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Argali food habits and dietary overlap with domestic livestock in Ikh Nart Nature Reserve, Mongolia

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ABSTRACT

The argali (*Ovis ammon*) is a species of great conservation concern throughout its range in central Asia, and is particularly sensitive to human disturbance and habitat degradation. Recent increases in livestock numbers have potentially reduced the capacity of habitats to sustain argali because of forage or interference competition. We studied the potential for forage competition between argali and domestic livestock in Ikh Nart Nature Reserve, Mongolia by quantifying overlap among seasonal diets using microhistological analysis of fecal samples. We collected 100 fecal samples from argali and 100 fecal samples from livestock during June 2002, August 2002, January 2003, and April 2003. Argali and livestock used the same plant species with the exception of five used only by livestock. We also quantified forage availability in both summer (2002) and winter (2003) seasons. Total mean biomass in summer ($\bar{x} = 19.0 \text{g/m}^2$) declined ~82% to a winter mean of 3.5 g/m^2 ($t = -10.00$, $P < 0.0001$). Dietary overlap between argali and livestock was high, varying from 72% in summer to 95% in winter. We concluded that high degree of overlap for forage coupled with the low available vegetative biomass in winter suggests the potential for competition between argali and livestock.

1. Introduction

The giant Asian wild sheep argali (*Ovis ammon*) is listed as Near Threatened on the IUCN (2008) Red List. The Mongolian government recognized argali declines and began to manage hunting as early as 1953 (Amgalanbaatar and Reading, 2003; Reading et al., 2001; Shagdarsuren et al., 1987; Zhirnov and Ilyinsky, 1986). Mongolia listed argali in the Mongolian Red Book of Threatened and Endangered Species as threatened in 1987 and now applies criminal sanctions for poaching under the Mongolia Law on Hunting (Shagdarsuren et al., 1987; Wingard and Erdene-Ochir, 2004). The Convention on International Trade of Endangered Species of Wild Flora and Fauna (CITES) includes all subspecies of argali on either Appendix I or II.

Traditionally, local people have hunted argali for meat; more recently, foreign sport hunters have hunted them for their large horns. However, beyond hunting pressure (legal and illegal), competition with domestic livestock for forage and habitat may also be a serious conservation concern (Dzieciolowski et al., 1980; Gruzdov and Sukhbat, 1982; Reading et al., 1999, 2003; Shrestha et al., 2005). Although both argali and domestic sheep and goats are selective ruminants with a common phylogeny, forage competition between these species may be expected to be reduced because of their differing body weights (Gordon and Illius, 1988; Jarman, 1974). Argali in the Mongolian Gobi typically are twice the mass of domestic sheep or goats (September mass of adult female argali in Ikh Nart ~60–70 kg, R. Reading, unpublished data; adult males reportedly >110 kg, Fedosenko and Blank, 2005; mean mass of domestic goats is approximately 35 kg for adult females and 50 kg for males; Badarch et al., 2003; Campos-Arceiz et al., 2004). However, where forage is limited, as in the Gobi desert of Mongolia, competition for it may be strong even if morphological differences tend to facilitate coexistence (Gordon and Illius, 1989; Mysterud, 2000). Harris and Miller (1995) found relatively little dietary overlap between argali and domestic livestock in the Kunlun Mountains of China during summer. However, these authors could not collect data during winter, and speculated that dietary overlap may increase when vegetative resources are more limiting.

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Inferring forage competition merely from dietary overlap is not straight-forward; depending on resource availability, body condition of individual animals, and density of each species, substantial dietary overlap might equally reflect a lack of such competition. However, overlap in dietary preference is at least a pre-condition to competition for forage. Where food resources are scarce and the biomass of one herbivore species greatly exceeds that of another, we reasonably could be concerned about possible competitive effects of the more abundant species on the less abundant one, especially if we find substantial dietary overlap and the more abundant species is non-native (Bertolino et al., 2009; Voeten and Prins, 1999).

The number of herding families and livestock in Mongolia has increased since 1991, and coupled with a lack of grazing management, this has amplified concern about possible livestock-argali conflicts (Fernandez-Gimenez, 2001; Mearns, 2004; Reading et al., 2006a). The economic crash that followed Mongolia's departure from communism brought with it a wave of "new" herders – some by choice and many out of necessity. Herder numbers more than doubled in just 2 years after reform, increasing from 130 000 in 1991 to almost 350 000 by 1993 (Reading et al., 2006a). Pastoralists quickly recognized cashmere goats as their most valuable commercial commodity, and goat numbers increased accordingly, growing 215% over 9 years (Reading et al., 2006a) For the same time period horse and cattle populations also rose sharply, increasing by 140% and 135% respectively, while sheep and camel numbers either remained relatively constant or declined slightly (Fernandez-Gimenez, 2001; Mearns, 2004; Reading et al., 2006a). Although livestock numbers crashed during 2 difficult winters from 2000 to 2002, they have subsequently returned to pre-crash numbers (Mongolia Statistical Office, 2007). Little rigorous research has examined the impacts of this growing number of livestock on native ungulates (Retzer et al., 2005). We initiated a study in 2000 to estimate dietary composition and overlap between argali and domestic goats and sheep (hereafter, simply livestock). We predicted that livestock and argali would display high dietary overlap, particularly when vegetative biomass was low.

