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Grassland responses to grazing disturbance: plant diversity changes with grazing intensity in a desert steppe

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Abstract

This study quantifies the impact of four different grazing regimes (heavy, moderate, light and ungrazed) on the vegetation dynamics of rangeland ecosystems along the southern boundary area of the Mu Us Desert, China. As the grazing intensities decreased, the soil quality, canopy cover, height, density, above- and below-ground biomass, litter, root/shoot ratio and native plant (*Aneurolepidium dasystachys*) and grass abundances significantly increased; the above-ground biomass of grasses increased, but the above-ground biomass of forbs decreased. Ungrazed grassland has significantly improved from grasslands experiencing three other levels of grazing pressure, especially in the grassland biomass. Species richness increased as the grazing intensity decreased in the grazing grasslands, but peak species richness appeared under moderate and light grazing against lower productivity. Grazing exclusion causes desirable transitions in plant communities of desert steppe rangelands. Therefore, appropriate and efficient grazing exclusion is an available way to counteract local grassland degradation and promote rangeland sustainability.

Keywords: Species richness, grazing gradient, permanent grassland, Mu Us Desert, China

Introduction

Grasslands are one of the largest terrestrial ecosystems, and grazing is the main land use on grasslands worldwide (UNCCD, 2004; Luo *et al.*, 2010). Recently, research efforts have focussed on the effects of land-use change on grassland ecosystem function (Elmqvist *et al.*, 2003; Parker *et al.*, 2003; Defries *et al.*, 2004; Garnier *et al.*, 2007). An understanding of ecosystem response to land-use change is vital for the formulation of management plans for today's multiple-use ecological landscapes, in particular those which are used for grazing (Hopkins and Holz, 2006; Quetier *et al.*, 2007; Liang *et al.*, 2009). Economic pressure leads to intensified grazing under some circumstances (Golodets *et al.*, 2010; Schönbach *et al.*, 2011) and widespread abandonment of livestock grazing under others (Hopkins and Holz, 2006; Peco *et al.*, 2006).

Globally, overgrazing is one of the most important causes of degradation of arid and semi-arid rangelands (van der Westhuizen *et al.*, 2005; Liang *et al.*, 2009; Schönbach *et al.*, 2011). The high percentage of the world's rangeland that suffers from overuse stems from the extensive, low-intensity character of pastoral land use, the slow response to land-management changes in arid climates and the social and economic problems associated with reducing livestock numbers on heavily used rangelands (Narjisse, 2000). China has a markedly higher percentage of degraded rangelands than other countries at the same latitude, primarily because of the heavier grazing pressure and recent extensive conversion to farmland (Jia, 1995). China's northern grasslands have been degraded by long-term (over) grazing (Su *et al.*, 2005). A worrying decline in the unique ecological functions of grasslands, e.g., water-source conservation, prevention of soil loss by wind or water erosion, wind-breaking and sand-fixing, was addressed at the national level. Under the country's Tenth Five-Year Plan, a host of sustainable development initiatives were introduced (China National People's Congress, 2001). Chief among them was the policy of 'Returning Grazing Land to Grassland'. As a consequence of this policy, grasslands in

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this area have improved (China Ministry of Agriculture, 2008). In the grasslands of northern China, policy implementation is the responsibility of local governments, usually in the form of specific projects such as prohibiting grazing and by the fencing of large parcels of grassland. However, both sheep and cattle grazing continue to occur near human residences, and illegal sheep and cattle grazing frequently occur at night on unfenced land far from residential areas.

