Rainfall variability may modify the effects of long-term exclosure on vegetation in Mandalgobi, Mongolia

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Abstract

Starting in 2005, we examined differences in vegetation for three consecutive years across an airport fence that separated heavily grazed areas from areas in which grazing had been excluded for 24 years in Mandalgobi, Mongolia. We performed repeated-measures analysis separately on two community types (dominated by *Allium polyrrhizum* and *Achnatherum splendens*, respectively) to compare the effects of fencing and year on the cover of different plant functional types. There was a significant fence × year interaction for grass cover in the *Allium* type (but not the *Achnatherum* type), due to greater cover of grasses inside the fence only when rainfall was sufficient during the growing season. The effect of grazing exclusion on perennial forb cover was confounded by a significant fence × year interaction in both types. In 2007, perennial forbs were found outside the fence, but had almost disappeared inside the fence, resulting in this interaction. Annual forbs only had much greater cover values inside the fence than outside in 2006, also resulting in a significant fence × year interaction in both community types. This study thus suggests that the high rainfall variability in arid and semi-arid rangelands may modify the effects of long-term exclosure on vegetation.

Keywords: arid and semi-arid rangelands, climatic variation, fence-line contrast, nonequilibrium dynamics, rangeland management

1. Introduction

It is widely believed that the composition and productivity of rangeland vegetation will change to a more productive state following grazing exclusion or a reduction in grazing pressure, particularly in heavily grazed systems. Previous studies have reported that grazing exclusion increased the cover of perennial grasses and forbs, which are generally palatable (Pettit and Froend 2001; Valone et al. 2002; Guo 2004; Firincioglu et al. 2007; Sasaki et al. 2007), increased species richness (Guo 2004; Firincioglu et al. 2007), and increased the soil organic matter content (Eldridge and Robson 1997; Shirato et al. 2005; Su et al. 2005). These results generally agree with the concepts of ecological succession, in which vegetation communities replace one another in a predictable and directional manner following disturbance, culminating in a stable climax state (Dyksterhuis 1949).

However, recent rangeland studies have suggested that not all plant communities exhibit such classical patterns of vegetation change (Westoby et al. 1989; Fernandez-Gimenez and Allen-Diaz 1999; Jackson and Bartolome 2002) and that plant production and community composition in some arid ecosystems may depend more on climate than on grazing by livestock; such systems are referred to as nonequilibrium systems (Ellis and Swift 1988). Whether vegetation responds to grazing exclusion in a predictable and directional way becomes questionable in the context of climatic variability.

Much of the empirical evidence on the effects of exclosure on arid and semi-arid rangelands used a "snapshot" design, with an inadequate duration of grazing exclusion. However, vegetation recovery after the cessation of disturbance in arid ecosystems can be quite slow (Valone et al. 2002; Guo 2004). In addition, at least a few years of monitoring are essential to ensure that the effects of interannual climatic variability will be seen.

Fence-line contrasts, in which a barrier such as a fence creates radically different grazing (disturbance) pressures on opposite sides of the barrier, usually reveal the effects of heavy grazing and can be viewed as natural experiments (*sensu* Diamond 1986) that provide a unique opportunity for testing the long-term consequences of grazing exclusion (e.g., Todd and Hoffman 1999; Oba et al. 2001; Valone et al. 2002). Monitoring these contrasts over a period of several years may help to reveal the effects of long-term exclosure in the context of climatic variability.

Here, we present data from a fence-line contrast that created a heavily grazed area and a neighboring grazing exclusion area (ungrazed for 24 years at the beginning of our study period) for three consecutive years in Mandalgobi, Mongolia. Our objectives were to address the following questions: (1) Does long-term exclosure affect the cover of different plant functional types? (2) Can rainfall variability modify the effects of long-term exclosure?