2. Materials and methods

2.1. Study area

The Mongolian government established Ikh Nart Nature Reserve (Ikh Nart, hereafter) in 1996 primarily because of its wildlife resources and interesting rocky outcrops (Reading et al., 2006b). Centered at 45.5° N, 108.6°E, Ikh Nart lies approximately 300 km south-southeast of Ulaanbaatar and roughly 50 km from the nearest Sum center (i.e., county seat) and transportation route (Fig. 1).

Ikh Nart (668 km^2) consists of the open valleys and worn granite outcrops, with flora representative of the desert-steppe communities (Reading et al., 2006b). Desert-steppe communities cover about 20% of Mongolia, lying between the true steppe to the north and the true desert to the south. In desert-steppe communities tall feather grasses give way to shorter feather grasses (*Stipa* spp.), and these communities include other characteristic tall grasses (e.g., *Achnatherum splendens*, *Agropyron* spp.), short grasses (e.g., *Cleistogenes squarrosa*, *Koeleria macrantha*), shrubs and semi-shrubs (e.g., *Caragana pygmaea*, *Ajania fruticulosa*, *Kochia prostrata*, *Gypsophila desertorum*, *Ephedra* spp.), and forbs (e.g., *Convolvulus ammanii*, *Scorzonera capito*, *Limonium* spp., *Tribulus terrestris*, *Iris tenuifolia*, *Artemisia* spp., *Allium* spp., *Corispermum mongolicum*).

The arid, continental climate characterized by cold winters (to −40 °C), dry windy springs (to 90 km/h), and relatively wet, hot summers (to 43 °C), coupled with frequent strong winds and powerful dust storms strongly influence the community of plants and animals that inhabit the region (Reading et al., 2006b). Permanent cold-water springs emanate from some of the numerous, shallow valleys draining the Reserve. Precipitation is low and seasonal, with most occurring in summer (Reading et al., 2006b).

The resident herder population included approximately 43 families with 180 members, all of whom used Ikh Nart intensively. Intensity of use by livestock varied seasonally. In winter, Ikh Nart served as the primary pasture for all 43 families. Additional families moved to the area during harsh winters, especially during "dzud" years (extreme winter weather). In summer, all families moved out of the Reserve, although a few families occasionally used the Reserve to water their livestock. There were no delineated or distinct pastures during any season; pastoralists herded livestock freely throughout the Reserve, and essentially all of the Reserve, excepting only rocky outcrops devoid of vegetation, received some grazing pressure during at least some portion of the year. The total number of livestock grazed in the Reserve during the study period included an estimated 3461 sheep, 3304 goats, 918 horses, 428 cattle, and 65 camels in 2003 (Annual Count of Livestock by Dalanjargalan Sum, Dornogobi Aimag, 2003). Assuming sheep equivalents of 6 for horses and 5 for cattle, this suggested a stocking

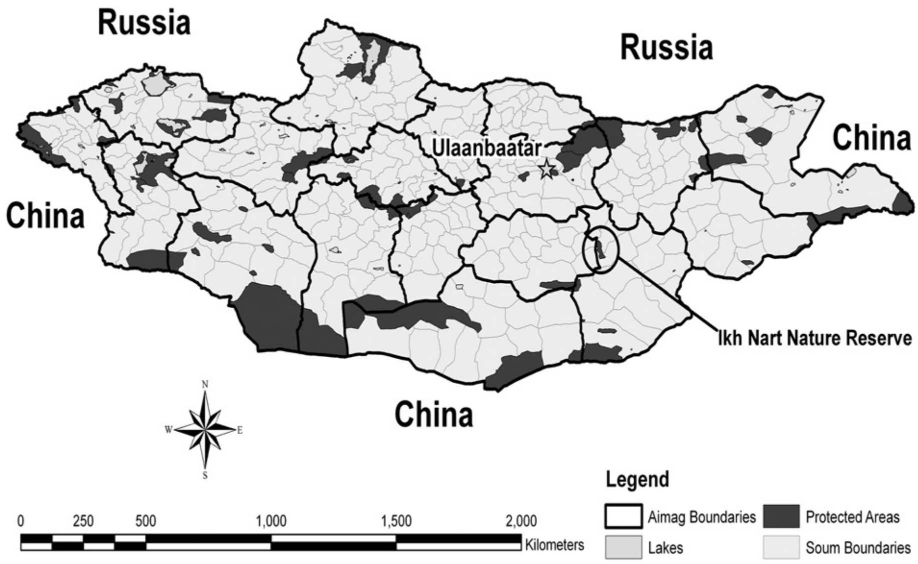

Fig. 1. Mongolia, showing location of study site.

rate of approximately 22 sheep units/km^2. Consistent with the overall trend in Mongolia, the number of livestock in the study site had been increasing yearly. Typically, argali are twice the mass of the domestic sheep or goats, or 2 sheep equivalents. Frisina et al. (2004) estimated that approximately 600 argali (i.e., about 2 sheep units/km^2) inhabited Ikh Nart, which if still the case 5 years later, suggests a stocking rate of approximately 2 sheep units/km^2. This comparison of stocking rates suggests that livestock stocking rate is 11 times that of argali on an adjusted biomass basis.

