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ORIGINAL ARTICLE

Patterns of floristic composition under different grazing intensities in Bulgan, South Gobi, Mongolia

Takehiro Sasaki[1], Tomoo Okayasu[1], Kazuhiko Takeuchi[1], Undarmaa Jamsran[2] and Sanjid Jadambaa[3]

1 Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo, Japan
2 Center for Ecosystem Study, Mongolian State University of Agriculture, Ulaanbaatar, Mongolia
3 Institute of Botany, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

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Correspondence
Takehiro Sasaki, Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657.
Email: aa46304@mail.ecc.u-tokyo.ac.jp

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Abstract

We surveyed the floristic composition and analyzed the patterns of floristic composition under different grazing intensities in the semiarid area of Bulgan, in the South Gobi, Mongolia. We sampled 90 quadrats at six points (15 quadrats each) along a transect from a spring and grouped them into five vegetation types by using TWINSPAN. All or most of the quadrats at each point corresponded to one of the five vegetation types. DCA axis 1 arranged all the quadrats in order of grazing intensity, and the floristic composition changed dramatically in a lopsided stepwise-pattern along this axis. The composition ratio for five groups clustered by TWINSPAN according to plant functional type (toxicity or palatability, and life-form) and family varied to a greater or lesser extent. Background environmental factors such as soil moisture or landform did not affect the pattern of the floristic composition at this site. The patterns of floristic composition were determined by grazing intensity (determined as distance from the spring) together with palatability, which was the dominant environmental effect at the site.

Introduction

Land degradation problems in arid and semiarid areas have been the focus of numerous studies; some of these studies have found overgrazing to be the most serious of all factors causing land degradation (Dregne *et al*., 1991; UNEP, 1992). In Mongolia, most of which forms part of the semiarid area of north-eastern Asia, the main cause of land degradation is also overgrazing (Gunin *et al*., 1999).

According to Ohkuro (1997), analysis of grassland ecosystems under various grazing intensities at the floristic composition level is a valid method of diagnosing grassland condition. Studies that have used this method have reported that floristic composition changes with grazing intensity (Li, 1989; Nemoto *et al*., 1994, 1997; Wang and Ripley, 1997; Nakamura *et al*., 1998, 2000; Wuyunna *et al*., 1999; Yiruhan *et al*., 2001). In most of these studies, however, background environmental factors such as landform and soil moisture have not been described, therefore their potential effects on the changes of floristic composition cannot be discussed. Fernandez-Gimenez and Allen-Diaz (2001) also pointed this out and, in fact, they attempted to measure the effect of different grazing intensities on the patterns of floristic composition by measuring background environmental factors. According to their results, the background environmental factors vary with distance from water source, and these factors potentially correlate with vegetation changes. Therefore we consider that variations in background environmental factors make it difficult to distinguish grazing effects from other environmental effects.

We selected a study site where landform did not appear to be a major influence for screening effects other than grazing effect, and to support this assumption, we measured background environmental factors such as soil moisture and landform at the study site. We then analyzed the patterns of change in floristic composition with changes in grazing intensity.

Materials and methods

Study site

The study site was located in Bulgan, in the South Gobi, Mongolia (Figure 1). The latitude was 43°54′–43°56′N and the longitude 103°30′–103°32′E, at an elevation of 1660–1690 m a.s.l. From 1993 to 2001, the mean annual air temperature was approximately 4°C and the total annual precipitation ranged from 100 to 150 mm. At the foot of a mountain in this area there is a spring from which a flat pediment spreads out (Figure 2). This spring is located approximately 20–25 km away from Bulgan village, and there are six *gers* (traditional Mongolian circular tent-houses) within 4–5 km of this spring.