2. Methods

2.1. Study site

The study was conducted from 2005 to 2007 in Mandalgobi, Dundgobi Province, Mongolia (45°47'N, 106°11'E). The region's climate is arid and cold, with a short summer. The study site is located within the steppe ecological zone. From 2000 to 2007, the mean annual air temperature was about 2 °C and the mean total annual rainfall was 130 mm (Table 1; data provided by the National Climatic Data Center). Monthly, growing-season, and annual rainfall during the study period are also shown in Table 1. In the first and last years of the study (2005 and 2007), growing-season rainfall was considerably lower than the average from 2000 to 2007. In the second year (2006), growing-season rainfall was above the average. Most studies from arid and semi-arid rangelands have reported that growing-season rainfall is a more important determinant of peak biomass than total annual rainfall (e.g., Xiao et al. 1996; Liang et al. 2002). This interannual variability during the course of the study allowed us to compare the effects of annual rainfall and grazing on vegetation. Although it is possible that there were other sources of interannual variability, such as differences in grazing pressure, the observed number of livestock at the site (which can serve as a proxy for grazing pressure) appeared to remain unchanged during the study period (T. Sasaki, personal observation). Near the town of Mandalgobi, an airport's fence-line created a contrast in grazing pressure along approximately 3 km of the airport fence (Appendix A). The inside of the fenced area had been ungrazed for 24 years at the beginning of study period (July 2005). Sheep comprise the main type of livestock at the site. There are no other native herbivores such as rodents inside or outside the fence. In addition, no forms of management such as mowing or fertilization have been conducted inside or outside the fence, and there is a low possibility of other disturbances such as vehicle traffic or human trampling (we saw no tire tracks or footprints at any of our sampling sites). The actual sheep stocking densities at the site were not available, but we believe that the grazing intensity outside the fence was probably heavy before the establishment of the airport because the site is located near the town. Historical vegetation states at the site are also unknown (there are no historical records or published literature about the vegetation), but it is likely that the vegetation community had to adapt to this heavy grazing pressure. The soil texture (to a depth of 5.0 cm) is a sandy clay loam (T. Okayasu, unpublished data), and the landform consists of a pediment. The study area has long been grazed by domestic livestock under nomadic or semi-nomadic patterns of land use.

2.2. Plot layout and data collection

Along the fence, a gentle slope (generally less than 5°) contributed to the existence of two different community types, one dominated by *Allium polyrrhizum* and the other dominated by *Achnatherum splendens* (Appendix B). We sampled vegetation annually at the end of July, which was the time of peak aboveground biomass in 2005, 2006, and 2007. We established 10 pairs of 1 × 1 m permanent plots in each of the two community types, both inside and outside the fence, for a total of 20 pairs of permanent plots. Because a fence itself may influence results through edge effects such as differences in the degrees of livestock trampling and seed dispersal across the fence, we chose plots at least 30 m from the fence. The pairs of plots on opposite sides of the fence were located at intervals of at least 10 m. In each plot, we sampled vegetation by identifying and estimating the aerial cover (percent) of all species (only for green material) present in the plot. The taxonomic nomenclature follows that of Grubov (1982). Species were classified into plant functional types based on their life history (perennial or annual) and their growth form (grass, forb, or shrub). All grasses found in our study area were perennials. These plant functional types are generally correlated with the plant's relative palatability at the study site (i.e., grasses, perennial forbs, and shrubs are more palatable, whereas annual forbs are less palatable) according to Jigjidsuren and Johnson (2003).

Unfortunately, long-term grazing exclosures such as the airport fence that we used are rare, and replicated exclosures of areas with similar soils and climate are nonexistent. In the absence of replication of exclosures, we thus replicated samples of vegetation inside and outside a single exclosure (the fence). We believe that an adequate sampling effort for three consecutive years should allow the perception of any general patterns in the differences across the fence.

2.3. Data analysis

Separately for each community type, we used repeated-measures ANOVA to compare the effects of fence (two levels: inside and outside) and year (three levels: 2005, 2006, and 2007, with different rainfall during the growing season) on the cover of each plant functional type. All the effects were considered fixed effects in the ANOVA. When the fence × year interaction was statistically significant, the repeated-measures ANOVA was followed by post-hoc contrast tests (*t*-tests with Bonferroni's correction) for the within-year comparisons. Before performing these analyses, all dependent variables were assessed for normality of their distribution and heterogeneity of variances. We used $\log_{10}(y + 1)$ transformations where needed (Sokal and Rohlf 1995). All statistical analyses were performed with the R software (version 2.4.1; R Development Core Team 2006). The level of significance was $P < 0.05$.

