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Diet Overlap Between Livestock and Wild Herbivores in the Greater Himalaya

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Understanding the niche usage and dietary habits of wild ungulate populations is crucial to monitoring their response to livestock grazing and changes in habitat quality. Livestock grazing is common throughout the Himalaya and may reduce available forage for wild ungulates, but few studies have assessed the impact of livestock grazing on the diets of wild herbivores in the Greater Himalaya. We assessed forage availability and used microhistological analysis to compare the diet composition of livestock (domestic goats and sheep) and 2 wild herbivores (blue sheep Pseudois nayaur *and musk deer* Moschus *sp.) in the Uttarkashi district of Uttarakhand, India. We calculated the diet preference and niche breadth of each species and the diet overlap between each pair of species. Our results suggest that musk deer may browse trees more than previously understood. In addition, blue sheep consumed fewer graminoids in the autumn than has been previously published. The seasonal increase in shrub and herb consumption by blue sheep during the winter may be amplified and shifted to earlier in the year as a result of reduced graminoid availability after intensive livestock grazing. We recommend monitoring livestock numbers in the study area and limiting livestock to current numbers to avoid further reducing forage availability.*

Keywords: *diet niche; forage availability; livestock; microhistology;* Moschus *sp.;* Pseudois nayaur.

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Introduction

It is crucial to understand the altered niches of wild ungulate populations in order to conserve and manage these populations. Ungulates are physiologically adapted to a specific diet that reflects the proportion of grazing (ie monocotyledons) to browsing (ie dicotyledons) that is preferred by that species (Hofmann 1989; van Wieren 1996). Thus, altering the diet of a wild ungulate could reduce its ability to fully digest the plants it consumes, restrict nutrient assimilation in individuals, and limit the biomasses of entire ungulate populations (Fritz and Duncan 1994).

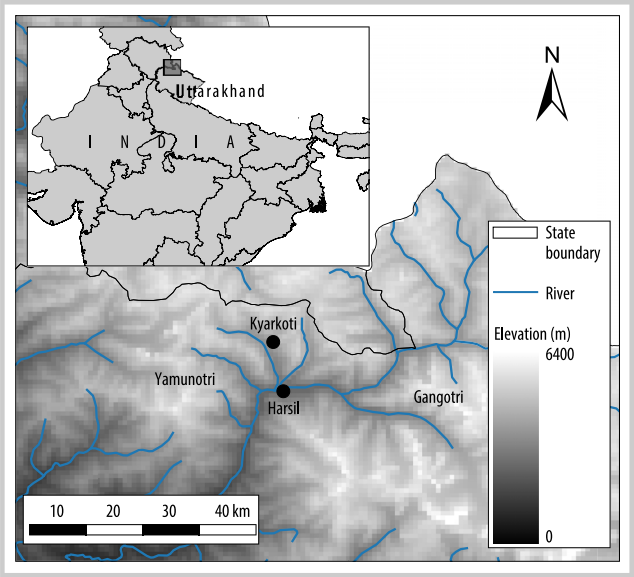
Ungulate habitat use and diet selection can be an indicator of habitat quality and are useful for informing management because ungulates modify their realized niche and activity pattern in response to habitat changes (Owen-Smith 1979; Bhattacharya and Sathyakumar 2011). Landscape alteration through competition from livestock grazing is a global threat to wild ungulates. In particular, India's reserves and the Indian Himalaya support substantial livestock populations (Kothari et al 1989; Bagchi et al 2004; Bhattacharya et al 2012). While some livestock grazing in alpine meadows can be sustainable, many rangelands in the Trans-Himalaya are overstocked to the point of reducing livestock outputs (Mishra et al 2001). Livestock grazing can alter the elevational niche (Mason et al 2014), habitat use (Kittur et al 2010), and dietary niche of wild ungulates (Namgail et al. 2009; Suryawanshi 2009). It can also reduce forage quantity and quality, which in turn can limit the biomass of wild ungulate populations. (Fritz and Duncan 1994; Mishra et al 2004). When preferred forage is in limited supply, herbivores are expected to increase their diet breadth to incorporate less favorable forage (Namgail et al 2009; Suryawanshi 2009).

