Efficacy of Exclosures in Conserving Local Shrub Biodiversity in Xeric Sandy Grassland, Inner Mongolia, China

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Abstract: This study investigated the abundance and frequency of occurrence of all shrub species present in the standing vegetation at four sites, including a 5-year exclosure (protected grassland) and three adjacent unprotected grazing sites that had been subjected to different levels of degradation (light, moderate and severe), in xeric sandy grassland of Inner Mongolia for three growing seasons. Shrub species abundance, richness, and diversity in the exclosure were compared with three unprotected sites to determine the efficacy of exclosure on shrub biodiversity conservation. Using the data set, the responses of individual shrub species to level of grassland degradation were also examined by means of detrended correspondence analysis (DCA). Individual shrub species responded differently to degradation level. From individual species responses we identified three main response types. The first type is represented by *Artemisia holodendren* showing a positive response to degradation level. The second type is represented by *Lespedeza davurica*, *Hedysarum fruticosum*, and *Caragana microphylla* indicating a negative response to degradation level. The third type included *Ceratoides arborescens* and *Artemisia frigida* following a different response pattern from the first two response types. Exclosure effects varied remarkably with different shrub species. The results suggest that it is generally necessary to apply an exclosure to the severely degraded grassland while light to moderate grazing disturbance is helpful for the maintenance of shrub species diversity. These findings are important for understanding how grassland degradation affected the population demography of shrub species and for developing appropriate management strategies for conservation of degraded shrub vegetation.

Introduction

Grasslands in the arid, semi-arid and dry semi-humid regions of northern China are becoming increasingly degraded or lost due to anthropogenic influences (Li 1997; Chen 1998; Chen and Wang 2000), such as overgrazing, over-cultivation (conversion of grassland to farmland), extensive firewood collection, and excessive groundwater withdrawal or surface water use for agricultural purposes. This is particularly true for those ecologically fragile ecosystems with a low resilience, such as the xeric sandy steppe grassland in the Horqin Sandy Land of Inner Mongolia (Liu and others 1996). The total area of the Horqin sandy steppe is approximately 518×10^4 ha, which constitutes an important part in Inner Mongolia's pasture resources (Jiang and others 2003). Due to human activities, however, almost 80 percent of the Horqin sandy steppes suffered from desertification (a form of land degradation resulting primarily from wind erosion activity after destruction of vegetation by overgrazing), of which about one third was severely desertified (Zhu and Chen 1994; Wang 2000). Thus, the Horqin Sandy Land has been identified as one of the worst examples of desertification in northern China (Wang and others 2003). The ecological consequences of unchecked desertification in this region are a substantial loss of the region's specific floristic biodiversity, as well as a range of negative environmental and socio-economic impacts (Chang and Wu 1997; Jiang and others 2003). For example, once the vegetation in sandy grasslands has been destroyed by overgrazing or other human activities, they become less stable and highly erodible during the dry and windy seasons (Li and others 2003a), which are most likely to become new sources of sand and dust that could contribute to sand-dust storms that occur frequently in the arid and semi-arid regions of the northern China (Xuan and others 2000).

Shrubs are an important component in degraded sandy grassland vegetation. Previous studies have shown that some of shrub species such as *Artemisia holodendren* is a pioneer sand-stabilizing plant and plays a key role in maintaining the stability of natural sandy grassland ecosystems (Liu and others 1996; Li and others 2002; Zhang and others 2004). Moreover, some of shrub species, such as *Artemisia frigida*, are commonly known as an indicator species. Its presence or absence in the grassland has been used for establishing whether grassland is degraded (Zhao and Zhou 1999; Li and others 2002). In the last decade, a number of experiments have been carried out in laboratory and experimental garden

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plots to explore the ecological and physiological adaptation mechanisms of several shrub species, such as *A. halodendron*, *A. frigida*, *Caragana microphylla*, and *Salix gordejevii*, to the harsh environmental conditions of sandy grassland ecosystems characterized by frequent drought, high temperature, and sand burial (Wang and Zhou 1999; Zhou 1999; Zhou and others 1999; Ren and others 2001; Zhou and Zhao 2002). However, few studies have examined the efficacy of short-term exclosure (grazing exclusion) in conserving local shrub species diversity and the response of individual shrub species to level of grassland degradation.

