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Agriculture, Ecosystems and Environment, **235**, 340-348 (2016)

doi: 10.1016/j.agee.2016.11.005

Published at http://www.sciencedirect.com/science/article/pii/S0167880916305424

Effects of excluding grazing on the vegetation and soils of degraded sparse-elm grassland in the Horqin Sandy Land, China

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Abstract

Livestock grazing is a crucial cause of vegetation degradation and desertification in sandy lands. The sparse-elm grassland of Horqin Sandy Land, China has suffered severe degradation of biodiversity and ecosystem services. Management to exclude grazing is often necessary for ecological restoration, especially in arid and semi-arid regions. We report effects on vegetation and soils in a 10-year experiment to exclude livestock, completely or seasonally, in comparison with a continuously grazed area in Horqin. Complete exclusion of grazing and restriction of grazing to summer both led to significantly increased plant cover and density relative to the grazed control. Species richness increased, reflected in higher Shannon-Wiener indices; only complete exclusion increased the Simpson diversity index, whereas Pielou evenness was significantly lowest under seasonal grazing. Exclosure treatments were also associated with improved soil texture, and increased water retention, available nitrogen, total nitrogen, total carbon and total phosphorus. Soil pH and C/N ratio were highest under the seasonal grazing regime. The results indicated that exclosure management indeed improved biodiversity and ecosystem services in an erosion-prone region. Although total exclosure was most effective in restoration of degraded sparse-elm grassland, seasonal grazing management was highly beneficial and represented a good compromise with resource utilization and economic development.

Keywords exclosure management; soil; vegetation; degraded grassland; Horqin Sandy Land

1. Introduction

As the most widely distributed and largest terrestrial ecosystem, grasslands are highly susceptible to human activities, especially long-term, continuous livestock grazing (White *et al.*, 2000; Molles, 2008). In arid and semi-arid regions, 73% of grassland ecosystems have suffered some degree of degradation (Foley *et al.*, 2005; Bai *et al.*, 2012). As a result, intense and increasing interest has been focused on changes in vegetation and soil physicochemical properties in response to grazing.

Numerous studies have reported effects on vegetation cover, species diversity and land productivity (Wu *et al.*, 2009; Schönbach *et al.*, 2010; Deléglise *et al.*, 2011; Su *et al.*, 2015). Other studies have drawn attention to modifications in nutrient availability and destruction of topsoil structure by livestock grazing and trampling (Wienhold *et al.*, 2001; Su *et al.*, 2005; Pei *et al.*, 2008; Li *et al.*, 2011; Miao *et al.*, 2014). Both vegetation degradation and soil deterioration have direct influences on ecological function and ecosystem services, and are thus a threat to socio-economic and cultural development (Jeddi and Chaieb, 2010; Zhang *et al.*, 2011).

Various measures have been implemented to limit further degradation and enhance ecosystem recovery. The most fundamental and economical approach to restoration involves management to exclude livestock and their damaging activities, taking advantage of the natural resilience of ecosystems to achieve recovery (Frank *et al.*, 2014; Su *et al.*, 2015). Indeed, previous studies have confirmed the value of grazing exclusion without any additional measures in the successful restoration of natural vegetation in moderately degraded areas, and also reported improved nutrient availability and water conservation (Jeddi and Chaieb, 2010; Deléglise *et al.*, 2011; Wang *et al.*, 2016). Whether this straightforward approach would be successful in such severely degraded grassland is not known, there having been very few quantitative studies, despite the growing appreciation of increasingly serious desertification and socio-economic losses.

The Horqin Sandy Land, located in the southeast of the Mongolian plateau, is in the semi-arid agro-pastoral transition zone of northern China (Jiang *et al.*, 2003; Tang *et al.*, 2014). Sparse-elm grassland constitutes the main original landscape, which is characterized by either isolated or (more often) groups of the sandy elm tree (*Ulmus pumila* var. *sabulosa*), and well developed grass-shrub vegetation. This community structure has proved to have the greatest stability and best adaptability to sandy soil in these arid and semi-arid regions (Li *et al.*, 2004; Yuan *et al.*, 2012). Horqin Sandy Land represents a traditional Mongolian landscape, where stock grazing has provided the main source of income for herdsmen since ancient times (Katoh *et al.*, 1998; Chang *et al.*, 2003). However, intensive human disturbance from excessive grazing, over-cultivation and gathering of firewood has become increasingly pronounced under the influence of settlement and warfare since the early 20th century (Cao *et al.*, 2008; Miao *et al.*, 2014). The local population has increased four-fold over the past 40 years and most herdsmen, lacking formal education, have little awareness of environmental protection (Chang *et al.*, 2003). Furthermore, the drive for economic benefit has increased stocking rates dramatically to 3.5-4.5 sheep units ha^{-1}, or nearly three times higher than the local recommended livestock capacity (1.5 sheep units ha^{-1}) since the household contract responsibility system, which advocated that village lands should be allocated to individual households, started in the 1980s (Liu and Diamond, 2005; Han *et al.*, 2008). Overgrazing has induced serious land desertification and has had a catastrophic influence on local productivity and life (Jiang *et al.*, 2003). The average above-ground dry biomass has been only 60-200 g m^{-2} over the past few decades. Consequently, herdsmen have had the expense of purchasing extra grass from other places for livestock feeding through the long winter (Yang and Dong, 2010; Jiang *et al.*, 2011).

