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Diet of *Gazella subgutturosa* (Güldenstaedt, 1780) and food overlap with domestic sheep in Xinjiang, China

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Abstract. The natural diet of goitred gazelle (*Gazella subgutturosa*) was studied over the period of a year in northern Xinjiang, China using microhistological analysis. The winter food habits of the goitred gazelle and domestic sheep were also compared. The microhistological analysis method demonstrated that gazelle ate 47 species of plants during the year. Chenopodiaceae and Poaceae were major foods, and ephemeral plants were used mostly during spring. *Stipa glareosa* was a major food item of gazelle throughout the year, *Ceratoides latens* was mainly used in spring and summer, whereas in autumn and winter, gazelles consumed a large amount of *Haloxylon ammodendron*. Because of the extremely warm and dry weather during summer and autumn, succulent plants like *Allium polyrhizum*, *Zygophyllum rosovii*, *Salsola subcrassa* were favored by gazelles. In winter, goitred gazelle and domestic sheep in Kalamaili reserve had strong food competition; with an overlap in diet of 0.77. The number of sheep in the reserve should be reduced to lessen the pressure of competition.

Key words: goitred gazelle, microhistological analysis, competition, *Ovis aries*

Introduction

The goitred gazelle (*Gazella subgutturosa* Güldenstaedt, 1780), which is classified as Vulnerable (VU) by IUCN, has a very wide distribution across the Middle East, Pakistan, Central Asia, China and Mongolia (Mallon 2008). In China, goitred gazelle are protected as a Grade II species under State protected animals, although constant expansion of agricultural lands, oil extraction, mines, poaching and habitat loss threaten its survival (Jiang 1998, Li et al. 2010).

A few ecological studies have been conducted on some aspects of goitred gazelle, such as population dynamics in captivity (Pereladova et al. 1998), habitat selection (Yang et al. 2005, Nowzari et al. 2007), mating behavior (Blank 1998), daily activity (Xia et al. 2010) and social organization (Wronski et al. 2010, Cunningham & Wronski 2011, Qiao et al. 2011). However little is known about the natural diet of *Gazella subgutturosa*. Although a few reports have been published (Zhevnerov 1984, Mohamed et al. 1991, Hu et al. 1998, Cunningham 2009), these reports have been limited to describing just one season (Hu et al. 1998), the margins of the distribution area (Zhevnerov 1984, Mohamed et al. 1991), or individual cases (Cunningham 2009). As part of a longer-term research, this paper aims to give preliminary results about the diet of goitred gazelle by using data collected throughout an entire year. In addition, this study measured the dietary overlap between goitred gazelle and domestic sheep (*Ovis aries*) in winter, since understanding the feeding niche of these herbivores may help to understand the competitive interactions with other herbivores and to direct proper range management (Shipley 1999). We hope this research will be useful for reserve management and habitat improvement for the local goitred gazelle populations.

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Study Area

Field work was conducted in Kalamaili Mountain Ungulate Nature Reserve (KNR) (44°36′-46°00′ N, 88°30′-90°03′ E). The reserve is located in eastern Junggar Basin, Xinjiang, China on the area of 18000 km^2 (Chu et al. 2009). During spring to autumn, there was no livestock in the reserve, but in winter, this area was utilized by ~2000 Kazakh shepherds with ~200000 heads of livestock, mostly domestic sheep (*Ovis aries*) (Ge et al. 2003). The climate of KNR is continental, which is characterized by long cold winters (October to early April) and shorter warm summers (mid May to September). Most precipitation is noted during winter, spring and early summer. From 2000 to 2007, the annual precipitation was only 186.8 mm. Average temperature during January is –24.3 °C with an absolute minimum of –45 °C and maximum of +1.4 °C. Average temperature during July is +20.5 °C with an absolute maximum of +38.4 °C and minimum of +6.0 °C. The annual average temperature is +1.99 °C, which is lower compared to deserts in Central Asia, but higher than in northern Mongolia. The most significant aspect of this region is the exceptional changes in temperatures over the period of a single day, when its possible to experience frost at dawn and very hot temperatures by midday (up to +30 °C). In spite of its vast area, there is no permanent surface water, and only about a dozen of permanent water springs and some artificial 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 the rolling hills of Mt. Kalamaili in the center. Altitudes range from 600 m to 1464 m above sea level. Vegetation is sparse in the region with dominant plants including: *Allium polyrhizum*, *Anabasis salsa*, *Artemisia desertorum*, *Atraphaxis frutescens*, *Calligonum mongolicum*, *Ceratocarpus arenarius*, *Ceratoides latens*, *Haloxylon ammodendron*, *Reaumuria songarica* and *Stipa glareosa*. Ephemeral plants, such as *Alyssum linifolium*, *Astragalus*, *Cancrinia discoidea*, *Chorispora tenella*, *Eremurus inderiensis*, *Erysimum flavum*, *Lappula*, *Scorzonera*, *Sonchus* and *Sterigmostemum matthioloides* are abundant and common in spring and early summer under patches of shrubs. As a hot spot for large herbivores and biodiversity in the Great Gobi ecosystem, KNR is an important refuge for a number of rare species of wild ungulates, including goitred gazelle, khulan (*Equus hemionus*), argali sheep (*Ovis ammon*), and reintroduced Przewalski's horses (*Equus przewalskii*). Saiga (*Saiga tatarica*) also occurred in the area before their extinction in the 1960s.