Overgrazing has a number of negative impacts, including increases in undesirable vegetation (Louhaichi *et al.*, 2009), decreases in biomass and loss of vegetation cover (Zhao *et al.*, 2011; Louhaichi *et al.*, 2012), and reduced species diversity (Li *et al.*, 2006). Grazing prohibition is the most commonly applied management tool when seeking to reverse grassland degradation (Golodets *et al.*, 2010; Wu *et al.*, 2010). Grassland management significantly influences plant density and composition and both above- and below-ground vegetation characteristics. In the grasslands of northern China, community composition is being simplified, desirable herbage species are being reduced, production is declining, and soil erosion is worsening (Jia, 2000; Louhaichi *et al.*, 2012). Previous research has mainly focussed on the effects of grazing intensity on carbon and nitrogen in soil and vegetation in a temperate meadow steppe (Han *et al.*, 2008), grazing intensity on vegetation dynamics of a temperate typical steppe (Liang *et al.*, 2009) or the effect of grazing exclusion on above- and below-ground plant species diversity in a temperate steppe (Zhao *et al.*, 2011). However, the effects of grazing on grassland structure and function in a desert steppe grassland have not yet been fully determined.

This study focuses on a desert steppe grassland ecosystem of low herbaceous biomass, a type of steppe for which there is little previous study (Jia, 2000). Desert steppe accounts for 80 million of China's more than 400 million hectares of grassland. Yet, neither the vegetation nor the soil characteristics and their responses to grazing are well understood for this important ecosystem type (Liang *et al.*, 2009; Lin *et al.*, 2010; Shahriary *et al.*, 2012). To effectively assess and predict the effects of both grazing and overgrazing on vegetation, data on plant cover, density, species richness and functional-group diversity are needed. Such benchmark data are needed before management frameworks – including carrying capacity and whether or not outright prohibition is the right tool for grassland restoration – can be appropriately designed.

In this study, we hypothesized that the different grazing intensities would have different effects on vegetation growth in the desert steppe. The purpose was to evaluate the effects of different grazing intensities on vegetation and soil dynamics in a desert steppe

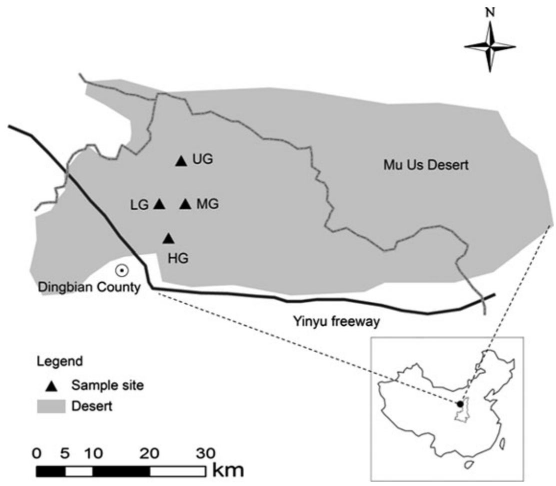

Figure 1 Location of the sampling site on the Mu Su Desert. Note: HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed.

located in northern China, along the southern boundary area of the Mu Us Desert. This study compared vegetation cover and density, vegetation composition, species richness, plant functional group, and the biomass of grazed and ungrazed areas with shared climate, terrain and soils.

Materials and methods

Study area

The study area was located along the southern boundary of the Mu Us Desert north of Dingbian County in Shaanxi, China (37°40′-37°46′N, 107°29′-107°33′E); altitude within the study area ranges from 1308 to 1317 m (Figure 1). The vegetation in the study area is that of typical desert steppe vegetation dominated by *Aneurolepidium dasystachys*, *Artemisia ordosica* and *Kalidium foliate*, of which the main species are *Suaeda* sp., *Elymus dahuricus*, *Chenopodium glaucum* and *Salsola collina*. *Aneurolepidium dasystachys* is widely distributed as a native species. The study area's aeolian soil(s) receives a mean annual precipitation of approximately 262 mm (1960–2010), which is distributed for the most part between July and September. The area's semi-arid temperate continental monsoon climate produces a mean annual temperature of 6·9°C (1960–2010), a mean annual total of 2199 sunshine hours (1960–2010), a mean annual evaporation of 1909 mm (1960–2010) and 110 frost-free days per year on average (1960–2010).