In order to redress the balance between the pastoralists' profits and ecosystem services, major top-down exclosure projects "Returning Grazing Land to Protected Grassland" and "Ecological Migration" have been carried out by the Chinese government in this region since the beginning of 21st century (Liu and Diamond, 2005; Reynolds *et al.*, 2007). However, because of the relatively limited remaining area of sparse-elm grassland, it has attracted little attention, with few quantitative studies of the impact on either vegetation or soil properties after exclosure management. Therefore, the specific objectives of our experiments were to examine the effects of exclosure measures on vegetation characteristics and soil properties in the degraded sparse-elm grassland of Horqin Sandy Land, in order to provide strategies for supporting restoration and utilization of degraded grassland ecosystems in this region.

2. Material and methods

2.1 Experimental area

The experiment was conducted in Baiyanhwa (a name meaning 'beautiful and prosperous flat' in Mongolian) near the Wulanaodu Desertification Experimental Station of the Institute of Applied Ecology, Chinese Academy of Sciences (43°02′ N, 119°39′ E, 480 m a.s.l). It was located in the degraded sparse-elm grassland within the western Horqin Sandy Land in Wengniute Banner, China (Figure.1). This area is characterized by a temperate continental climate, with a mean annual temperature of 7.3 °C and mean annual precipitation of 318 mm from 1980 to 2014 (Liu *et al.*, 2014). Nearly 70% of the rainfall is concentrated between June and August in the growing season (Figure 2). Annual average wind speed is 4.4 m s^{-1}; the windy season is from March to June (Liu *et al.*, 2012b; Miao *et al.*, 2014). The soils are classified as Orthi-sandic Entisols according to the FAO- UNESCO soil taxonomy classification system. They are highly susceptible to wind erosion because of their coarse texture and loose structure (Cao *et al.*, 2008). Sparse-elm grassland alternates with gentle undulating lowlands to constitute the main landscape, which is regarded as the traditional pasture. There are also gentle undulating dunes with inter-dunal lowlands, and small areas of grassland with good water availability that are reclaimed for planting crops in the growing season. The indigenous species of tree is the sandy elm, *Ulmus pumila* var. *sabulosa*; other important species include the shrub *Caragana microphylla* and annual and perennial herbs, such as *Chenopodium acuminatum, Artemisia scoparia* and *Carex duriuscula*.

2.2 Experimental design

Historically, the experimental area once belonged to a people's commune (a Chinese village government that carried out collective economics before the 1980s) and had undergone moderate grazing since the 1990s. It lies in a homogeneous flat-land landscape. Three adjoining exclosure management areas were established on 10 April 2005 with: complete grazing exclusion (EX), seasonal grazing (SG) and continuous grazing (CG) control (Figure 3). The complete grazing exclusion area of c. 35 ha in total was surrounded by 1.2 m high cement blocks, surmounted with a barbed wire fence (1 m high x 3.5 m wide) and no livestock was permitted within it during the experiment. The seasonal grazing area was c. 25 ha, with the same exclosure mechanism, but livestock (3.5 sheep units ha^{-1}) were allowed to enter during the summer and autumn (from 15 July to 15 September) of each year. Adjacent large areas followed a year-round, continuous pattern of free grazing, with 3.5 sheep units ha^{-1}, representing the traditional grazing regime for local pastoralists. During the period of the experiment, daily guard patrols enforced the restricted grazing regimes.

After 10 years of exclosure management, six representative sampling plots (c. 6 ha in total) were randomly chosen within each experimental area. At the peak of the growing period (mid-August) in 2014, a standard field vegetation survey method was adopted within them. A typical transect (150 m long) was randomly located in each plot. Eight quadrats were established at 20-m intervals for vegetation and soil sampling within each transect. Concentric quadrats of 2 m x 2 m and 1 m x 1 m were used to survey shrubs and herbs, respectively. Plant species were recorded and counted, and vegetation cover was estimated visually by skilled workers who have been engaged in this work for 30 years. Then three random soil cores (0-20 cm depth) were obtained in each quadrat along a diagonal and mixed into a single composite sample for each transect.

2.3 Soil analysis

Soil penetration resistance was measured using a soil penetrometer (SC-900, Spectrum, USA) and soil bulk density was measured using the cores of known volume. Soil water content was obtained by the gravimetric method. All soil samples were air-dried and passed through a 1-mm sieve to remove debris and litter. Particle size distribution was determined using an Intelligent Granularity Laser (Mastersizer 2000, Malvern, England) after boiling 5 g soil samples with 0.5 M $Na_2OP_2O_5$ solution (5 ml) and cooling. Soil pH was measured in a soil-water aqueous extract (1:2 by mass) after 30 min shaking at low speed (Orion Star 310p, Thermo, USA). 10 g of air-dried soil was extracted using 2M KCl solution (50 ml) and then the extracted solutions were measured for NH_4^+-N and NO_3^--N, concentrations using a Smart Chem 200 (Westco Scientific Instruments, Brookfield, CT, USA). Soil total C and N content were analyzed with an Elemental Analyzer (Vario MICRO cube; Elementar Analysen Systeme GmbH, HessenHanau, Germany). The total phosphorus (TP) concentration was determined using an Auto Analyzer (AA3, Bran + Luebb GmbH, Germany).