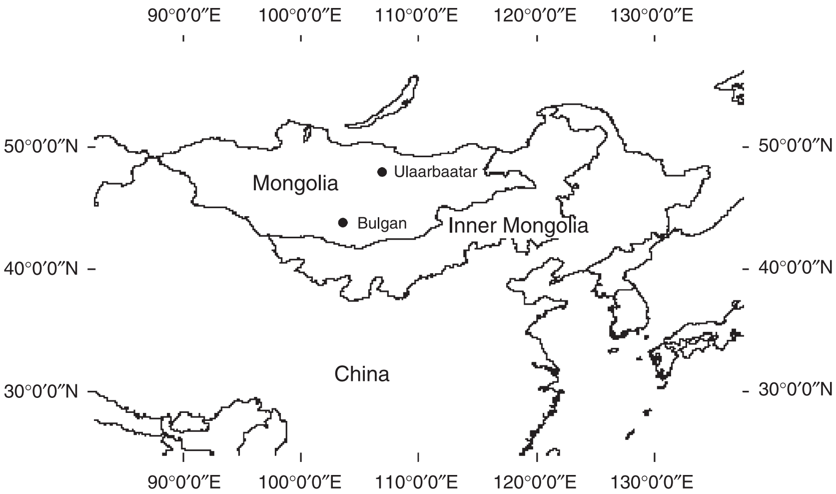

Figure 1 Location of the study site in Bulgan, in the South Gobi, Mongolia.

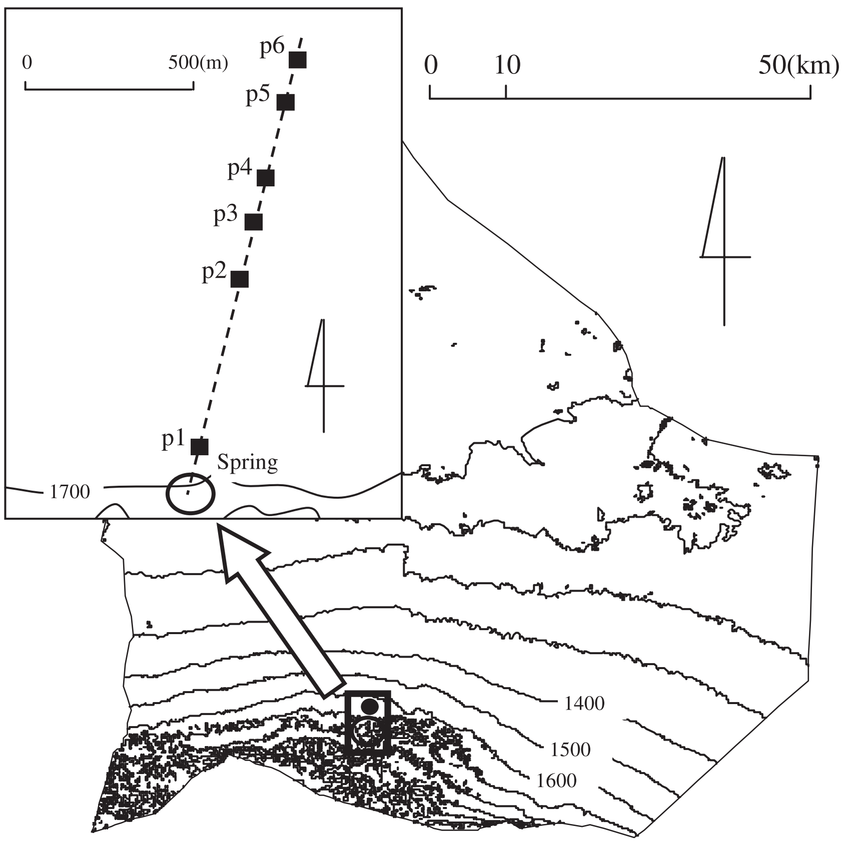

Figure 2 Map of the study site. Contour lines are 100 m. (●), study site; (○), spring. P1–6, points 1–6 on the transect.