Within the study area, grazing animals are fenced in near residences at night and then graze freely as

Table 1 Longitude and latitude, altitude, soil properties and plots characteristic of four sampling belts.

Grazing intensity	Latitude (N)	Longitude (E)	Altitude (m)	Soil properties (0–10 cm) pH	Moisture (%)	Bulk density (g cm^{-3})	Plot characteristic
Heavy	37°40′	107°32′	1317	9·21a	0·97b	1·51a	Grazed area near residential areas
Moderate	37°42′	107°29′	1312	9·04b	1·41b	1·50ab	Cessation of grazing for 8 years, but illegal grazing continues
Light	37°43′	107°33′	1308	9·02b	1·67ab	1·45bc	Enclosed for 8 years
Ungrazed	37°46′	107°31′	1310	8·48c	2·53a	1·41c	Ungrazed area located near tombs, enclosed since 1980s

The data on soil properties (0–10 cm) are averages. Different lower-case letters indicate varied significantly at 0·05 level ($P < 0{\cdot}05$).

they move away from the residential area during the day. Consequently, grasslands are grazed all the time near residences ensuring that the grassland suffers disproportionately. In this study, such pressure is defined as 'heavy grazing'. For reasons of convenience and due to the time required for the animals to walk to outlying pastures, grazing pressure decreases as the distance from the residential area increases. Thus, between residence and rangeland, the grasslands are unfenced. This level of pressure is defined as 'moderate grazing'. Those grasslands deemed too far away for animals to graze were unfenced before the implementation of China's 'Returning Grazing Land to Protected Grassland' policy, but have been fenced off since 2003. This level of pressure is defined as 'light grazing'. The final category of grazing pressure in this study is that of 'ungrazed', which consists primarily of burial land fenced off since the 1980s to avoid disturbing local gravesites. Defining grazing intensity in relation to distance from residence has been used in many studies (Han *et al.*, 2008; Liang *et al.*, 2009).

Sampling and measurements

Experimental design

Four sample belts (each sample belt had a minimum area of 3 ha) extending from the residential area to outlying rangelands were delimited in *Aneurolepidium dasystachys* grasslands to represent grasslands experiencing four types of grazing: heavy, moderate, light and ungrazed, according to the definitions provided. Ten quadrats (1 m × 1 m) were separately chosen every 30 m in all the sample belts, and a sample survey was carried out in the central part of the sample belts in August 2011 when grassland community biomass peaked. We numbered the ten quadrats 1, 2, 3, … 10. In the odd-coded quadrats (No. 1, 3, …9), the canopy cover and height, species composition and height, density (number of individuals per square metre) and above-ground biomass of individual species were investigated. In the even-coded quadrats (No. 2, 4, …10), the canopy cover and height, above- and below-ground biomass, litter, soil properties (pH, moisture and bulk density) in 0 to 10-cm soil cores were observed (Table 1). We used a steel tape to measure the vertical height of plants in a natural state. We divided each survey quadrat (1 m × 1 m) into 100 small quadrats (0·1 m × 0·1 m), according to the proportion of the plants in the small quadrats, to estimate the canopy cover of plant community in the survey quadrats. The soil bulk density (g cm^{-3}) was measured using a soil bulk sampler with a 5-cm diameter and 5-cm high stainless steel cutting ring. The original volume of each soil core and its dry mass after oven-drying at 105°C were measured.

Biomass measurement

In the odd-coded quadrats, the above-ground parts of green plants were cut and placed into envelopes by species and then tagged. In the even-coded quadrats, all the above-ground parts of green plants were cut, collected and put into envelopes and tagged, and all litter was collected and put into envelopes and tagged. To measure below-ground biomass, soil sampling was carried out five times using a root corer of 9 cm diameter in 0- to 100-cm-deep soil in each quadrat. The majority of the roots were found in the soil samples thus obtained and then isolated using a 2-mm sieve. The remaining fine roots taken from the soil samples were isolated by spreading the samples in shallow trays, overfilling the trays with water and allowing the outflow from the trays to pass through a 0·5-mm-mesh sieve. No attempts were made to distinguish between living and dead roots. All the roots thus isolated were oven-dried at 65°C and weighed to within 0·01 g. Because the biomass samples were large, they were weighed fresh and then only a part of each sample was dried and weighed. The above-ground biomass of the samples was calculated by multiplying the ratio of the dry weight/fresh weight ratio by the fresh weight.

