Quantifying the resilience of plant communities under different grazing intensities in a degraded shrubland: A case study in Mandalgobi, Mongolia

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Introduction

Resilience is the changing rate at which a system returns to its former state after it has been perturbed from that state (Gunderson 2000). Arid and semi-arid ecosystems are vulnerable ecosystems; losses of resilience make the system more fragile (van de Koppel *et al*. 1997; Scheffer *et al*. 2001). Most field studies on the relationship between vegetation and grazing in arid rangelands have shown that the quantity of vegetation or the species composition changes according to grazing intensities (e.g., Fernandez-Gimenez and Allen-Diaz 2001; Sasaki *et al*. 2005). However, few studies have measured changes in vegetation and grazing intensities to quantify the resilience.

Plant functional types (PFTs) have been widely used by ecologists to quantify the relationship between vegetation and various disturbances (e.g., Lavorel *et al*. 1997; Sternberg *et al*. 2000) because PFTs are non-phylogenetic groupings of species that show close similarities in their response to environmental and biotic controls such as grazing (Smith *et al*. 1997). Previous rangeland studies have suggested that the responses of a community to grazing are strongly associated with plant life-form and palatability to livestock (Sternberg *et al*. 2000; Fernandez-Gimenez and Allen-Diaz 2001).

In the present study, we quantified the resilience of plant communities under different grazing intensities in a degraded shrubland in southern Mongolia. We hypothesized that the community resilience in a particular site differs according to the grazing intensity.

Materials and methods

Study area and experimental design

The study was conducted in Mandalgobi, Dundgobi Province, Mongolia (45°47'N, 106°11'E). From 1993 to 2001, the mean annual air temperature was about 2 °C and the total annual precipitation ranged from 150 to 225 mm (data provided by the Institute of Meteorology and Hydrology, Ministry of Nature and Environment, Mongolia).

In the study area, there is a livestock camp (hereafter, the camp) where nomadic people start to graze their livestock and this is located about 10–15 km away from the town of Mandalgobi. Most livestock grazed at this area are sheep (approximately 500 head). The soil texture (0.0–5.0 cm) is sand (Sasaki *et al*. in press), and the landform consists of gently sloping hills (generally less than 1.5°). Nomenclature follows Grubov (1982).

We assumed that the grazing intensity would decrease radially outwards from the camp. In summer 2004, we performed a preliminary survey and determined the changes in vegetation at increasing distances from the camp. Distance was measured by using global positioning system, GPS. The area surrounding the camp was then stratified into three impact zones: < 100 m, 100-400 m and > 400 m from the camp. Based on this stratification, three exclosures were established for restoration at the distances of 75m (the site 1), 150m (the site 2), and 550m (the site 3) in summer 2004. Sizes of each exclosure were 15 × 25 m, 20 × 40 m, and 50 × 100 m, respectively. We acknowledged that this design was in fact pseudo-replicated design. However, our decision to establish only one exclosure as large as possible in each impact zone rather than ensuring the statistical replicates by setting small cages allowed us to account for the potential spatial heterogeneity of vegetation pattern and process based on our knowledge of the study area.

Sampling design

We performed a vegetation survey in July 2005. We set 10 quadrats in open and exclosure area of each site (2 m × 2 m at the site 3, 1 m × 1 m at the sites 1 and 2, based on the patch size of *Caragana microphylla*). These quadrats were located systematically, taking into consideration the spatial heterogeneity of vegetation pattern and process. We therefore accounted these samples to be statistical replicates in the following analysis. In each quadrat, we recorded the cover (%) and the height (cm) of all plant species.

Soil was sampled from each open site (6 replicates, at a depth of 0.0–10.0 cm) in October 2004. In the laboratory, we analyzed the soil organic carbon (SOC) using a dry combustion method (Matejovic 1993).

Data analysis

We calculated the volume of each plant species in each quadrat by multiplying the cover and height of each plant species (i.e., vegetation volume; *sensu* Ohtuka *et al*. 1993; Kawada *et al*. 2005).

We used a plant functional approach (Sternberg *et al*. 2000) to quantify the differences in the resilience of plant communities on the assumption that perennial herbs (or palatable species) were more abundant in a mixed community with shrubs in sandy soils (Gunin *et al*. 1999) before the community was perturbed. The 24 plant species found in the survey were classified by PFTs (which we defined by life history and relative palatability). Relative palatability of plants was classified according to the interviews with nomadic people, the information from Mongolian botanists, and *Forage Plants of Mongolia* (Jigjidsuren and Johnson 2003). We analyzed the variation in the individual quadrats using two-way ANOVA to examine the factors grazing intensity (three levels), exclosure (two levels) and their interactions. In the ANOVA model, we used the vegetation volume of each PFT as a parameter. If the interaction was significant, then Tukey post hoc comparison was performed. We also explored the differences in soil organic carbon according to grazing intensities using Bonferroni multiple comparison tests. All statistical analyses were performed using R (version 2.1.1, R Development Core Team 2005).