Material and Methods

Field surveys were conducted in the study area using vehicles traveling less than 30 km/h during September (autumn, 2006), December (winter, 2006), early May (spring, 2007) and July (summer, 2007), and crossed all vegetation types in the reserve. Anthony & Smith (1974) indicated that 15 fecal samples would provide the same level of precision as 50 rumen samples. During this study we randomly collected 30 faecal samples of goitred gazelle throughout the area each season. In addition, during winter, the harshest season of the year, 30 dung samples of domestic sheep, were also collected in the same areas as the gazelle samples. All faecal samples were collected fresh. In total 54 plant species from 19 families were collected from within the habitat of the gazelle.

We use microhistological analysis of faeces to study the diet of gazelle. The protocol used was developed based on work by Williams (1969) and Stevens et a1. (1987). Briefly, fresh droppings were preserved separately in plastic bags after air drying, oven-dried at 60 °C for 24 hours, ground in a mortar, dissolved in water and treated in various solutions. Each season, we made five slides from each composite sample and microscopically examined 20 fields for each slide under 100× magnification. We examined the frequency of recognizable plant fragments for each slide, 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.

Food diversity of goitred gazelle was calculated on the basis of Shannon-Wiener index (Hanski 1978).

$$H = -\sum P_{ij} \ln P_{ij}$$

Where P_i is the proportion of plant species/genus i in gazelle diet, N is the number of food categories; this index assumes values between 0 and 1.

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

$$O_{jk} = 1 - \frac{1}{2} \sum \left| P_{ij} - P_{ik} \right|$$

Where O_{jk} is the overlap between ungulate species j and k; P_{ij} is the proportion of species j feeding on plant species/genus i; and P_{ik} 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.

We quantified goitred gazelle diet using key plant species (i.e., species representing > 3 % of the mean diet of gazelle in at least one season), and major plant categories (plant categorical levels included shrubs, graminoids and forbs) (Table 1). One-Sample Kolmogorov-Smirnov Test was used to check whether the data fit a normal distribution: if not, the nonparametric tests was used; and if yes, the One way ANOVA and Independent Samples Test was used to test seasonal differences in proportional diet composition, difference in diet composition between gazelle and sheep during winter. Statistical significance was set at the $p < 0.05$ level.

Results

Seasonal diet of goitred gazelle

Over an observation period of one year, gazelle consumed 47 plant species from 16 families. The composition of their diets varied seasonally; 24 plant species (7 families) in autumn, 17 plant species (6 families) in winter, 41 plant species (16 families) in spring, and 30 plant species (12 families) in summer (Table 1). The diversity indices of each season are: 2.87 in autumn, 2.59 in winter, 3.59 in spring and 2.97 in summer, respectively.

The proportion of the major plant categories eaten by goitred gazelle differed over seasons (one way ANOVA, shrubs: $F = 31.25$, df = 3, $p < 0.0001$; graminoids: $F = 13.49$, df = 3, $p < 0.0001$; forbs: $F = 29.27$, df = 3, $p < 0.0001$) (Table 1). Year round, Chenopodiaceae and Poaceae were the main food source of the gazelle, comprising 38.8 %-85.1 % of their diet. Gazelle ate *Stipa glareosa* often, with the percentage varying from the least in spring (7.7 %) to the most in summer (22.1 %). *Ceratoides latens* were mainly used in spring (9.2 %) and summer (10.5 %), while in autumn and winter, gazelles consumed a large amount of *Haloxylon ammodenron* (9.7 % and 14.9 %, respectively). The portion of *Anabasis*, *Achnatherum splendens* and *Phragmites australis* in winter were evidently higher than in the other three seasons, since the use of *Anabasis brevifolia* was found to be over six times higher in winter than in autumn.