3. Results

We recorded 25 species in the *Achnatherum* community, of which 6 were annual forbs, 14 were perennial forbs, 4 were grasses, and 1 was a shrub, versus 28 species in the *Allium* community, of which 5 were annual forbs, 19 were perennial forbs, 3 were grasses, and 1 was a shrub (Appendix B). In both community types, shrub cover did not vary significantly across the fence or between years (Fig. 1; Table 2), probably because shrubs were rare at the site and as a result, variation in their cover values between plots was very large. Grass cover (mainly by *A. splendens*; Appendix B) was significantly higher inside the fence and varied between years in the *Achnatherum* community, without a significant fence × year interaction (Fig. 1; Table 2). In the *Allium* community, however, there was a significant fence × year interaction for grass cover (Table 2). This interaction is probably related to the complete disappearance of grasses (mainly *Stipa glareosa* and *Cleistogenes squarrosa*; Appendix B) from all the plots in 2007 (Fig. 1). Post-hoc within-year contrasts indicated that the effects of the fence on grass cover in the *Allium* community were significant in 2006, but not significant (P = 0.10) in 2005. In both community types, there was a significant fence × year interaction effect on perennial forb cover (mainly by *A. polyrrhizum*, *Allium mongolicum*, and *Sibbaldianthe sericea*; Appendix B, Table 2). Post-hoc within-year contrasts revealed that the cover of perennial forbs was significantly greater inside the fence in 2005 and 2006 in the *Allium* community but only in 2006 in the *Achnatherum* community (Fig. 1). However, perennial forbs could be found outside the fence in 2007 in both community types, whereas this group almost disappeared inside the fence (Fig. 1). Post-hoc within-year contrasts were significant in 2007 in the *Allium* type, but not in the *Achnatherum* type (P = 0.12), resulting in a significant fence × year interaction effect on perennial forb cover in both community types. Because cover values for annual forbs (mainly *Salsola collina*, *Chenopodium album*, and *Chenopodium acuminatum*; Appendix B) were much greater inside the fence only in 2006 (post-hoc within-year contrasts were evident only in 2006 in both types), there were significant fence × year interactions in both community types (Fig. 1; Table 2).

4. Discussion

The data collected in this study came from a natural experiment with no replicated treatments, which limits our ability to draw statistical inferences about the effects of the exclusion of livestock grazing. However, consistency in the results obtained during the three growing seasons suggests the existence of some general patterns.

4.1. Effects of long-term exclosure on vegetation in the context of climatic variability

In both community types, grass cover was generally significantly higher inside the fence (Fig. 1; Table 2). There was no significant fence × year interaction in the *Achnatherum* community, possibly due to the high drought resistance of *A. splendens* (Liu et al. 2003). However, the interpretation of differences in grass cover was confounded by a significant fence × year interaction in the *Allium* community. The effect of this interaction on grass cover was probably due to greater cover of grasses inside the fence only when there was sufficient rainfall during the growing season (from June to July). Drought was particularly severe during the 2007 growing season (Table 1). This agrees with a previous report that desirable changes in vegetation may occur with protection from grazing, but only during relatively favorable climatic periods (Alzerreca et al. 1998).

The cover of perennial forbs was generally greater inside the fence in both community types, but this effect was confounded by a significant fence × year interaction in both community types. Under complete protection from grazing, some undesirable changes may occur, such as an excessive accumulation of litter that changes the habitat enough to reduce or eliminate some desirable species (Milchunas et al. 1988; Adler et al. 2004). In contrast, Virtanen (2000) demonstrated that grazing during the winter season prevents an accumulation of plant litter. However, we only saw litter accumulation inside the fence in 2007 (T. Sasaki, personal observation) because a number of high-intensity rainfall events occurred from May until the end of July in 2005 and 2006, and surface flows may have swept away this litter. Thus, one possible explanation for the reversed pattern for perennial forb cover in 2007 (i.e., higher levels outside the fence) is that most forb species could not sprout and grow due to shading caused by accumulated plant litter. There would also have been a concomitant large amount of sand trapped by the standing and fallen litter under the strong winds that occur in early spring (i.e., before the main sprouting period) at the site (T. Sasaki, personal observation; see also Facelli and Pickett 1991).