Table 1 Characteristics of some community attributes and soil attributes at each point

Survey point	1	2	3	4	5	6
Distance from the spring (m)	150	800	950	1050	1400	1500
Classification by TWINSPAN	1P	5P	5N†	5N†	4N†	4P†
Total coverage (%)	6.30 ± 2.46‡	4.53 ± 2.13	14.63 ± 3.68	10.10 ± 3.52	22.13 ± 4.53	21.40 ± 5.16
Community height (cm)	7.10 ± 3.29	4.80 ± 1.26	3.62 ± 0.87	3.93 ± 1.27	4.10 ± 0.68	5.27 ± 1.31
Vegetation volume (× 100 cm^3 m^{-2})§	58.90 ± 45.78	36.12 ± 20.35	26.89 ± 4.76	24.30 ± 10.55	91.98 ± 38.18	90.62 ± 40.45
Soil hardness (mm)	19.67 ± 1.84	21.00 ± 3.29	23.00 ± 2.25	22.50 ± 2.01	19.30 ± 1.84	20.05 ± 2.09
Soil moisture (%)	13.40 ± 0.84	14.60 ± 1.82	15.60 ± 1.82	15.00 ± 1.22	14.80 ± 1.30	15.40 ± 1.14

† The majority of the groups identified by TWINSPAN corresponded to quadrats at this point. ‡ Mean with standard deviation. § Vegetation volume was the sum of height (cm) × coverage (%) of each plant species.

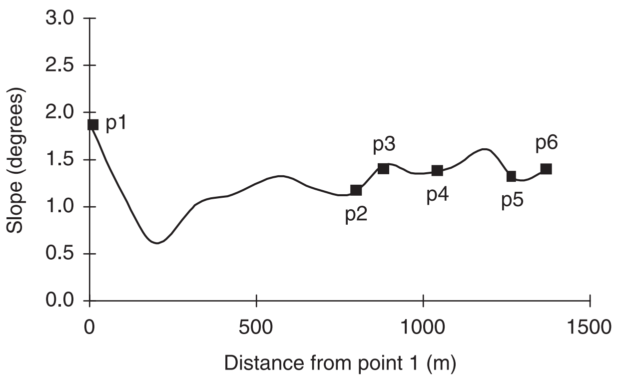

Figure 3 Change of slope from point 1 to point 6.

Because livestock (mainly sheep and goats, approximately 5000 head around this site) concentrate around the spring to drink, we hypothesized that the grazing intensity would decrease radially outward from the spring. After performing a preliminary survey we set six points at which both floristic composition and soil structure appeared to be characteristic along a transect from the spring. The distances from the spring to each point are shown in Table 1. Because we expected the grazing intensity to increase toward point 1, which was located closest to the spring, we used the distance of each point from the spring (transformed logarithmically) as an indicator of grazing intensity. The changes in the slope along the transect are shown in Figure 3.

Survey methods

We performed a vegetation survey in early August 2004. At each point, we set 15 quadrats (1 m × 1 m) randomly, and recorded the total vegetation coverage in each quadrat, and the coverage and the maximum height of all plant species. Soil hardness (n = 15) was also measured at each point using Yamanaka's soil hardness tester. As background environmental factors, we measured soil moisture (at a depth of 0–12 cm; n = 5) at each point by using time-domain reflectometry (TDR) and surveyed the slope of the pediment from points 1–6 along the transect.

Data analysis

We calculated the species volume of each plant species in each quadrat by multiplying the coverage and maximum height of each plant species to give the volume of space occupied by the species (Ohtuka *et al.*, 1993), and after calculating the sum of species volume (we called this summed value a vegetation volume) of each plant species at each point, we standardized the vegetation volume to a relative value, the relative species dominance. We then determined the dominant species on the basis of a dominance analysis (Ohsawa, 1984) and compiled a table of floristic composition (Table 2).

We compared some community and soil attributes among the points by using one-way analysis of variance (ANOVA). Because we could not identify changes in trends by using one-way ANOVA (only differences among the points could be identified in this way), we then examined the correlations between some community attributes, soil hardness (which differed between the points) and distance from the spring (transformed logarithmically) using Pearson's correlation coefficient.

Data for each point were subjected to two-way indicator species analysis (TWINSPAN; Hill, 1979b) and detrended correspondence analysis (DECORANA; Hill, 1979a) using values for relative species dominance. We examined the correlations between the DECORANA axes and some community attributes using Pearsons' correlation coefficient.

The 20 plant species that we found were classified by family and by plant functional type, which we defined as toxic or palatable, and life-form. Toxicity and relative palatability at this site were determined according to information from a field survey we carried out and a plant dictionary (Jigjidsuren and Johnson, 2003). We then compared the composition ratio by family and by plant functional type among five vegetation groups clustered by TWINSPAN to reveal changes in them.

