Food habits of blue sheep, *Pseudois nayaur* in the Helan Mountains, China

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Received 5 April 2005; Accepted 8 January 2007

A b s t r a c t . Food habits of blue sheep, *Pseudois nayaur* in the Helan Mountains of China were studied from November 2003 to October 2004 to better understand diet composition, seasonal variation, and feeding habitat preference. Blue sheep consumed 41 plant species that contributed >0.01% to the diets. During autumn, winter, and spring, primary species consumed were *Stipa* spp., *Ulmus pumila*, and *Poa* spp. Blue sheep also showed the different preference for these plant species. Graminoids were the largest proportion of the diet (36.7–58.8%) throughout the year, followed by the tree and shrub categories. Sedges were the smallest proportion of the diet (0.7–7.1%). Among the four habitat types, blue sheep showed pronounced preference for montane woodland steppe. Differences in the diets of Helan Mountains blue sheep from those of blue sheep elsewhere may reflect adaptations for geographical range, vegetation, and other factors.

Key words: ungulates, diet composition, habitat preference, foraging

Introduction

Information of food habits is an important component of an animal's life history. Knowledge of diet selection is fundamental to understanding many aspects of ungulate ecology (H o b b s et al. 1983). The diets of ungulates can be viewed as the result of decisions made on several hierarchical scales, from foraging habitat down to parts of individual plants (W a r d & S a l t z 1994, B a i l e y 1996, M y s t e r u d et al. 1999). Diet selection is influenced by body size, rumen anatomy, social structure, and energy requirements (B e l l 1971, H o f m a n n & S t e w a r t 1972, G e i s t 1974, J a r m a n 1974, I l l i u s & G o r d o n 1987, J a n i s & E h r h a r d t 1988, H o f m a n n 1989). In addition, ungulates adapt to changes in availability and quality of forage in seasonal environments by choosing among plant species (B u f a l h o et al. 2001).

The Jarman-Bell principle (J a r m a n 1974) can explain the relationships between body size and diet selection of ungulates. Large-bodied species can eat poor-quality but abundant foods including roughage grasses. Small-bodied species need high-quality foods, such as shoots, browse, and fruits, to maintain their relatively high metabolism. Intermediate or mixed feeders feed on browse and grasses in different proportions, based on seasonal changes in quality.

Blue sheep (*Pseudois nayaur*) are medium-sized ungulates which are distributed widely across the Tibetan plateau and surrounding mountain areas (S c h a l l e r 1977). Most studies from the Tibetan Plateau and Himalaya region have indicated that the blue sheep are intermediate feeders, subsisting mainly on graminoids (S c h a l l e r & G u 1994,

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Schaller 1998, Awasthi et al. 2003, Mishra et al. 2004, Shrestha et al. 2005). Harris & Miller (1995) showed that blue sheep in Qinghai Province, on the Tibetan Plateau in China consumed a high proportion of sedge species, including *Carex* and *Kobresia*. Their study was mostly restricted to the summer season. Because the availability and quality of forage in temperate regions change seasonally, we felt it useful to conduct a year-long, relatively intensive study of the diets of blue sheep in Helan Mountains. Studies of blue sheep diets are useful not only in providing insight into potential competition with other ungulates and influences that the sheep may have on forest ecosystems, but also in providing initial steps towards understanding resources used (Bookhout 1996, Parker & Bernard 2005).

The eastern boundary of blue sheep's distribution appears to be the Helan Mountain region of China (Wang & Liu 1999). The Helan Mountains are located at the boundary between temperate grassland and desert. As a result of its geographical location, the region is recognized as an important site for biodiversity conservation in China (Wang 1994). The blue sheep (*P. n. szechuanensis*) population in the Helan Mountains is believed to be an isolated geographical population (Wang & Schaller 1996), whereas its distribution in other areas in China is continuous. Within the Helan Mountains, blue sheep inhabit montane grasslands, montane woodland steppe, montane conifer forest, sub-alpine shrublands, and meadows (Liu et al. 2005a,b). In contrast, blue sheep habitats in their main range on the Tibetan Plateau are mostly alpine steppe and fell-fields. Because of the uniqueness of blue sheep habitats in the Helan Mountains, we are interested in knowing whether diet composition would reflect this relatively diverse environment.