Ephemeral plants (mostly from Asteraceae and Brassicaceae) were used mostly in spring (27.0 %). During spring and summer, succulent forbs like *Allium polyrhizum*, *Zygophyllum rosovii* and *Astragalus* were often consumed; and in autumn and winter, *Ceratocarpus arenarius* and *Salsola subcrassa* were favoured by gazelle.

Diet overlap between goitred gazelle and domestic sheep during winter

During winter, domestic sheep ate 15 species from five families ($H = 2.51$), and gazelle ate 17 species from six families ($H = 2.59$) (Fig. 1). Similar to the winter diet of gazelle, Chenopodiaceae and Poaceae plants were also the staple food of domestic sheep. The diet overlap between goitred gazelle and domestic sheep reached 0.77 in winter.

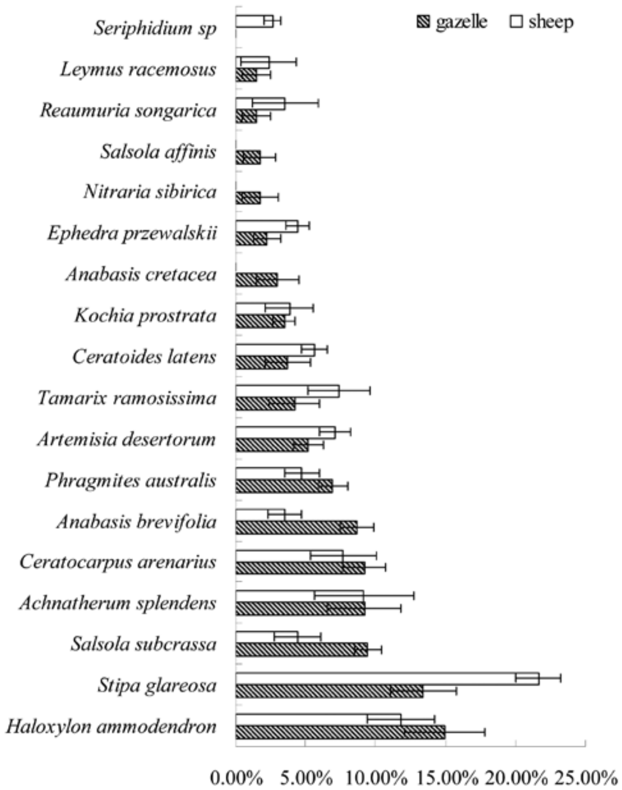

Fig. 1. *Winter diet of goitred gazelle and domestic sheep.*

Discussion

Seasonal diet of goitred gazelle

Analysis of fecal samples revealed that goitred gazelle fed on a wide variety of plant species (Table 1), and previous studies supported this finding (Zhevnerov 1984, Mohamed et al. 1991). Our results showed that the composition of the gazelle diet was 34.2 %-43.4 % shrub, 16.8 %-31.1 % graminoid, and 25.6 %-41.9 % forb (Table 1). Hofmann & Stewart (1972) classified that the mixed feeders' diet contains over 25 % browse and no more than 75 % fruits, dicotyledonous foliage, and shoots. Therefore

Table 1. *Diet composition of* Gazella subgutturosa *during autumn, winter, spring and summer in KNR, Xinjiang.*