Studies have compared the diets of livestock and wild ungulates in the Trans-Himalaya (Mishra et al 2004; Shrestha et al 2005; Shrestha and Wegge 2008; Suryawanshi 2009), but few have done so in the Greater Himalaya (Bhattacharya et al 2012). Furthermore, the diets of ungulates vary depending on local environmental conditions, so site-specific studies are critical for informing management decisions (Shrestha et al 2005). In the Uttarkashi district in Uttarakhand, India, shepherds bring livestock to alpine meadows between June and October. This practice has an ancient history (Bhattacharya 1995), but both pastoral livelihoods and wildlife populations would benefit from monitoring the impacts of livestock on the environment and ensuring the sustainable use of alpine meadows.

Shifts in habitat use by wild herbivores in response to livestock grazing presence have been shown in the Uttarakhand State (Kittur et al 2010; Bhattacharya and Sathyakumar 2011). Although livestock and wild ungulates

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FIGURE 1 Study area, lying in the Jalandhari river valley between Kyarkoti lake and Harsil, in the Bhagirathi river catchment, Uttarkashi district, Uttarakhand, India. (Map by Lisa Jeanne Koetke)



use the same meadows while grazing, there is temporal separation between the use of meadows by the livestock and wild ungulates. During spring, wild ungulates occupy our study area as the snow melts, then livestock arrive, and the wild ungulates move out of the grazing areas, which contain an abundance of high-quality forage. In autumn, livestock are present in the study area; wild ungulates use the area only once the livestock travel to lower elevations for the winter. It is expected that the second group of animals to occupy the grazing areas (ie wild ungulates in autumn) could experience pressure through exploitative competition. While changes in habitat use have been documented by wild ungulates in and around the Uttarakhand State in response to livestock grazing (Kittur et al 2010; Bhattacharya and Sathyakumar 2011), the dietary niches of the wild ungulates and livestock in this area have not been assessed. This paper presents plant availability and diet composition of livestock (domestic goats and sheep) and 2 wild ungulate species (blue sheep *Pseudois nayaur* and musk deer *Moschus* sp.) in the alpine meadows of the Uttarkashi district in Uttarakhand, India. Using these data, we examine the diet preference, breadth, and overlap between these species. The results of this study provide information on the dietary niche of livestock, blue sheep, and musk deer in high elevation alpine meadows of the Greater Himalaya.

Study area

The study was carried out in the Bhagirathi river catchment, in the Uttarkashi district of Uttarakhand, India. The study area (31°04′–31°14′ N, 78°41′–78°72′ E) is near Kyarkoti lake and Jalandhari river, which lie east of Yamunotri and west of Gangotri (Figure 1). The mountainous study area ranged from 3500 to 4100 m in elevation and included alpine meadows and birch/fir forests. The composition of the alpine meadows varied with elevation and aspect, with northern-facing slopes dominated by grasses and sedges and southern-facing slopes dominated by heather (*Cassiope fastigiata*) and dwarf rhododendron (*Rhododendron anthopogon*). Shepherds bring livestock to the study area from June through October. The wild ungulates present in the study area are blue sheep and musk deer, while predators include snow leopards (*Panthera uncia*) and Himalayan brown bears (*Ursus arctos isabellinus*).

Study species

Blue sheep live in groups and graze in open alpine pastures from 3500 to 5500 m elevation (Harris and Miller 1995; Namgail et al 2004; Namgail 2006). Distance-based camera trapping estimated blue sheep density to be between 0.41 and 0.84 individuals/km^2 in the study area, which is lower than in Gangotri National Park (unpublished data). Their craniodental morphology is adapted for a graminoid-dominated diet (Tempel and Vrigi 2008), and they feed mostly on graminoids such as *Stipa*, *Carex*, *Kobresia*, and *Agrostis* (Mishra et al 2004; Shrestha et al 2005; Liu et al 2007; Suryawanshi 2009; Aryal et al 2015). Their diet has been shown to consist of up to 80% graminoids, but as little as 46% graminoids when browsing increases in winter and in highly grazed areas (Mishra et al 2004; Shrestha et al 2005; Liu et al 2007; Suryawanshi 2009; Aryal et al 2015). Blue sheep are a primary prey species of snow leopards (Oli et al 1993; Aryal et al 2014; Lyngdoh et al 2014), which are classified as Vulnerable in the IUCN Red List Data (IUCN 2017) and are listed in Appendix I of CITES (CITES 2017).

