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ORIGINAL ARTICLE

Heavy grazing constraints on foraging behavior of Mongolian livestock

Yu Yoshihara[1], Buyanaa Chimeddorj[2] and Bayarbaatar Buuveibaatar[3]

1 School of Agriculture and Life Sciences, The University of Tokyo, Tokyo, Japan
2 WWF Mongolia Programme Office, Ulaanbaatar, Mongolia
3 Institute of Biology, Mongolian Academy of Sciences, Ulaanbaatar 51, Mongolia

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Correspondence
Yu Yoshihara, School of Agriculture and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan.
Email: marmota.sibirica@gmail.com

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Abstract

We investigated the effects of overgrazing on the foraging behavior of livestock on a Mongolian steppe, by quantifying some behaviors of cattle, sheep and goats foraging in a lightly and a heavily grazed area in summer and winter. All animal species showed higher walking velocity and tended to show higher step/bite ratio when they foraged in the heavily grazed area than in the lightly grazed area. The effect of overgrazing on the step/bite ratio was greater in sheep and goats than in cattle, and the effect on the walking velocity was stronger in winter than in summer. The results indicate that heavy grazing altered the foraging behavior of animals imposing higher foraging costs, which varied among the animal species and between the seasons. The declined quantity of preferred species in the heavily grazed area required high searching efforts and decreased the bite rate, for selecting acceptable plants and better feeding sites. The stronger effects on sheep and goats than on cattle and in winter than in summer may reflect different foraging behavior potentials among the animals and different food availabilities between the seasons. We suggest that the ongoing increase in the number of goats in Mongolia is problematic not only from the viewpoint of grassland deterioration but also from feeding cost of whole livestock animals.

Introduction

The Mongolian steppes have provided stable feed resources for livestock for a long time. Recently, however, populations of livestock and humans have increased, reaching values up to three times that of the early 20th century (National Scientific Office of Mongolia 2007). Due mainly to this, the Mongolian steppes are now confronting problems such as deterioration of vegetation (e.g. vegetation removal) and soil (e.g. soil erosion) through livestock grazing (e.g. Sasaki *et al*. 2005; Onda *et al*. 2007; Yoshihara *et al*. 2008a). Grassland deterioration seriously imperils the economy of many herder households, especially small, poor ones (Lise *et al*. 2006). In Mongolia, poor herders tend to maximize livestock numbers to reap short-term economic rewards (Lise *et al*. 2006). This tendency often leads to the degradation of grasslands in the long-term due to the increased animal population in excess of the grassland's carrying capacity. Moreover, the increase in livestock density decreases performance (bodyweight gain, milk yield, reproductive success) and/or survival rate of animals due to reduced daily forage intake animal^{-1} (Sevi *et al*. 1999; Clutton-Brock & Pemberton 2004; Zhao *et al*. 2004), which leads to further increase in animal population by poor herders.

Heavy grazing by livestock decreases plant biomass and modifies plant communities and/or plant structure (Sasaki *et al*. 2005), and such vegetation changes in turn affect foraging behavior of livestock; for example, elevated searching efforts because of animal selectivity in obtaining acceptable plants from the poor sward (Lazo & Soriguer 1993; Orr *et al*. 2004). The effects of these vegetation changes on the livestock may be different among the animal species and/or seasons according to attributes such as their type of digestive system (ruminant versus non-ruminant), body size or differences in food abundance in summer and winter (Bell 1970; Jarman 1974; Rook *et al*. 2004; Brinkman *et al*. 2005). For example, large-sized grazers are less selective in their diet and can adapt to the decline of quantity of preferred species by reducing handling time (Gross *et al*. 1993; Ruckstuhl *et al*. 2003), whereas small-sized browsers cannot alter their foraging behavior when food abundance of preferred species decline because of selective foraging in their diet.

Mongolian animal husbandry consists of five species differing in digestive system or body size: goats, sheep, horses, cattle

Table 1 Comparison of animal husbandry and grassland vegetation in lightly and heavily grazed areas