2.2. Forage availability

We quantified forage availability during August 2002 and January 2003 by collecting biomass data. Given the summer monsoonal rain pattern in Mongolia, typically August represents the month with maximum plant biomass. We used simple random sampling to place 100 plots (1 m^2) within the approximate argali herd distribution area within the study area; we based the boundaries of this distribution area on Global Positioning System (GPS) locations of argali collected manually by study personnel during the preceding 4 years. Within this approximate boundary, we determined sample plot locations using a handheld calculator's pseudo-random number generator (Fig. 2), and located each position in the field using a handheld GPS unit. Within each sample plot, we identified all above ground plants. In August 2002, we estimated biomass by clipping all vegetation in the sample plot to ground level. In January 2003, we moved plots approximately 1 m away from their summer positions to avoid sampling previously clipped vegetation, and biomass was clipped only to above the snow line (if present). Because argali and livestock may dig through snow for forage, clipping vegetation above snow line may have introduced a source of bias into our study.

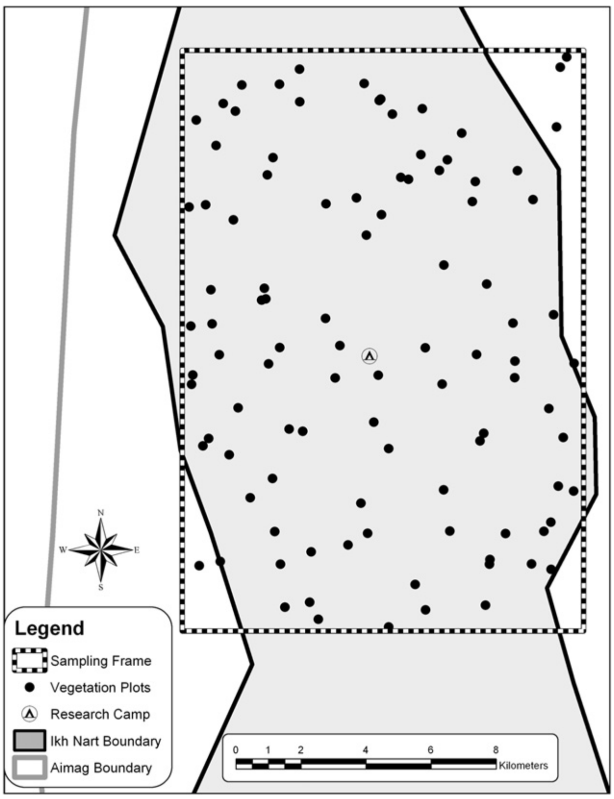

Fig. 2. Ikh Nart Nature Reserve, showing locations of random vegetation plots based on argali observations during years 1998, 1999, 2000 and 2001.

In both cases, samples were air-dried for two weeks and weighed by species. If more than 70% of a tussock perennial's base was present in the random plots, we cut all above ground parts of this plant and included it in the sample; if less than 70% was present, we did not cut any parts of the plant and excluded it from the sampling (Shennikov, 1964). For shrubs within plots, we collected and weighed 10 samples from new growth only. We used two-sample *t*-tests to evaluate seasonal differences of overall biomass and three of the most common plants, *Carex* spp., *Stipa* spp., and *Artemisia frigida*.

2.3. Seasonal food habits

We used microhistological fecal analysis to estimate food habits of argali and livestock. We collected 25 composite fecal samples from argali and 25 from livestock during each of 4 seasons defined as summer (June 2002), autumn (August 2002), winter (January 2003), and spring (April 2003). Fresh fecal samples were collected only from observed animals. More specifically, we located argali and observed them until they moved off, noting which animals defecated and where. After they moved off we collected fresh fecal samples from those exact locations only, searching for pellets that remained moist. We collected the same amount of fecal samples from shoats using the methods described above. To be certain our sampling was from domestic livestock, we collected them only from observed livestock.

To obtain a composite fecal sample, we collected 3–6 pellets from each pellet group up to a maximum 45 pellets from each group of animals per date of collection. Where >45 pellets were easily collected from any given animal group, we took only 1–3 pellets from each pellet group. We attempted to obtain composite samples from a variety of topographic and vegetative areas – valleys, open grassy plateaus, and rugged, rocky terrain. Fecal samples from livestock were collected using the same protocols as for argali. We did not sample from horses, cows, or camels because the funding of this study was limited to only sheep and goats samples.

Fecal samples were dried in an area of good air circulation to prevent molding. After drying, each pellet sample from each animal group was stored in a separate paper bag and labeled with the name or size of the animal group, date, time, and GPS location. All microhistological analyses were conducted at Wildlife Habitat Nutrition Laboratory, Washington State University, Pullman, Washington. Dr. Mandakh (Botanist) and Ms. Wingard collected species for keying out plant species.

Relative cover (Korfhage, 1974) of plant cuticle and epidermal fragments were quantified for 25 randomly located microscope views on each of 8 slides (total 200 views per sample). A 10 × 10 square grid mounted in the eyepiece of the microscope was used to measure area covered by each positively identified fragment observed at 100× magnification (Holechek and Vavra, 1981). Measurements of area covered were recorded by plant species, genus, or forage class category, as possible. Percent diet composition was calculated by dividing cover of each plant by total cover observed for all species, then multiplying by 100.