Musk deer are small deer with a fragmented distribution across the Himalaya (Green 1986; Sathyakumar 1991; Sathyakumar et al 1993). Distance-based camera trapping estimated musk deer density to be between 0.05 and 0.50 individuals/km^2 in the study area (unpublished data). Although most studies of musk deer populations have estimated relative abundances, the density of musk deer in our study area is similar to that estimated in Kedarnath Wildlife Sanctuary (Sathyakumar 1994). Due to poaching, shrinkage in distribution, and habitat destruction and degradation, the population is confirmed as Endangered in the IUCN Red List Data (IUCN 2017) and is listed in Appendices I and II of CITES (CITES 2017). Musk deer are primarily browsers; much of their diet comprises shrubs and forbs such as *Gaultheria*, *Ophiopogon*, *Cyperus*, *Sibbaldia*, and *Quercus*, but they can also consume lichens and mosses (Green 1987; Syed and Ilyas 2016).

Domestic goats and sheep are the primary livestock in the study area and they are kept in mixed herds, so we refer to these herds as livestock. The number of shepherds or livestock in the study area is not monitored, but shepherds reported estimates of livestock numbers between 2500 and 7000. Livestock graze in the same relatively flat meadows that wild ungulates (especially blue sheep) use when livestock are not present and noticeably reduced forage biomass relative to slopes which are not accessible to shepherds (personal observation). Livestock are primarily grazers but can incorporate some herbs and shrubs in their diet (Shrestha and Wegge 2008; Bhattacharya et al 2012).

Methods

Forage availability

We classified the study area into 3 habitat types: graminoid-dominated meadows (ie Poaceae and Cyperaceae families were dominant), heather–rhododendron meadows (ie

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Cassiope fastigiata and *Rhododendron anthopogon* were dominant), and forests (birch *Betula utilis* and fir *Abies spectabilis* were dominant). The forage availability in the study area was estimated between 3 and 16 October in 4 areas representative of the available habitat types in the study area and again between 4 and 14 May in 3 areas. Late snow melt on northern-facing slopes reduced the study area in spring, preventing the fourth availability assessments. Each sampling area was about 1 ha in size. Twenty sampling points were placed roughly 20 m away from each other in a grid pattern across the sampling area. The observer stood at each sampling point and tossed a 1 m^2 quadrat behind their back to randomize its exact location. In each quadrat, the cover of each species was assessed by eye (Higgins et al 2012; Bonham 2013).

Microhistology

Samples of each of the available plant species and of fecal pellets from each ungulate species were collected throughout the study area in autumn (September–November 2016) and spring (May–June 2017). Samples were stored in paper bags and air-dried and/or oven-dried at 50°C. Plant samples (autumn $n = 28$; spring $n = 26$) were separated into leaves and stems. To prevent incorrect identification of pellets, fecal pellets of livestock ($n = 33$) and blue sheep ($n = 47$) were collected from sites where livestock or blue sheep were directly observed, once they had moved away. Only fresh, moist pellets were collected to ensure collection of pellets from the intended species. Since musk deer defecate in latrine sites and their pellets appear different in shape and size from those of livestock and blue sheep, fecal pellets of musk deer were easily identifiable and thus were collected even if musk deer were not directly observed ($n = 44$).

Reference slides were prepared for each of the available plant species from each season. Five pellet samples from each season were randomly selected from the collected fecal pellet samples for each of the 3 ungulate species. Three replicate slides were prepared for each fecal pellet sample, totaling 15 slides per ungulate species per season.

