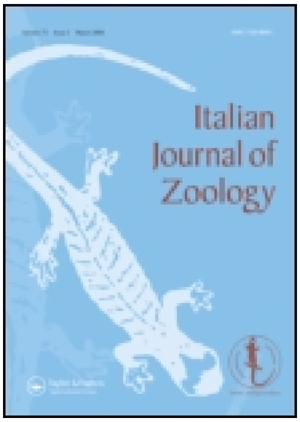

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Seasonal diet of Khulan (Equidae) in Northern Xinjiang, China

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Abstract

The natural diet of khulan (*Equus hemionus* Pallas, 1775) was observed over the period of a year in northern Xinjiang, China, using faecal analysis. The winter food habits of the khulan and domestic sheep were also compared. The faecal analysis method demonstrated that khulan ate 46 species of plants during the year. Diets varied seasonally, with the widest food breadth in winter (0.43) and the least in summer (0.10). Chenopodiaceae and Poaceae were major foods of khulan, and during spring, forbs were quite important as well. In contrast, *Stipa glareosa* was preferred during spring and summer, but consumed less during autumn and winter. Shrubs dominated the khulan's natural diet during autumn and winter. The dietary overlap between khulan and domestic sheep was 48.3% during winter. As a grazer living in arid environments, khulan ate more shrubs than other equids living in grassland, and their winter diet was an adaptation to avoid competition from domestic sheep. The number of sheep in the reserve should be reduced to lessen the pressure of competition.

Keywords: Equus hemionus*, microhistological analysis, competition,* Ovis aries

Introduction

Mongolian khulan, khulan or Mongolian wild ass, are the largest surviving subpopulation of the Asiatic wild ass (*Equus hemionus* Pallas, 1775). The former range of the khulan between the seventeenth and the middle of the nineteenth century encompassed the greater parts of Mongolia, small areas of Siberia and northeast China, west Inner Mongolia and north Xinjiang, China (Harper 1945). Due to the loss of habitat as a result of human settlement and developmental activities, poaching and competition with domestic livestock, the total population of khulan has declined significantly. Now the range of the khulan is located only in the Gobi region of southern Mongolia and northern China (Feh et al. 2002). The species is listed as rare in the China Red Data Book of Endangered Animals (Zheng 1998), and classified as a Category I protected species since 1989. *Equus h. hemionus* is also included in Appendix I of CITES and listed as EN by IUCN (Moehlman et al. 2008). Scientists believe that the population of khulan in Inner Mongolia is probably sustained only by migration from Mongolia (Wang & Schaller 1996; Reading et al. 2001), while the Kalamaili Mountain Ungulate Nature Reserve is the most important refuge of khulan in China, with a population of as many as 3300–5300 (Chu et al. 2009).

An animal's diet is a fundamental aspect of its ecological niche, and quantifying diets has long been and continues to be one of the first steps in studying a species' basic ecology (Sih & Christensen 2001). To date, the feeding ecology of khulan has not been analysed in detail, and early studies were mostly descriptive (Feh et al. 2002) or restricted to autumn (Hu et al. 1998; Lengger et al. 2007; Liu et al. 2008) and the cold seasons (Chu et al. 2008). The major purpose of this study was to give preliminary results about quantitative botanical analysis of forage samples obtained from faeces, and compare their diet with that provided by their range over all seasons. Herdsmen with domestic animals stay in the nature reserve mostly during winter. Domestic sheep

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(*Ovis aries*) are the main livestock animals, which have a considerable impact on the khulan's diet and feeding behaviour, in contrast to the few domestic horses (*Equus caballus*) and camels (*Camelus bactrianus*) (Chu et al. 2008) also in the region. Therefore, we wanted to determine the dietary overlaps between khulan and domestic sheep in winter. We hope this research on the diet of the khulan is useful for reserve managers and will be used as supportive information for management of this species.

Materials and methods

Study area

Fieldwork was conducted from September 2006 to August 2007 in the Kalamaili Mountain Ungulate Nature Reserve (KNR) (44°36′–46°00′N, 88°30′–90°03′E). The reserve is located in the eastern Junggar Basin, Xinjiang, China, with an area of 18,000 km^2 (Chu et al. 2009). For about 3–5 months in winter (from November to March), herder camps are allowed at established locations, and are used by about 2000 Kazakh shepherds with ~200,000 head of livestock (mostly domestic sheep); domestic horses and camels are rare in the reserve, and no goat (*Capra hircus*) or donkey (*Equus asinus*) species live there (Ge et al. 2003; Chu et al. 2008). National Highway 216 traverses the reserve (Figure 1). In winter, snow cover often limits mobility within the reserve. Twice as large as Gobi B in size, KNR lies only 200 km west of the Gobi B National Park in Mongolia. Both ecosystems are very similar.