	Light	Heavy
Livestock numbers within site (225 km²)		
Cattle	112	1372
Horse	60	1413
Sheep and goat	393	2387
Camel	5	13
Total livestock	570	5185
AU†	1348	17 816
Nomads numbers within site (225 km²)		
Ger	4	16
People	15	103
Vegetation‡		
Cover of *Stipa grandis* (%)	27.5 ± 5.62§*	11.0 ± 3.86
Cover of *Elymus chinensis* (%)	3.8 ± 0.65, NS	4.6 ± 1.57
Cover of *Cleistogenes squarrosa* (%)	0.5 ± 0.15*	5.6 ± 2.05
Cover of *Caragana microphylla* (%)	6.3 ± 2.12*	0.6 ± 0.33
Cover of *Artemisia adamsii* (%)	0 ± 0*	6.8 ± 2.85
Grass height (cm)	29.2 ± 2.93*	9.7 ± 1.16
Above-ground biomass in summer (g m^{-2})	92.2 ± 13.8*	45.6 ± 3.85
Above-ground biomass in winter (g m^{-2})	37.7 ± 2.71*	28.2 ± 4.59
Cover of grass (%)	37.8 ± 3.11*	22.1 ± 2.98
Cover of forbs (%)	62.2 ± 5.75*	77.9 ± 6.63
Cover of rhizomatous plants (%)	5.1 ± 0.90*	13.0 ± 2.12
Cover of palatable plants (%)	95.3 ± 2.23*	75.3 ± 9.37

*Significant difference between the means ($P < 0.05$). †Animal unit (cattle = 5, horse = 6, sheep and goat = 1, camel = 7). ‡Five most abundant plant species based on the cover are shown. According to Jigjidsuren and Johnson (2003), *A. adamsii* was unpalatable, while the other four species were palatable to all animal species. §Mean ± standard error.

and camels. However, there have been few attempts to examine the effects of overgrazing on the foraging behavior of livestock under a free-ranging, nomadic condition such as on a Mongolian steppe with particular research attention to the variations among animal species in the same field. We therefore addressed the following three questions: (i) do animals incur a higher cost for grazing in heavily grazed areas than in lightly grazed areas?; (ii) are these effects different for different livestock species?; and (iii) are these effects different in different seasons?

Materials and methods

The study was conducted at Tumentsogt (47°39′N, 112°25′E) in Sukhbaatar Aimag Province (82 000 km² in size), located 500 km east towards Ulaanbaatar. The study sites were approximately 1000 m a.s.l. with a mean annual precipitation of 250 mm. Typical steppe vegetation prevails (Hilbig 1995), with no forest stands other than woody vegetation within riparian areas. Soils within the study sites were identified as Kastanozems by the world reference base for soil resources (FAO/ISRIC/ISSS 1998) based on soil profile morphology and physico-chemical properties. The main human population in the area is a village called Soum, inhabited by approximately 200 families and 11 000 livestock heads. Most of the herders have a nomadic lifestyle, living in gers (tent-type movable houses, the basic unit of nomadic societies), which they move seasonally with their livestock herds. Recently, there has been a tendency for nomads to abandon the ger lifestyle and settle in sedentary houses in the Soum center, resulting in deterioration of the surrounding grasslands.

Two 15 km × 15 km sites were established, with one site located close to the Soum center and the other far from the Soum center. Grazing intensity was determined by counting the numbers of each livestock species, gers and residents within each site (Table 1). Plant cover, above-ground biomass and plant height of *Stipa grandis*, the dominant grass, were determined on each site by using 15 1-m² quadrats. Vegetation samples were randomly collected in the center of each study site. Total above-ground biomass was determined in June and December 2004. Also, plant species were classified according to their life form, root structure and relative palatability (Jigjidsuren & Johnson 2003). Biomass and plant height between the two sites were statistically analyzed by using a Student's *t*-test, and cover of each species and percentage of forage that are grass, forbs, rhizomatous plants and palatable plants based on cover were analyzed by Mann–Whitney *U*-test. From these results (Table 1), we determined the site close to the Soum center to be a heavily grazed area, and the site far from the Soum center to be a lightly grazed area.

Foraging behavior traits of livestock are considered an indirect method of measuring forage intake and the costs of foraging under different vegetation conditions (Forbes 1988; Hepworth *et al.* 1991). Bite rate was used as an index of foraging intensity (Gillingham & Bunnell 1985), and step/bite ratio and walking velocity were used as an index for searching effort (Renecker & Hudson 1986). We focused on the variation in these variables among three livestock species (sheep, goats and cattle) and between two seasons (summer and winter). We excluded horse and camel from our observation objects, because horses were foraging inactively during our observation time and camels were rare in this study site.