2.4 Calculation

An Importance Value (Curtis and Mcintosh, 1951) was calculated for each species as a comprehensive index reflecting its function and status in the community. The classic formula was reconfigured to be appropriate and practical for grassland survey data. A common formula for the grassland is:

$$\text{Importance Value (IV)} = (\text{RA}+\text{RH}+\text{RC})/3 \qquad (1)$$

where RA, RH and RC are the relative abundance, relative height and relative cover, respectively, representing the ratios of number of individuals, height and cover of a species to the total number of individuals, height and cover in each quadrat.

Biodiversity and heterogeneity were quantified by using the Simpson index (D), the Shannon-Wiener index (H) and the Pielou evenness index (E). The Shannon-Wiener index (H) measures the species richness and the equitability (evenness) of individual species distributions (Shannon, 1948). The Simpson index (D) expresses the probability that two individuals taken at random from the community represent the same species (Simpson 1949). The Pielou evenness index (E) is a measure of the relative abundance of different species making up the richness of an area (Pielou, 1975). Indices were calculated using the equations:

$$D=1-\sum_{i=1}^{s} P_i^2 \qquad (2)$$

$$H=-\sum_{i=1}^{s}(P_i \ln P_i) \qquad (3)$$

$$E=\frac{H}{\ln S} \qquad (4)$$

where S is the total number of species, and P_i is the proportion of individuals belonging to species i.

2.5 Statistical analysis

As it was impossible to replicate the large exclosure treatments, the pseudo-replicated approach of (Frank and Follett, 1995) was adopted, which considered each plot as a replicate for summary statistics. Values from all quadrats within a plot were averaged. All data were tested for normality and homogeneity of variance prior to analysis. The parameters for vegetation characteristics and soil properties were compared for significant differences by one-way ANOVA followed by a LSD post hoc test at $P<0.05$. Pearson correlation coefficients were adopted to examine the relationship between vegetation characteristics and soil properties. All statistical analyses were carried out SPSS 21.0 (SPSS Inc., Chicago, USA) and graphs were drawn with Origin Pro 9.0 (Origin Lab Corp, USA).

3. Results

3.1 Species composition and Importance Value

The total numbers of plant species recorded increased dramatically from 6 in the grazed control to 23 under seasonal grazing and 31 with the complete exclosure of livestock. There were also distinctive differences in species composition between treatments (Table 1). The continuous grazing treatment was dominated in importance by two species of annual grass *Setaria viridis* and *Tribulus terrestris*. The perennial forb *Carex duriuscula* became the most important under seasonal grazing, with the annuals *Tragus bertesonianus, Chloris virgata* and *Lappula myosotis* also prominent. *Setaria viridis, Artemisia scoparia,* and *Chenopodium acuminatum* were amongst the most important of the numerous species under continuous exclosure. Many species were represented in both the seasonal grazing and ungrazed treatments, including notably the shrub *Caragana microphylla*. Remarkably, seedlings of *Ulmus pulima* var. *sabulosa*, although present in all three treatments, were most important in the continuously grazed and control treatments.

3.2 Diversity index and vegetation characteristics

Vegetation cover and Shannon-Weiner diversity index increased significantly ($P<0.05$) as grazing pressure was reduced (Figure 4A, 4B). The Simpson index was also significantly higher in the continuous exclosure treatment than in either grazing treatment (Figure 4C). The Pielou evenness index varied less between treatments but was significantly lower under seasonal grazing (Figure 4D). On the other hand, the total density of plants was much the highest under seasonal grazing at 191 individuals m^{-2}, being 15.2 and 2.2 times greater than those in freely grazed and enclosed areas, respectively (Figure 4E); all differences were significant.

3.3 Soil physical properties

After 10 years of grazing management, there were substantial differences in particle size distribution between the treatments, with generally greater fine fractions and smaller coarse fractions associated with reduced grazing pressure (Table 2). The most striking differences were in the opposing trends in the coarse sand (>0.25 mm) and coarse silt (0.01-0.05 mm) fractions; the former dropped significantly from continuous grazing (44%) to seasonal grazing (37%) and again to ungrazed (23%) conditions; the latter increased concomitantly from 5%, to 10% and to 16 %, respectively. Other fractions showed less significant or less consistent trends.

Soil water content was consistently low, restricted by persistent drought and generally coarse texture, but it was nevertheless significantly greater in soils from the continuous exclosure than in those from treatments that had been freely or seasonally grazed (Figure 5A). Soil bulk density showed the inverse trend, being significantly lower in the exclosure than in the other two treatments (Figure 5B). Soil penetration resistance (Figure 5C), was greatest in the seasonally grazed treatment (237.2 kPa) and lowest under continuous grazing (161.2 kPa).