We quantified argali and livestock diets using key plant species (i.e., species representing >5% of the mean diets of argali or livestock in at least 1 season), and major plant categories (plant categorical levels included shrubs, grasses, sedges, forbs, and other; category "other" included flowers, insects, lichens, and fruits). We compared the proportion of items in seasonal argali diets with their proportional seasonal availability by plotting means and 95% confidence intervals. We estimated nonparametric confidence intervals surrounding mean seasonal diets and seasonal biomass by direct interpolation. At all levels of resolution, we used 2-way

Model I analysis of variance (ANOVA) to test for seasonal differences in (proportional) diet composition, differences in diet composition between argali and livestock, as well as interactions among these two factors. That is, proportions of plant species in each diet ($n = 25$ in each case) were response variables, and animal species and seasons were considered fixed factors. If the overall model was significant, we made comparisons using the Bonferroni procedure and statistical significance was set at the $P < 0.05$ level.

2.4. Dietary overlap

We used Morisita's (1959) index as modified by Horn (1966) to quantify dietary overlap between species:

$$C_\lambda = \left(2\sum_{i=1}^{s} P_{ij}{*}P_{ik}\right) \Big/ \left(\sum_{i=1}^{s} P_{ij}^2 + \sum_{i-1}^{s} P_{ik}^2\right)$$

In this equation, C_λ = the overlap between ungulate species j and k; P_{ij} and P_{ik} = the proportion of species i in the diet of ungulates j and k; and s = the number of species in the diet. We developed approximate 95% confidence intervals for each C_λ by bootstrapping, randomly re-sampling with replacement from each of the 25 diet samples for each species for $n = 25$, 800 times for each overlap index (PopTools (G.M. Hood, 2004; PopTools version 2.6.2, http://www.cse.csiro.au/poptools).

3. Results

3.1. Forage availability

In summer 2002, we recorded 69 species of plants from 46 genera and 20 families (Table 1). Species with the highest frequency included *Stipa* spp. (77%), *A. frigida* (63%), *Allium* spp. (61%), *Carex* spp. (59%), and *C. squarrosa* (46%). Another 47 species had a frequency of 22% or less within the sampled plots. Mean dried biomass during summer was 19.0 g/m^2 (SD = 14.6). Four genera (or species) accounted for 68% of the total mean biomass (Table 1): *A. frigida* (2.7 g/m^2), *Stipa* spp. (2.6 g/m^2), *Carex* spp. (1.7 g/m^2), and *Allium* spp. (1.4 g/m^2).

In winter 2003, we recorded only 22 species (Table 2). Species with the highest frequency of occurrence included *Carex* spp. (60%), *A. frigida* (58%), *Stipa* spp. (43%), *C. squarrosa* (27%), *C. pygmaea* (18%), *K. prostrata* (17%), *Agropyron cristatum* (15%), *Artemisia* spp. (9%), and *Allium* spp. (7%). *Allium* spp., and *C. squarrosa* decreased substantially in frequency from summer to winter (from 61% to 7% and from 46% to 27%, respectively). Shrubs and graminoides comprised most of the forage available during winter.

Total above ground and above snow vegetative biomass in winter declined approximately 82% (to a mean of 3.5 g/m^2) from summer ($t = -10.00$, $P < 0.0001$). *A. frigida* decreased from a summer biomass of 2.7 g/m^2 to a winter biomass of only 0.7 g/m^2 ($t = -4.81$, $P < 0.0001$). Similarly, *Stipa* spp. decreased from 2.6 g/m^2 in summer to 0.5 g/m^2 in winter ($t = -5.04$, $P < 0.0001$), and *Carex* spp. declined from 1.7 g/m^2 in summer to 0.9 g/m^2 in winter ($t = -4.90$, $P < 0.0001$).

3.2. Seasonal food habits

3.2.1. Argali

We identified 37 plant species in argali diets. Of these, 12 constituted ≥5% of mean seasonal diets in at least 1 season, and they accounted for 59.9% of the mean diet in argali feces in summer, 55.5% in fall, 72.6% in winter, and 76.4% in spring (Table 3). Key shrubs used were *Ajania achilleoides*, *A. frigida/Artemisia ruthifolia*, *C. pygmaea*, and *Caryopteris mongolica*; key grasses were *A. cristatum*, *C. squarrosa*, *Festuca/Poa* spp., and *Stipa* spp.; key forbs were *Bassia dasyphylla*, *Erysimum/Convolvulus* spp., and *Oxytropis* spp.; *Carex* spp. was the only key sedge. Argali predominantly fed on shrubs and forbs in summer and fall. However, they fed more on grasses and shrubs in winter and spring (Fig. 3).

We identified no key forage plants that argali consumed in significantly higher or lower proportions than their availability, based on overlap of asymmetrical confidence intervals (Fig. 4). In summer, although not a large part of argali diets, *Erysimum* and *Oxytropis* appeared to be selectively consumed because they were sufficiently rare that none of the 100 vegetation plots contained them (Fig. 4a). *Stipa* and *Carex* were relatively abundant in summer, but did not appear to be preferentially used by argali. Patterns were broadly similar in winter, but it appeared that *Agropyron* assumed increased importance for argali (Fig. 4b).

3.2.2. Livestock

We identified 42 plant species in livestock diets. Of these, 9 constituted ≥5% of the mean diet in at least 1 of the seasons (62.3%

Table 1
Plant species summer biomass (g/m^2) as estimated by random vegetation sampling ($n = 100$) in Ikh Nart, Mongolia, 2002. * indicates that SD and SE cannot be calculated because the sample size is only 1.