Reference plant and fecal pellet samples were processed for microhistological analysis following established methods (Sparks and Malechek 1968; Johnson et al 1983; Carriere 2002; Shrestha et al 2005; Namgail et al 2009; Bhattacharya et al 2012). The plant and fecal samples were ground to a very fine powder and soaked in 50% H_2O_2 (hydrogen peroxide) for 3–8 days (Kittur et al 2007; Bhattacharya et al 2012) then washed over a fine sieve to remove the H_2O_2 and pigments. The samples were then oven-dried at 50°C and mounted on a slide using DPX Mountant. Due to differential rates of digestion, some dicotyledons tend to be underemphasized in fecal microhistology (Holechek et al 1982; Aryal et al 2015), but it still appears be a more precise method of assessing diet composition than bite-count and utilization methods (Holechek et al 1982; Henley et al 2001). Moreover, fecal pellet collection from the field is a noninvasive method that does not require seeing or being near wild animals—which would not have been possible for musk deer and blue sheep in our study area.

Slides were viewed under a Discovery v8 Zeiss microscope at ×10 and ×40 magnification and were photographed using a Canon Powershot G9. On the plant reference slides, at least 6 fragments, each containing at least 3 complete cells, were photographed. The maximum length and width of 10 randomly selected cells were measured using Image J. Boxplots of these quantitative measurements were made to give a representative idea of the length and width of cells which is characteristic of each plant species. Other epidermal structures, including the shape of the cell, cell wall, stomata, silica cells, cork cells, crystals, micro- and macro-hairs, and bristles, were used to create a photographic key (Johnson et al 1983; Carriere 2002).

On the fecal pellet slides, the first 20 nonoverlapping fragments on a randomly determined transect were photographed. A total of 1 transect per slide, 3 slides per pellet sample, and 5 pellet samples per ungulate species yielded 300 fragments examined per ungulate species per season. The maximum length and width of 3 randomly selected cells per fragment were measured using ImageJ. These quantitative measurements and other qualitative epidermal structures and characteristics were compared with the plant reference slides, and the fragments were identified at the family level and, when possible, at the species level.

Data analysis

The following methods for analyzing diet preference, breadth, and overlap were selected because they compare consumption by the herbivore with availability of forage resources. Diet preference was estimated using a forage ratio (Savage 1931; Cock 1978; Manly et al 1993; Krebs 1999):

$$\widehat{w}_i = \frac{\widehat{o}_i}{\widehat{p}_i}, \tag{1}$$

where o_i is the proportion of species i in the diet and p_i is the proportion of resource i in the available resources. This measure was then standardized as suggested by Manly et al (1993):

$$\widehat{B}_i = \frac{\widehat{w}_i}{\sum_{i=1}^{n} \widehat{w}_i}, \tag{2}$$

where n is the total number of possible resources. When $B_i = 1/n$, the species shows no preference for the resource, when $B_i > 1/n$ the species shows a relative preference for the resource, and when $B_i < 1/n$, the species shows a relative avoidance of the resource, where n is the number of forage resources.

Diet breadth was estimated using Hurlbert's standardized measure of niche breadth (Hurlbert 1978; Krebs 1999; Forsyth 2000; Elbroch et al 2016):

$$\widehat{B}' = \frac{1}{\sum \left(\frac{\widehat{p}_j}{\widehat{a}_j} \right)^2}, \tag{3}$$

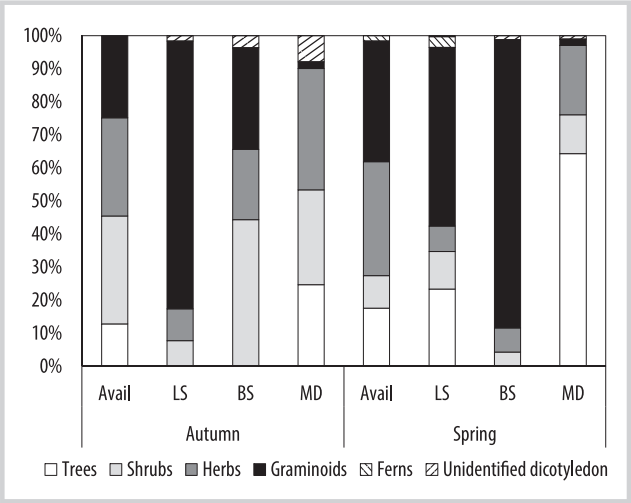
where $\widehat{p}_j$ is the proportion of resource j in the ungulate diet, and $\widehat{a}_j$ is the proportion of resource j that is available to the ungulates. This measure was then standardized to a 0–1 scale:

$$\widehat{B'_A} = \frac{\widehat{B}' - \widehat{a_{min}}}{1 - \widehat{a_{min}}}, \tag{4}$$

where $\widehat{a_{min}}$ is the smallest observed proportion of all resources.

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FIGURE 2 Percent occurrence of forage resources available in the study area (avail) and as cell fragments in the pellets of livestock (LS), blue sheep (BS), and musk deer (MD) in October–November 2016 (autumn) and April–May 2017 (spring).



Diet overlap between each pair of species was estimated using Hurlbert's measure of niche overlap (Hurlbert 1978; Krebs 1999):

$$\hat{L} = \sum_{i}^{n} \left(\frac{\widehat{p_{ij}} \widehat{p_{ik}}}{\widehat{a_i}} \right), \quad (5)$$

where $\widehat{p_{ij}}$ is the proportion of resource i in the diet of ungulate species j, $\widehat{p_{ik}}$ is the proportion of resource i in the diet of ungulate species k, $\widehat{a_i}$ is the proportion of resource i in the available resources, and n is the total number of possible resources. When $L = 1$, both species utilize each forage resource in proportion to its abundance; when $L = 0$, the 2 species share no resources; and when $L > 1$, the 2 species consume similar forage resources more intensely than their availability.

Each measure was bootstrapped from 100,000 pseudosamples to generate means and 95% confidence intervals (CI). Preference was considered significant if the 95% CI did not overlap $1/n$. For analyses of diet breadth and diet overlap, pairs of measures were considered significantly different if the 95% CI were nonoverlapping. All analyses were conducted in RStudio (RStudio 2017).

Results

Forage availability

In autumn, the forage available in the study area comprised mostly shrubs (32.6%), herbs (29.7%), and graminoids (24.9%) (Figure 2). The most common families were Poaceae, Rosaceae, Ericaceae, and Asteraceae, which made up 70.9% of available forage (see *Supplemental material*, Table S1, https://doi.org/10.1659/MRD-JOURNAL-D-19-00016.1.S1, for forage availability at the species level). In spring, the reduced study area was covered mostly by graminoids (36.5%) and herbs (34.5%), followed by trees (17.6%) and shrubs (9.8%). The most common families available were Poaceae, Pinaceae, Lamiaceae, and Rosaceae, which together made up 65.4% of the available forage.

Diet composition

A total of 1800 fragments were analyzed in the fecal samples. Only 60.1% and 71.3% of fragments were identified to the species level in autumn and spring, respectively. Thus, measures of diet breadth and overlap were carried out at the family level. In the autumn and spring, 88.7% and 85.3% of fragments were identified to the family level, respectively.

In autumn, livestock diet was dominated by graminoids (82.0%) (Figure 2). The most common family in the livestock diet was Poaceae (63.7%) (see Table S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-19-00016.1.S1, for diet composition at the species level). Blue sheep relied heavily on shrubs (44.3%), graminoids (30.7%), and herbs (21.3%). Poaceae (25.7%) and Ericaceae (22.7%) were the most common families in the blue sheep diet. The musk deer diet comprised almost entirely browse (herbs = 36.7%, shrubs = 28.7%, trees = 24.7%). The most common family in the musk deer diet was Pinaceae (24.7%).

In spring, livestock diet again mostly comprised graminoids (54.0%) yet contained more browse (trees = 23.3%, shrubs = 11.3%, herbs = 7.7%) than in autumn. Poaceae (32%) was the most common family, followed by Pinaceae (22.7%). Blue sheep diet was dominated by graminoids (87.0%). The most common family in the blue sheep diet was Poaceae (68.3%). Musk deer diet was dominated by trees (64.3%), followed by herbs (21.0%) and shrubs (11.7%). Pinaceae was again the most common family in the musk deer diet (64.0%).