Results

Effects of grazing intensity and exclosure on the abundance of plant functional types

Results of the two-way ANOVA for PFTs revealed that shrubs (e.g., *Caragana microphylla*; Fig. 1a) and moderately-palatable species (e.g., *C. microphylla* and *Convolvulus ammanii*; Fig. 1e) were affected significantly only by grazing intensity (Table 1). In both perennial herbs (e.g., *Stipa krylovii*, *Agropyron cristatum*, and *Cymbaria dahurica*; Fig. 1b) and palatable species (e.g., *S. krylovii* and *A. cristatum*; Fig. 1d) there was a significant interaction between grazing intensity and exclosure (Table 1); the effect of exclosure was evident in the less grazed site (the site 3). Although the vegetation volume of annual herbs (e.g., *Heteropappus biennis*) increased in the exclosure of the sites 2 and 3 (Fig. 1c), and low-palatable species (e.g., *Panzeria lanata*) decreased in all exclosures (Fig. 1f), the results of the two-way ANOVA showed that grazing intensity and exclosure did not have significant effects on these PFTs (Table 1).

Changes in soil organic carbon according to grazing intensities

Changes in the soil organic carbon among the sites were shown in Figure 2. The soil organic carbon contents in the sites 1 and 2 were significantly lower than that in the site 3 ($P < 0.05$).

Discussion

A key finding of the restorative experiment was that PFTs such as perennials and palatable species did not recover in abundance at the sites 1 and 2, whereas these PFTs did recover at the site 3 (Figs. 1b, 1d; Table 1). Resilience of a particular site may differ from that of another site even at a local scale. SOC decreased at the sites 1 and 2; this may be evidence that wind erosion is greater at the sites 1 and 2 (Fig. 2), as wind erosion can cause losses of SOC (Yan *et al*. 2005). Around the sites 1 and 2, vegetation volumes of PFTs were generally less than those at the site 3 (Fig. 1), indicating potential positive feedbacks between vegetation cover and wind erosion. Previous studies demonstrated that vegetation plays an important role in protecting topsoil against wind erosion, as the presence of vegetation decreases wind force exerted on the soil surface (Buckley 1987). In contrast, wind erosion fractures bare vegetation cover mainly due to wind stream damage to plants and soil nutrient losses (Zhao *et al*. 2005). The difficulty of plant recovery at the sites 1 and 2 was consistent with previous studies that reported positive feedbacks between biotic factors and components of the physical environment (van de Koppel *et al*. 1997; Suding *et al*. 2004).

At the site 3, however, PFTs such as perennial herbs and palatable species did recover in abundance (Figs. 1b, 1d; Table 1). *Caragana microphylla* dominated both with greater size and higher abundance at the site 3 than at the sites 1 and 2 (T. Sasaki, unpublished data). In arid and semi-arid areas, large plants may have a positive effect on understorey species (Raffaele and Veblen 1998), and shrubs such as *C. microphylla* generally reduce the intensity of wind erosion (Su *et al*. 2004). Nurse effects (Raffaele and Veblen 1998) of *C. microphylla* as a benefactor species may possibly limit the positive feedbacks and support the resilience at the site 3. Moreover, *C. microphylla* gathers sand around its mound, with the depth of sand deposition around each plant apparently depending on canopy size and volume (T. Sasaki, personal observation). Sand burial often has a positive effect on stabilisation during seedling establishment, stimulation of growth and flowering (Maun 1997). Katoh *et al*. (1998) also reported that *C. microphylla* may play a role as a nurse plant; however, because sheep like to forage *Caragana* leaves, this species will not act as a nurse plant under heavy grazing intensities. In the study area, most livestock are sheep and the relative palatability of *C. microphylla* is moderately high. Nurse effects of *C. microphylla* may therefore be much less at heavily grazed sites.

Although the experimental period was short, differences in the community resilience were relatively clear. However, long-term monitoring should be needed to more definitively examine the community resilience that may underlie the vegetation dynamics. Vegetation responded to intense grazing with a decrease of shrubs, perennial herbs, palatable species and moderately-palatable species. These results essentially agree with those of the previous studies (e.g., Naveh and Whittaker 1979; Newsome and Noble 1986).

The present study revealed differences in resilience at a local scale. After grazing removal, grazing-sensitive PFTs did not recover in abundance in a formerly heavily grazed site, whereas these PFTs did recover in abundance at a lightly grazed site. Our findings may provide additional empirical evidence for ecological theories of resilience.