To address this deficiency, we carried out an experiment in the Horqin sandy grassland to examine how degradation level affects shrub species abundance, richness, and diversity and to assess the efficacy of short-term exclosure. The objectives of this study were to: (i) determine changes in the abundance, richness, and diversity of shrub species present in the established vegetation and (ii) determine the specific efficacy of a 5-year exclosure on the restoration of degraded shrub vegetation and the maintenance of shrub species diversity. Here, two specific hypotheses we posed were as follows: (1) Individual shrub species respond differently to degradation level due to their distinct life-history and plant morphological attributes. Some species will be advantaged by the local disturbances associated with moderate to heavy grazing, and will thus show trends of increasing abundance with increasing disturbance intensity (degradation level) and consequently occur more frequently in grasslands under moderate to severe degradation. Some species will be disadvantaged and will thus show patterns of decreasing abundance with increasing degradation level, and consequently disappear or occur less frequently in grasslands under moderate and severe degradation and (2) The effect of exclosure on the conservation of shrub biodiversity varies with different shrub species.

Materials and Methods

Site Description

The study site is located in Naiman county (42º55' N, 120º44' E; altitude *c.* 360 m a.s.l.) in the eastern part of Inner Mongolia, China, about 500 km northeast of Beijing (Li and others 2003b). Naiman is in the southwestern part of the Horqin Sandy Land, which represents the most desertification-threatened area in northern China (Jiang and others 2003). General landscape in this area is characterized by sand dunes alternating with gently undulating lowland areas. The soils are sandy, light yellow, and loose in structure (Zhu and Chen 1994). The main soil type is classified as an Arenosols in WRB (ISSS, ISRIC and FAO 1998). The climate is temperate, semi-arid and continental, receiving 360 mm annual mean rainfall, with 75 percent of the annual rainfall falling in the June–September period. The annual mean potential evaporation is 1, 935 mm, and the annual mean temperature is 6.5°C.

The original vegetation of this area was an open, sparse forest steppe (Liu and others 1996). Due to human activities, however, woody species (mainly elm *Ulmus* spp.) have almost disappeared and most of the grass cover is gone (Andrén and others 1994). Degraded sandy grasslands are generally classified into three main forms: fixed or stabilized (light degradation), semi-fixed or semi-stabilized (moderate degradation), and mobile or least stabilized (severe degradation), representing a realistic range of historically grazing impacts. Over space, these differently degraded grassland patches occur in a complex mosaic (Zhao and others 2003).

Vegetation Survey Design and Sampling

A field survey of the abundance and frequency of occurrence of all shrub species present in the established vegetation was conducted in four sites, including a demonstration exclosure (protected grassland) and three adjacent communal grazing sites that were selected over an area of 3×3 km. The exclosure was established in an open and level grassland area of about 10 ha in April 1997. The grassland had been subjected to severe degradation due to a history of heavy grazing by livestock prior to fencing the exclosure. Three adjacent communal grazing sites differed in degree of vegetation degradation in terms of vegetation cover, species richness, and composition. According to the classification criteria of desertification degree of Zhu and Chen (1994), one of the three sites was identified as light degradation (LDG, lightly degraded grassland), another as moderate degradation (MDG, moderately degraded grassland), and the third one as severe degradation (SDG, severely degraded grassland). Thus, these three sites constitute a gradient of degradation in sandy grasslands. LDG was situated on a typical fixed sand dune area (two separated fixed dunes were selected for sampling). MDG was situated on a typical semi-fixed sand dune area (two separated semi-fixed dunes were selected for sampling). SDG was located on a typical mobile sand dune area (two separated mobile dunes were selected for sampling). Three unprotected grazing sites were at least 1 km apart from one another while their distances from the exclosure were 1.5 to 2 km apart.

A hundred and eighty plots (2 × 2 m) were randomly selected along five parallel transects (each 25 m apart) in the exclosure and 120 plots were randomly selected in each of the three unprotected grazing sites to investigate species composition and density of each shrub species present in each plot in the last week of August at the time of peak biomass production and species diversity. For each site, richness of the shrub species was assessed by the total number of shrub species per site and the mean number of shrub species m^{-2}. Abundance of each shrub species was assessed by its number of established plants m^{-2} and its frequency of occurrence that was calculated as the percentage of the number of plots occupied by a species relative to the total number of plots per site. The sampling of the standing vegetation was repeated for three consecutive growing seasons (2002–2004).