3.4 Soil chemical status

The two stages in the reduction of grazing intensity resulted in progressive, significant increases in total carbon, total nitrogen and inorganic (available) nitrogen in the soil (Table 3). Total phosphorus increased similarly but that in soil from the exclosure was not significantly greater than in soil from the seasonally grazed treatment (Table 3). The C/N ratio in the soil was considerably enhanced in both treatments with restricted grazing, relative to that under continuous grazing. The same significant trend was seen in pH, although the absolute differences in pH were small (Table 3).

3.5 Correlations between vegetation characteristics and soil properties

Taken across the three treatments, there were many significant correlations between vegetation characteristics and soil properties (Table 4). Most striking were the strong, positive associations between the Shannon-Wiener Diversity Index and available nitrogen, total nitrogen, total carbon and water content in the soil. There were similarly strong positive correlations between vegetation cover and available nitrogen, total nitrogen, total carbon and C/N ratio. The Simpson Diversity Index was significantly correlated with the same soil characteristics and also pH. The highest correlation of all was between the Simpson Index and soil C/N ratio. Significant correlations between soil bulk density and Shannon-Wiener Index and vegetation cover were both negative. The Pielou evenness index showed no significant correlations.

4. Discussion

4.1 Changes in the vegetation characteristics in response to exclosure

Vegetation characteristics are generally regarded as important indicators for evaluating the restoration process (Wilkins *et al.*, 2003; Wang *et al.*, 2012) and in the case of the degraded sparse-elm grassland, our research suggested that the exclosure treatments had been highly effective after a

10-year experiment to exclude livestock; there had been dramatic changes in the vegetation cover, composition and biodiversity. Under both exclosure regimes the relief from grazing allowed the development of much greater vegetation cover and individual plant density. Cover was greatest with complete exclusion of grazing but plant density was maximized by seasonal grazing, probably because of changes in species composition (Table 1).

One of the most conspicuous results of exclosure was the great increase in the number of species recorded. This was in agreement with the results reported by Jeddi and Chaieb (2010) and Pei et al (2008), who noted that cessation of grazing enhanced the numbers of species and their cover in degraded arid environments of South Tunisia in Africa and the Alxa desert steppe of China, respectively. The source of the additional species is not entirely clear but a possible reason is likely to involve rarefaction; some species previously too rare to have been recorded could have become more abundant. Another possibility is the existence of a long-term seed bank in soils from which recruitment occurred under reduced grazing. Alternatively, species may have arrived by dispersal from more distant refugia (Li *et al.*, 2014; Qian *et al.*, 2016). The changes in species richness were also evident in the Shannon-Weiner and Simpson biodiversity indices, both of which were greatest under complete exclosure, although the Simpson index under seasonal grazing was no greater than under continuous grazing. These findings were similar to those in degraded alpine meadow and sandy grassland (Wang *et al.*, 2012; Yuan *et al.*, 2012). In contrast, the Pielou evenness index was unaffected by complete exclusion and somewhat reduced under seasonal exclusion of grazing. This reduction could be explained by the dominance of *Carex duriuscula*, with high overall density relative to vegetation cover under seasonal grazing; no species achieved comparable dominance in the other two treatments, where evenness was probably maintained by resource limitation on species' competitive intensity in the heterogeneous environments (Zhang, 1998; Wu *et al.*, 2009).

The effects of grazing management were also reflected in the resulting species composition, depending particularly on the palatability of different species for livestock (Li *et al.*, 2008; Wu *et al.*, 2009; Jeddi and Chaieb, 2010). Some species such as *Erodium stephanianum* and *Lespedeza davurica* only became abundant in the complete exclusion treatment and others, such as *Cyperus rotundus* and *Trigonella korshinskyi* were seen only there. They all have high palatability and are usually regarded as fine forage. However, these highly palatable species were largely displaced by the less palatable and less desirable species, *Chloris virgata*, *Setaria viridis*, *Tragus bertesonianus* and *Tribulus terrestris* in the seasonal grazing treatment. Indeed the weed *Setaria viridis* and the agriculturally worthless species *Tribulus terrestris* provided the majority of the plant composition under continual grazing. Thus the results could be explained by the effects of grazing selectivity and trampling by domestic herbivores, which modify plant species abundance and vegetation cover. The consequence of this is that exclosure management ameliorates habitat quality and provides improved ecosystem services (Grime, 2002; Wal *et al.*, 2004; Su *et al.*, 2005). Comparable findings were found by Li et al (2008) and Jing et al (2014) who reported that exclosure management similarly isolated rangelands from disturbances by livestock and accelerated the recovery of degraded pasture species.

The only potentially undesirable effect of grazing management was on seedlings of the sandy elm (*Ulmus pumila* var. *sabulosa*) themselves. They were more abundant and had a higher importance under continual grazing than in either of the grazing management treatments. It seems that grazing was conducive to the establishment, survival and growth of these woody plants perhaps through increasing the potential for contact of their seeds with the soil surface, and then by reducing competition from herbaceous species in the early stages of growth (Wu *et al.*, 2009; Tang *et al.*, 2013).