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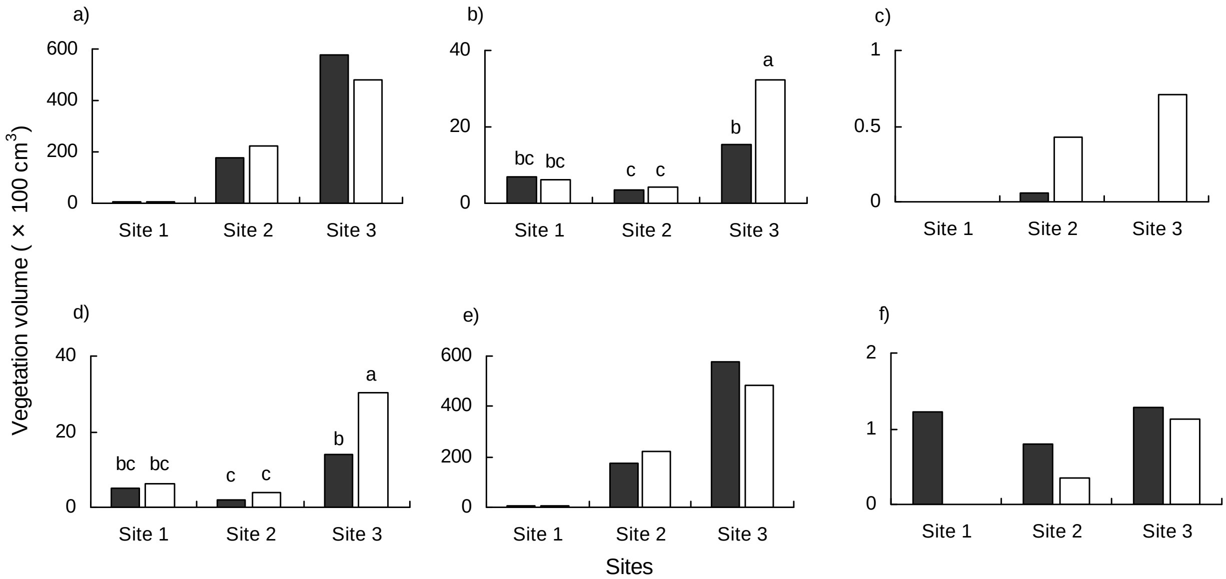

Figure 1. The effects of grazing intensity and exclosure treatments on the vegetation volume of each plant functional type among the sites. (a) Shrubs, (b) perennial herbs, (c) annual herbs, (d) palatable species, (e) moderately-palatable species, (f) low-palatable species.

Bars represent open sites (■) and exclosure sites (□). Vegetation volume was calculated by multiplying the cover (%) and height (cm). If the interaction between grazing intensity and exclosure was significant (see also Table 1), Tukey post hoc comparison was performed. Dissimilar letters above bars denote statistically significant differences (P < 0.05).

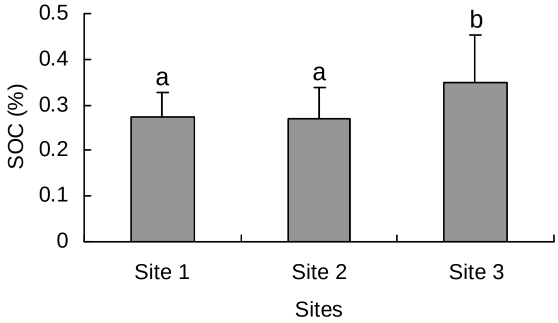

Figure 2. Soil organic carbon (%) at sites 1, 2 and 3. SOC (+SD) at depths of 0.0–10.0 cm (n = 6) are shown. Dissimilar letters above bars denote statistically significant differences ($P < 0.05$, Bonferroni multiple comparison tests). Note that the wind erosion rate is greater at sites 1 and 2.

Table 1. Results from the two-way ANOVA of plant functional types.

		Life-form						Palatability					
		Shrubs		Perennial herbs		Annual herbs		Palatable species		Moderately-palatable species		Low-palatable species	
Treatment	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Grazing intensity	2	3.818	**0.030**	33.912	< **0.001**	0.652	0.526	36.881	< **0.001**	3.820	**0.030**	0.670	0.517
Exclosure	1	0.016	0.900	9.162	**0.004**	3.637	0.063	12.717	< **0.001**	0.016	0.899	0.868	0.357
Grazing intensity × Exclosure	2	0.093	0.911	6.247	**0.004**	0.675	0.514	5.746	**0.006**	0.092	0.913	0.270	0.765

Bold figures indicate significant differences ($P < 0.05$). In the model, we used a vegetation volume of each PFT as a parameter. Treatments included manipulations of grazing intensity (sites 1, 2 and 3), exclosure (open sites vs. exclosure sites), and their interaction.