Visual observation of livestock behavior was conducted by a single observer for each of the three livestock herds (one observer for each species: cattle, sheep and goat). Observers followed the animals continuously for a 9-h period (from 9.00 to 18.00 hours) in summer and for 6 h (from 10.00 to 16.00 hours) in winter until sheep and goats were kept in their ger as their daily lifestyle. Lazo and Soriguer (1993) reported that body size influenced bite rate and other feeding activities, therefore we randomly selected a focal individual from equal-sized adults. These animals spent all their day either within the heavily or the lightly grazed area under nomadic condition. We observed animal behavior at distances of 10–30 m from each herd either visually or with binoculars (7 × 40d.f.) to capture their movements and feedings. Behavioral recording bouts of bite rate and step rate began when the focal individual moved one of the front hooves (considered as the first step) and finished when the 5-min period ended every 30 min. The recording was continued whether or not the individual took a short walk between feeding patches during feeding activity. However, if it stopped feeding activity within 5 min, we discarded the data, and then recounted. Activity of the focal animal (eating, moving, standing, resting or others) was scan sampled visually and the animal location was collected using a global positioning system (GPS; Garmin, Taiwan) at intervals of 30 min. During the period of observation, usual herding of sheep and goats was stopped so as not to affect their walking velocity. Animal observations were conducted continuously for 5 days with a different focal animal selected each day (i.e. five individuals in each species) from the end of June to the beginning of August (summer) and in December (winter) 2004. The total records of 661 bite rates, 654 step rates and 1000 positions were taken over a 20-day period.

Step/bite ratio was calculated using step rate and bite rate in each turn. Records were grouped by categories of grazing intensity (two levels), animal species (three levels) and seasons (two levels). The positions of animals were connected in order from the earliest point in the day to the last one to calculate their walking distances h^{-1} $animal^{-1}$. Because sheep and goats moved together in flocks, we treated their walking velocity data as one. We analyzed the effects of factors on bite rate, step/bite and walking velocity by using repeated measures mixed ANOVA including fixed and random effects, after confirming normality in the data (STATISTICA ver. 5.5; Statsoft, Tulsa, OK, USA). The order of entry of the factors and interactions was season, species, grazing intensity, season × species, season × grazing intensity, species × grazing intensity and season × species × grazing intensity. In addition, because differences in grazing behavior may exist between individual animals, the individual animal was considered a random effect. A repeated measurement was used to take into account the fact that the individual animals were sampled more than once. To test the significant differences for multiple comparisons, we used Scheffe's post-hoc test. All differences among comparisons with $P \leq 0.05$ were considered significant.

Results

Above-ground plant biomass was lower in the heavily grazed area compared with the lightly grazed area in both seasons ($P < 0.05$, Table 1). In terms of botanical composition, the heavily grazed area showed lower ($P < 0.05$) percentage cover of grass and palatable plants (e.g. *S. grandis*) and higher ($P < 0.05$) cover of forbs and rhizomatous plant species than the lightly grazed area.

The mean (±standard error) percentage time spent foraging by cattle, sheep and goats was 56% (±3.3), 60% (±5.5) and 66% (±2.8) in the lightly grazed area and 60% (±4.9), 63% (±2.1) and 64% (± 4.4) in the heavily grazed area, respectively. The percentage of time spent moving by cattle, sheep and goats averaged 10% (±2.3), 19% (±6.3) and 9% (±5.2) in the lightly grazed area and 15% (±5.7), 13% (±1.0) and 15% (±2.2) in the heavily grazed area, respectively.

The interaction between animal species and grazing intensity had a significant effect on bite rate (Table 2). Sheep and goats in the lightly grazed area had a 9.50 and 5.47 higher bite rate min^{-1} than those in heavily grazed area ($P < 0.01$, Figure 1). In contrast, cattle bite rate min^{-1} was 2.80 lower in the lightly grazed area compared to the heavily grazed area. Step/bite ratio was marginally higher ($P = 0.09$) in the heavily grazed area than in the lightly grazed area (Table 2). The mean step/bite ratios in the lightly and the heavily grazed areas were, respectively, 0.44 and 0.50 in cattle, 0.63 and 0.83 in sheep and 0.59 and 0.85 in goats.

Walking velocity varied according to species, grazing intensity and interactions between season and species and between season and grazing intensity (Table 2). The velocity was higher in the heavily grazed area than in the lightly grazed area. In winter, the mean walking velocity in sheep and goat was approximately twice higher in the heavily grazed area than in the lightly grazed area (Figure 2).