4.2 Changes in soil properties in response to exclosure

Although less obvious than the changes to vegetation characteristics, grazing management potentially can also facilitate changes in soil properties as part of the process of restoration (Su *et al.*, 2005; Liebig *et al.*, 2006; Mekuria *et al.*, 2007), and this appeared to be the case in the sparse-elm grassland of the Horqin Sandy Land. As wind erosion tends preferentially to remove the finer, more mobile soil particles, it leads to coarsening and degradation of the soil structure (Gomes *et al.*, 2003). Although this would have happened historically, it is reasonable to assume that the soil in the three treatment areas would have been similar in composition at the beginning of the experiment. However, the mechanism leading to larger fractions of fine particles after 10 years of grazing exclusion is not clear. The increased cover and the height of the vegetation resulting from lower grazing pressure would have increased the surface roughness and thus favored the interception and deposition of fine soil particles carried by the wind (Fearnehough *et al.*, 1998; Li *et al.*, 2008; Pei *et al.*, 2008). In any event, an increase in the fraction of fine soil particles as a consequence of exclosure managements was in conformity with reported results from western Inner Mongolia, China (Fu *et al.*, 2002; Su *et al.*, 2005; Pei *et al.*, 2008).

The negative impact of livestock on grassland depends on effects of their trampling, as well as removal of vegetation by grazing or browsing (Su *et al.*, 2002; Zhu *et al.*, 2007; Li *et al.*, 2011). Release from trampling may have contributed to the progressive decrease in soil bulk density with exclosure; however, it was associated with an inverse trend for organic matter content (manifested in measurements of total carbon) which would also have reduced bulk density. The trends in organic matter, bulk density and fine particle fractions might also explain the greater ability of soil to retain water after the exclusion of grazing. Soil resistance to penetration was a measurement designed to mimic the resistance that roots encounter in the process of growth (Barber, 1994; Mullins *et al.*, 1994). Frequent trampling would be expected to increase resistance, causing a rearrangement of soil particles and creating a barrier to root growth (Barber, 1994; Brevik, 2013). The high value for soil penetration resistance after seasonal grazing was inconsistent with previous studies (Xie and Wittig, 2004; Zhao *et al.*, 2004; Li *et al.*, 2008), which suggested that a decrease in soil penetration resistance should accompany grazing exclusion. The anomalous result might have been due to different underlying soil aggregation characteristics and spatial patterns of soil porosity in the different treatment areas (Abdelmagid *et al.*, 1987; Franzluebbers *et al.*, 2000).

Grazing exclusion would be expected to reduce nutrient losses, both directly from grazing and indirectly by enhancing the accumulation and incorporation of litter in the soil (Abril and Bucher, 2001; Harris *et al.*, 2007; Liu *et al.*, 2012a). The rapid decomposition and mineralization of animal dung would promote nutrient losses by leaching. Progressive exclusion of grazing in Horqin Sandy Land indeed generally resulted in increasing concentrations of the main nutrients: available N, total N, total C and total P. These results confirmed previous studies (Naeth *et al.*, 1991; Xie and Wittig, 2004) that such exclosure management facilitates nutrient accumulation and fixation. Soil pH is potentially an important factor because it can influence nutrient availability and assimilation, thus affecting plant growth and development. The finding of the highest value under seasonal grazing was not consistent with previous studies by Jeddi and Chaieb (2010) and Wu et al. (2009) who conducted grazing exclusion managements in the south of Tunisia and in the Qinghai-Tibetan Plateau, respectively. However, the differences between our treatments were small. Such variations in pH depend on the secretion of organic acids and amounts of CO_2 released by roots, as well as microorganism metabolic activities in the rhizosphere (Hinsinger *et al.*, 2003; Jones *et al.*, 2004). In principle, changes of pH could influence mineralization and nutrient accumulation in arid and semi-arid regions (Chen *et al.*, 2013). The C/N ratio was significantly higher under seasonal grazing and grazing exclusion than in the continual grazing treatment, which demonstrated that exclosure management had influenced the concentration of total C to a greater degree than total N in the process of vegetation restoration. Similar results were obtained by Su et al (2005) and Pei et al (2008) in the semi-arid sandy grassland of northern China.

4.3 Implications of exclosure management

The management of grazing by exclosure had beneficial influences on vegetation composition and cover, and on soil properties, all of which was consistent with established views of effective ecological restoration. The improvements in soil physical properties and increasing litter accumulation associated with reduced grazing and trampling should benefit ecosystem services that depend on soil organic matter decomposition and nutrient dynamics. Thus grazing management promoted the recovery of this grassland ecosystem and helped to suppress desertification in an ecologically fragile area (Liebig *et al.*, 2006; Loydi *et al.*, 2012; Wang *et al.*, 2016). The significant correlations among a range of vegetation and soil characteristics were suggestive of a holistic recovery process; in particular, positive correlations between Simpson and Shannon-Weiner indices of diversity and AN, TN and TC were very striking, as were those between plant cover and AN, TN, TC and C/N ratio. Such findings are in general agreement with those from previous studies by Liu et al. (2012) and Miao et al. (2014), which also highlighted the interactions between vegetation structure and soil nutrient availability. The causal relationships underlying these correlations are likely to be complex: although organic matter accumulation associated with increased vegetation cover undoubtedly affected soil properties, the ameliorated soil conditions may well have promoted establishment of a wider range of species and therefore biodiversity.