Data Analysis

One-way analysis of variance (ANOVA) was used to test for differences in shrub vegetation parameters between sites. Significant differences between sites were compared using LSD tests. Data for species richness (measured as the mean number of shrub species m^{-2}) and abundance (measured as the number of established plants m^{-2}) were log-transformed to normalize the distributions. To detect any general patterns in species abundance relationships with sites, we undertook detrended correspondence analysis (DCA) based on the species abundance (density and frequency) data for the four sites. Shannon-Wiener diversity index (H'; Magurran 1988) and Pielou's evenness index (J; Pielou 1975) were used to analyse changes in shrub species diversity and evenness across sites. H' and J were calculated by the following formula:

$$H' = -\sum P_i \ln P_i$$
$$J = H'/\ln S$$

where P_i is the abundance of the ith species that was measured as the importance value (IV) of the ith species in the shrub community containing S species. IV was calculated as $IV = (D_r + F_r)/200$, where D_r is the relative abundance that is calculated as the percentage of the observed abundance of a species relative to the cumulative abundance for all species occurring in the shrub community; F_r is the relative frequency that is calculated as the percentage of the observed frequency of a species relative to the cumulative frequency for all species occurring in the shrub community. Data were pooled from the 3 years in the analyses because the interest in this study is to determine differences in shrub vegetation between sites rather than to determine inter-annual variability in shrub vegetation within sites.

Results

A total of six shrub species were recorded in the established vegetation of the four sites sampled and biological characteristics of these shrub species are shown in table 1. Degradation level had significant effects on the abundance, richness, and diversity of shrub species in the established vegetation. The total number of shrub species per site was much lower in grassland under severe degradation than in other three sites that were similar in this variable (fig. 1a). There were striking differences in the mean number of shrub species m^{-2} among sites ($F_{3, 1616} = 142.14$, $P < 0.0001$), with the lightly degraded grassland having a significantly higher mean number of shrub species m^{-2} than other sites. At the same time, the mean number of shrub species m^{-2} was also significantly higher in the moderately degraded grassland than in both the protected and severely degraded grasslands and in the protected grassland than in the severely degraded grassland (fig. 1b). Almost the same patterns were observed when comparing the shrub species diversity and evenness index values between sites (fig. 1c, d).

Total shrub abundance was significantly higher in the lightly degraded grassland than in other sites, because of high densities of established *Lespedeza davurica* and *Hedysarum fruticosum* plants at this site (table 2). Total shrub abundance was also significantly higher in the moderately degraded grassland than in the protected and severely degraded grasslands, because of high density of established *Artemisia halodendron* plants at this site, and in the protected grassland than in the severely degraded grassland (table 2).

Detrended correspondence analysis (DCA) showed tight associations between shrub species and particular sites (fig. 2). Of the six shrub species occurred at the study site, *Ceratoides arborescens* and *Artemisia frigida* were restricted to the

Table 1. Main biological characteristics of shrub species recorded at the study sites.

	Family	Life form	Growth form	Root growth form	Ecological type of water	Palatability
Artemisia halodendron Turcz. ex Bess.	Compositae	Hemicrypto-geophyte	Limb	Rhizome	Mesoxerophyte	Less palatable
Artemisia frigida Willd.	Compositae	Chamaephyte	Stolon	Taproot	Xerophyte	Palatable
Lespedeza davurica (Laxm.) Schindl.	Leguminosae	Chamaephyte	Limb	Taproot	Mesoxerophyte	Palatable
Hedysarum fruticosum Pall.	Leguminosae	Hemicryptophyte	Limb	Taproot	Mesoxerophyte	Palatable
Caragana microphylla Lam.	Leguminosae	Chamaephyte	Limb	Taproot	Mesoxerophyte	Palatable
Ceratoides arborescens (Losinsk.) Tsien et Ma	Chenopodiaceae	Chamaephyte	Turb	Taproot	Xerophyte	Less palatable