The much greater cover of annual forbs inside the fence in 2006 may have resulted from the relatively high persistence of annual forb seeds until the seeds were able to germinate in the sand trapped around the standing and fallen litter, because the relatively low level of spring rain from April to May 2006 (Table 1) could not sufficiently flush away the sand and litter. However, this result does not match those of Loeser et al. (2007), who reported an increase in the cover of annual species after a severe drought and observed that this increase was greatest in the high-impact grazing plots. Any speculation about the cause of this difference will thus require further testing with longer-term data sets.

Although our results suggest that vegetation differences observed across the fence were generally related to the exclusion of livestock grazing, the higher abundance of annual forbs inside the fence in 2006 and the reversed pattern for perennial forbs (higher values outside the fence in 2007; Fig. 1; Table 2) differ from the results of previous studies (e.g., Pettit and Froend 2001; Valone et al. 2002; Guo 2004; Firincioglu et al. 2007). The latter studies reported that grazing exclusion increased the cover of perennial grasses or forbs that are generally palatable and decreased the cover of unpalatable forbs and annual weeds. Our results suggest that high rainfall variability in arid and semi-arid rangelands such as our study site may modify the effects of long-term exclosure on vegetation.

4.2. Management implications

Despite the limitations of a small sample size and small scale (i.e., the small number of permanent plots and the small total area covered by the plots), several tentative management implications can be drawn from the present study. First, the observed modification of the effect of exclosure by rainfall variability does not necessarily mean that grazing exclusion is not valuable as a management option. Some desirable changes in vegetation will occur as a result of protection from grazing during relatively favorable climatic periods. Second, in arid and semi-arid rangelands with high interannual rainfall variability, interactions between grazing exclusion and climate should be anticipated by ecologists and land managers. In the context of seeking the most cost-effective management options in such highly stochastic systems, managers should consider alternative management options such as preventive management based on the concept of an ecological threshold (Sasaki et al. 2008). This approach relies on an ongoing evaluation of rangeland conditions. However, we could not determine whether the patterns of modification of the effects of long-term exclosure by rainfall variability during the study period are deterministic trends that will persist in the long term. To differentiate rainfall-induced fluctuations from directional changes in vegetation dynamics (i.e., vegetation recovery or degradation processes) caused by grazing, monitoring must be conducted for extended periods that will be long enough to include a wider range of rainfall cycles and patterns. In addition, the study should be replicated across more sites, particularly if differences in grazing intensity can be quantified. The present study nonetheless provides useful insights into how climatic variations can affect the efficacy of grazing exclosure as a possible management option in arid and semi-arid rangelands.

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Table 1. Monthly, growing-season (from June to July), and annual rainfall (mm) at the Mandalgobi study site. Data were provided by the National Climatic Data Center.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Growing season	Annual
2000-2007 mean	1.8	1.7	3.5	13.0	11.5	32.1	28.1	29.6	4.3	1.6	1.7	1.4	60.2	130.1
2005	1.0	4.3	0.0	0.5	16.3	5.6	31.8	8.9	2.5	0.0	0.0	0.0	37.4	70.9
2006	0.0	2.0	0.3	3.3	1.0	10.4	66.8	6.1	0.5	0.5	1.0	1.5	77.2	93.5
2007	0.0	1.0	4.3	0.0	3.6	3.0	17.0	32.0	0.0	3.0	0.0	0.3	20.0	64.3

Table 2. Results of the repeated-measures ANOVA for the effects of fence (inside, exclosure; outside, grazing) and year (our proxy for annual rainfall, from 2005 to 2007) on the cover of different plant functional types in the two different community types.