Plant species identification, species richness and functional group

In all the quadrats of the study area, the dominant species is *Aneurolepidium dasystachys*. The majority of plant species identification was made in the field. Unidentified specimens were collected and dried with a plant press and later identified by plant taxonomists. Species richness (Shannon and Weaver, 1949) is the number of species in each quadrat (Stirling and Wilsey, 2001). The terminology of Allen *et al.* (2011) was used as the basis to divide all the plants found in the quadrats into two functional groups: grass (plant or plant species of the *Poaceae* family) and forb (any herbaceous, dicotyledonous broad-leaved plant). The aim of forming functional groups is to represent the ecological structure of a flora and perhaps to use that structure to make predictions at a level that is more practicable and more general than the level of individual species and that enables better prediction of species assemblages (Santiago do Vale *et al.*, 2010).

Soil sampling and determination

Soil water content was measured gravimetrically and expressed as a percentage of soil water to dry soil weight. Soil bulk density was calculated depending on the inner diameter of the core sampler, sampling depth and the oven-dried weight of the composite soil samples. Soil pH was measured with a glass electrode. When measuring the soil pH, soil samples were diluted with water (the ratio of soil to water was 1:2·5).

Data processing

SPSS 17.0 was used for data processing and analysis. Plant cover, density, height, biomass, root/shoot ratio and the soil properties of the grasslands under individual grazing intensities were analysed using one-way ANOVA. Differences were evaluated at the 5% significance level. When significant differences were observed among individual grazing intensity at the $P < 0{\cdot}05$ level, LSD (least significant difference) post hoc test was used to carry out the multiple comparisons.

Results

Cover, height and density

The plant cover, density and height decreased significantly as grazing intensity increased ($P < 0{\cdot}01$) (Figure 2). The ungrazed grassland differed significantly

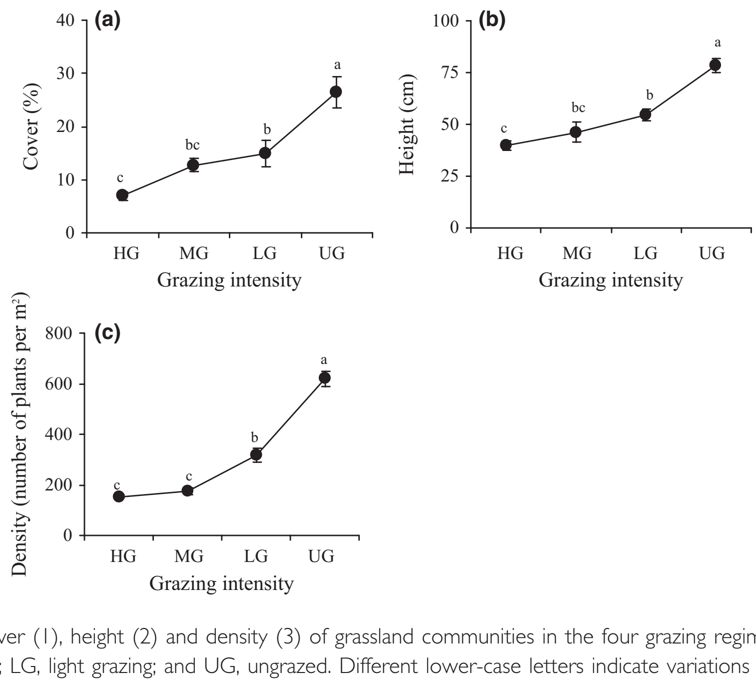

Figure 2 Canopy cover (1), height (2) and density (3) of grassland communities in the four grazing regimes. HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed. Different lower-case letters indicate variations significant at 0·05 level ($P < 0{\cdot}05$). Error bar indicates the SE.

