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Short communication

Comparison of vegetation changes along grazing gradients with different numbers of livestock

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A B S T R A C T

The objective of this study was to clarify whether the changes in percent cover of plant functional types (i.e., life forms and growth forms) along a grazing gradient reflect the livestock number, which would reinforce the reliability of using a grazing gradient design and improve the management of rangeland. We selected two livestock camps that for many years have had different numbers of livestock, with approximately six times more sheep-equivalents at site 1 than at site 2. Vegetation was sampled in 10 quadrats on five transects along the grazing gradient at each site. In each quadrat, we recorded percent cover of each plant species. Our findings suggested that vegetation changes along the grazing gradient under different livestock numbers were characterized by changes in the cover of life forms: perennial species were replaced by annual species near the camps (10–50 m). However, we did not find growth form change that reflected the difference in the number of livestock.

1. Introduction

Heavy grazing causes significant changes in vegetation. The vegetation degradation process is generally characterized by changes in plant functional types, that is, by changes in life forms such as an increase in the abundance of annual species with a concomitant decrease in perennial species (McIntyre and Lavorel, 2001; Pakeman, 2004; Diaz et al., 2007), and several studies have also reported this to be the case in Mongolia (Fernandez-Gimenez and Allen-Diaz, 1999, 2001; Sasaki et al., 2005, 2007). Moreover, studies of the steppes of Inner Mongolia, northeastern China, and North America reported a change in growth form: the original dominant caespitose grasses were being replaced by rhizomatous grasses due to the change from moderate or low-level to heavy grazing (Mack and Thompson, 1982; Milchunas et al., 1988; Xie and Wittig, 2003).

To facilitate the management of arid and semi-arid ecosystems for both biological conservation and sustainable use, understanding the response of vegetation to different grazing intensities is critical. According to Fernandez-Gimenez and Allen-Diaz (2001), grazing gradients provide a way to observe vegetation changes under different grazing intensities in areas where it is not possible to manipulate livestock densities of free-ranging grazers. Previous studies used the distance from a source of water (Fernandez-Gimenez and Allen-Diaz, 1999, 2001; Sasaki et al., 2005) or from a livestock camp (Whalley et al., 1978; Rogers and Whalley, 1989; Riginos and Hoffman, 2003; Sasaki et al., 2007) to assess the impact of grazing on rangeland structure and function, while controlling the background environmental factors.

In studies of grazing gradients, the number of livestock should be one critical factor affecting the patterns of vegetation responses to the variation in relative grazing intensity (Sasaki et al., 2008). Most previous studies using the grazing gradient approach assumed that the plant community differs according to the grazing intensity along the gradient, and a few such studies investigated the effects of the period of grazing along the gradient (Adler et al., 2004; Nangula and Oba, 2004) and the effects of livestock number over a relatively short period of grazing (Dorrough et al., 2004). If the grazing gradient does differ with the number of livestock, however, it remains unclear how vegetation would change along the grazing gradient. Therefore, in this study we attempted to clarify the influence of livestock number on changes in vegetation, thus reinforcing the reliability of studies using a grazing gradient design and improving the management of rangeland. The objective of this study was to clarify whether the changes in the cover of

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plant functional types—that is, life form (annual vs. perennial) and growth form (caespitose vs. rhizomatous)—along a grazing gradient reflect the livestock number.

2. Materials and methods

2.1. Study area

The study area is located in the Hustai National Park (HNP), Mongolia (47°46–48′N, 105°54–56′E, mean elevation 1378 m a.s.l.). Based on the data from the HNP climatic station, from 1999 to 2005 the mean seasonal temperatures were approximately 13 °C from April to September and −12 °C from October to March, and the mean annual precipitation was approximately 232 mm (CV, 31%). HNP is surrounded by a buffer zone, where the number of livestock has been controlled and managed, and the HNP has records of the number of livestock grazing in the area.