The climate of KNR is continental, which is characterized by long cold winters (October to early April) and hot summers (mid May to September).

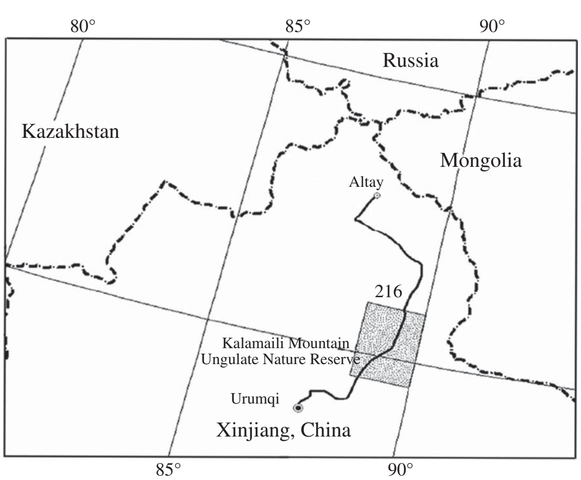

Figure 1. Location of Kalamaili Mountain Ungulate Nature Reserve.

Most precipitation is noted during winter, spring and early summer. From 2000 to 2007, the average January temperature was –24.3°C with an absolute minimum of –45°C and a maximum of +1.4°C. July's average temperature was +20.5°C with an absolute maximum of +38.4°C and a minimum of +6.0°C. The annual average temperature is +1.99°C, which is lower compared to Middle Asia, but higher than in northern Mongolia. The most significant aspect of this region is the exceptional swing in temperatures over the period of a single day, when it is possible to experience frost at dawn and very hot temperatures by midday (to +30°C). The annual precipitation was only 186.8 mm, with an annual evaporation rate of 2090 mm (Chu et al. 2009). In spite of its vast area, there is no permanent surface water, and only about a dozen permanent waterholes can be used by wildlife in the region.

The landscape of KNR is dominated by plains in the north and south, sand dunes in the west and rolling hills of the Kalamaili Mountains in the centre. Altitudes range from 600 to 1464 m above sea level. Vegetation is sparse and undersized in the region; dominant plants include: *Haloxylon ammodendron*, *Ceratoides latens*, *Anabasis salsa*, *Stipa glareosa*, *Reaumuria soongorica*, *Artemisia desertorum*, *Atraphaxis frutescens*, *Ceratocarpus arenarius*, *Calligonum mongolicum*, *Allium polyrhizum*, etc. Ephemeral plants such as *Sterigmostemum*, *Astragalus*, *Alyssum*, *Scorzonera*, *Chorispora tenella*, *Erysimum flavum*, *Eremurus inderiensis*, *Sonchus*, *Lappula* and *Cancrinia discoidea* are abundant and common in spring and early summer under patches of shrubs. As a hotspot for large herbivores and biodiversity in the Great Gobi ecosystem, KNR is an important refuge for wild ungulates that are distributed here, including khulan, goitred gazelle (*Gazella subgutturosa*), Argali sheep (*Ovis ammon*), and more than 50 reintroduced Przewalski's Horses (*Equus przewalskii*). Saiga (*Saiga tatarica*) also distributed here before their extinction in the 1960s.

Dung collection

Field surveys were made in the study area in September (autumn 2006), December (winter 2006), early May (spring 2007) and July (summer 2007), thus covering every season of the year. By car (≤30 km/h) all vegetation types in the reserve were crossed. Anthony and Smith (1974) indicated that 15 faecal samples would provide the same level of precision as 50 rumen samples. Based on observations with binoculars of the khulan's defecations, we randomly collected 25 faecal samples throughout the area each season. In addition, during winter, the harshest season of the year, surveys collected 30 dung samples of domestic sheep, gathered randomly in the same areas as the khulan samples. Only fresh faeces of the khulan were collected after the animal left, and faecal pellets of sheep were collected at different herder camps throughout the reserve. Plant species were taken for herbarium study from locations of faecal sample collections.

