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Floristic compositions of Inner Mongolian grasslands under different land-use conditions

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Abstract

The severe degradation of grasslands caused by overgrazing and other diverse human operations has become widespread in Inner Mongolia, China. In this study, the vegetations of several grasslands under different land-use conditions were compared to examine the relationships between the vegetation and the disturbance of the grassland. Floristic and life-form compositions of the stands representing the six different sites were researched by the quadrat method: a non-grazed grassland (G1), a lightly grazed grassland (G2), a path (P), an abandoned field (AF) and two artificial meadows (M1 and M2). P, AF, M1 and M2 were located in a part of the grazed grassland. AF, M1 and M2 had been tilled when planted. The dominant species found in G1 and G2 were *Potentilla fragarioides*, *Poa annua*, and *Cleistogenes squarrosa*. *Artemisia annua*, *Chenopodium album*, *Cannabis sativa* f. *ruderalis* and *Calystegia hederacea* were found in P and AF, being scarce in the grassland areas. *Amaranthus retroflexus*, *Kochia scoparia* and *Setaria viridis*, which are cosmopolitan weeds, were dominant only in AF. *Leymus chinensis*, *Agropyron cristatum*, *Potentilla bifurca*, and *Potentilla tanacetifolia* were widely observed across all the surveyed sites. The land-use change from grassland to path caused a decrease of perennial species and an invasion of annual species by heavy trampling. A similar vegetational change occurred with the land-use change from grassland to abandoned field due to the destruction of original vegetation by tillage. Human disturbance such as tillage and trampling also resulted in a decrease in the species with the tufted- and branched-form and an increase in the species with the erect-form. Tillage could produce a more serious impact on the grassland vegetation as compared to grazing.

Introduction

Grassland in Inner Mongolia, China, is a part of the steppe distributed across the cool temperate region that receives extremely low annual precipitations (50–500 mm). It covers approximately 68 Mha, accounting for 70% of the total land area of the province (Zhanbula *et al.* 2004). Based on the vegetation and the amount of precipitation, the Inner Mongolian grassland is classified into “meadow”, “typical”, and “desert” steppes.

The grassland vegetation mainly comprises perennial grass species such as *Leymus chinensis* L. (*Aneurolepidium chinense* [Trin.] Kitag.), *Agropyron cristatum* (L.) Gaertn, *Stipa* spp., and *Cleistogenes squarrosa* (Trin.) Keng, and also includes some dicots such as *Potentilla* spp. (Rosaceae), *Artemisia* spp. (Asteraceae) and leguminous species. Most of them are used as good-quality fodder for grazing animals, however, they provide fodder sufficient for only 4–5 months for grazing animals due to the short growing period (China Agricultural University 2004). The annual production of the steppes is as low as 1 t ha^{-1}; this is lower than the 2.5 t ha^{-1} of the prairie grassland (Okubo *et al.* 1990).

Despite the numerous efforts to arrest land desertification, grassland degradation is advancing over wide areas in China through overgrazing, cropland misuse and unregulated collection of fuel and medical plants (Akiyama & Kawamura 2007), leading to the quantitative and qualitative changes in vegetation. The floristic composition has been changing in large areas of the Inner Mongolian grassland. This is probably due to increased feeding and trampling by grazing animals, and also due to cultivation for the conversion to meadows, or other operations in the surrounding areas (Ito *et al.* 2006). The degeneration of vegetation caused by overgrazing is the most serious problem in the Inner Mongolian grassland that has intrinsically low productivity. In addition to overgrazing, land-uses such as traffic and cultivation have recently caused vegetation changes in Inner Mongolian grassland (Ito *et al.* 2006).

To date, a number of studies have reported the effects of overgrazing on the vegetation changes in the Inner Mongolia grasslands (Wang & Earle 1997; Kawanabe *et al.* 1998; Wuyunna *et al.* 1999; Nakamura *et al.* 2000; Yiruhan *et al.* 2001; Chen *et al.* 2004; Li & Yang 2004). Wang *et al.* (2006) demonstrated that both climate changes and human activities, such as the increases in the arable land area, the number of livestock and human population, have promoted desertification in semiarid regions of China over the past 50 years. However, there is limited information regarding the vegetation changes caused by the land-use other than grazing and it is also unknown whether grazing and other human disturbances exert similar influences.