The aim of this study was to assess the diet composition of blue sheep, analyze variation across different seasons at the plant category and plant species level, compare the diet in relation to plants available, and determine the feeding habitat preference of blue sheep.

Study Area

The Helan Mountains (38°21'–39°22' N, 105°44'–106°42' E) are located between the eastern Yinchuan Plain in Ningxia and the western Alashan Plateau in Inner Mongolia. The range stretches > 200 km from north to south and 20–40 km from east to west. Elevations within the area used by blue sheep vary from 2 000 to 3 000 m. Climate is characterized by cool and dry conditions with mean annual temperature of -0.9 °C. Annual rainfall averages 420 mm, with most rainfall occurring during summer. Snow depth averages 4.52 cm during winter in 2003 (Liu et al. 2005a).

Four vegetation types are found in the study area: (1) montane grassland dominated by *Stipa breviflora* and *Ajania fruticulosa*, interspersed with *Ptilagrostis pelliotii*, *Oxytropis aciphylla*, *Convolvulus gortschakovii*, and *Salsola laricifolia*; (2) montane woodland steppe, sparsely vegetated with Siberian elm (*Ulmus pumila*) and large patches of *Prunus mongolica*, and locally with the grasses *Stipa grandis* and *S. bungenana*; (3) montane conifer forest, dominated by Qinghai spruce (*Picea crassifolia*) and Chinese pine (*Pinus tabulaeformis*); (4) sub-alpine shrubland and meadow characterized by *Salix cupularis*, *Caragana jubata*, *Kobresia* spp., *Polygonm viviparum*, and *Arenaria* spp.

Wolves (*Canis lupus*) and leopards (*Panthera pardus*) have been extinct since the 1980's (Wang & Schaller 1996). In addition to blue sheep, other ungulates in the study area include red deer (*Cervus elaphus alxaicus*) and musk deer (*Moschus chrysogaster*). Blue sheep and red deer are quite common, but musk deer have become quite rare. Our surveys

conducted during 2003–05 yielded an estimated population size for blue sheep of about 10 000 (Liu et al., unpublished data). Pastoralists formerly grazed approximately 100 000 sheep and goats in the Helan Mountains, but no livestock have used the area since 1997 (Wang et al. 2005).

Methods

Forage availability and diet

We established 32 line transects to collect information on forage availability. Transects ranged in length from 2.4 to 42.5 km for a total of 469.2 km. Those transect traversed the entire study area from east to west and covered all the habitat types. A total of 10m ×10m 390 plots were randomly selected on these transects from different vegetation types, of which we sampled 72 in spring (11th April–20th June), 85 in summer (21st June–10th August), 139 in autumn (11th August–10th October), and 94 in winter (11th October–10th April) (Encyclopedist Committee of Ningxia 1998). Availability of tree and shrub species was determined by the twig-count method (Schafer 1963). Available biomass of browse was estimated by weighing the edible part of a single twig below 2 meters and multiplying that by the number of twigs available within each of the 390 quadrats once in each of the 4 seasons (Shafer 1963, Bookhout 1996). Species were recorded and biomass of grasses and forbs were weighed in five 1 m ×1 m quadrats once in each season. Aboveground biomass available to blue sheep was estimated by clipping all grass species in five 1 m × 1 m plots. All plant samples were air dried and later oven dried for 24 hours at 60 °C to obtain dry weights.

Blue sheep diets were recorded by direct observation (Bookhout 1996). We searched for sheep herds, selecting one individual randomly from the herd. Direct observations were carried out from a distance of 10–50 m using 8×42 Kowa binoculars and a 40–60 zoom spotting scope. For each plant species, we quantified intake by the number of bites of that species. Forage intake for each plant species was estimated by multiplying bite counts by the average mass per bite. Mass per bite was estimated from the average weight of plants grazed by the tamed blue sheep in Xining Zoo and Yinchuan Zoo. Samples of plant species that could not be positively identified in the field were taken to the Helan Mountain Nature Reserve headquarters in Yinchuan for identification by specialists from Department of Ecology and Environment Science, Inner Mongolia University.