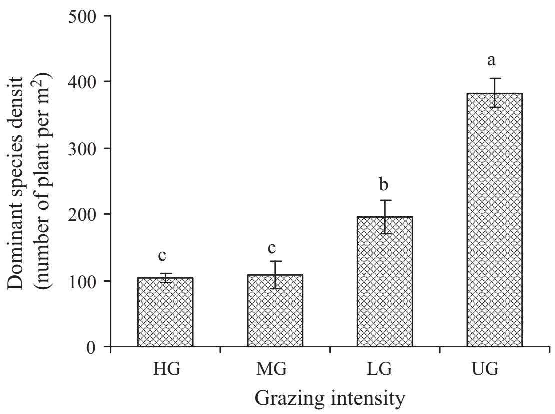

Figure 3 Dominant species (*Aneurolepidium dasystachys*) density in the four grasslands of different grazing regimes. HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed. Different lower-case letters indicate variations significant at 0·05 level ($P < 0{\cdot}05$). Error bar indicates the SE.

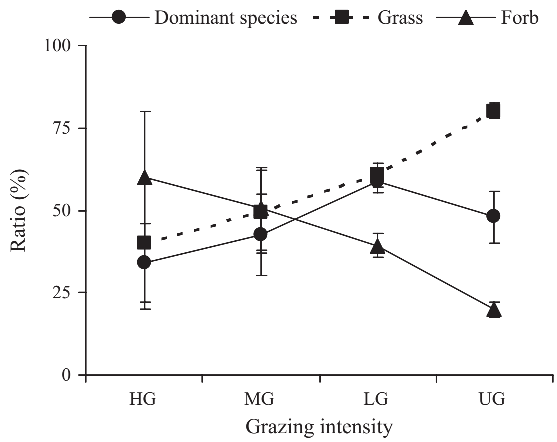

Figure 4 The ratio of above-ground biomass of the dominant species (*Aneurolepidium dasystachys*) and the two functional groups (grass and forb) in the four grazing regimes. HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed. Error bar indicates the SE.

from those grasslands subjected to grazing at other intensities ($P < 0{\cdot}01$) (Figure 2). The densities of dominant species also increased significantly with reduced grazing intensity (Figure 3). In the ungrazed parcel, the density of dominant species was the highest, and in the grassland experiencing heavy grazing, dominant species density was the lowest (Figure 3).

Above-ground biomass ratios of the three functional groups

The above-ground biomass ratios of the main functional groups in the grasslands grazed at the four intensities differed (Figure 4). The above-ground biomass of dominant species was the highest under light grazing, accounting for 58·75% of total above-ground biomass, and the lowest under heavy grazing with the ratio of 33·97%. As the grazing intensity decreased, the above-ground biomass of grasses increased, but the above-ground biomass of forbs presented the opposite pattern (Figure 4).

Species richness

The species richness of the grasslands grazed at the four different intensities differed significantly, but there was no significant difference between the three grazing intensities of heavy, moderate and light (Figure 5). Species richness values in both the light and moderate grazing regimes were higher than were those of either heavy grazing or ungrazed. The species richness of the ungrazed grassland was the lowest, differing significantly from the plots grazed at the other three intensities ($P < 0{\cdot}05$). Furthermore, there was a

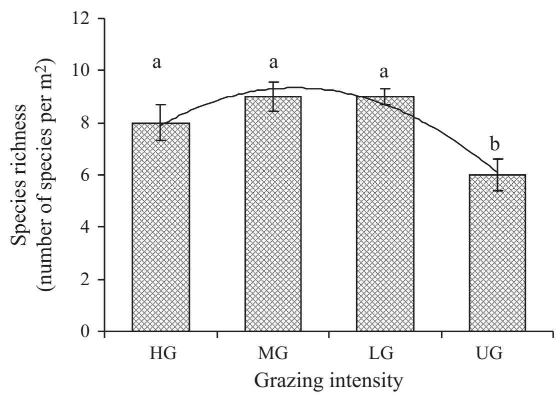

Figure 5 Species richness in the four grasslands of different grazing regimes. HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed. Different lower-case letters indicate variations significant at 0·05 level ($P < 0{\cdot}05$). Error bar indicates the SE.

significant unimodal relation between species richness and grazing intensity (Figure 5).