Table 2 Floristic composition at each point (dominant species are in italics)†

Species	Life form†	Growth form‡	RD value in each survey point 1 (*n* = 15)	2 (*n* = 15)	3 (*n* = 15)	4 (*n* = 15)	5 (*n* = 15)	6 (*n* = 15)
Herbs								
Peganum nigellastrum	Per	e	*63.38*	3.14				
Achnatherum inebrians	Per	t	*25.82*					
Salsola collina	Ann	b	5.46	0.72	0.21	0.41		
Tribulus terrestris	Ann	p	4.07					
Chenopodium album	Ann	e	0.65					
Bassia dasyphylla	Ann	e	0.35					
Artemisia macrocephalla	Ann	e	0.27		0.25			
Artemisia pectinata	Ann, Bie	e		*90.89*	*48.35*	*58.03*	*51.24*	*43.11*
Sibbaldianthe sericea	Per	p		0.65	*43.89*	*34.85*		
Stipa gobica	Per	t			0.00	0.82	*26.53*	*42.45*
Allium polyrhizum	Per	t					11.38	2.28
Convolvulus ammanii	Per	p		3.77	5.76	1.78	6.16	1.07
Cleistogenes songorica	Per	t		0.00	0.25	3.29	3.19	6.99
Carex stenophylloides	Per	t		0.83	1.24	0.71	0.40	0.12
Gypsophylla desertrum	Per	e				0.03	0.54	1.51
Heteropappus altaicus	Bie	e					0.18	0.18
Haplophyllum dahuricum	Per	e					0.13	0.29
Iris bungei	Per	t					0.22	
Shrub (semi-shrub)								
Ajania achilleoides	–	b			0.05	0.07	0.04	1.78
Artemisia caespitosa	–	b						0.22

RD, relative species dominance. † Life form: Per, perennial; Ann, annual; Bie, biennial. ‡ Growth form: b, branched; e, erect; p, prostrate: t, tussock.

Results and discussion

Floristic composition

Twenty species were recorded in total at the six points (Table 2). Floristic composition changed dramatically along the transect. At point 1, *Peganum nigellastrum* dominated, and annual species such as *Salsola collina* and *Tribulus terrestris* appeared. At points 2–4, *Artemisia pectinata* dominated, and prostrate species such as *Sibbaldianthe sericea* and *Convolvulus ammanii* appeared. At points 5 and 6, grasses such as *Stipa gobica* and *Cleistogenes soongorica* appeared.

Characteristics of some community attributes and soil attributes at each point

The characteristics of some community attributes and soil attributes at each point are shown in Table 1. From the results of one-way ANOVA, total coverage, community height, vegetation volume, and soil hardness varied significantly (ANOVA, $P < 0.001$) with distance from the spring, but soil moisture did not (Table 3), and was therefore not a major influence on the patterns of floristic composition. Figure 3 shows that the slope from points 1–6 ranged from 0.7° to 1.8°; that is, the slope was very shallow. Therefore, at this site the background environmental factors of soil moisture and landform (see Figures 2, 3) did not have a significant potential effect on the pattern of floristic composition.

Table 3 Results of one-way ANOVA among the six points on the transect

	Sum of squares	d.f.	Mean squares	*F* value	*P*
Total coverage	4221.43	5	844.29	60.63	$P < 0.001$
Community height	121.52	5	24.30	8.61	$P < 0.001$
Vegetation volume	71117.61	5	14223.52	14.87	$P < 0.001$
Soil hardness	234.56	5	46.91	9.17	$P < 0.001$
Soil moisture	18.17	5	3.63	1.85	NS

NS, not significant.