Methods

Microhistological analysis of faeces has been confirmed as a reliable method for estimating diet composition for grazing animals (Stewart 1967) and was used to study the diet of the khulan. The protocol used was developed based on work by Williams (1969) and Stevens et al. (1987). Briefly, fresh droppings were preserved separately in plastic bags after air drying, oven-dried at 60°C for 24 h, ground in a mortar, dissolved in water and treated in various solutions. Fifteen microscopic slides were made each season. Twenty microscope fields per slide were examined on 5 microscopic slides at 100× magnification under a binocular microscope. We examined the frequency of recognizable plant fragments for each sample, and calculated the relative density (RD) of these plant species in the diet for each season (Johnson 1982). The identification of the fragments was based on different features and dimensions of the epidermal cells and other valuable taxonomical structures (e.g. trichomes, stomata form). All identifications were conducted by the same person to reduce inconsistencies due to observer bias.

Levins index (Levins 1968) was used for food breadth:

$$B = 1 \Big/ \sum Pij^2$$

Where B is the Levins index. Pij is the proportion of ungulate species j feeding on plant species/genus i. Hulbert (1978) suggests the following measure for standardized food breadth:

$$B' = (B - 1) \big/ (N - 1)$$

where N is the number of food categories; this index assumes values between 0 and 1.

The dietary overlap between khulan and sheep was qualified using Schoener's index (Schoener 1968):

$$Ojk = 1 - \frac{1}{2} \sum |Pij - Pik|$$

where Ojk is the overlap between ungulate species j and k; Pij is the proportion of species j feeding on plant species/genus i; and Pik is the proportion of species k feeding on plant species/genus i. The index ranges from 0 to 1 and is considered to be biologically significant when it exceeds 0.60 (Mathur 1977). This index has been recommended by Abrams (1980) as the best overall index of niche overlap.

Results

Seasonal diet of khulan

We collected in total 54 plant species from 19 families from within the khulan's habitat. Over the year of observations, the khulan consumed 46 plant species from 17 families. The composition of their diets varied seasonally: 25 plant species (8 families) in autumn, 13 plant species (5 families) in winter, 30 plant species (14 families) in spring, and 26 plant species (13 families) in summer. Khulan had the widest food breadth in winter (0.43) and the least in summer (0.10); food breadth in spring and autumn was 0.18 and 0.23, respectively.

Year round, but especially in autumn and winter, Chenopodiaceae, Poaceae, Asteraceae and Tamaricaceae were the khulan's main food source, comprising 69.4–99.8% of their diet. Chenopodiaceae and Poaceae were dominant in all seasons (Figure 2). The proportion of the main plant groups eaten differed over the year, with the use of graminoids greatest in spring (38.5%) and summer (50.2%), and the use of shrubs greatest in autumn (55.5%) and winter (72.7%) (Table 1). Forbs were very important in spring, at 27.7% of the diet (Table I), and *Stipa glareosa* was a major food in both spring (33.1%) and summer (47.3%). Of lesser but still significant importance in autumn and winter were *Haloxylon ammodendron* (12.8% and 22.1%, respectively) and *Ceratoides latens* (11.3% and 7.2%, respectively). Correspondingly, *Stipa glareosa* was still a considerable portion in autumn and winter (24.1% and 11.2%, respectively), but shrubs were eaten more often. In winter, *Anabasis* and *Reaumuria soongorica* were the major foods and constituted, respectively, 28.6 and 17.3% of the winter diet (Table I).

Diet overlap between khulan and sheep

The staple foods of sheep in winter were also the Chenopodiaceae and Poaceae plants while the sheep ate more grass than khulan (Figure 3). The diet overlap between khulan and domestic sheep was 48.3% during winter.

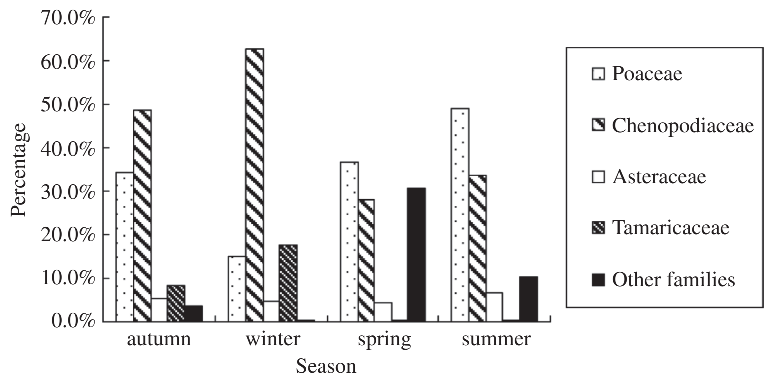

Figure 2. Main plant families consumed by the khulan through the year.