Food habits were also determined by examining feeding sites (Knowlton 1960, Bookhout 1996). After locating a herd, we waited until it had moved away. We then visited the feeding area, and recorded recently grazed or browsed plants in the exact location in which the herd was observed were counted. One instance of use was defined as a bite of a stem or leaf from grasses or forbs, of a twig or leaf from trees or shrubs. We defined a feeding site as one with ≥50 instances of uses. Biomass consumption was defined as the sum of the products of mean bite size based on the tamed blue sheep and the number of observed bites for each species. For blue sheep flushing before we could approach closely enough to observe the plant species being eaten, we identified forage sites by fresh bite marks on plants.

Habitat availability and use

We used the same 390 plots to estimate the relative availability of each habitat category. Proportional habitat availability was equated to the proportion of these plots in each habitat

type in 390 plots. Whenever we observed the sheep feeding or examined the feeding sites, we determined the habitat type of feeding activities. Habitat selection was determined by comparing the habitat use with availability as described by N e u et al. (1974) using a chi-square goodness-of-fit test and the Bonferroni confidence intervals to define preference and avoidance of each habitat type.

D a t a a n a l y s e s

Because there were no significant difference in the rank order of vegetation selected from the direct observation and feeding sites examination data sets (Mann-Whitney *U*; Z=-1.059, P=0.36), we pooled the two sets of data. We used Ivlev's Electivity index (I v l e v 1961) to describe electivity for each plant species:

$$E_i = \frac{r_i - p_i}{r_i + p_i}$$

where (*r*) is proportion of diet made up by the species and (*p*) is proportion of the available sample made up by the species. To determine whether the food preference of blue sheep changed during the year, the electivity index was also calculated separately for each season.

To simplify both diet description and analyses, and allow for comparison with other blue sheep diet studies, we assigned all forage species to one of the following broad categories: trees; shrubs or browse, graminoids (Gramineae); sedges (Cyperaceae); and forbs (other dicotyledonous herbs, including monocotyledonous plants such as Liliaceae). Seasonal diet variations in diet were tested using a Kruskal-Wallis *H* test. Chi-square tests were used to test pairwise differences in the consumption of plants between seasons.

Results

Blue sheep consumed 137 plant species from 41 families. We list the 41 plant species contributing > 0.01% to seasonal proportion of diets in Table 1. These included 2 woody plant species, 10 shrubs, 10 graminoids, 2 sedges and 17 forbs. *Stipa* spp. was consumed at the highest rate, followed by *Ulmus pumila* and *Poa* spp. In winter, as much as one-fourth of the blue sheep diet consisted of tree species *Ulmus pumila*, whereas the proportion of this species decreased to approximately one-seventh of the diets during spring and autumn, the lowest proportion (7.62%) being found in summer. *Stipa* spp. predominated in diets during summer and autumn, accounting for >30% of the total biomass consumed, and one-fourth during winter and spring. Although *Poa* spp. made up only 7% of the diet during winter and spring, it increased to about 15% during summer and autumn.

During autumn, winter, and spring, *Ulmus pumila* was preferred whereas it was avoided in summer (Table 1). Of the shrubs, *Lespedeza* spp. was preferred in all seasons. Browse species, such as *Dasiphora mandshurica* and *D. parvifolia*, were preferred in spring and winter, whereas they were avoided in summer and autumn. Graminoid species used significantly more than expected included *Poa* spp., *Bromus inermis*, *Roegneria* spp., and *Stipa* spp. during each season. The only Graminoid species used less than available was only *Setaria* spp. throughout the year. Of the sedges, *Kobresia* spp. and *Carex* spp. were preferred in winter, whereas they were avoided during other seasons. Forbs, such as *Ceratoides lateens*, *Kochia prostrate*, *Melissitus ruthenica*, *Madicago* spp., *Seseli intramonglicum*, *Allium* spp. were preferred throughout the year, whereas *Bassia dasyphylla*, *Salsola* spp., *Astragalus* spp., *Ajania fruticulosa*, *Artemisia* spp. were avoided in all seasons.