Correlations between some community attributes and distance from the spring

We then searched for correlations between some community attributes and distance from the spring (transformed logarithmically). There was a moderate positive correlation ($r = 0.59$; $P < 0.001$) between total coverage and distance, whereas there was a moderate negative correlation ($r = -0.49$; $P < 0.001$) between community height and distance. There were no significant correlations between vegetation volume and distance. With the exception of the correlation between total coverage and distance, this result did not agree with the general findings of previous studies (Li, 1991; Ohkuro, 1997; Wang and Ripley, 1997; Wuyunna *et al.*, 1999; Nakamura *et al.*, 2000; Yiruhan *et al.*, 2001), which have reported that attributes of the vegetation cover, such as total coverage, community height, vegetation volume, and biomass, decrease as grazing intensity increases. However, the present results accord with the findings of Fernandez-Gimenez and Allen-Diaz (2001), who surveyed vegetation on the desert steppe in Mongolia. The Bulgan site is also part of the desert steppe in Mongolia and is characterized by the presence of sparsely distributed short grasses and very low biomass (approximately 20 g m^{-2}). Because the vegetation volume of unpalatable or toxic species was much higher than that of other species at points 1 and 2 (where there was heavy grazing intensity; see later in this paper), and these species were also much taller than other species there despite the heavy grazing, we considered that the decrease in the quantity of vegetation cover as grazing intensity increased did not need to be recognized.

This result and that of a previous study (Fernandez-Gimenez and Allen-Diaz, 2001) suggest that vegetation cover does not always decrease as grazing intensity increases. Thus, we considered that analyzing the effect of grazing intensity on vegetation from a quantitative viewpoint would not give a valid measure of the effect of grazing intensity at our site.

Correlation between soil hardness and distance from the spring

We also tested for correlations between soil hardness and distance from the spring (transformed logarithmically), and found that there were no significant correlations between soil hardness and distance. Ohkuro (1997) reported that soil hardness was well correlated with grazing intensity, but at our site there was no such correlation. We consider that at our site the soil compaction caused by livestock was inconsistent because the ground surface was rudaceous. However, we cannot examine the generality of this result because previous studies are scarce.

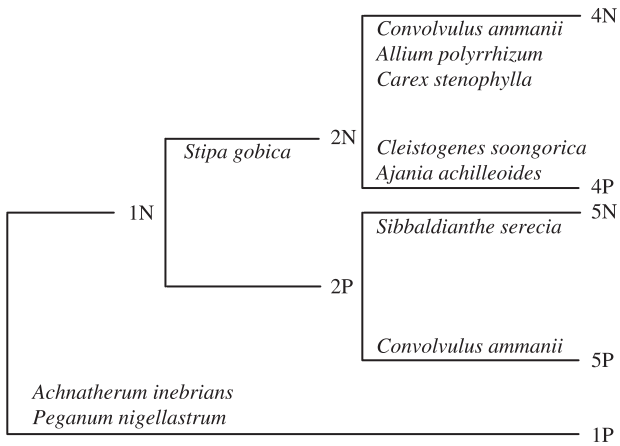

Figure 4 Process of classification using TWINSPAN and pseudospecies. Pseudospecies are in italics.

TWINSPAN classification

TWINSPAN cluster analysis categorized the 90 quadrats into five vegetation groups (Figure 4). All the quadrats in group 1P were located at point 1, and all those in group 5P were located at point 2 (Table 1). Most quadrats in group 5N were found at points 3 and 4, and most quadrats in groups 4N and 4P were located at points 5 and 6, respectively.