We selected two livestock camps that had long-term differences in the number of livestock but approximately the same seasonal use and environmental conditions. These camps are used by herders during the winter and spring to gather their livestock together at night. Both sites are located on the eastern side of a mountain and have a slight slope (2–5%). Based on soil analysis (pipette method 3A1: USDA-NRCS, 1996), the soil texture at both sites was loamy sand and the soil type was classified as "dark chestnut" (according to HNP documents).

These two camps had records of the number of livestock for every year from 1977 to 2006, and the number of livestock before 1977 was more or less the same as during these years. These numbers were reported by owners of the livestock camps, who said these same camps had been used for at least a few hundred years. In this study, we use the number of livestock as an indication of grazing intensity, because grazing gradients are representative of cumulative grazing intensity (Adler and Hall, 2005).

The livestock were mainly sheep and goats. The sheep-equivalent coefficients used by the National Statistical Office of Mongolia are 7.0, 5.0, 6.0, 1.0, and 0.9 for horse, camel, cattle, sheep, and goat, respectively. The mean annual number of livestock at each study site from 1977 to 2006 was as follows: site 1, horse 23 ± 1, camel 1 ± 0, cattle 22 ± 2, sheep 200 ± 32, and goat 472 ± 34, for a sheep-equivalent of 923 ± 62; site 2, horse 9 ± 1, camel 0 ± 0, cattle 1 ± 1, sheep 24 ± 3, and goat 46 ± 14, for a sheep-equivalent of 139 ± 19. Thus, site 1 has had a larger number of livestock than site 2 over the long term.

2.2. Sampling design

A vegetation survey was performed in early August 2007. The grazing gradient was set parallel to the contour lines from each camp to minimize the effects of topography. We set five survey transects perpendicular to the gradient at 10, 50, 100, 200, and 500 m from the camps. Vegetation was sampled in 10 quadrats (1×1 m) established at intervals of 1 m along each transect. In each quadrat, we recorded cover (%) for each species. Our sampling procedures were determined *a priori* based on previous work in Mongolian rangelands (Fernandez-Gimenez and Allen-Diaz, 1999, 2001; Sasaki et al., 2005, 2007). In those studies, transects were set 500–2000 m outward from camps, but our study sites included concave slopes at distances between 500 and 1000 m from the camps. Therefore, we considered 10–500 m transects as the most representative. There were no features other than the camps, such as wells, that affected animal movement.

2.3. Data analysis

We analyzed whether the changes in the cover of plant functional types, with a focus on life forms and growth forms, along a grazing gradient are related to the livestock number. Data for each gradient were subjected to detrended correspondence analysis (DCA; Hill, 1979) using values for plant cover. We examined the correlations between the DCA axes and distances from camps using Pearson's correlation coefficients. All species were classified by life form (perennial grasses, perennial forbs, annual forbs, shrubs), and the dominant species of perennial grasses were classified by growth form (caespitose or rhizomatous). These classifications were based on Jigjidsuren and Johnson (2003), Grubov (2001), and information provided by Mongolian botanists. We calculated the ratio of each life form along the gradient from each site, using relative values for plant cover. Dominant species were determined based on the relative values of each species at each transect. The differences in life form and growth form were considered fixed effects in an ANOVA. When site × distance interactions were statistically significant, the two-way ANOVA was followed by post-hoc contrasts using *t*-tests with Bonferroni corrections for the within-distance comparisons. Before performing these analyses, all dependent variances were assessed for normality of distribution and heterogeneity of variances. We used $\ln(y+1)$ transformation where needed (Sokal and Rohlf, 1995). The level of significance was $P < 0.05$.

3. Results

There was a negative correlation between DCA axis 1 and the distance from camp ($r = -0.68$, $P < 0.001$), and this axis represented the vegetation differences with increasing distance from the camps.