Biomass and root/shoot ratio

The total biomass, both above- and below-ground biomass and litter accumulation at the four different grazing intensities differed significantly (Figure 6); they increased as grazing intensity decreased. The ungrazed grasslands differed significantly when compared with the other three grazing intensities of heavy, moderate and light grazing ($P < 0{\cdot}05$). The total biomass, both

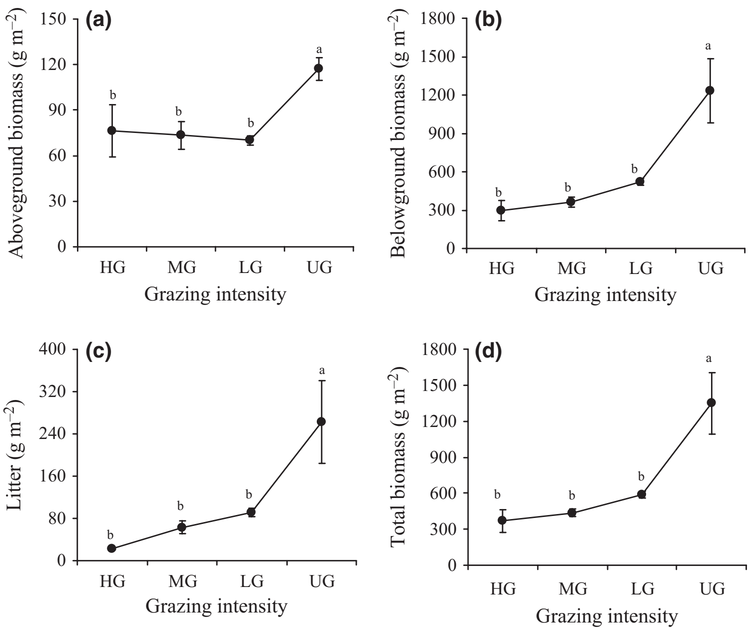

Figure 6 Above-ground biomass (a), below-ground biomass (b), litter (c) and total biomass (d) changes with grazing regimens. HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed. Different lower-case letters indicate variations significant at 0·05 level ($P < 0{\cdot}05$). Error bar indicates the SE.

above- and below-ground biomass and litter accumulation did not significantly differ among the plots experiencing heavy, moderate or light grazing ($P > 0{\cdot}05$) (Figure 6). The root/shoot ratios increased significantly as the grazing intensity decreased presenting significant differences among the four grassland grazing intensities ($P < 0{\cdot}05$) (Figure 7).

Discussion

Overgrazing has a negative impact on the composition, diversity and biomass of plant functional groups (Sun *et al.*, 2011), thus limiting the ability of grasslands to recover after disturbance or stress such as drought (Simons and Allsopp, 2007). Overgrazing can affect ecological succession and regeneration by removing the photosynthetically active tissues of palatable plant species required for grassland maintenance and survival (Louhaichi *et al.*, 2009). In contrast, long-term grazing exclusions are shown to significantly improve vegetation cover, biomass, above-ground species evenness (Liang *et al.*, 2009; Zhao *et al.*, 2011), species composition recovery (Liang *et al.*, 2009; Golodets *et al.*, 2010) and increase species richness and seed density in the soil seed bank (Fensham *et al.*, 2011; Zhao *et al.*, 2011), but significantly decrease below-ground species evenness (Zhao *et al.*, 2011). In this study of the desert steppe, as the grazing