Table I. Annual percentage of plant species occurrences in the khulan diet.

Classification	Species	Autumn (%)	Winter (%)	Spring (%)	Summer (%)
Graminoids		34.2	14.8	38.5	50.2
	Stipa glareosa	24.5	11.2	33.1	47.3
	Achnatherum splendens	3.2	2.2	0.4	0.8
	Phragmites australis	2.8	1.4	0.8	0.6
	Bromus japonicus	2.5	T	0.8	*T*
	Eremopyrum orientale	T	T	1.2	0.2
	Carex physodes	T	T	1.9	1.3
	Others	1.2	T	0.4	T
Forbs		10.2	12.4	27.7	9.9
	Salsola affinis	2.0	4.8	T	T
	Salsola subcrassa	1.2	6.0	T	0.6
	Ceratocarpus arenarius	4.4	1.6	0.4	0.3
	Atriplex sp.	T	T	1.2	1.0
	Allium polyrhizum	T	T	7.0	1.6
	Iris tenuifolia	T	T	5.4	2.6
	Astragalus sp.	T	T	9.7	1.6
	Others	3.5	T	4.7	2.1
Shrubs		55.5	72.7	33.8	39.9
	Haloxylon ammodendron	24.1	16.5	12.8	22.1
	Ceratoides latens	11.6	5.2	11.3	7.2
	Anabasis sp.	3.4	28.6	T	T
	Seriphidium santolinum	4.1	4.6	T	T
	Artemisia desertorum	1.0	T	3.1	6.5
	Salsola arbuscula	T	T	2.3	1.9
	Atraphaxis frutescens	T	T	3.1	0.6
	Tamarix sp.	4.8	0.4	0.4	0.3
	Reaumuria soongorica	3.4	17.3	T	T
	Ephedra przewalskii	1.8	0.2	T	T
	Others	1.3	T	0.8	1.1

T: Not found in the faeces. Others:
Plant species consumed by khulan under 1%. Graminoids (*Leymus racemosus*, *Aeluropus* sp., *Schismus arabicus*); forbs (*Halogeton glomeratus*, *Salsola ruthenica*, *Acroptilon repens*, *Cancrinia discoidea*, *Scorzonera* sp., *Limonium* sp., *Goniolimon* sp., *Eremurus* sp., *Zygophyllum rosovii*, *Peganum harmala*, *Plantago minuta*, *Lappula* sp., *Dodartia orientalis*); shrubs (*Kochia prostrata*, *Kalidium foliatum*, *Asterothamnus fruticosus*, *Calligonum mongolicum*, *Limonium suffruticosum*, *Lycium ruthenicum*).

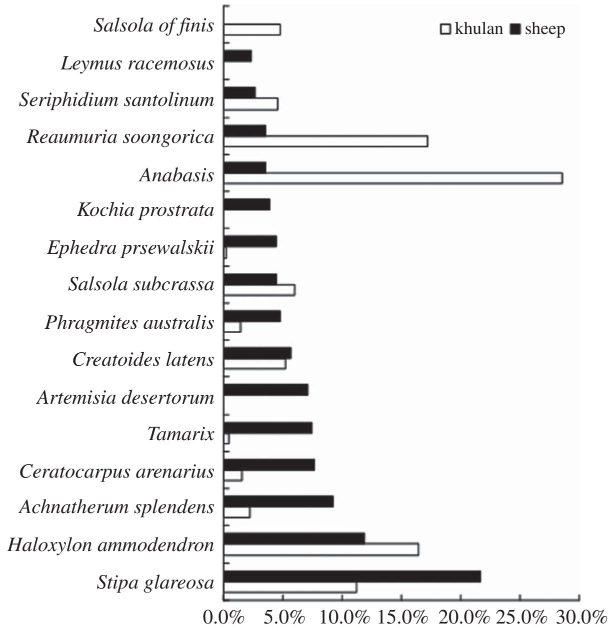

Figure 3. Dietary compositions of khulans and domestic sheep in winter.