Species	Mean	SD	SE	Plots containing species
Artemisia frigida	2.7	5.0	0.6	63
Artemisia spp.	1.2	12.4	3.9	10
Artemisia dracunculus	0.3	14.0	9.9	2
Stipa spp.	2.6	3.5	0.4	77
Kochia prostrata	0.4	1.3	0.3	19
Carex spp.	1.7	2.1	0.3	59
Allium spp.	1.4	3.2	0.4	61
Agropyron cristatum	0.4	2.1	0.5	19
Achnatherum splendens	1.7	18.1	6.9	7
Cleistogenes squarrosa	0.5	0.9	0.1	46
Caragana pygmaea	0.6	2.6	0.6	21
Ajania achiloides	0.3	1.5	0.5	11
Koeleria machrantha	0.0	0.5	0.2	5
Gypsophila desertorum	0.2	0.8	0.2	19
Haplophyllum dahuricum	0.2	1.3	0.4	11
Chenopodium aristatum	0.1	1.0	0.4	7
Cymbaria dahurica	0.0	0.1	0.0	15
Bassia dasyphylla	0.2	1.7	0.6	9
Peganum nigellastrum	0.1	3.5	2.5	2
Scorzonera spp.	0.1	1.1	0.5	5
Convolvulus ammanii	0.7	3.0	0.7	20
Limonium spp.	0.0	0.8	0.3	5
Salsola pestifera	1.0	9.4	2.4	16
Salsola passerina	0.0	*	*	1
Orostachys fimbriata	0.1	1.6	0.7	6
Erysimum altaicum	0.0	*	*	1
Elymus pabaonus	0.7	11.2	5.6	4
Asparagus dahuricus	0.1	0.9	0.4	6
Stelleria dichotoma	0.0	*	*	1
Vincetoxicum sibiricum	0.0	1	0.7	2
Potentilla bifurca	0.0	*	*	1
Heteropappus hispidus	0.3	1.1	0.2	22
Sibbialdanthe adpressa	0.1	1.2	0.7	3
Puccinella hauptiana	0.0	*	*	1
Reaumuria soongorica	0.0	*	*	1
Astragalus miniatus	0.0	0.7	0.3	4
Tribulus terrestris	0.0	1.2	0.9	2
Dontostemon integrifolius	0.0	*	*	1
Caryoptris mongolica	0.3	1.6	0.5	10
Eragrostis minor	0.0	*	*	1
Iris tenuifolia	0.0	0.6	0.3	3
Ephedra sinica	0.9	28.3	14.2	4
Melandrum apricum	0.0	*	*	1
Leptoferum fumaroides	0.0	*	*	1
Setaria viridis	0.0	*	*	1
Ptilotrichum canescens	0.0	0.0	0.0	2
Total	19.0	14.6	1.5	100

Table 2
Plant species winter biomass (g/m[2]) as determined by random vegetation sampling ($n = 100$) in Ikh Nart, Mongolia, 2003. Ten plots had no vegetation. * indicates that SD and SE cannot be calculated because the sample size is only 1.

Species	Mean	SD	SE	Plots containing species
Artemisia frigida	0.7	0.68	0.09	58
Artemisia spp.	0.1	1.41	0.47	9
Stipa spp.	0.5	1.03	0.16	43
Kochia prostrata	0.1	0.49	0.12	17
Carex spp.	0.9	1.22	0.16	60
Allium spp.	0.0	0.39	0.15	7
Agropyron cristatum	0.2	1.02	0.26	15
Achnatherum splendens	0.7	6.05	2.29	7
Cleistogenes squarrosa	0.1	0.40	0.08	27
Caragana pygmaea	0.2	1.39	0.33	18
Ajania achiloides	0.0	0.07	0.05	2
Koeleria machrantha	0.0	*	*	1
Gypsophila desertorum	0.0	0.21	0.15	2
Arenaria capillaris	0.0	0.57	0.4	2
Setaria viridis	0.0	0.13	0.06	5
Cymbaria dahurica	0.0	0.00	0.00	2
Bassia dasyphylla	0.0	*	*	1
Scorzonera spp.	0.0	0.57	0.40	2
Reaumuria songorica	0.0	0.00	0.00	2
Crepis spp.	0.0	0.07	0.05	2
Salsola pestifera	0.0	0.49	0.28	3
Heteropappus hisidus	0.0	0.00	0.00	2
Total	3.5	3.35	0.35	90

of livestock diets in summer, 62.0% in fall, 77.9% in winter, and 79.1% in spring (Table 4)). Key plants used by livestock were the shrubs *A. achilleoides*, *A. frigida/A. ruthifolia*, and *C. pygmaea*; grasses *A. cristatum*, *Festuca/Poa* spp., and *Stipa* spp.; forbs *Erysimum/Convolvulus* spp. and *Oxytropis* spp., and the sedge *Carex* spp. *Erysimum/Convolvulus* spp. had highest composition, followed by *A. frigida/A. ruthifolia* and *A. cristatum.*

Shrubs (Fig. 3) comprised higher proportions of argali than livestock diets during summer (43.8% vs. 25.2%) and fall (52.1 vs. 38.7%), but this pattern did not hold during winter (37.4% vs. 39.6%) or spring (35.9% vs. 44. 3%; species × season interaction, $F_{3,192} = 4.02$, $P = 0.0084$). Sedges were minor components for both argali and livestock, with argali diets consisting of fewer sedges than livestock in summer (1.3% vs. 3.6%), fall (3.5% vs. 4.5%), and winter (2.7% vs. 4.2%), but not in spring (7.5% vs. 6.1%; interaction $F_{3,192} = 2.65$, $P = 0.050$). Species by season interaction terms were not significant for the 2 remaining plant categorical levels. Forbs declined ($F_{1,192} = 159.4$, $P < 0.0001$) for both argali and livestock