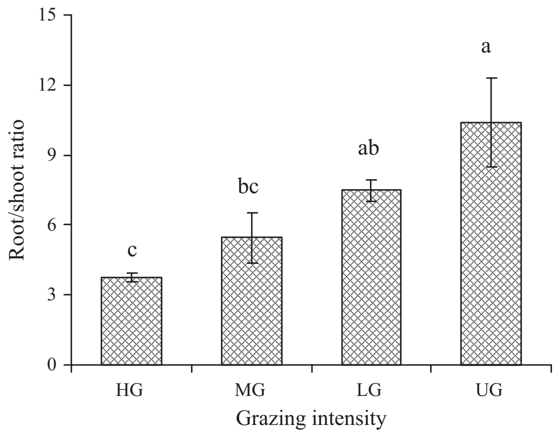

Figure 7 Root/shoot ratio in the four grasslands of different grazing regimes. HG, heavy grazing; MG, moderate grazing; LG, light grazing; and UG, ungrazed. Different lower-case letters indicate variations significant at 0·05 level ($P < 0{\cdot}05$). Error bar indicates the SE.

intensities decreased, canopy cover, height, density, biomass, litter and native plant and grass abundances significantly increased, which agrees with the results of previous studies on other steppe types (Li *et al.*, 2006; Liang *et al.*, 2009; Golodets *et al.*, 2010; Fensham *et al.*, 2011; Zhao *et al.*, 2011; Louhaichi *et al.*, 2012). To adapt to their environment, the root/shoot ratio of plants is often modified in different environmental conditions in ways that maximize the ability to capture resources (Wang *et al.*, 2010). We found that root/shoot ratios increased significantly as grazing intensity decreased, indicating that grazing changes above- and below-ground biomass allocations. When grazing pressure is decreased, plants allocate more biomass to support root growth. However, we found that there was no difference in either above- or below-ground biomass between the plots experiencing heavy, moderate or light grazing ($P > 0{\cdot}05$). This result was also found in typical steppe (Liang *et al.*, 2009). Liang *et al.* (2009) also found there was no difference in ungrazed and grazed grasslands, but the results of our study were different, perhaps because the ungrazed grassland we chose had been fenced for a different length of time.

Higher plant biomass and litter production protect soil by helping to reduce run-off and erosion, provide forage for livestock grazing and enhance seed production and recruitment potential (Louhaichi *et al.*, 2012). Salkini *et al.* (2008) report that overgrazing reduced pasture production, increased erosion rates and under some circumstances caused desertification. With decreased grazing intensity, the plant biomass, litter and root/shoot ratio significantly increase, suggesting that grazing exclusion does improve the grassland ecological function of soil and water conservation. In rangeland ecosystems, productivity varies with plant community composition, climate, topography, soil and human activities, as well as their interaction (Li *et al.*, 2006; Cong *et al.*, 2008; Parton *et al.*, 2012). Human activities can influence plant growth by improving their environmental conditions. Reducing grazing pressure can improve soil properties. Sun *et al.* (2011) reported that increases in grazing pressure could lead to a gradual change in alpine meadow soils from 'carbon sinks' to 'carbon sources'. In this study, as grazing intensity decreased, soil moisture and soil pH have significantly improved (Table 1). This indicates that grazing exclusion improves soil quality which positively affects plant functional group composition, diversity and biomass. This is possible because grazing exclusion significantly improves community composition, plant cover, height, above- and below-ground biomass, litter and root/shoot ratios. Grazing is one of the key factors behind changing soil organic matter input and associated soil properties (Steffens *et al.*, 2009; Wiesmeier *et al.*, 2009). Wiesmeier *et al.* (2011) demonstrated that heavy grazing reduced soil organic C and the stocks associated with higher topsoil bulk densities in the semi-arid steppes of Inner Mongolia. In this study on desert steppe, soil bulk density significantly decreased after long-term grazing exclusion, supporting Wiesmeier *et al.*'s (2011) findings, which suggest that soil organic C contents and stocks increase with decreasing grazing intensity.