Diet preference

In autumn, livestock displayed a strong preference for graminoids and avoided herbs, shrubs, trees, and ferns (Figure 3). Blue sheep also displayed a strong preference for graminoids as well as shrubs. Musk deer, on the other hand, displayed a strong preference for trees and herbs and avoided graminoids. In spring, livestock avoided herbs and showed no preference for trees, shrubs, graminoids, and ferns. Blue sheep displayed a strong preference for graminoids and avoided herbs. Musk deer displayed a strong preference for trees and avoided herbs and graminoids.

Diet breadth

In autumn, the diet breadth of blue sheep was largest, with livestock having a comparatively narrow diet breadth (Figure 4). In spring, the diet breadth of livestock and blue sheep was the largest, with musk deer having a narrower diet breadth. Livestock diet breadth was wider in spring than in autumn, whereas musk deer diet breadth was narrower in spring than in autumn.

Diet overlap

The diet of livestock overlapped with that of a wild ungulate species in both seasons (Figure 5); it overlapped with blue sheep in the autumn and with musk deer in the spring. These overlaps were high, such that they consumed similar families to a greater extent than their availability. The diet of livestock also overlapped with blue sheep in the spring but to a lesser extent. In the autumn, the diets of blue sheep and musk deer also displayed high amount of overlap.

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FIGURE 3 Diet preference of livestock, blue sheep, and musk deer in October–November 2016 (A; autumn) and April–May 2017 (B; spring), using the standardized forage ratio (when $B_i = 1/n$ the species shows no preference for the resource, when $B_i > 1/n$ the species shows a relative preference for the resource, and when $B_i < 1/n$, the species shows a relative avoidance of the resource). Error bars represent 95% CI, created by bootstrapping the data. Preference was considered significant if the 95% CI did not overlap $1/n$.

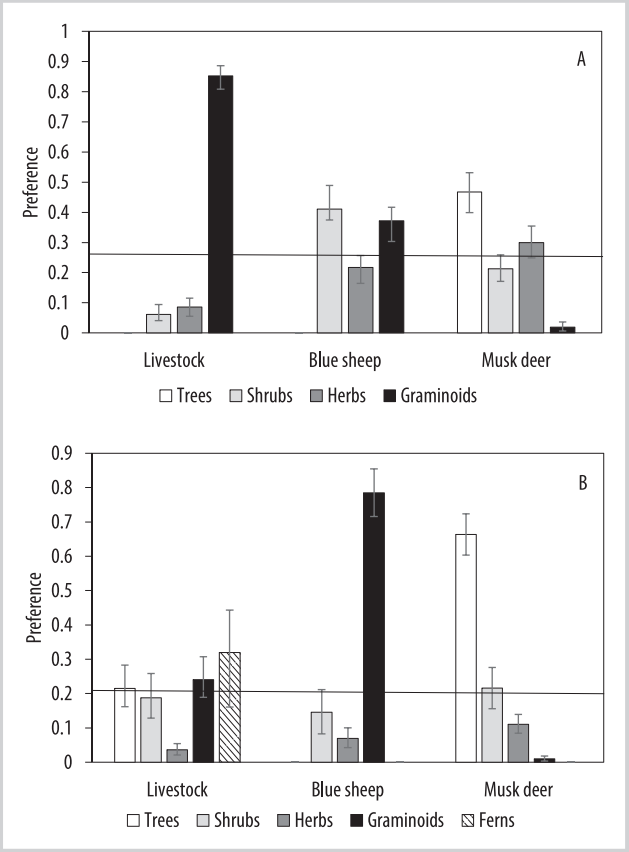
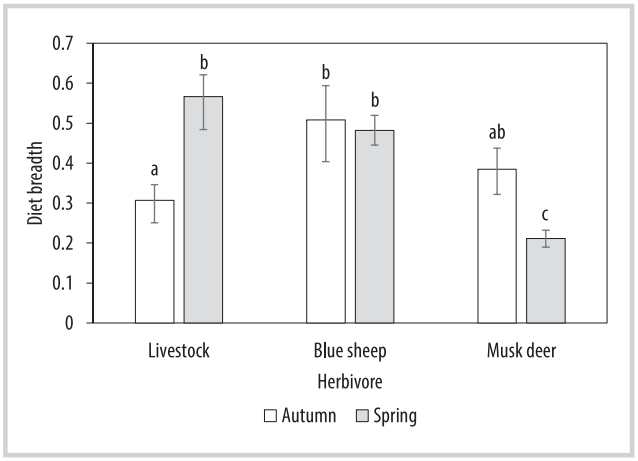