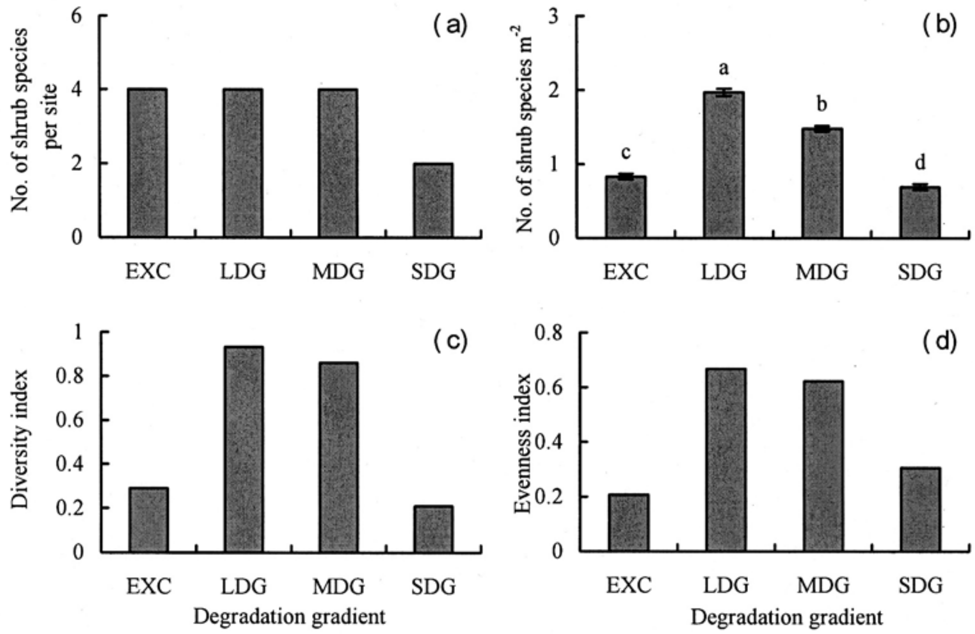

Figure 1. Changes in (a) total number of shrub species per site, (b) mean number of shrub species m^{-2}, (c) shrub diversity index and (d) shrub evenness index in the established vegetation of the four sites along the degradation gradient. EXC = exclosure (protected grassland). LDG = lightly degraded grassland. MDG = moderately degraded grassland. SDG = severely degraded grassland. Means with different letters indicate significant differences at P < 0.05 between the four sites (ANOVA followed by LSD tests).

Table 2. Mean (± SE) density of established plants m^{-2} (% frequency) of shrub species present in the established vegetation of the four sites along the degradation gradient. EXC = exclosure (protected grassland), LDG = lightly degraded grassland, MDG = moderately degraded grassland, and SDG = severely degraded grassland. Means with different letters within each species indicate significant differences between the four sites (ANOVA followed by LSD tests). *P < 0.05, **P < 0.01, ***P < 0.0001 and ns = not significant.

	EXC	LDG	MDG	SDG	$F_{(3, 1616)}$
Artemisia halodendron	0.003 ± 0.001c (1)	0.50 ±0.16b (26)	1.62 ± 0.09a (91)	0.60 ± 0.07b (62)	53.45***
Artemisia frigida	0.01 ± 0.004a (1)	0.00 ±0.00b (0)	0.00 ±0.00b (0)	0.00 ±0.00b (0)	2.01ns
Lespedeza davurica	1.71 ± 0.28b (75)	11.60 ± 1.22a (91)	0.82 ± 0.19bc (41)	0.013 ± 0.003c (6)	91.82***
Hedysarum fruticosum	0.00 ± 0.00b (0)	1.13 ±0.18a (67)	0.05 ± 0.01b (9)	0.00 ± 0.00b (0)	52.63***
Caragana microphylla	0.00 ± 0.00a (0)	0.07 ±0.05a (13)	0.02 ± 0.004a (5)	0.00 ± 0.00a (0)	2.08ns
Ceratoides arborescens	0.05 ± 0.02a (6)	0.00 ±0.00b (0)	0.00 ± 0.00b (0)	0.00 ± 0.00b (0)	5.69**
Total shrub abundance	1.77 ± 0.27c	13.30 ± 1.29a	2.51 ± 0.20b	0.61 ± 0.06d	99.61***

exclosure, whereas *A. halodendron* occurred more frequently in grasslands under moderate and severe degradation (fig. 2a and table 2). Moreover, *L. davurica* and *Caragana microphylla* were far more frequent in occurrence in the lightly degraded grassland, although the former was present in all four sites (fig. 2a and table 2). Similar patterns were observed when performing DCA using the species abundance data for the four sites (fig. 2b and table 2).