Table 1. Seasonal availability (r), use (p), and selectivity index (E) of plants recorded as eaten by blue sheep. This table is simplified in that only forage species contributing >0.01% to seasonal recorded diets of blue sheep are mentioned. Those contributing less are combined into the others category. The "—" symbol signifies under 1% contribution during that season.

Forage Species	Spring			Summer			Autumn			Winter		
	r_i	p_i	E_i	r_i	p_i	E_i	r_i	p_i	E_i	r_i	p_i	E_i
Trees												
Ulmus pumila	14.17	10.36	0.16	7.62	9.15	-0.09	15.42	8.09	0.31	26.37	12.85	0.34
Cotoneaster spp.	2.58	4.88	-0.31	—	3.25	-1.00	—	3.18	-1.00	—	4.36	-1.00
Shrubs												
Berberis spp.	3.49	5.11	-0.19	1.25	4.93	-0.60	2.57	5.84	-0.39	4.83	5.32	-0.05
Spiraea spp.	1.05	7.04	-0.74	—	6.49	-1.00	—	6.42	-1.00	2.53	7.16	-0.48
Rosa xanthina	0.53	3.54	-0.74	—	4.81	-1.00	0.61	4.05	-0.74	0.24	2.74	-0.84
Potentilla mandshurica	3.17	1.45	0.37	1.52	1.67	-0.04	3.28	1.51	0.37	0.94	1.26	-0.15
P. parvifolia	7.62	4.93	0.21	4.08	4.12	0.00	8.59	4.05	0.40	2.51	4.50	-0.28
Prunus monglica	3.42	5.15	-0.20	—	5.66	-1.00	—	5.47	-1.00	4.27	5.22	-0.10
P. tomentosa	—	2.76	-1.00	—	1.89	-1.00	—	1.15	-1.00	0.54	1.99	-0.57
Caragana spp.	2.81	3.88	-0.16	1.20	3.96	-0.53	2.34	3.71	-0.23	3.51	3.62	-0.02
Lespedeza spp.	2.58	1.26	0.34	1.95	1.28	0.21	2.21	1.17	0.31	2.94	1.05	0.47
Leptodermis ordosica	0.22	1.30	-0.71	—	1.17	-1.00	—	1.37	-1.00	0.28	1.24	-0.63
Graminoids												
Aristida adscensionis	0.24	0.33	-0.16	0.88	0.42	0.35	0.81	0.45	0.29	0.14	0.33	-0.40
Poa spp.	7.35	5.36	0.16	15.46	5.06	0.51	14.08	5.70	0.42	7.64	4.61	0.25
Bromus inermis	0.14	0.04	0.56	0.18	—	1.00	0.17	0.02	0.79	0.12	—	1.00
Roegneria spp.	3.27	2.07	0.22	6.84	2.15	0.52	5.18	2.20	0.40	2.22	1.32	0.25
Clinelymus spp.	1.57	1.43	0.02	2.40	1.62	0.19	1.68	1.28	0.14	0.92	1.74	-0.31
Leymus secalinus	0.81	0.07	0.84	—	0.07	-1.00	—	0.06	-1.00	—	0.05	-1.00
Stipa spp.	23.54	15.92	0.19	30.62	17.18	0.28	30.17	16.02	0.31	25.11	14.39	0.26
Achnatherum spp.	0.12	0.14	-0.08	0.64	0.16	0.60	—	0.15	-1.00	0.19	0.34	-0.28
Ptilagrostis spp.	0.54	0.35	0.21	1.82	0.41	0.63	0.64	0.37	0.27	0.38	0.54	-0.17
Setaria spp.	0.15	0.17	-0.06	—	0.19	-1.00	—	0.19	-1.00	—	0.27	-1.00

Table 1. (continued)