Even though water deficit is regarded as the greatest constraint in arid and semi-arid lands (Jiang *et al.*, 2003; Dulamsuren *et al.*, 2009), it is remarkable that vegetation could recover so well during a period when the mean annual precipitation in the growing season of 213mm was lower than the long-term (34-year) average of 242mm. Hence this experiment proved all the more convincingly the effectiveness of exclosure management in severely degraded regions. Further work could examine more closely the timing and local stocking-level of livestock species for a sustainable operational model of husbandry in sparse-elm grasslands (Hulme *et al.*, 2001). However, from the perspective of balancing ecological restoration and economic development, grazing restricted to the growing season appears to be a pragmatic approach, which takes into consideration the carrying capacity of the grassland and the incomes of herdsmen to some extent. In addition, a suite of integrated measures (artificial reseeding, intensive forage planting and straw silage technology) could also be incorporated into the process of exclosure management to ease grazing pressure (Normile, 2007; Jiang *et al.*, 2011; Xu *et al.*, 2014), and to the benefit of ecosystem sustainability and development in the sandy grassland.

5. Conclusions

For the degraded sparse-elm grassland, exclosure management represents a straightforward and efficient method for ecological restoration and management. Field vegetation survey and soil analyses demonstrated that exclosure treatments had a profound impact on both vegetation characteristics and soil properties. Management contributed to promoting the number and cover of plant species, and hence their Shannon-Weiner and Simpson Indices, as well as the overall density of individuals in the community. It was also associated with changes to the texture and bulk density of the topsoil, and influenced soil penetration resistance. Most significantly for the restoration of ecosystem services, soil nutrient concentrations (total carbon, total nitrogen, available nitrogen and total phosphorus) were all increased by the exclosure of grazing animals. These results indicate that the degraded grassland ecosystems of the erosion-prone region in Horqin Sandy Land are readily amenable to restoration by exclosure management, without any additional artificial measures, over a reasonable period of time. In order to pursue ecological conservation and sustainable economic development, appropriate management measures such as seasonal exclosure managements should be applied to these degraded arid and semi-arid lands.

Acknowledgements

This research was supported by National Natural Science Foundation of China (31370706). Thanks are due to Yongming Luo, Hongmei Wang, Xuehua Li and Quanlai Zhou for valuable meteorological dataset from Wulanaodu Desertification Experimental Station, Institute of Applied Ecology, Chinese Academy of Sciences. We acknowledge Meiyu Jia and Xu Han, and the Mongolians Kingchuang and Baterbain for preliminary vegetation survey and soil-sample collections; Shaonan Huang for help with soil analyses in the laboratory.

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Table 1. Species composition and Importance Values for grazing exclusion (EX), seasonal grazing (SG) and continuous grazing (CG) treatments

Species	Life Form	Importance Value		
		EX	SG	CG
Allium ramosum	PF	0.002		
Amaranthus retroflexus	AF		0.001	
Aristidaad scensionis	AG	0.005	0.042	
Artemisia lavandulaefolia	PF	0.054		
Artemisia scoparia	AF	0.144	0.051	
Artemisia sieversiana	BF	0.026		
Asparagus dauricus	PF	0.002		
Bassia dasyphylla	AF	0.002		
Calamagrostis pseudophragmites	PG	0.002		
Caragana microphylla	SS	0.040	0.019	
Carex duriuscula	PF	0.004	0.422	
Chenopodium acuminatum	AF	0.164	0.005	0.005
Chloris virgata	AG	0.003	0.088	
Cleistogenes squarrosa	PG	0.026	0.004	
Corispermum candelabrum	AF	0.041	0.006	0.051
Cuscuta chinensis	AF	0.006		
Cynanchum thesioides	PF	0.002		
Cyperus rotundus	PF	0.016		
Diarthron linifolium	AF	0.027	0.034	
Digitaria sanguinalis	AG	0.001		
Echinops gmelini	AF		0.002	
Enneapogon desvauxii	AG	0.002	0.035	
Eragrostis pilosa	AG	0.042	0.012	
Erodium stephanianum	PF	0.047	0.003	
Euphorbia humifusa	AF		0.004	
Lappula myosostis	AF		0.075	
Lespedeza davurica	PF	0.067	0.012	
Leymus chinensis	PG	0.002		
Melilotus officinalis	BF		0.001	
Portulaca oleracea	AF			0.005
Salsola ruthenica	AF	0.050	0.002	
Saposhinikovia divaricata	PF	0.004		
Setaria viridis	AG	0.205	0.022	0.546
Tragus bertesonianus	AG	0.082	0.096	
Tribulus terrestris	AF	0.012	0.062	0.292
Trigonella korshinskyi	PF	0.007		
Ulmus pulima var. *sabulosa*	T	0.001	0.002	0.096

AF, annual forb; AG, annual grass; BF, biennial forb; PF, perennial forb; PG, perennial grass; SS, semi-shrub.