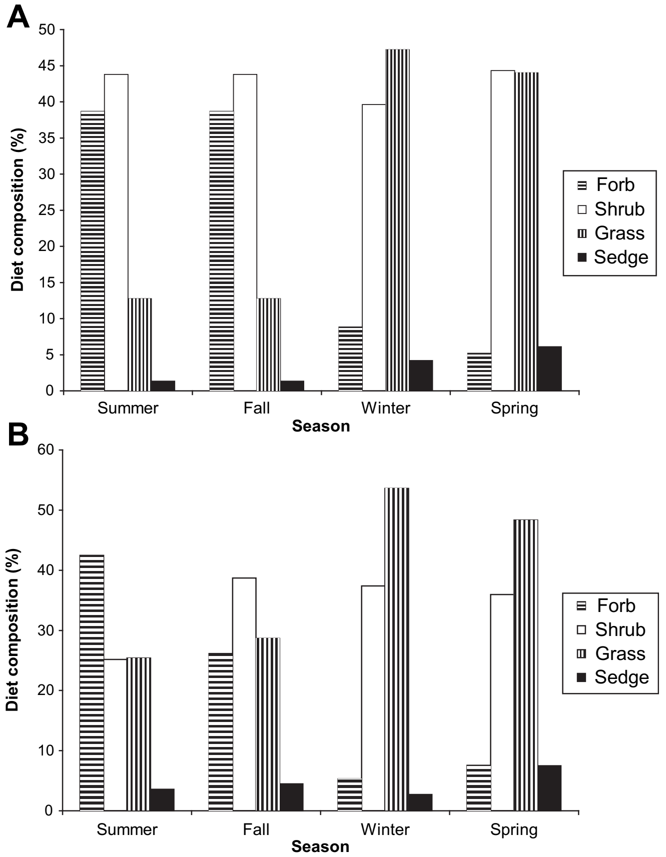

Fig. 3. Proportional dietary composition of argali (A) and livestock (B) diets in summer, fall, winter, and spring in Ikh Nart, Mongolia 2002–2003.

from summer (38.7% vs. 42.5%), through fall (20.9% vs. 26.1%), winter (5.3% vs. 8.8%), to spring (7.6% vs. 5.2%). Grasses comprised lower proportions of argali diets than livestock diets ($F_{1,192} = 16.3$, $P = 0.001$) during summer (12.8% vs. 25.4%), and fall (21.1% vs. 28.7%), although not for winter (53.6% vs. 47.2%) or spring (48.3% vs. 44.0%). Grasses were more common in both species' diets during winter and spring (argali: 53.6%, 48.3%; livestock 47.2%, 44.0%) than summer and fall (argali: 12.7%, 21.1%; livestock 25.4%, 28.7%; $F_{1,192} = 65.6$, $P = 0.0001$). We found no significant difference between argali and livestock in the use of forbs ($F_{1,192} = 2.34$, $P = 0.127$).

Table 3
Key plant species used by argali (*Ovis ammon*) during summer, fall, winter, and spring in Ikh Nart, Mongolia, 2002–2003 (percentage of diet by biomass).

Plant species	Season							
	Summer		Fall		Winter		Spring	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bassia dasyphylla	6.40	4.59	0.90	0.75	0.83	0.76	1.33	1.24
Erysimum/ Convolvulus spp.	5.26	3.80	5.56	4.94	0.52	1.52	0.10	0.05
Oxytropis spp.	8.34	3.90	2.40	1.25	1.80	9.57	1.20	1.11
Ajania achilleoides	1.90	1.83	1.86	1.09	4.04	2.63	10.02	4.33
Artemisia frigida/ A. ruthifolia	16.83	10.47	16.26	7.82	15.09	8.13	15.58	5.98
Caragana pygmaea	7.12	5.09	6.90	3.86	2.56	2.45	1.76	1.87
Caryopteris mongolica	4.65	2.65	6.24	3.41	0.30	0.56	0.06	0.21
Agropyron cristatum	3.36	2.77	2.76	3.11	16.94	6.58	18.16	9.73
Cleistogenes squarrosa	1.29	2.11	3.08	2.07	6.00	3.72	4.59	2.95
Festuca/Poa spp.	0.00	[a]	0.00	[a]	8.91	3.72	7.67	2.63
Stipa spp.	3.41	3.72	6.05	3.57	11.41	5.47	9.80	5.28
Carex spp.	1.34	2.99	3.47	2.37	4.20	3.11	6.11	3.40
Total:	59.90	[a]	55.48	[a]	72.60	[a]	76.38	[a]

[a] SD were not calculated.

3.3. Dietary overlap

The highest dietary overlap between argali and livestock at the plant categorical level occurred in winter and spring ($C_\lambda = 99\%$ for both seasons), followed by fall ($C_\lambda = 93\%$), and summer ($C_\lambda = 92\%$; Table 5). Dietary overlap for key forage species was lower than for plant categories. Summer remained the season with the least overlap ($C_\lambda = 72\%$). Diets of argali and livestock overlapped most during spring ($C_\lambda = 95\%$), followed by winter ($C_\lambda = 90\%$), and then fall ($C_\lambda = 88\%$). As with forage category and all forage species analyses, key species overlap increased through fall to winter and then to spring.