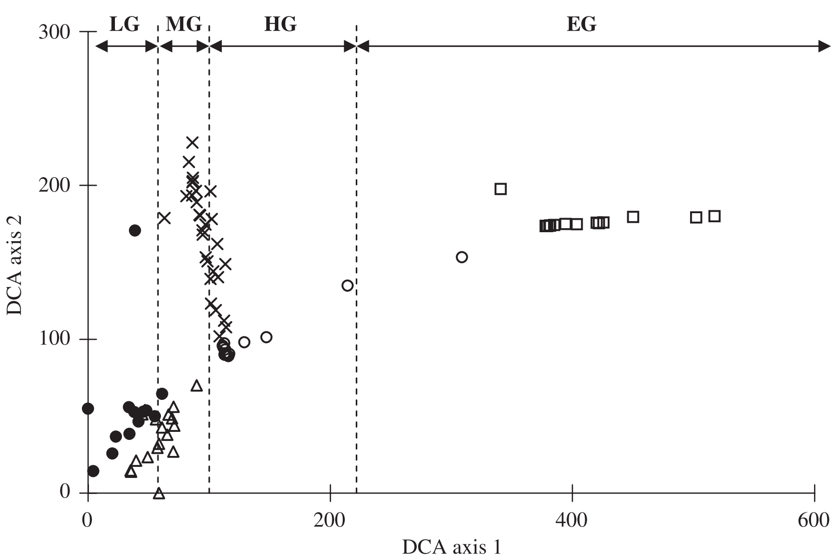

Figure 5 Ordination of 90 quadrats by using DECORANA (DCA) for five vegetation groups clustered by TWINSPAN. (□), 1P; (○), 5P; (×), 5N; (△), 4N; (●), 4P. EG, extremely grazed; HG, heavily grazed; MG, moderately grazed; LG, lightly grazed. The four stages (EG, HG, MG and LG) were distinguished by considering the distribution, mean and standard deviation of DCA scores at each point. Floristic composition changed dramatically in a lopsided stepwise-pattern along DCA axis 1.

Ordination

The quadrats at each point that corresponded to most or all of the five vegetation groups identified by TWINSPAN were ordered along the first axis of the DECORANA (DCA) ordination (Figure 5). This order was a good indicator of grazing intensity. Because the background environmental factors of landform and soil moisture did not have a significant potential effect on the changes in floristic composition along the transect, we considered that the characteristics of the floristic composition were directly represented by the second axis of the DCA. This result agrees with the fact that ordination by DCA gives an accurate output when the first environmental factor has a dominant effect (Kenkel and Orloci, 1986). Therefore, we considered that the patterns of floristic composition were summarized well by the DCA, and that grazing intensity was the dominant environmental factor at this site.

We also examined the relationships between DCA axis 1 and some community attributes (Figure 6). Total coverage increased ($r = 0.56$; $P < 0.001$) and community height decreased with decreasing values along DCA axis 1 ($r = -0.52$; $P < 0.001$). Vegetation volume had no significant relationship with DCA axis 1. Thus, the relationship between DCA axis 1 and some community attributes was similar to the relationship between distance from the spring and the same community attributes. We therefore confirmed that DCA axis 1 represented grazing intensity well.

Community composition ratio by family and by plant functional type

We also compared the community composition ratio by family and by plant functional type for five groups clustered by TWINSPAN (Figure 7). Comparisons of the composition ratio for five groups by family revealed that the composition ratio of the Compositae, Zygophyllaceae, and Chenopodiaceae was very high in 1P and 5P, whereas that of the Poaceae increased from 5N toward 4P. Exceptionally, Poaceae appeared in 1P, but the species was *Achnatherum inebrians*, which is toxic. Comparison of the composition ratio for five groups by plant functional type revealed that unpalatable or toxic species tended to increase in prevalence as the transect moved toward extremely (1P) and heavily (5P) grazed stands. If there were few unpalatable or toxic species present, then annual or biennial herbs replaced perennial herbs as the transect moved toward extremely and heavily grazed stands. The prevalence of palatable species tended to increase as the transect moved towards lightly grazed stands.

These results, with the exception of our analysis of composition ratio by family, agree more or less with the general results of some previous studies (Newsome and Noble, 1986; Pettit *et al.*, 1995; Crawley, 1997; Ohkuro, 1997). From these findings and these studies, we conclude that grazing intensity,

