Mountain, China. *Chinese Biodiversity*, 6(1): 1–5 (in Chinese)
- Wang X M, Schaller G B (1996). Status of large mammals in Inner Mongolia, China. *J. East China Normal. Univ. (Special Issue of Mammals)*, 6: 94–104
- Wilson P (1981). Ecology and habitat utilization of blue sheep *Pseudois nayaur* in Nepal. *Biol. Conserv.*, 21: 55–74
- Zeng Z G, Song Y L, Zhong W Q, Gong H S, Zhang J, Dang G D (2001). Food habits of golden takin. *Chinese J. Zool.*, 36(3): 36–44 (in Chinese)
- Zhang M H, Xiao Q Z (1990). A study on feeding and bedding habitat selection by red deer in winter. *Acta Theriol. Sinica*, 10(3): 175–183 (in Chinese)