Table 2 ANOVA results for bite rate, step/bite ratio and walking velocity

Variable	Factor	d.f.	MS	F	*P*
Bite rate	Season (S)	1	26 921.62	86.41	<0.001
	Animal (A)	2	244.17	0.78	0.463
	Grazing intensity (G)	1	677.42	2.17	0.147
	S × A	2	255.54	0.82	0.446
	S × G	1	95.05	0.31	0.583
	A × G	2	1026.85	3.30	0.046
	S × A × G	2	60.28	0.19	0.825
	Error	48	311.54	–	–
Step/bite	Season (S)	1	7.83	7.32	0.009
	Animal (A)	2	3.85	3.60	0.035
	Grazing intensity (G)	1	3.11	2.90	0.095
	S × A	2	0.35	0.33	0.721
	S × G	1	0.48	0.45	0.505
	A × G	2	0.97	0.91	0.411
	S × A × G	2	0.41	0.38	0.687
	Error	48	1.07	–	–
Walking velocity	Season (S)	1	0.05	0.75	0.394
	Animal (A)	1	2.66	36.38	<0.001
	Grazing intensity (G)	1	1.24	17.01	<0.001
	S × A	1	1.96	26.82	<0.001
	S × G	1	0.46	6.27	0.018
	A × G	1	0.14	1.95	0.172
	S × A × G	1	0.33	4.49	0.062
	Error	32	0.07	–	–

d.f., degrees of freedom; MS, mean sum of squares.

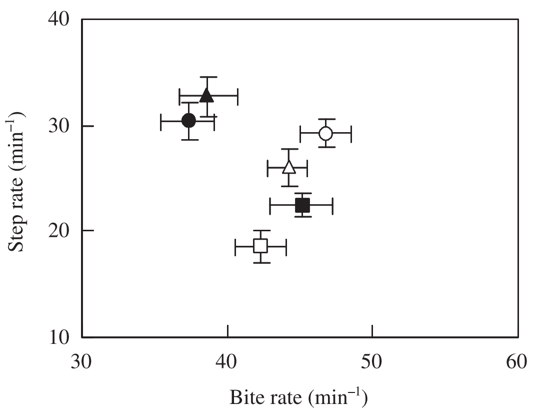

Figure 1 Bite rate and step rate (mean ± standard error) of animals in lightly and heavily grazed areas (□, cattle light; ■, cattle heavy; ○, sheep light; ●, sheep heavy; △, goat light; ▲, goat heavy).

Discussion

Animals showed higher walking velocity and tended to show higher step/bite ratio when they foraged in the heavily grazed area (Figures 1,2). Our results exhibited a similar trend with past studies (Hepworth *et al.* 1991; Lazo & Soriguer 1993; Orr *et al.* 2004). This is because of the reduced quantity of the preferred species in the heavily grazed area. Within the heavily grazed area, animals spent more of their grazing time, with their heads down close to the sward, searching for edible green leaves among the unpalatable plants, which effectively increased step rate and reduced biting rate. Low bite rates are typically associated with elevated searching efforts for selecting food items from the poor sward (Lazo & Soriguer 1993; Orr *et al.* 2004). Animals may have decreased their bite rate under conditions of low abundance of acceptable food and increased their step rate and walking distance to find and select more nutritious forage within feeding site or better feeding sites.

The effects of heavy grazing on searching effort seem to be moderate for cattle and severe for sheep and goats (Figure 1), corresponding with the previous reports (Gibb *et al.* 1997; Dumont *et al.* 2007). This may reflect their different grazing patterns based on body size (Bailey *et al.* 1996). Bite rate can be affected by many factors, and is mostly affected by the quantity of the preferred species and time spent moving (Arnold & Maller 1985; Lazo & Soriguer 1993). The smaller biomass and larger proportion of densely distributed plants (rhizomatous plants) in the heavily grazed area may have reduced handling times and hence resulted in a higher bite

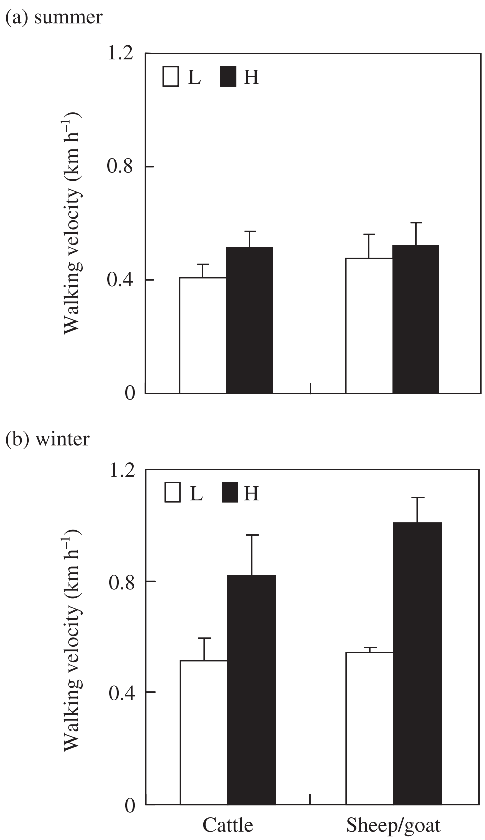

Figure 2 Walking velocity (mean ± standard error) of animals in lightly (□) and heavily (■) grazed areas in summer (a) and in winter (b).