FIGURE 4 Diet niche breadth measurements of livestock, blue sheep, and musk deer in October–November 2016 (autumn) and April–May 2017 (spring), using Hurlbert's standardized measure of niche breadth ($0 \leq B_A' \leq 1$). Error bars represent 95% CI, created by bootstrapping the data. Pairs of measures were considered significantly different (ie do not share a letter) if the 95% CI were nonoverlapping; means that do not share a letter are significantly different.



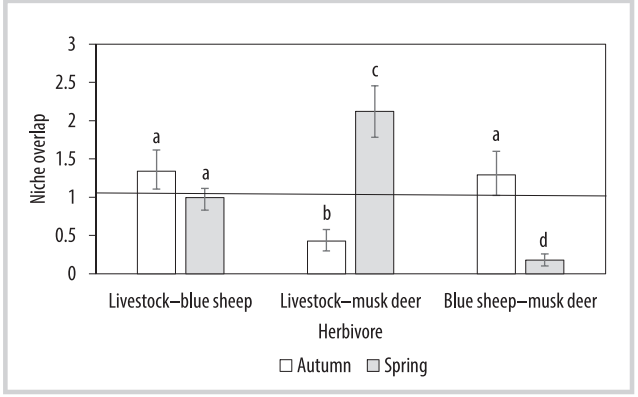
Discussion

Both livestock and blue sheep are expected to be primarily grazers, but there is temporal separation between the grazing of these 2 ungulates. Wild ungulates occupy the study area before livestock in spring and after livestock in autumn. Thus, exploitative competition might occur if wild ungulates experience reduced availability of shared resources in autumn.

Our results indicate that blue sheep relied heavily on graminoids in spring, as is expected but much less in autumn. In autumn, when livestock occupy the prime grazing areas before blue sheep, shrubs, such as the Ericaceae, Lamiaceae, and Roseaceae families, made up a larger proportion of the blue sheep's diet than did graminoids. Livestock showed a preference only for graminoids, while blue sheep showed an equally strong preference for shrubs and graminoids. The diet breadth of blue sheep was also wider than that of livestock, indicating preferred forage resources may have been limited, causing blue sheep to expand their diet niche to incorporate less preferable forage options in autumn (Suryawanshi 2009). The large number of livestock in the Uttarkashi district and the increased reliance of blue sheep on browse suggest that intense livestock grazing may be reducing blue sheep's preferred graminoid forage. However, blue sheep are a flexible grazer and occupy a wider elevational range than livestock, which may also contribute to the relatively wide diet niche.

This dietary shift by blue sheep may also be due to seasonal changes in diet, as blue sheep tend to consume more browse in the winter (Mishra et al 2004; Liu et al 2007). Nevertheless, our results represent the lowest reported proportion of graminoids in the diet of blue sheep both in the Trans-Himalaya (Mishra et al 2004; Liu et al 2007; Suryawanshi 2009) and in the Greater Himalaya (Bhattacharya et al 2012). Our results indicate that the typical seasonal change in the blue sheep diet to incorporate more browse in the winter may be amplified and begin earlier in the year in the Uttarkashi district than found in other studies of blue sheep diet. This may be related to differences in available forage resources between study areas, reduced graminoid availability as a result of livestock

FIGURE 5 Diet overlap measurements between livestock and blue sheep, livestock and musk deer, and blue sheep and musk deer, in October–November 2016 (autumn) and April–May 2017 (spring), using Hurlbert's measure of niche overlap (when niche overlap, $L = 0$ the 2 species share no resources, when $L = 1$ the 2 species use resources in proportion to abundance, and when $L > 1$ the 2 species consume similar forage resources more intensely than their availability). Error bars represent 95% CI, created by bootstrapping the data. Pairs of measures were considered significantly different (ie do not share a letter) if the 95% CI were nonoverlapping; means that do not share a letter are significantly different.