In this study, we investigated the vegetation of several Inner Mongolian grasslands under different land-use conditions and compared them in terms of floristic and life-form compositions. The aim of the study was to obtain some information on the relationships between the vegetation and the human disturbance in the region.

Materials and methods

The study was performed in July 2005 in Hailaer District, Hulunbeir (49°20′N, 119°59′E). The surveyed grassland was the meadow steppe that was covered with taller and more productive grasses and herbs as compared to the other steppes. The mean annual temperature and annual precipitation of the area are –1.2°C and 370 mm (mostly in summer), respectively. The growing period of grasses is 5 months from mid-April to mid-September, when the land is not covered with snow. The soil of the surveyed area is classified as dark chestnut according to the Chinese classification system (National Soil Investigation Office 1998).

The following six study sites were chosen:

G1, grassland: no grazing. Mowed once at the end of every August. A research plot (1000 m^2) was set up in a 300-ha grassland.

G2, grassland: lightly grazed by cattle and sheep, mowed at the end of every August, and also exposed to the trampling of humans and movements of farming machines to a limited extent. A research plot (1000 m^2) was set up in an 850-ha grassland.

P, path: originated as the results of the repeated movements of machines, humans, and livestock toward G2 site. This site borders with the grassland. A research plot (300 m^2) was set up in a 0.7-ha grassland.

AF, abandoned field: abandoned artificial meadow that had been used for cutting until several years ago. Cultivations were carried out several times in the past. After abandonment following the last use of cutting, the field received grazing by domestic animals and trampling by human. A research plot (300 m^2) was set up in a 2.7-ha grassland.

M1, alfalfa (*Medicago sativa* L.) meadow: artificial meadow cultivated with 4-year-old alfalfa plants. Alfalfa yield in 2005 was 1.5 t ha^{-1}. The disturbances were tillage once at the planting and also harvesting operation at the end of every August. A research plot (300 m^2) was set up in a 13-ha grassland.

M2, *Psathyrostachys juncea* (Fisch.) Nevski. meadow: artificial meadow cultivated with 2-year-old *P. juncea* plants. The disturbances were tillage once at the planting and also harvesting operations at the end of every August. A research plot (300 m^2) was set up in a 13-ha grassland.

The G2, P, AF, M1 and M2 sites were established in the Beishan Experiment Station of the Grassland Bureau in Hailaer District located at 10 km from Hailaer, while the location of the G1 site was further away from the city and 5 km distance from the other sites.

Twenty 4 m × 5 m (20 m^2) quadrats were randomly set in each of the G1 and G2 sites. Ten 2 m × 5 m (10 m^2) quadrats were set in each of the P, AF, M1 and M2 sites. The quadrat size was based on the results of our preliminary research on species–area curve. The coverage of each species that appeared in the quadrat was recorded using the Braun-Blanquet cover scale (Braun-Blanquet 1964). The frequency of the occurrence of each species was obtained as the percentage of the quadrats in which the species existed. In order to evaluate the significance of each species in the surveyed site, the Extended Summed Dominance Ratio (E-SDR_2; Yamamoto *et al.* 1995) was calculated using the values of coverage (C) and frequency (F):

$$\text{E-SDR}_2 = (C' + F')/2$$

where C′ and F′ are relative values in C and F against to the highest-scored species (C = 100, F = 100) at all sites, respectively.

To evaluate a floristic similarity (Goldsmith *et al.* 1986) among the sites, the Euclid distance was calculated using the E-SDR_2 for the score of each species:

$$D_{j.h.} = \sqrt{\sum_{i=1}^{n}(X_{ij} - X_{ih})^2}$$

where X_{ij} and X_{ih} are the score of the species i in site j and h, respectively, and n is the number of species.

Alfalfa (*M. sativa*) and *P. juncea* were not surveyed in this study because they covered almost the whole parts in the M1 and M2 sites, and consequently we omitted M1 and M2 sites in the E-SDR_2 and the Euclid distance calculations.