Discussion

Seasonal diet of khulan

Analysis of faecal samples revealed that khulan fed on a wide variety of plant species, similar to results from studies in Turkmenistan (Solomatin 1973), and their diets changed with resource abundance and season. Food habits are related to body size and the digestive physiology of herbivores. As a large non-ruminant animal, similar to other equids, khulan could be considered grazers that eat lower-quality grasses non-selectively, with diets containing $< 25\%$ browse (Hofmann & Stewart 1972). Graminoids, especially *Stipa glareosa*, constituted a large portion of the diet of the khulan during spring and summer, while shrubs were more often used in autumn and winter (Table I). The results indicate that the khulan are mixed feeders as an adaptation to their arid environment.

In spring, large numbers of ephemeral plants appeared in the study area and the khulan used most of these plants over the seasons (Figure 2 and Table I). In addition, *Stipa glareosa* and shrubs like *Ceratoides latens* and *Haloxylon ammodendron* started growing earlier than other species in spring. Growing plant tissue is the most nutritious form of food because of its high soluble cell content (Van Soest 1982). During the time when green food was lacking, khulan ate all the sprouts they could get, profiting from the first access to nutritious growth. With regard to the other three seasons, forbs constituted a higher portion of the khulan's diet in spring (Table I), and juicy ephemerals such as *Astragalus* were favoured due to their rich nutrients, vitamins and water (Xia 1993). Similarly, it has been found that with greater nitrogen content, forbs are strongly preferred by desert bighorn sheep in western Texas (Fulbright et al. 2001). So khulan consumed a wider range of species in spring, especially graminoids and forbs, in order to meet their food and nutrient requirements.

In summer, the number of plant species that were used by the khulan decreased due to the withering of the ephemerals, but their food supply was still adequate. During the summer, khulans preferred *Stipa glareosa* (47.3%) and *Haloxylon ammodendron* (22.1%) (Table I), and were specialized grazers on Graminoids, such as the perennial and annual grasses *Stipa* spp., *Agropyron* spp., *Achnatherum splendens*, etc., which were often used by the khulan in Great Gobi B (Feh et al. 2001); *Carex*, *Bromus*, *Hordeum* and *Secale* were used in Turkmenistan (Solomatin 1973); and *Eremopyrum*, *Phragmites* and *Stipa* in Kazakhstan (Dzhanyspaev & Blank 1990). Due to a shortage of water, plants such as *Haloxylon ammodendron* with juicy twigs were also browsed often by khulan (Dzhanyspaev & Blank 1990). According to Westoby (1974) and Belovsky (1978), herbivores specialize when resource levels are high and generalize when they are low. Due to the abundant supply of food resources, the khulan had the least food breadth (0.10) in summer.

Shrubs became more important (Table I) in autumn, as more and more plants used by the khulan withered. Similar to a former study (Hu et al. 1998), *Stipa glareosa* was noted as a considerable food source in the khulan's autumn diet. Autumn was the driest season of the year, when the *Haloxylon ammodendron*, with its juicy twigs, were more important than even in summer. Juicy plants such as *Allium mongolicum* were the main food of Khulan in Great Gobi B in autumn (Lengger et al. 2007). Our data showed that, similar to the studies in Kazakhstan and Turkmenistan, khulan ate *Allium* less often than the khulan in Mongolia, and mostly during the short spring period (Solomatin 1973). We think this difference was due to the fact that the *Allium* in Kazakhstan, Turkmenistan and Junggar basin is a less-abundant species than that found in Mongolia. Habitats of oases are important for khulan in the Great Gobi B (Feh et al. 2001), and in our study, plants near water pools, such as *Phragmites australis*, *Achnatherum splendens*, *Tamarix*, etc., were also often consumed. The value of grasses decreased in summer and autumn, and gradually shrubs were browsed more often (Solomatin 1973), because shrubs like *Haloxylon ammodendron* and *Ceratoides latens* have a relatively high nitrogen content (Xia 1993). Northern ungulates undergo pronounced seasonal fluctuations in body reserves, with peak body masses generally reached in the fall (Mautz 1978; Adamczewski et al. 1987). In autumn, in order to survive the harsh winter, energy is deposited as body fat and khulan have a ubiquitous need for crude protein to maintain and build their body weight. Shrubs like *Haloxylon* are important because they can provide supplemental protein and energy when grasses have dried and are of low nutritional value (Zhevnerov 1984).