Discussion

Effects of Degradation Level

This study indicates that degradation level strongly affected shrub plant diversity and abundance of individual species in the xeric sandy grasslands. This is consistent with observations from other studies to have demonstrated that overgrazing

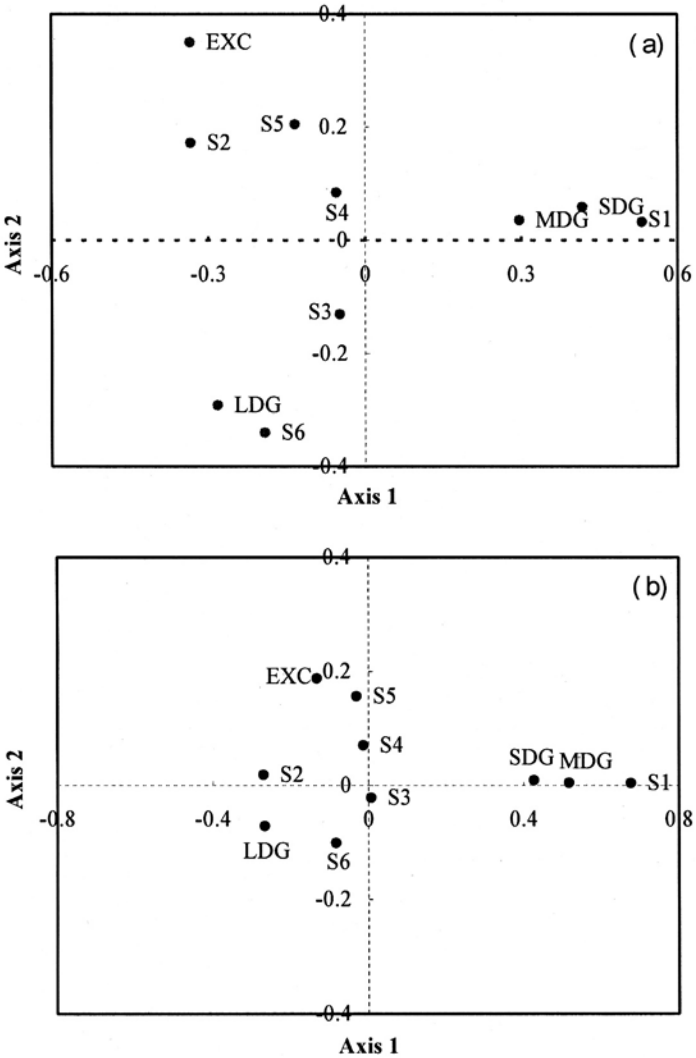

Figure 2. Derended correspondence analysis based on (a) frequency and (b) abundance of shrub species present in the established vegetation of the four sites along the degradation gradient. EXC = exclosure (protected grassland), LDG = lightly degraded grassland, MDG = moderately degraded grassland, and SDG = severely degraded grassland. S1 = *Artemisia halodendron*, S2 = *Lespedeza davurica*, S3 = *Hedysarum fruticosum*, S4 = *Ceratoides arborescens*, S5 = *Artemisia frigida*, and S6 = *Caragana microphylla*.