The cover values of perennial species were different between sites (Table 2), and the value at site 2 was higher than that at site 1(Fig. 1). These cover values increased with increasing the distance from the camps at both sites. The cover values of annual forbs (mostly *Chenopodium album*) were significantly higher at site 1 (higher grazing intensity) than at site 2 at the 10-m transects (Fig. 1). Thus, the pattern of life forms was a high value of annual forbs cover within 10 m of the camp at site 1 and a high value of perennial species far from the camps at site 2.

The values of caespitose grasses (mostly *Stipa krylovii*) were higher at site 1 than at site 2. At 200 m from the camps, *S. krylovii* was the dominant species at both sites (Table 1). The values of rhizomatous grasses (mostly *Leymus chinensis*) were significantly higher at site 2 than at site 1 (Fig. 1). In addition, the cover of rhizomatous grasses at the 50-m transects was significantly greater than at other transects at site 1 and significantly greater at site 2 than at site 1.

4. Discussion

Despite the limitation of small sample size, our findings suggest that vegetation changes along the grazing gradient at sites with different numbers of livestock (Fig. 1) were characterized by changes in the cover of various life forms, from annual forbs to perennial species, close to the camps (10–50 m). Although we did not find changes in growth form from rhizomatous to caespitose grasses according to the difference in livestock number, the lower value of rhizomatous grasses at site 1 than site 2 may indicate the stronger grazing intensity at site 1.

DCA axis 1 indicated differences in the vegetation at each transect along each grazing gradient (Fig. 1), with more annual forbs near the camps and more perennial species far from the camps at both sites.

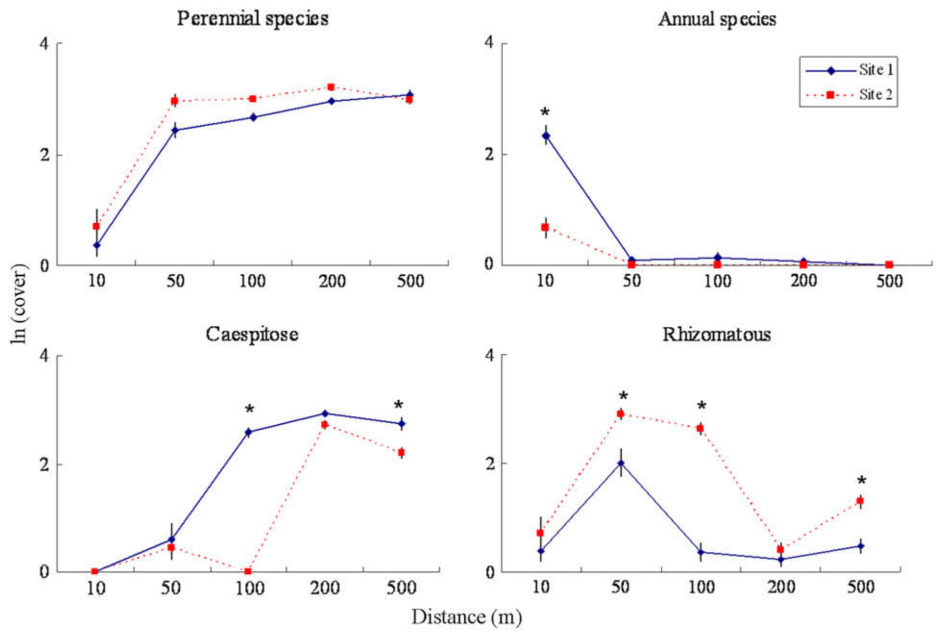

Fig. 1. The cover value of each life form and growth form at each transect. *: means that there is significant difference in cover value of each site at the same distance.

Annual forbs (mostly *C. album*) had greater cover at site 1, supporting previous reports of annual forbs increasing markedly with increasing density of livestock (Sternberg et al., 2000). In addition, *C. album* grows at disturbed and nutrient-enriched sites (Hilbig, 1995), which reflect the higher enrichment from dung by the numerous livestock at site 1, as dung frequency decreases with increasing distance from the camps (T. Okayasu, unpublished data). There was a significant difference in perennial species cover between sites. Thus, the influence of livestock number on vegetation was clear at shorter distances from the camps.