Table 2. Soil particle size distributions for continuous grazing (CG), seasonal grazing (SG) and grazing exclusion (EX) treatments

Treatment	Particle Size Distribution (%) Coarse Sand (>0.25mm)	Fine Sand (0.05-0.25mm)	Coarse Silt (0.01-0.05mm)	Fine Silt (0.005-0.01mm)	Clay (<0.005mm)
CG	43.68±1.95a	46.37±1.55b	5.42±0.78c	1.07±0.19b	3.47±0.37b
SG	36.58±2.79b	48.07±2.73b	10.27±1.63b	1.51±0.30a	3.57±0.40b
EX	23.43±2.03c	54.23±1.57a	15.98±0.90a	1.60±0.25a	4.75±1.02a

Means with the different letters within the same variable represent significant differences at P<0.05.

Table 3. Chemical properties of soil for continuous grazing (CG), seasonal grazing (SG) and grazing exclusion (EX) treatments

Treatment	pH	Available N mg/kg	Total N g/kg	Total C g/kg	Total P g/kg	C/N
CG	6.68±0.05b	0.83±0.14c	0.09±0.01c	0.41±0.05c	0.18±0.02a	4.56±0.60b
SG	7.34±0.11a	1.65±0.27b	0.35±0.05b	3.73±0.12b	0.19±0.01ab	10.85±1.42a
EX	7.11±0.27a	2.31±0.38a	0.65±0.04a	6.21±0.34a	0.21±0.02b	9.58±0.65a

Means with the different letters within the same variable represent significant differences at $P<0.05$.

Table 4. Pearson correlation coefficients between vegetation characteristics and soil properties in the three grazing treatments

	pH	AN	TN	TC	TP	C/N	SWC	BD	SP
Density	0.81*	0.37	0.37	0.47	0.16	0.81*	0.21	-0.03	0.73*
Simpson Index	0.77*	0.80*	0.74*	0.83*	0.39	0.91**	0.61	-0.50	0.76*
Shannon-Weiner Index	0.43	0.89**	0.89**	0.89**	0.56	0.59	0.85**	-0.82*	0.29
Pielou Index	-0.41	0.16	0.16	0.08	0.24	-0.33	0.28	-0.36	-0.64
Cover	0.67	0.89**	0.92**	0.96**	0.54	0.85**	0.79*	-0.67*	0.70*

AN, available nitrogen; TN, total nitrogen; TC, total carbon; TP, total phosphorus; C/N, the ratio of carbon and nitrogen; SWC, soil water content; BD, bulk density; SP, soil compaction. * and ** represent significance at $P< 0.05$ and $P<0.01$, respectively; N=18.

Figure. 1 The geographic location of the study area in Horqin Sandy Land, China.

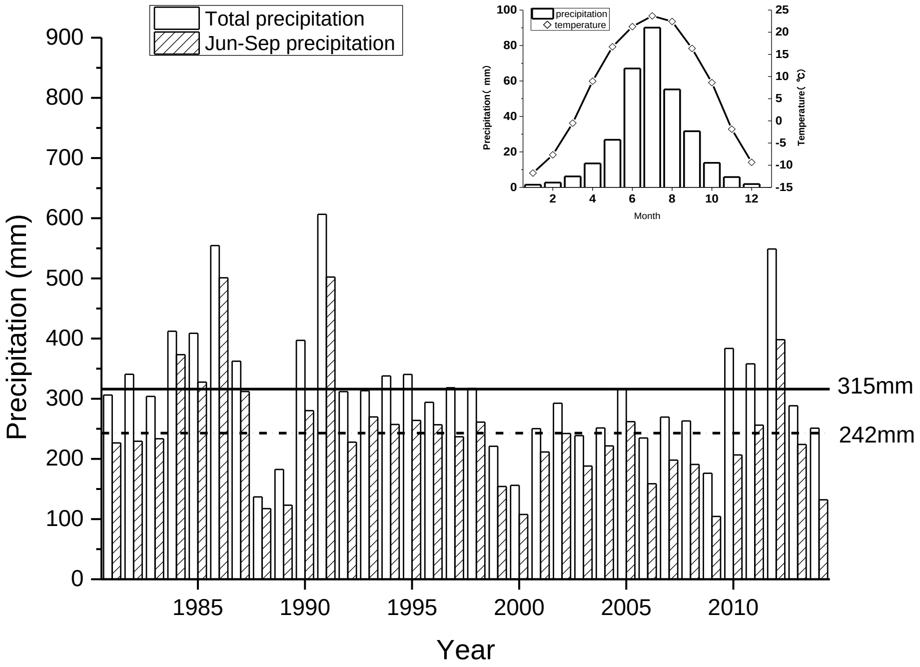

Figure 2.Changes in precipitation and temperature from 1980 to 2014 at Wulanaodu District. The top panel shows the average monthly precipitation (mm) and temperature (℃); the solid line shows the average annual precipitation and the dashed line shows the average precipitation from June to September.

Figure 3 The appearance of the three treatments in the grazing experiment: (A) complete grazing exclusion (EX); (B) seasonal grazing (SG); and (C) continuous grazing control (CG).