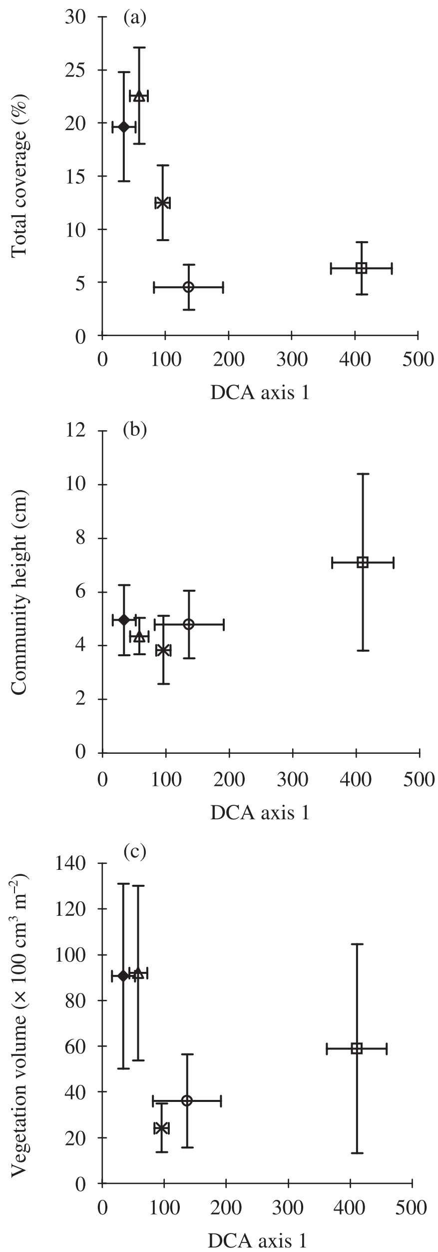

Figure 6 Relationships between DCA axis 1 and some community attributes for five vegetation groups clustered by TWINSPAN. (a) Total coverage; (b) community height; (c) vegetation volume. Horizontal and vertical bars indicate SD. (□), 1P; (○), 5P; (×), 5N; (△), 4N; (●), 4P.

together with palatability to livestock, affect the pattern of floristic composition.

Conclusion

We conclude that at this study site, the pattern of floristic composition was determined by grazing intensity as the dominant environmental factor along the transect, and that

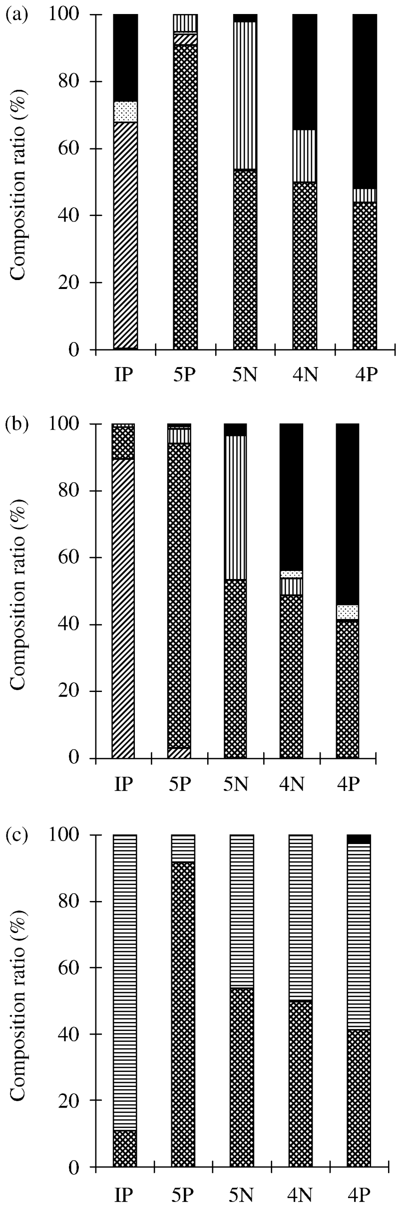

Figure 7 (a) Composition ratio by family; (b) composition ratio by toxicity and palatability; (c) composition ratio by life-form, for the five vegetation groups clustered by TWINSPAN. (a) (■), Poaceae; (▥), others; (▨), Chenopodiaceae; (▨), Zygophyllaceae; (▩), Compositae. (b) (■), Palatable; (▨), others; (▥), moderately palatable; (▩), unpalatable; (▨), toxic. (c) (■), Sub-shrubs; (▤), perennial; (▩), annual or biennial. Composition ratios were calculated using relative species dominance.

changes in grazing intensity were distinct. Analysis of the relationships between composition ratio by plant functional type and grazing intensity revealed that grazing intensity, together with palatability to livestock, affects the pattern of floristic composition. Furthermore, our results suggest that not only analyses of the quantitative aspects, but also analyses of the qualitative aspects of vegetation, such as floristic composition and plant functional type, can be an important method of diagnosing grassland condition using common criteria.

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