Rhizomatous *L. chinensis* was the dominant species and caespitose *S. krylovii* was not the dominant species at the 50-m transect of both sites, reflecting the higher intensity of grazing due to the proximity of each camp. In addition, the greater relative cover of *L. chinensis* at the 50-m transect at site 2 compared to site 1 (Table 1) reflected the difference in the number of livestock. Although *L. chinensis* can tolerate herbivory (Wang, 2004; van Staalduinen and Anten, 2005), it appears that the intensity of grazing still has an effect on the cover of this species, as the value was lower at the camp with more livestock. If rhizomatous grasses replace caespitose grasses due to increased grazing intensity, then the cover value of caespitose grasses would have been greater at site 2 than at site 1. However, the cover value of caespitose grasses was greater at site 1 than at site 2. Thus, our results indicate that an increase in livestock number did not cause a shift in growth form from caespitose to rhizomatous. One reason for this may have been spatial heterogeneity of livestock at greater distances from the camps, but we were unable to set more than one gradient due to geomorphic changes at 500 m.

Although it may be difficult for other researchers to obtain precise data on the number of livestock, as we were able to do in this study, our findings indicate that information on the number of livestock in an area is important in studies of grazing gradients in terms of assumptions about the degree of grazing intensity. The plant functional types near livestock camps are likely to depend on the number of livestock, and the livestock number may be considered as one factor determining the length of the grazing gradient. The results of this study may also serve as a model case for the management of grazing in semi-arid regions: as more livestock are grazed in an area for long periods, the area's value as grazing pasture will decrease.

Table 1
Dominant species composition at each study site.

Species	Plant functional type	Distance from winter camps (m), relative cover (%)									
		Site 1					Site 2				
		10	50	100	200	500	10	50	100	200	500
Cleistogenes squarrosa	PC		1.0	**50.6**	11.4	29.6				7.1	4.1
Stipa krylovii	PC		15.7	40.6	**85.8**	**34.6**		5.7		**45.1**	33.5
Agropyron cristatum	PR					6.8				6.3	6.1
Carex korshinskyi	PR				0.7	2.6		11.5	**71.8**	2.4	11.7
Leymus chinensis	PR	7.4	**76.2**	5.1	1.6	0.9	**68.1**	**81.7**			3.1
Cymbaria dahurica	PF					1.5					
Kochia prostrata	PF					19.6		1.1	18.7	24.1	**36.0**
Caragana pygmaea	SR									5.2	2.0
Artemisia adamsii	AF		6.1	2.1					9.4	2.1	
Chenopodium album	AF	**88.1**									
Kochia melanoptera	AF	4.4	1.0	1.6	0.5		31.9				

Only those species that occurred more than 10 times in each 1-m^2 quadrat. In each column, the boldface value indicates the dominant species at each transect.
PC: perennial grass, caespitose; PR: perennial grass, rhizomatous; PF: perennial forb; SR: shrub; AF: annual forb.

Table 2
Results of the two-way ANOVA of the effects of distance from the camp (Distance), site with different number of livestock (Site), and their interaction (Distance × Site) on each life form and growth form.

	df	MS	*F*	*P*
Perennial species				
Distance	4	22.92	112.75	<0.001
Site	1	1.80	8.85	0.004
Distance × Site	4	0.26	1.26	0.29
Annual species				
Distance	4	8.77	99.44	<0.001
Site	1	3.76	42.62	<0.001
Distance × Site	4	2.55	28.87	<0.001
Caespitose perennial species				
Distance	4	29.67	156.58	<0.001
Site	1	12.16	64.17	<0.001
Distance × Site	4	5.76	30.41	<0.001
Rhizomatous perennial species				
Distance	4	14.82	41.29	<0.001
Site	1	19.92	55.48	<0.001
Distance × Site	4	3.42	9.52	<0.001

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