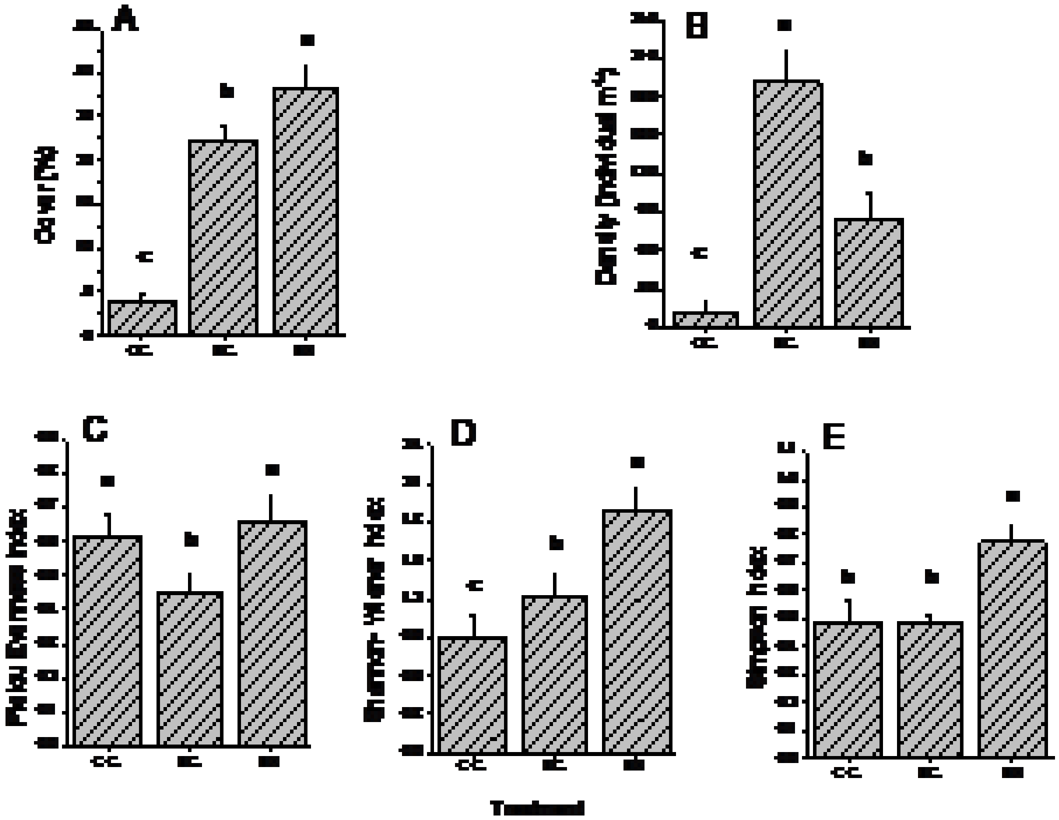

Figure 4. Changes in (A) vegetation cover, (B) Shannon-Wiener diversity index, (C) Simpson index, (D) Pielou evenness index and (E) vegetation density for continuous grazing (CG), grazing exclusion (EX) and seasonal grazing (SG) treatments. Different letters above histograms among different treatment represent significant differences at P<0.05.

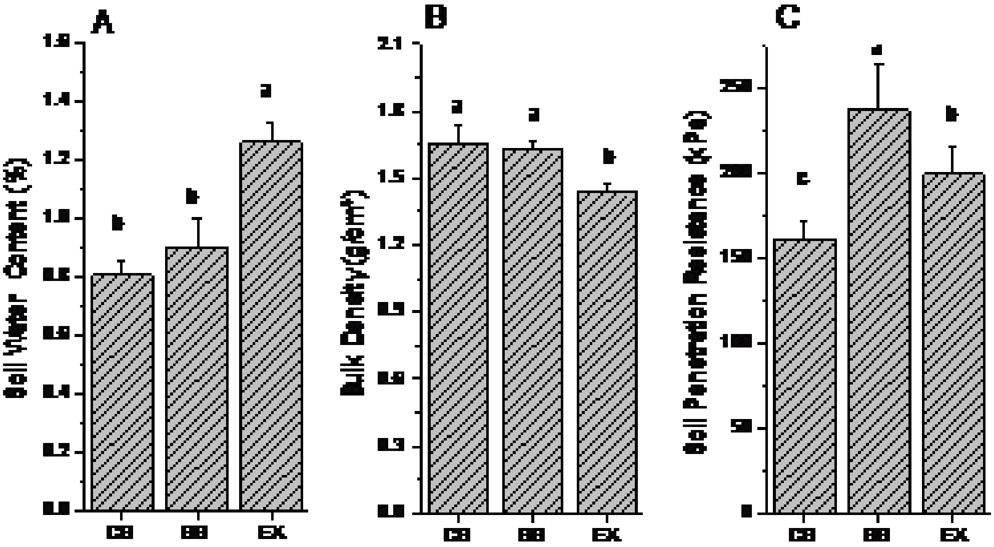

Figure 5. Soil physical properties for continuous grazing (CG), grazing exclusion (EX) and seasonal grazing (SG) treatments: (A) soil water content; (B) bulk density; and (C) resistance to penetration. Different letters above histograms among different treatment represent significant differences at P<0.05.