Winter diet and overlap with sheep

Winter, with low temperatures and cold harsh winds, was the most difficult season of the year for the khulan. Their food resources decreased drastically, and it became difficult for them to find food under the snow cover (Solomatin 1973). Nudds (1980) suggested that a change in feeding strategy from specialist to generalist occurs when food is scare. During the winter season, khulan ate any available food resource, and their food breadth reached its highest level (0.43) of the year. Because of heavy snow, shrubs and tall grasses dominated the composition of their diet (Table I). They had to turn to poorer food sources, and ate considerably more shrub twigs, as the more palatable foods were insufficient (Solomatin 1973). The strategy of the khulan's diet in winter switched from selection for plant quality early in the year, to a preference for plant quantity later in the year.

The Schoener's dietary overlap index (48.3%) between khulan and sheep was not significant. The sheep is a small ruminate ungulate (body weight = 25–40 kg), while the khulan is a large non-ruminate herbivore (body weight = 200–300 kg). Janis (1976) postulated that equids and bovids have very different digestive systems (hindgut, ruminant), which, theoretically, lead them to adopt different foraging strategies, resulting in niche separation. According to this hypothesis, khulan should use more grasses than sheep. However, in winter, khulan consumed more woody plants and less grasses than sheep (Figure 3) (Chu et al. 2008). We think the reason for this disparity is human interference. Because of the intrusion of nomadic herders, areas with relatively better vegetation quality were occupied by livestock, especially sheep (Li et al. 2009). Khulan is a very vigilant species, and to avoid the livestock in winter, the khulan grazed in dense herds in the open clay desert region, an area where they were rarely seen in other seasons. The vegetation quality was very poor here, where the dominant plant species are *Anabasis* spp. and *Reaumuria soongorica*; even the herdsmen avoided selecting the clay desert area as pasture (Li et al. 2009). This type of winter pasture selection by the khulan could explain our result that the total percentage of *Anabasis* and *Reaumuria soongorica* in their winter diet reached almost 50%, while this food scarcely existed in the khulan's diet in other seasons (Table I and Figure 3). We support the idea that dietary overlap is not sufficient for exploitative competition (Colwell & Futuyuma 1971); in winter, the supply of food is irrelevant to the domestic sheep due to the intervention of the herdsmen. The diet of khulan in winter was a result of a choice due to human presence and an adaptation to avoid competition with sheep during the harsh weather. This strategy is the same as that used by *Gazella subgutturosa* in winter (Xu et al. 2008). We believe that pasture partitioning could facilitate the co-existence of both khulan and domestic sheep during winter.

Management implications

When KNR was established in 1982, the population of khulan was only 358 individuals (Chu et al. 1985); now the khulan population has grown by more than 10 times (Chu et al. 2009). Increasing the livestock population during the harsh winters could and did lead to overgrazing and food shortages in the reserve. Competition is considered to be a major selective force causing the differential use of resources between species (Cody 1974; Schoener 1974, 1982). In this study, due to the scarcity of food resources in winter, competition shaped the pasture partitioning of the khulan and domestic sheep. When competition was perceived, decreasing the livestock population numbers was looked at as the solution. *Stipa glareosa* and *Haloxylon ammodendron* are not only the primary food resources of khulan in winter, but also the primary food resources of sheep during this time. In addition, a large amount of *Haloxylon ammodendron* was cut and used as firewood by herdsmen during the winter. In order to conserve khulan and other rare wild ungulates, the number of domestic sheep allowed in the reserve should be restricted to lessen the pressure of competition through winter.

The Gobi area of northern Xinjiang (KNR) and southwest Mongolia (Great Gobi A and B SPA) are habitat for the greatest wild populations of khulan in the World (Lkhagvasuren 2007; Yang 2007), and the border fence established in 1995 (Ge et al. 2003) hinders the population exchange between them (Kaczensky et al. 2011). Moreover, khulan had a regular summer–winter migration across this region, migrating to the Junggar Basin in China, with less snow cover, for winter and the Gobi desert in Mongolia for summer (Bannikov 1981). Therefore, we suggest opening the fence gates on the China–Mongolia border for creation of an ecological corridor between the Chinese and Mongolian khulan populations. As a result, three large protected areas (KNR, Great Gobi A and B SPA), that together cover over 70,000 km^2 of khulan habitat would be connected (Kaczensky et al. 2011). We believe that the border corridors would lead to considerable improvement in ecological conditions for both Chinese and Mongolian khulan populations.

Acknowledgements

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