4. Discussion

4.1. Forage availability

Mongolia has a very short growing season from June to August, which coincides with a summer monsoonal rain pattern during

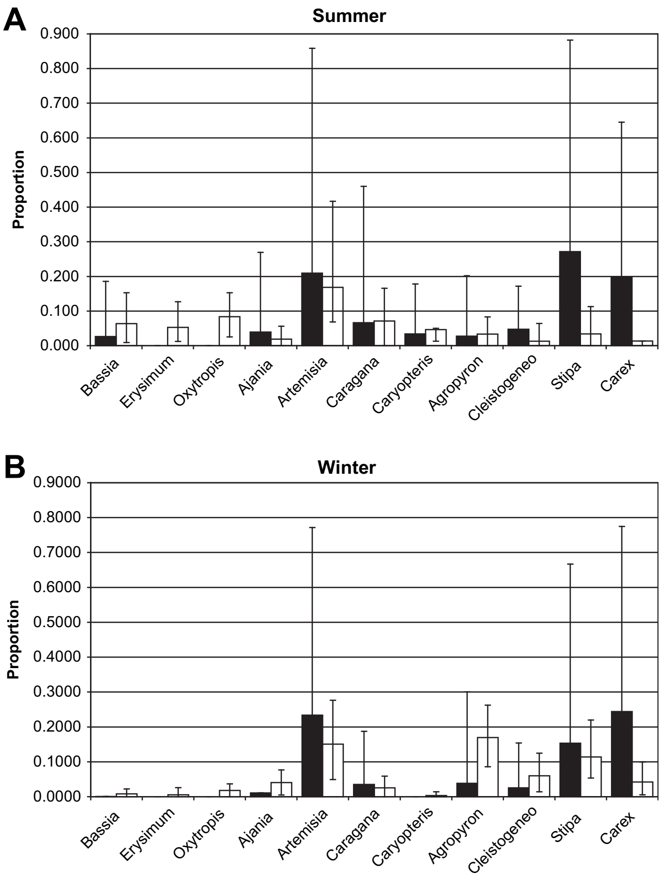

Fig. 4. Mean proportional availability (solid bars with 95% confidence intervals) and mean proportional argali diets (open bars with 95% confidence intervals) of key vegetation species consumed by argali during summer 2002 (a) and winter 2003 (b) in Ikh Nart Nature Reserve, Mongolia.

which over 90% of the precipitation occurs. Mean plant biomass of summer was higher than other seasons primarily due to this weather patterns; our data showed that summer biomass values were more than 81% higher than winter values. Importantly, however, our results may be skewed in favor of summer values as a result of our sampling technique, winter samples were cut from above the snow level.

Although Ikh Nart is a designated wildlife reserve, traditional grazing practices and recent changes in demographics by doubling of herders' numbers in just 2 years after reform (Reading et al., 2006a) have combined to strongly impact the rangeland by heavy

Table 4
Key plant species used by livestock during summer, fall, winter, and spring in Ikh Nart, Mongolia, 2002–2003 (percentage of diet by biomass).

Plant species	Season							
	Summer		Fall		Winter		Spring	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Erysimum/Convolvulus spp	22.22	15.49	10.76	9.91	0.10	0.38	0.24	0.50
Oxytropis spp.	6.35	2.77	2.94	1.90	2.09	2.41	0.93	2.13
Ajania achilleoides	2.83	2.04	3.82	5.27	4.79	4.27	6.48	2.20
Artemisia frigida/ruthifolia	13.58	6.92	14.03	6.38	21.42	11.48	23.30	8.30
Caragana pygmaea	2.34	3.12	7.79	4.63	3.48	4.55	2.64	1.58
Agropyron cristatum	7.42	4.75	9.11	6.11	13.72	5.70	14.89	7.26
Festuca/Poa spp.	2.50	2.69	0.20	[a]	7.19	3.93	8.12	3.37
Stipa spp.	6.44	4.85	8.89	4.59	22.41	16.03	15.02	6.28
Carex spp.	3.59	3.93	4.46	4.35	2.70	2.21	7.48	4.63
Total	62.27	[a]	62.0	[a]	77.88	[a]	79.10	[a]

[a] SD were not calculated.

Table 5
Indices of overlap (Morisita, 1959) among seasonal diets of argali and domestic livestock, Ikh Nart Nature Reserve, Mongolia, 2002–2003.

Season	Forage category	Key species
Summer		
$\bar{x}$	0.921	0.783
95% CI	(0.885–0.951)	(0.688–0.851)
Fall		
$\bar{x}$	0.960	0.915
95% CI	(0.926–0.981)	(0.848–0.948)
Winter		
$\bar{x}$	0.993	0.937
95% CI	(0.960–0.998)	(0.927–0.960)
Spring		
$\bar{x}$	0.990	0.954
95% CI	(0.968–0.997)	(0.913–0.961)

livestock grazing. In addition, the region has always been characterized by limited forage availability during the dormant season, which lasts from October to April (Bayasgalan and Mandakh, 2004). This is especially true in late winter and spring when mean biomass falls to 3.5 g/m^2 compared to 19.0 g/m^2 in summer.