Sedges												
Kobresia spp.	0.25	0.55	-0.38	1.17	0.83	0.17	0.28	0.72	-0.44	0.21	0.50	-0.41
Carex spp.	3.47	4.13	-0.08	5.94	4.25	0.17	0.88	3.84	-0.63	0.52	4.67	-0.80
Forbs												
Polygonm sibiricum	0.12	0.05	0.41	—	0.09	-1.00	0.22	0.11	0.33	—	0.07	-1.00
P. viviparum	0.28	0.24	0.08	0.13	0.37	-0.48	0.17	0.32	-0.31	—	0.19	-1.00
Ceratoides latens	0.45	0.27	0.25	0.51	0.46	0.05	0.86	0.49	0.27	1.49	0.35	0.62
Kochia prostrata	0.31	0.21	0.19	0.38	0.27	0.17	0.97	0.15	0.73	0.75	0.12	0.72
Bassia dasyphylla	—	0.25	-1.00	—	0.29	-1.00	0.14	0.32	-0.39	—	0.27	-1.00
Salsola spp.	0.26	1.56	-0.71	—	1.43	-1.00	—	2.33	-1.00	0.34	1.35	-0.60
Ptilotrichum canescena	0.35	0.87	-0.42	0.82	0.95	-0.07	0.37	0.91	-0.42	1.40	0.75	0.30
Melissitus ruthenica	0.54	0.07	0.77	0.91	0.11	0.78	0.60	0.07	0.79	0.82	0.07	0.84
Madicago spp.	0.12	0.04	0.50	0.17	0.05	0.55	0.15	0.05	0.50	0.12	0.03	0.60
Melilotus spp.	0.57	0.50	0.41	—	0.52	-1.00	—	0.49	-1.00	—	0.41	-1.00
Astragalus spp.	0.25	0.30	-0.09	—	0.35	-1.00	0.15	0.35	-0.40	—	0.22	-1.00
Seseli intramonglicum	2.55	0.85	0.50	5.48	1.34	0.61	3.21	1.42	0.39	3.62	1.47	0.42
Amethystea coerulea	0.15	0.04	0.58	—	0.04	-1.00	—	0.02	-1.00	—	—	0.00
Heteropappus altaicus	1.85	1.84	0.00	—	1.93	-1.00	—	2.05	-1.00	1.20	2.01	-0.25
Ajania fruticulosa	2.82	3.55	-0.11	—	3.67	-1.00	—	3.85	-1.00	—	3.73	-1.00
Artemisia spp.	1.52	5.67	-0.58	—	7.15	-1.00	—	7.04	-1.00	—	6.29	-1.00
Allium spp.	1.45	0.13	0.84	4.62	0.16	0.93	1.71	0.16	0.83	1.05	0.05	0.91
Others	3.32	17.73		3.41	19.19		2.54	22.88		2.80	19.86	
Total	100	100		100	100		100	100		100	100	