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grazing, or perhaps the availability of relatively nutritious dicotyledons in our study area in the autumn.

The high autumnal reliance of blue sheep on browse is further suggested by the similar amount of overlap of the diet of blue sheep with both livestock and musk deer. This result is surprising since blue sheep are expected to have a diet more similar to that of livestock than to musk deer, which are primarily browsers. However, musk deer showed a preference for trees and herbs, while blue sheep preferred shrubs and graminoids, so they likely maintain distinct dietary niches.

The reliance of musk deer on browse in autumn was expected, but our results reveal an unexpected decrease in herbs and increase in trees in spring diet of musk deer (Green 1987; Syed and Ilyas 2016). In spring, the musk deer diet niche was narrower than in autumn, suggesting a plentiful supply of new growth of preferred forage. Musk deer showed a high preference for browsing trees in spring, and a larger proportion of their diet in spring was composed of the family Pinaceae than in autumn. These results suggest that musk deer may browse trees and shrubs of Pinaceae in the Uttarkashi district more than previously estimated.

In spring, the diet of blue sheep overlapped minimally with that of musk deer, such that they shared almost no resources, revealing strict niche separation. Blue sheep showed a strong preference for graminoids only in spring, and the proportion of graminoids in their diet almost tripled relative to their autumn diet. In contrast with autumn, blue sheep did not incorporate much browse in their diet in spring. However, the blue sheep diet niche was the same breadth in spring as it was in autumn, suggesting that they incorporated a wide variety of graminoids. These results support those of Mishra et al (2004) and Liu et al (2007), who saw an increase in blue sheep graminoid consumption in the summer.

In spring, livestock diet breadth was wider than in autumn, likely due to incorporating more browse. While the majority of their diet was still made up of graminoids, they incorporated trees, shrubs, and ferns and showed no preference for any forage category. The increased consumption of browse led to a high overlap with musk deer, but this overlap in spring likely does not impact musk deer spring diet since livestock arrive in the study area after the musk deer.

The implications of this study are limited by the inability to identify cell fragments to species level. Yet, at the family level, our results highlight the potential for wild ungulates, especially blue sheep, to be impacted by livestock grazing in the Uttarkashi district. This result is further supported by the observation of the researchers that blue sheep frequently grazed in the same meadows that livestock had grazed, so overlap in habitat use for these species does occur.

Although information is lacking as to whether the blue sheep and musk deer populations are decreasing in the Uttarkashi district, changes in the diets of wild ungulates can limit ungulate populations (Fritz and Duncan 1994). Therefore, our research highlights the need for more comprehensive monitoring of both livestock and wild ungulate populations in the Greater Himalaya, where these systems are understudied. Furthermore, less intense and intermittent livestock grazing can help increase wild ungulate populations (Kittur et al 2010). Thus, we suggest managing livestock grazing to ensure the sustainable use of alpine meadows.

Conclusions

In the Uttarkashi district of Uttarakhand, India, blue sheep displayed a broad diet niche in the autumn and an earlier and more intense shift in diet to consuming browse rather than graminoids compared to earlier observations. This could be an indicator of reduced habitat quality due to livestock grazing. In order to sustainably manage alpine meadows in the Greater Himalaya, we strongly recommend more frequent monitoring of (1) forage availability, (2) livestock and wild ungulate population abundance, and (3) livestock and wild ungulate habitat. Limiting future increases in livestock grazing may also be necessary to protect wild herbivores and their predators. Finally, the diet composition of musk deer appears to include more trees in some habitats than previously understood and should be more thoroughly documented throughout the Greater Himalaya.

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Supplemental material

TABLE S1 Percent occurrence of forage species available in the study area.

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