Grazing protection increases either species richness in or abundance of native plants (Fensham *et al.*, 2011). However, the species richness peak, which occurred under moderate grazing, is counter to the response shape predicted by an emerging theory on species richness recovery in low-productivity environments (Fensham *et al.*, 2011). For example, the theory predicts species diversity will not be as strongly suppressed by competitive exclusion in low-productivity environments as under low grazing disturbances (Sasaki *et al.*, 2009). In this study, the significant unimodal relation between species richness and grazing pressure in which species richness under both light and moderate grazing was higher than that under heavy grazing and long-term ungrazed grassland supports the results of both Fensham *et al.* (2011) and Sasaki *et al.* (2009). But Sasaki *et al.* (2009) also predicted that high species richness appeared in high-productivity environments where a few species became dominant, a finding which differs from what was found in this study. Jelinski *et al.* (2011) reported that high diversity did not ensure high productivity. High productivity causes high population growth, thereby leading to the quick removal of some species through competition (Kassen *et al.*, 2000). This is probably the reason why higher species richness under moderate grazing appeared at a lower level of productivity. In addition, in this study, species richness showed no significant difference between the three grazing intensities of heavy, moderate and light, which suggests that grazing pressure on its own may not be an important factor influencing species richness in the desert steppe. Chen *et al.* (2011) found that species richness did not vary with grazing pressure in the desert steppe zone, which supports the results of our study; however, in the steppe zone, species richness varied significantly with grazing pressure (Chen *et al.*, 2011) leading Chen *et al.* (2011) to conclude that precipitation is more important than grazing pressure on vegetation changes in drier areas with high rainfall variability.

The increased vegetation cover and higher native species density resulting from grazing exclusion were observed with reduced grazing pressure, in keeping with the results obtained within similar grassland by Louhaichi *et al.* (2012). Golodets *et al.* (2010) reported that grazed vegetation dominated by short annual grasses and annual forbs protected from grazing over the long term would be dominated by tall annual and perennial grasses. In this study, similar findings were obtained. As the grazing intensities decreased, the above-ground biomass ratio of grasses increased. In contrast, the above-ground biomass ratios of forbs varied in the opposite direction. The reason for this was probably that grasses have a higher capacity to maintain viable seed banks for their regeneration (Aboling *et al.*, 2008). In addition, floristic changes resulting from grazing exclusion could involve replacing unpalatable plants with palatable plants such as dominant functional group grasses (Jia, 2000). Such competition can result in long-term shifts in plant community structure and function lasting for a long period of time (Louhaichi *et al.*, 2012). The above-ground biomass ratio of the dominant species (*Aneurolepidium dasystachys*) was the highest under light grazing and the lowest under heavy grazing. The above-ground biomass ratio of the dominant species (*Aneurolepidium dasystachys*) was not the highest under ungrazed grassland, rather the highest biomass and density appeared under ungrazed. This was probably because high productivity caused high population growth, thereby leading to the quick removal of some species by potential competition (Kassen *et al.*, 2000), so that finally, there were several dominant grasses.

Conclusion

In the grazed grassland, grazing exclusion improved vegetation cover, biomass, root/shoot ratios, recovery of the grasses, as well as increasing species richness. However, long-term protection in the form of fencing significantly reduced species richness, although grassland biomass and abundance of grasses were both significantly increased. Species richness peaked under moderate grazing against lower productivities. In desert steppe rangelands, appropriate grazing management could be used to bring about desirable transitions in plant functional communities. Grazing exclusion had positive effects on the sustainability of rangeland ecosystems, especially on grassland near residential areas. Overall, it would appear that balanced use and the long-term effective management of grasslands through moderate grazing regimes can both counteract their local degradation, leading to their recovery, and jump-start their functional restoration. Importantly, the improvement in soil quality associated with decreased grazing pressure strongly suggests that future research would investigate the capacity for soil organic C storage in grazed grasslands as a potential carbon sink for our globally warming world.

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