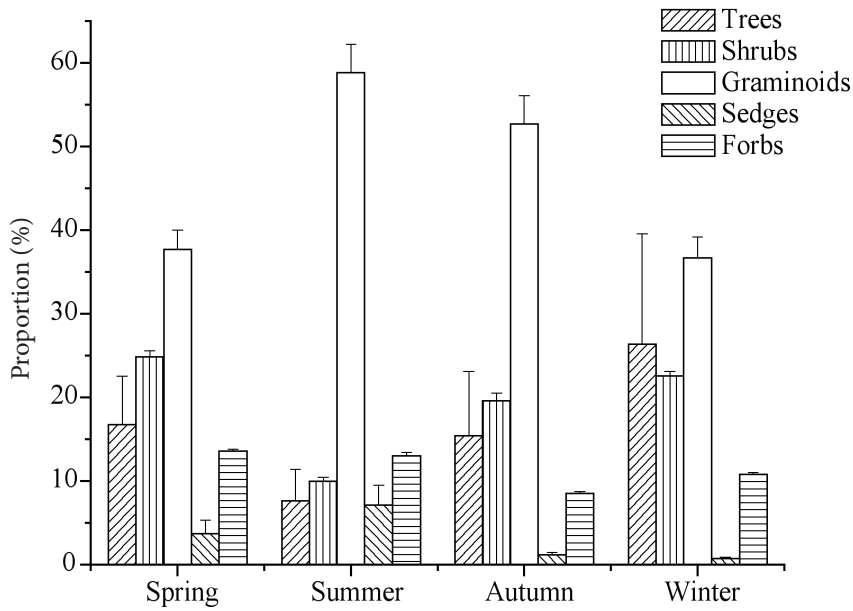

Fig. 1. Proportion of different forage categories (±SE) in the diets of blue sheep during different seasons.

Table 2. Habitat preference of blue sheep during foraging periods in the Helan Mountains (* preference abbreviation: +, forage species utilized significantly more than available based on the Bonferroni confidence intervals; 0, forage species utilized in proportion to their availability; –, forage species utilized significantly less than available).

Seasons	Habitat types	Actual proportion used	Expected proportion used	Bonferroni confidence interval	Preference*
Spring	Montane grassland	0.115	0.125	-0.132 7≤p_i-r_i≤0.152 7	0
	Montane woodland steppe	0.798	0.375	-0.623 5≤p_i-r_i≤-0.222 5	+
	Montane conifer forest	0.048	0.438	0.203 5≤p_i-r_i≤0.576 5	–
	Subalpine shrubland and Meadow	0.039	0.062	-0.075 7≤p_i-r_i≤0.123 7	0
Summer	Montane grassland	0.092	0.133	-0.095 6≤p_i-r_i≤0.177 6	0
	Montane woodland steppe	0.780	0.362	-0.611 9≤p_i-r_i≤-0.224 1	+
	Montane conifer forest	0.055	0.429	0.193 9≤p_i-r_i≤0.554 1	–
	Subalpine shrubland and Meadow	0.073	0.076	-0.108 0≤p_i-r_i≤0.114 0	0
Autumn	Montane grassland	0.060	0.157	-0.041 7≤p_i-r_i≤0.235 7	0
	Montane woodland steppe	0.812	0.333	-0.667 1≤p_i-r_i≤-0.290 9	+
	Montane conifer forest	0.077	0.412	0.152 0≤p_i-r_i≤0.518 0	–
	Subalpine shrubland and Meadow	0.051	0.098	-0.068 8≤p_i-r_i≤0.162 8	0
Winter	Montane grassland	0.207	0.120	-0.223 6≤p_i-r_i≤0.049 6	0
	Montane woodland steppe	0.649	0.340	-0.497 7≤p_i-r_i≤-0.120 3	+
	Montane conifer forest	0.107	0.480	0.187 6≤p_i-r_i≤0.558 4	–
	Subalpine shrubland and Meadow	0.037	0.060	-0.067 7≤p_i-r_i≤0.113 7	0

Although there was no significantly seasonal variation in the forage categories used by blue sheep(χ^2=0.58, df=3, P=0.90), the graminoid category accounted for a large proportion

of blue sheep's diet throughout the year, peaking in summer (Fig. 1). Shrubs and trees made up the second largest proportion except during summer. The sedge category only contributed less than 8%. Trees were used significantly more in winter than in summer (χ^2=89.89, df=4, P<0.01). Shrubs were used significantly more in spring than in summer (χ^2=42.33, df=4, P<0.01).

Habitats used during foraging differed from that available (spring χ^2=86.71, df=3, P<0.01; summer χ^2=89.54, df=3, P<0.01; autumn χ^2=111.69, df=3, P<0.01; winter χ^2=120.83, df=3, P<0.01) (Table 2). Blue sheep used all four habitat types for feeding, but during all four seasons they showed a strong preference for montane woodland steppe whereas montane conifer forest was used less than expected. Montane grassland and sub-alpine shrubland and meadow were used in proportion to their availability in all seasons.