		Allium community			*Achnatherum* community		
Variable	Source	df	*F*	*P*	df	*F*	*P*
Shrub cover	fence	1	0.34	ns	1	1.63	ns
	year	2	1.08	ns	2	1.63	ns
	fence × year	2	1.86	ns	2	1.63	ns
	between error	18	—	—	18	—	—
	within error	36	—	—	36	—	—
Grass cover	fence	1	19.15	***	1	7.28	*
	year	2	32.63	***	2	3.87	*
	fence × year	2	12.73	***	2	1.46	ns
	between error	18	—	—	18	—	—
	within error	36	—	—	36	—	—
Perennial forb cover	fence	1	52.26	***	1	4.59	*
	year	2	738.98	***	2	90.9	***
	fence × year	2	38.17	***	2	6.92	**
	between error	18	—	—	18	—	—
	within error	36	—	—	36	—	—
Annual forb cover	fence	1	126.73	***	1	4.73	*
	year	2	130.71	***	2	117.69	***
	fence × year	2	126.73	***	2	6.46	**
	between error	18	—	—	18	—	—
	within error	36	—	—	36	—	—

ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

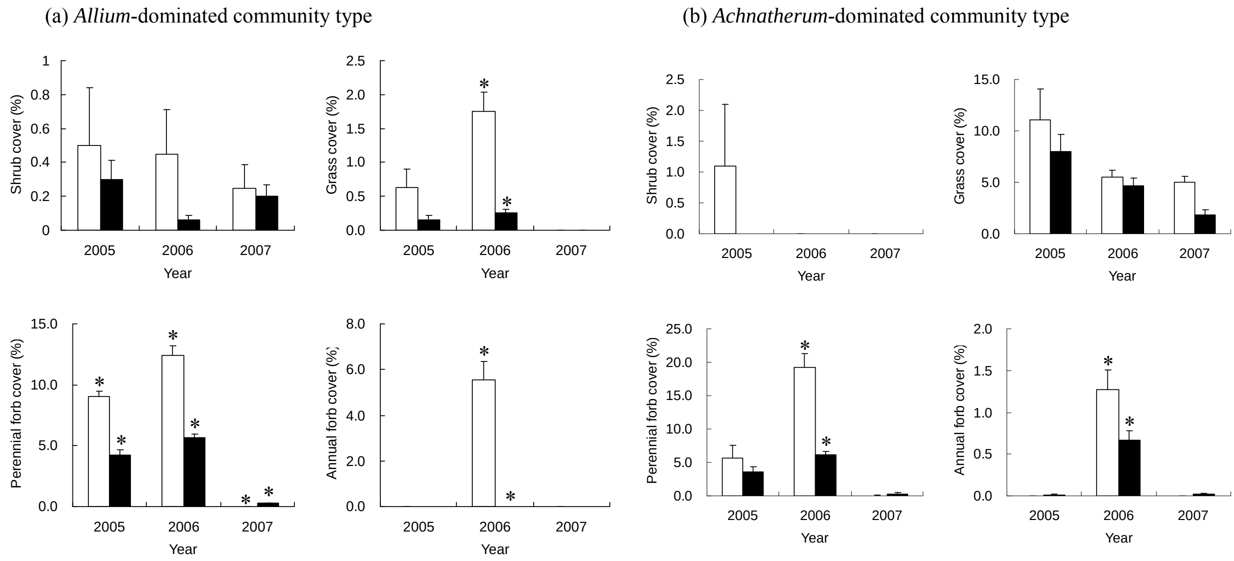

Fig. 1. Differences in cover of the various plant functional types across the fence (inside, exclosure; outside, grazing) between years (our proxy for annual rainfall) in the two community types. Bars (mean ± SE) represent the values inside (□) and outside (■) fence. When fence × year interactions were statistically significant, the repeated-measures ANOVA was followed by post-hoc contrast tests (*t*-tests with Bonferroni's correction) for the within-year comparisons (* denotes statistical significance within each year at $P < 0.05$). To facilitate visual comparisons, the scales of the vertical axes are optimized for each plant functional type in each community type instead of using a consistent scale in all graphs.

Appendix A. A typical fence-line contrast observed along the airport fence in Mandalgobi, Mongolia. On the left side of the fence, grazing had been excluded for 24 years at the start of the study.

Appendix B. Mean cover of individual plant species inside and outside the fence during the study period. (a) *Achnatherum splendens* community type, (b) *Allium* community type. Grazing had been excluded inside the fence for 24 years at the start of the study period. The taxonomic nomenclature follows that of Grubov (1982).