by herbivores generally has negative impacts on recruitment and regeneration of many species in most plant communities (Tiver and Andrew 1997; Li and others 2002; Landsberg and others 2003; Zhao and others 2004). However, the influence of degradation level varied with different shrub species, providing evidence supporting the hypothesis we originally posed, that is, different shrub species are likely to have had different responses to level of grassland degradation. From the responses of individual shrub species, we were able to identify three definite response types relating to degradation level. The first type is represented by *A. halodendron* showing a positive response to degradation level. Its number of established plants m^{-2} and its frequency of occurrence in the vegetation increased with increasing degradation level, and maximum abundance and frequency were noted in the moderately degraded grassland. This indicates that moderate grazing disturbance favors the survival and growth of this species. This is in line with the study of Chao and others (1999) on the distribution of *A. halodendron* population in differently degraded grassland types, reporting that abundance of *A. halodendron* plants was highest on moderately degraded semi-fixed sand dunes, intermediate on severely degraded mobile sand dunes, and lowest on lightly degraded fixed sand dunes. In contrast, some shrub species such as *L. davurica*, *H. fruticosum* and *C. microphylla* belonged to the second type demonstrating a negative response to degradation level. Their number of established plants and their frequency of occurrence in the vegetation decreased dramatically with increasing degradation level, and peak abundance and frequency occurred in the lightly degraded grassland. This suggests that these three shrub species appear to be adapted to survive under light grazing pressure. *C. arborescens* and *A. frigida* belonged to the third type exhibiting a different response pattern from the first two response types. Both species had disappeared from the three unprotected sites and occurred only in the protected grassland (exclosure), again suggesting that they are very sensitive to grazing disturbances. Previous studies have shown that the survival and growth of *A. frigida* was strongly affected by defoliation due to its low grazing tolerance, and light to moderate grazing is likely to result in extinction of this species (Li and others 2002). Therefore, presence or absence of *A. frigida* in the community is usually used as an indicator for establishing whether grassland is overgrazed (Zhao and Zhou 1999). The observed differences in response patterns of individual shrub species to degradation level resulted most probably from the differences in their life-history and plant morphological traits, which in turn led to the differences in their ecological adaptation abilities to grazing disturbances. Many studies have shown that life history and plant morphology are important attributes in determining the responses of plant species to grazing intensity (Noy-Meir and others 1989; McIntyre and others 1995; Lavorel and others 1997). In the present study, for example, an explanation for high grazing tolerance of *A. halodendron* is its massive perennating buds on rhizomes that are buried near the soil surface (Li and Zhang 1991). Further, persistence of *A. halodendron* may also be associated with its superior capacity to produce offspring through vegetative propagation under the condition of sand burial (Chao and others 1999). This is because vegetative propagation of *A. halodendron* can take place only when its shoots are partially buried by moving sand, as the buried shoots can form roots from their nodes under favorable moisture conditions and consequently become new ramets (Chao 2000). The grasslands under moderate and severe degradation are generally characterized by a highly erodible environment (Li and others 2003a), providing greater opportunities for *A. halodendron* shoots to be buried by moving sand and thus encouraging its vegetative propagation. In contrast, both the protected and lightly degraded grassland are characterized by a significantly less erodible environment, providing less chance for *A. halodendron* shoots to be buried by moving sand and thus limiting *A. halodendron*'s vegetative propagation. For that reason, it is not surprising why *A. halodendron* had significantly higher abundance and frequency in grasslands under moderate and severe degradation in comparison with the protected and lightly degraded grasslands.

Analysis of the associations between shrub species and sites sampled also provided further evidence for supporting the hypothesis above. In these analyses, we found that most of the shrub species were closely associated with particular sites relating to different degrees of degradation. Of the six shrub species recorded in the study site, *A. halodendron* and *L. davurica* occurred in all four sites but the former had the highest frequency in the moderately degraded grassland and the latter had the highest frequency in the lightly degraded grassland. *H. fruticosum* and *C. microphylla* were restricted to the lightly and moderately degraded grasslands and *C. arborescens* and *A. frigida* occurred only in the exclosure.

Role of Exclosure Management

Our results indicate that the short-term (5 years) exclosure resulted in an increase in shrub plant diversity through conserving species that decreased or disappeared under intense grazing conditions. However, exclosure effects were found to vary remarkably with the community parameter considered (for example, shrub species richness, species diversity, or shrub density of buried seeds). For example, the total number of shrub species per site was only higher in the exclosure than in the severely degraded grassland but no differences were found between the exclosure and both the lightly and moderately degraded grasslands. Nonetheless, the mean number of shrub species m^{-2} and shrub species diversity index in the exclosure were consistently higher than in the severely degraded grassland but were significantly lower as compared with the lightly and moderately degraded grasslands. These results suggest that exclosure practice is generally necessary to the severely degraded grassland while light to moderate grazing disturbance is helpful for the maintenance of shrub species diversity. This agrees with findings of a 5-year grazing experiment conducted in a sandy grassland in the Horqin Sandy Land (Zhao and others 2004), reporting that light grazing favors vegetation restoration and community stability of the deteriorated grassland. Li and Wang (1999) and Li and Li (2000) also reported that light grazing is helpful in maintaining plant species diversity and standing crop biomass production in sandy grasslands of Inner Mongolia.

The effect of exclosure also changed with shrub species. The short-term exclosure only resulted in an increase of *L. davurica* abundance as compared with the moderately and severely degraded grasslands and re-colonization of *C. arborescens* and *A. frigida* that had disappeared from the unprotected grassland. However, exclosure had less impact on abundances of established *H. fruticosum* and *C. microphylla* plants. This species-specific response to exclosure may reflect a major difference in that the short-term exclosure may create a new biotic and abiotic environment by allowing only certain species to establish and survive but preventing recruitment of other species. Further information on the mechanism how the survival and growth of individual shrub species is affected by interactive effects of a set of biotic and abiotic factors is needed to guide the management for conservation of degraded shrub plants in the studied sandy grassland ecosystem.

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