Plant Categories and Species	Autumn Mean ± SD (%)	Winter Mean ± SD (%)	Spring Mean ± SD (%)	Summer Mean ± SD (%)
Shrubs	37.71 ± 2.85	43.42 ± 4.02	41.31 ± 1.85	34.16 ± 1.33
Haloxylon ammodendron	9.69 ± 2.19	14.91 ± 2.86	3.13 ± 1.39	2.54 ± 0.84
Ceratoides latens	6.45 ± 1.31	3.72 ± 1.62	9.13 ± 2.54	10.46 ± 1.13
Ephedra przewalskii	6.05 ± 1.59	2.23 ± 0.98	1.99 ± 1.55	3.39 ± 1.12
Reaumuria songarica	5.04 ± 1.25	1.49 ± 1.04	1.42 ± 1.34	1.98 ± 1.81
Tamarix ramosissima	2.62 ± 0.84	4.21 ± 1.82	0.57 ± 1.38	1.13 ± 0.84
Kochia prostrata	2.42 ± 0.54	3.47 ± 0.75	3.42 ± 2.14	2.54 ± 0.74
Anabasis brevifolia	1.41 ± 0.53	8.68 ± 1.23	2.85 ± 2.26	T
Atraphaxis frutescens	T	T	5.41 ± 2.54	3.95 ± 1.04
Salsola arbuscula	T	T	3.99 ± 2.01	2.82 ± 1.15
others	4.03 ± 2.48	4.71 ± 1.21	9.40 ± 1.91	5.36 ± 0.66
Graminoids	27.83 ± 2.08	31.03 ± 4.63	16.84 ± 1.34	31.12 ± 2.31
Stipa glareosa	11.51 ± 1.04	13.41 ± 2.36	7.70 ± 1.61	22.09 ± 1.65
Achnatherum splendens	6.05 ± 1.85	9.18 ± 2.60	2.56 ± 0.58	2.54 ± 0.81
Phragmites australis	4.23 ± 1.74	6.95 ± 1.05	2.85 ± 1.34	2.26 ± 0.74
Leymus racemosus	3.63 ± 1.15	1.49 ± 1.04	1.14 ± 0.64	1.13 ± 0.80
others	2.41 ± 0.89	T	2.59 ± 0.86	3.10 ± 2.50
Forbs	34.46 ± 1.71	25.55 ± 3.15	41.85 ± 2.48	34.72 ± 2.83
Salsola subcrassa	8.47 ± 0.58	9.43 ± 0.95	T	1.69 ± 0.46
Ceratocarpus arenarius	7.87 ± 1.56	9.18 ± 1.49	0.57 ± 0.82	3.39 ± 0.87
Salsola affinis	4.23 ± 0.88	1.73 ± 1.15	T	T
Zygophyllum rosovii	3.43 ± 1.18	T	1.42 ± 1.56	7.63 ± 1.73
Halogeton sp	3.02 ± 0.94	T	T	T
Artemisia desertorum	2.01 ± 0.99	5.21 ± 1.10	2.56 ± 0.58	3.10 ± 0.58
Acroptilon repens	2.01 ± 0.71	T	3.13 ± 0.98	1.41 ± 0.46
Allium polyrhizum	T	T	4.27 ± 1.49	5.93 ± 1.66
Astragalus sp	T	T	3.70 ± 0.55	T
Scorzonera sp	T	T	3.13 ± 1.62	T
others	3.42 ± 1.46	T	23.07 ± 1.64	11.57 ± 1.11

T: Not found in the faeces.

*Others: Plant species consumed by goitred gazelle under 3 %. Shrubs (*Nitraria sibirica, Anabasis cretacea, Calligonum *spp.,* Caragana *sp.,* Asterothamnus fruticosus, Kalidium foliatum, Convolvulus tragacanthoides*); Graminoids (*Bromus japonicus, Carex physodes*); Forbs (*Bassia dasyphylla, Seriphidium *sp.,* Limonium *sp.,* Limonium suffruticosum, Erysimum cheiranthoides, Iris tenuifolia, Sonchus *sp.,* Eremurus inderiensis, Goniolimon *sp.,* Echinops gmelini, Cancrinia discoidea, Sterigmostemum matthioloides, Lepidium latifolium, Lagochilus *sp.,* Plantago minuta*).*

goitred gazelle should be classified as a mixed feeder. Clauss et al. (2002) also approved this classification. According to Hofmann's theory, a mixed feeder has the widest niche breadth compared with concentrate selector and grazer (Hofmann 1989). So we believe that the natural diet of goitred gazelle is an adaptation to the desert environment.

In spring, gazelle ate most plants they encountered, and had the greatest diversity of food categories (Table 1). New growing plant tissue is the most nutritious form of food because of its high soluble cell content (van Soest 1982). *Stipa glareosa* and shrubs like *Ceratoides latens* are the most abundant plants and started growing earlier than other species in spring, so they were often consumed by gazelle. During this time, a large number of ephemeral plants (mostly Asteraceae and Brassicaceae) appeared in the study area. Succulent ephemerals were favored by gazelle (27 %) due to their rich nutrients, vitamins and water (Xia 1993). Spring is an important season for gazelles, during which moulting, birthing and rearing of young occurs (Zhevnerov 1984). Gazelle consumed a wider range of plant species in spring to meet their energy and nutritional requirements.