The biomass available for wild herbivores in Ikh Nart was much lower than reported by Jiang et al. (2002) in Inner Mongolia. Their study found that the largest moderately grazed areas provided a mean biomass of 30 g/m^2 and lightly grazed areas provided approximately 100 g/m^2 during spring and summer. However, Ikh Nart is more arid and vegetation is poorer than the areas studied in Inner Mongolia (Campos-Arceiz et al., 2004). Situated on the northern edge of the Gobi Desert, Ikh Nart's vegetation is representative of the semi-arid regions of Central Asia that are substantially less productive than neighboring grasslands (Bayasgalan and Mandakh, 2004).

Grass height decreases with grazing intensity, and the short grasses in Ikh Nart provide little available food during winter. The situation is intensified by occasional snow cover and the presence of more herders in winter in Ikh Nart. Harris and Miller (1995) speculated that winter forage availability in their study area in the Kunlun Mountains of Qinghai, China could be negatively impacted by summer livestock grazing. We believe this is likely in Ikh Nart, although our data are not capable of showing it definitively.

4.2. Seasonal food habits

Microhistological fecal analysis has limitations as a method to estimate proportional dietary components because of varying digestibility of plant species in different phenological stages and among different animal species. Generally, shrubs tend to be overestimated due to their higher fiber content and associated lower digestibility, while readily digested forbs are often underestimated (Holechek et al., 1982; McInnis et al., 1983; Holechek and Vavra, 1981). Frazer and Gordon (1997) and Korfhage (1974) maintained that fecal analyses can be appropriate when comparing herbivores, and may be especially beneficial in comparing herbivorous species using the same range. Baldi et al. (2004) similarly concluded that microhistological fragment analysis comparing 2 species did not introduce systematic bias into the assessment of diet. Therefore, our dietary comparison results between argali and livestock can be interpreted with less caution than the individual diet results for the species.

The overall diet composition of argali and livestock for all seasons was similar with a few exceptions. Both argali and livestock used the same plant species with the exception of five (*C. mongolicum*, *Dracocephalum foetidum*, *Saussurea* spp., *Silene jenisseensis*, and *Haplophyllum dahuricum*) used by livestock and not argali. Snow depth varied from 3.7 to 5.4 cm throughout our winter sampling during January 2003, and snow tended to be mostly loose and granular with little moisture content. Observations suggested that both snow depth and structure did not prevent argali or livestock from digging for forage (Bayasgalan and Mandakh, 2004).

Schaller (1998: 244) in Mongolia's Gobi and Fedosenko (2000) in the Altai-Sayan Region found that argali were mixed feeders, and at lower elevations in the summer, tended to forage largely on shrubs, followed by graminoids and forbs. In contrast, on the Tibetan Plateau, argali summer diets were dominated by forbs and grasses (Harris and Miller, 1995; Miller and Schaller, 1995; Shrestha et al., 2005). Reasons for differences among diets are likely due to the timing of the study and vegetation species present (Shrestha et al., 2005), both of which affect forage availability. Our summer (conducted in June) and fall (conducted in August) sampling was similar to those reported by Schaller (1998), and Fedosenko (2000) in that diets were dominated by shrubs. Higher forb digestibility may have resulted in our underestimating the proportion of forbs in the diet and therefore created a bias in favor of shrub content. In our study, we directly observed argali and livestock feeding on several forbs (including *Allium mongolicum*, *Allium polyrrhizum*, *Allium antisopodium*, *Clematis fruticosa*, and *Serratula centauroides*) that did not appear in our fecal analysis results (G. Wingard, unpublished data).

Summer livestock diets in Ikh Nart were similar to those reported from Omnogobi, Southern Mongolia (Campos-Arceiz et al., 2004; Mandakh et al., 2005), where livestock diets were dominated by forbs, with shrubs and grasses each comprising 25% of the diet. In contrast, Cincotta et al. (1991) and Harris and Miller (1995) reported summer livestock diets dominated by graminoids. Harris and Miller (1995) also reported that domestic sheep diets varied significantly depending on vegetation communities in local areas and were likely influenced by herding practices that potentially limit the variability of their diet. Because herders direct domestic animal foraging rather than allowing livestock to move on their own. Mongolian nomadic herding practices have the potential to similarly limit livestock diet variability, as shown by more focused diet composition with 9 key species comprising a majority of their diet compared to 12 key species for argali in the same area making up majority of their total diet.

4.3. Dietary overlap

We expected high dietary overlap at the category level because this general analysis combines several species and genera, precluding the ability to account for differences in more refined forage selection. Lower dietary overlap in summer might be explained by better forage availability (greater biomass and more species) relative to other seasons. It is important to note that the greatest diet overlap between argali and livestock occurred in spring and winter when forage was most limited. The potential for competition between argali and livestock is therefore greatest during these seasons. To compound matters, pastoralists typically exploit the pastures of Ikh Nart most heavily during winter and spring. By late spring, most pastoralists move their herds to other pastures.

In addition to domestic sheep and goats, pastoralists in the study site also herd 918 horses and 428 cows. Given ratios to smallstock of about 6:1 for horses and 5:1 for cows based on equivalent intake, the impacts on forage biomass by total domestic livestock herbivory would have been greater than our study could show. That said, demonstrating inter-specific forage competition definitively would be very difficult in the absence of manipulative experiments well beyond what is feasible in Mongolia. Thus we cannot conclude that livestock competed with argali for a limiting resource from these overlap data alone (Bertolino et al., 2009; Morrison et al., 1992). However, we find the combination of high overlap and low overall vegetative biomass suggestive of resource competition, particularly during seasons in which argali are nutritionally stressed.

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