rate for cattle (Gross *et al.* 1993; Ruckstuhl *et al.* 2003; Hirata *et al.* 2008). This can be explained by the usual inverse relationship between bite size and bite rate (Renecker & Hudson 1986; Spalinger & Hobbs 1992; Perez-Barberia & Gordon 1999). However, other more selective feeders (e.g. goats) could not do it because of their sensitivity to the change in species composition and decline of quantity of preferred species in relation to heavy grazing (Negi *et al.* 1993). Furthermore, a large-sized grazer was less selective in its diet than the small-sized browsers (Hofmann 1973) and cannot alter its foraging behavior when food abundance of preferred species changes (Lazo & Soriguer 1993). These characteristics may have prevented increase of time spent moving between feeding patches in the heavily grazed area, leading to the relatively constant bite rate for cattle. In fact, large animals maintained a foraging strategy that maximized food quantity rather than food quality, which agrees with their low ability for manipulation of food because of their wide mouths (Gordon & Illius 1988; Janis & Ehrhardt 1988), and with their high capacity for processing low-quality forages because of their voluminous digestive systems (Demment & Van Soest 1985; Lazo & Soriguer 1993). Our results also showed that heavy grazing increased the cover of *Cleistogenes squarrosa* (Table 1), which is the preferred species for cattle in this region (Yoshihara *et al.* 2008b). Thus, cattle handle lower quality forage in the heavily grazed area than sheep or goats. On the other hand, all of the combined results (i.e. increase of step/bite ratio and walking velocity in the heavily grazed area) suggest that the sheep and goats will perform poorly in the heavily grazed area in terms of weight gain, and that the results (i.e. decrease of bite rate) suggest that sheep and goats in this area are not able to compensate by decreasing consumption of palatable plant species.

There were significant differences in bite rate and step/bite ratio between summer and winter (Figure 1). The effects of grazing intensity on walking velocity were stronger in winter (Table 2, Figure 2), which is similar to that of moose in boreal forests (Renecker & Hudson 1986). Because summer is a period of feed abundance (Table 1), the effect of heavy grazing was insufficient to produce a change in foraging behavior. In contrast, heavy grazing in winter removed plants close to the ground, resulting in eradication of forage plants for animals. In addition, the low-height grasses in the heavily grazed area were completely covered with snow with the exception of long cereal plants like *S. grandis* in our site. Therefore, animals may have been forced to move long distances seeking edible forage. Brinkman *et al.* (2005) showed and concluded that the mean home range of white-tailed deer (*Odocoileus virginianus*) in croplands in winter was twice as large as their home range in summer because of the low abundance of cover and nutritious food in winter. Indeed, snow depth and walking velocity had a positive correlation in the heavily grazed area (Yoshihara *et al.*, unpubl. data).

A limitation of the approach presented here includes the fact that the population of inference is limited to this study site. Additional research is needed to extend the approach to other areas in Mongolian grassland that represent a large portion of rangelands.

Conclusion

Our results suggest that heavy grazing altered the foraging behavior of livestock animals imposing higher cost in foraging, although the effects varied depending on species and season. The decline of quantity of preferred species in the heavily grazed area required high searching efforts and decreased the bite rate, for selection of acceptable plants and better feeding sites. The effects were stronger on sheep and goats than on cattle and were stronger in winter than in summer. One possible explanation for these results is different potential foraging behavior among species and food availability between seasons. The decline of forage quantity of preferred species for sheep and goats is a critical factor changing their foraging behavior. Winter severity may emphasize the impacts of heavy grazing on foraging behavior. Therefore, we suggest that the ongoing increase in the number of goats in Mongolia (National Scientific Office of Mongolia 2007) is problematic not only from the viewpoint of deterioration of Mongolian grasslands but also from feeding cost of whole livestock animals. In addition, cautious management of livestock herding for avoidance of a heavily grazed area is needed especially in winter.

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