In summer, when most ephemerals desiccate, the number of plant species in the gazelle's diet decreased. Because summer is the main growing season in northern plant associations, the food supply is adequate during summer. Westoby (1974) and Belovsky (1978) believed that herbivores would specialize when resource levels were high and generalize when they were low. Thus, with adequate food supply in summer, gazelle focused on the more palatable foods, such as *Stipa glareosa* (22.1 %) and *Ceratoides latens* (10.5 %) (Table 1). Due to a shortage of water in this arid area, forbs like *Allium polyrhizum* (5.9 %) and *Zygophyllum rosovii* (7.6 %) that have a high water content were consumed more often by gazelle.

Autumn was the driest season in the reserve with water being the main factor affecting the presence and existence of goitred gazelle. *Haloxylon ammodendron*, with succulent twigs, replaced the consumption of *Ceratoides latens* in spring and summer, and succulent forbs such as *Salsola subcrassa* are favored in this season (Table 1). Plants near water sources, such as *Phragmites australis*, *Achnatherum splendens*, *Tamarix ramosissima* were more often used in autumn than during spring and summer. Plants like *Ceratoides latens*, *Ephedra przewalskii* and *Ceratocarpus arenarius* that were consumed often in autumn have relatively high crude protein content (Jia 1987). These plants probably meet the requirements of goitred gazelle during the rutting period and harsh winter.

Winter diet of gazelle and competition with sheep

Winter is the most difficult season of the year for gazelles, because of cold temperatures and strong winds (Chu et al. 2009). Food resources decrease drastically, and it is difficult for gazelles to find plants under the snow cover. Shrubs like *Haloxylon ammodendron* and *Anabasis* became more important in winter than in other seasons (Table 1). The high number of domestic sheep in the area in winter (Ge et al. 2003) leads to a substantial reduction of available forage for gazelles due to livestock overgrazing (Yang et al. 2010), which resulted in an inadequate food supply in the reserve to meet the demands of the gazelle. A high dietary overlap can imply competition if resources are limited (Schoener 1983, de Boer & Prins 1990, Putman et al. 1993). Since the gazelle and domestic sheep had a large overlap in their winter diets (Schoener's index = 0.77), there was a high competition for food resources in the Kalamaili reserve during this season. The Geographic Information System (GIS) data showed that gazelle habitat loss to livestock during winter was 48.5 %, with the relatively good vegetation areas occupied by domestic sheep; this in turn forced the gazelle to live in the open clay desert where they were seldom seen in other seasons (Li et al. 2010). The quality of vegetation was poor in the open clay desert, with the dominant plant species being *Anabasis* and *Reaumuria songarica* (Li et al. 2009). *Anabasis* is scarcely used by gazelle during its growing season (Table 1) due to its poison content as well as a low nutritional value, and the toxicity level falls after it dries up during winter (Jia 1987). Domestic sheep utilized significantly more *Stipa glareosa* than goitred gazelle ($t = 6.38$, $p = 0.0002$), while gazelle significantly utilized more *Anabasis brevifolia* than sheep ($t = 6.80$, $p = 0.0001$) (Fig. 1). We suspect that the winter diet of gazelle was a result of a selection and adaptation to the competition with livestock during the harsh winters. This strategy is the same as that of *Procapra przewalskii* around Qinghai Lake (Liu & Jiang 2004). During the winter food stress, the trade-off between diet quality and diet quantity forced gazelle to use any edible food available.

Management implications

Our study shows that the high degree of dietary overlap between the goitred gazelle and domestic livestock may pose a threat to the survival of the gazelle during the cold and food-scarce winters. Competition is considered to be a major selective force causing the differential use of resources between species (Schoener 1974, 1982). The livestock competition forced gazelle to consume secondary foods that were less digestible and had lower nutritional value (Table 1, Fig. 1). When competition between gazelle and sheep is perceived, decreasing the domestic livestock numbers could serve as a solution. We suggest that the number of domestic sheep in the reserve should be restricted to prevent competition especially during the harsh winters as well as initiating a strict protected area exclusively for gazelle can be recommended.

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