Discussion

Graminoid species are important for blue sheep throughout most of their range (Schaller 1998, Awasthi et al. 2003, Mishra et al. 2004, Shrestha et al. 2005). Graminoids constituted 58.8% of summer diets and 36.7% of winter diets in the Helan Mountains. Proportions of graminoids reported in blue sheep diets from other study areas varied between 10% and 80% (Schaller 1998, Mishra et al. 2004, Shrestha et al. 2005). In the Trans-Himalaya, graminoid proportion in diets was high (80%) in summer because the growing season for vegetation is restricted to the few summer months in the arid region (Shrestha et al. 2005). Differing proportions of graminoids in diets of blue sheep could result from variation in vegetation composition of these regions. Each region also has distinct plant formation affected by the elevation, precipitation, sunlight, temperature, and other factors (Awasthi et al. 2003).

The diet of blue sheep in our study area included the tree species, *Ulmus pumila* and *Cotoneaster* spp., which have not been recorded in any other distribution region (Harris & Miller 1995, Schaller 1998, Awasthi et al. 2003, Mishra et al. 2004, Shrestha et al. 2005). The great difference may be partly explained by the geographical location of the Helan Mountain, with associated ecological adaptation of the blue sheep. Trees are absent in blue sheep distribution regions of Tibetan Plateau.

According to Hofmann (1989), intermediate feeders choose a mixed diet, and show a remarkable degree of forage selectivity. They show a short-term or seasonal adaptation to changes in forage quality. Our results confirmed that blue sheep in the Helan Mountains are intermediated feeders, consuming different proportion of plant species and categories throughout the whole year. The food habits of blue sheep in our study did show a seasonal shift. In winter, the woody species (including trees and shrubs) formed nearly 50% of the recorded diet, whereas they accounted for only 17% of the diet in summer. Seasonal variation in food habits have also been documented from other areas in China (Harris & Miller 1995, Schaller 1998).

Selectivity may be result from nutritional requirements, the need to decrease fiber intake, and maximization of protein intake in order to increase digestibility (Harborne 1991, Tixier & Duncan 1997, Klaus-Hügi et al. 1999). Plant species differ in protein and fiber content (Klaus-Hügi et al. 1999), which also influence an animal's choice. Our results indicated that plant nutritional value could influence the forage species eaten by the blue sheep. For example, blue sheep preferred *Ulmus glaucescens* which typically contain more protein (12.52%) and less fiber (14.99%) (Liu et al. unpublished data). Forbs

and shrubs can provide higher quality nutrients than grasses or graminoids (S c h a l l e r 1998), however, the graminoid-dominated diet did not agree with it. The result may be explained by the palatability and availability of graminoids in the Helan Mountains.

Blue sheep in the Helan Mountains typically favor habitats dominated by *Ulmus glaucescens* and *Populus davidiara* during winter and spring (L i u et al. 2005b). Similarly, in our study, blue sheep preferred montane woodland steppe with high abundance of *Ulmus glaucescens* and *Stipa* spp. Although *Ulmus glaucescens* formed 26% of blue sheep diet in winter, for the other months it formed 7 and about 14% of the diet. However, the proportion of *Stipa* spp. in diets is always much higher (>23%) than that of other forage species throughout the study period. Foraging habitat selection of blue sheep in the Helan Mountains was probably related to the availability of *Stipa* spp. in the habitat.

A c k n o w l e d g e m e n t s

This research was supported financially by the National Nature Science Foundation of China (No.30470231, 30670309), Trans-Century Training Programme Foundation for the Talents by the State Education Commission, the State's tenth five-year "211 project" -supported key academic discipline program of ECNU, Chinese Postdoctoral Science Foundation (No. 2005037496). We thank the personnel of Ningxia and Inner Mongolia Helan Mountain National Nature Reserves for invaluable help. Special thanks to Mr. Jianhai H o u and Mr. Zhenshan M a for permission to conduct the fieldwork. Thanks to Prof. Zongyuan Z h u and Dr Cunzhu L i a n g of Inner Mongolia University for help with plant identification. We are very grateful to Dr Richard B. H a r r i s for his helpful comments and English improvement on the revision of manuscript.

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