(a) *Achnatherum* community type

	Cover (%)					
	Inside the fence			Outside the fence		
	2005	2006	2007	2005	2006	2007
Shrubs						
Caragana leucophloea	1.10	—	—	—	—	—
Perennial grasses						
Achnatherum splendens	11.10	5.03	5.00	7.85	3.50	1.80
Carex duriuscula	0.01	—	—	0.12	0.01	0.04
Cleistogenes squarrosa	—	0.45	—	—	1.16	—
Stipa glareosa	—	—	—	0.06	—	—
Perennial forbs						
Ajania achilleoides	—	—	—	0.06	0.02	—
Allium anisopodium	—	—	—	0.02	—	0.03
Allium mongolicum	1.15	0.20		1.23	4.10	0.01
Allium polyrrhizum	—	4.90	0.02	1.55	2.00	0.12
Artemisia frigida	0.50	—	0.01	0.10	—	—
Asparagus gobicus	—	—	—	—	0.03	—
Bupreurum bicaule	—	—	—	0.01	—	0.07
Convolvulus ammanii	2.52	14.15	0.01	0.01	0.03	0.01
Dontostemon integrifolius	—	—	—	—	0.01	0.01
Heteropappus hispidus	—	—	0.01	0.05	—	—
Kochia prostrata	—	—	—	0.10	—	—
Limonium tenellum	0.70	—	—	—	—	—
Potentilla bifurca	0.70	—	—	0.45	—	0.01
Scorzonera divaricata	0.11	—	0.01	0.06	—	0.05
Annual forbs						
Artemisia adamsii	—	—	—	—	0.03	0.01
Chenopodium acuminatum	—	0.65	—	—	0.19	—

Chenopodium album	—	0.09	—	—	0.04	—
Chenopodium aristatum	—	0.03	—	—	—	—
Salsola collina	—	0.50	—	—	0.41	—
Salsola pestifera	—	—	—	0.01	—	0.01

(b) *Allium* community type

	Cover (%)					
	Inside the fence			Outside the fence		
	2005	2006	2007	2005	2006	2007
Shrubs						
Caragana leucophloea	0.50	0.45	0.25	0.30	0.06	0.20
Perennial grasses						
Carex duriuscula	0.07	0.01	—	0.09	0.16	—
Cleistogenes squarrosa	0.19	1.71	—	—	0.06	—
Stipa glareosa	0.37	0.03	—	0.07	0.04	—
Perennial forbs						
Ajania achilleoides	0.01	0.11	—	0.01	0.08	0.01
Allium anisopodium	0.10	0.30	—	—	0.34	—
Allium mongolicum	—	0.28	—	—	0.12	—
Allium polyrrhizum	4.25	7.15	—	3.50	4.45	0.14
Artemisia frigida	0.30	0.30	0.01	0.13	0.01	0.03
Astragalus junatovii	0.05	—	—	—	—	—
Bupreurum bicaule	0.40	—	—	0.05	—	—
Convolvulus ammanii	0.70	0.57	—	0.34	0.25	—
Cymbaria dahurica	0.01	—	—	—	—	—
Dontostemon integrifolius	—	0.01	—	—	0.01	0.03
Haplophyllum dauricum	0.50	0.30	0.01	—	—	—
Heteropappus hispidus	1.24	—	—	0.03	—	0.02
Iris bungei	—	—	—	—	0.01	—
Kochia prostrata	—	0.03	—	—	—	0.03
Lagochilus ilicifolius	0.15	0.25	—	—	0.02	—
Limonium tenellum	0.10	—	—	—	—	—
Potentilla bifurca	—	—	—	0.01	—	—
Scorzonella divaricata	0.28	0.78	—	0.01	0.04	0.01
Sibbaldianthe sericea	0.92	2.35	—	0.17	0.31	—
Annual forbs						
Bassia dasyphylla	—	—	—	—	0.01	—
Chenopodium acuminatum	—	0.31	—	—	—	—

Chenopodium album	—	0.01	—	—	—	—
Chenopodium aristatum	—	0.23	—	—	—	—
Salsola collina	—	5.00	—	—	—	—