The species were identified according to the "Key to the Hulunbeir Plants" (Wang & Liu 1993) and the "Chinese Colored Weed Illustrated Book" (Chinese People's Republic Pesticide Part, Pesticide Official Approval Place and Japan

Plant Regulation Study Association 2000). The life forms of the species (Numata 1969) were also determined by referring to the latter book.

Results

A total of 62 species of 22 families were recorded. Species that were encountered in two or more surveyed sites out of the six (G1, G2, P, AF, M1 and M2) are listed in Table 1. *Potentilla fragarioides* L., *Poa annua* L. and *C. squarrosa* were the dominant species in the grassland areas (G1 and G2 sites). *Stipa baicalensis* Rosher. and *Carex* sp. were commonly dominant in the grassland areas and the path (P site), but their dominance in the non-grazed grassland (G1 site) was generally higher than in the path. *Corispermum* sp. was dominant in the P site and *Cannabis sativa* f. *ruderalis* (Janisch.) Chu, *Lappula myosotis* Moench, *Artemisia annua* L., *Chenopodium album* L. and *Calystegia hederacea* Wall. ex Roxb. were common throughout the path and the abandoned fields (P and AF sites) but were scarce in the grasslands. *Amaranthus retroflexus* L., *Kochia scoparia* (L.) Schrad., *Setaria viridis* (L.) Beauv., and *Polygonum bungeanum* Turcz. were dominant almost only in the abandoned fields (AF site). *L. chinensis*, *Artemisia scoparia* Waldst. et Kit., *A. cristatum*, *Serratula komarovii* Iljin., *Potentilla tanacetifolia* Willd. ex Schlecht. and *Potentilla bifurca* L. were widely distributed in the G1, G2, P and AF sites. The dominance of *L. chinensis* was higher in the grassland areas than in the other surveyed sites.

Table 2 shows the number of species by families in the six study sites. Comparing the two grassland sites, the total number of species was considerably higher in the lightly grazed grassland (G2 = 43) than in the non-grazed grassland (G1 = 22). Here, the Gramineae and Rosaceae species occupied the largest area, followed by the Compositae and Leguminosae species. The numbers of Compositae species were high in all the sites (Table 2), but the species differed among the sites. *A. annua* was the Compositae species that was observed only in the P and AF sites, whereas *A. scoparia* and *S. komarovii* were common to all the sites (Table 1). The Chenopodiaceae species were common in all the sites except for the G1 site (Table 2). The M1 and M2 sites showed the lowest total numbers of species (18–19).

The annual/perennial ratios and the life-form compositions of grasses as determined by the percentage of the number of species are shown in Table 3. From the grasslands to the abandoned field, the perennials decreased from 77% to 41%, and the annuals increased from 23% to 59%. Approximately in the same order, the species of the tufted- and branched-forms decreased from 27% to 15% and from 27% to 6%, respectively, while the species having the erect-forms increased from 18% to 44%. From the grasslands to the meadows (M1 and M2), the similar changes, i.e. the decrease of the perennial species and the branched-species and the increase of the annual species and the erect-species, were observed.

To compare the similarity of the floristic composition between the four sites (G1, G2, P and AF), we calculated the Euclid distances (Table 4) where smaller value indicates higher similarity between the two sites. The Euclid distance was relatively low between the G1 and G2 sites, while it was the highest between the grassland (G1 or G2) and the AF sites. Similar Euclid distances were observed between the P site and each of the other sites, indicating that the vegetation characteristics in the path were ranked between the grasslands and the abandoned field.

Discussion

Since the vegetation of the surveyed grasslands (G1 and G2) substantially showed the general features of a meadow steppe, the results obtained in this study might be applicable to most meadow steppes.

From the non-grazed grassland (G1), the grazed grassland (G2) and the path (P) to the cultivated fields (AF, M1 and M2 sites), the vegetation generally demonstrated the following cline: disappearance of species typical to the grassland and the appearance of weedy species (Table 1), a decrease in the Gramineae and the perennial species (Tables 2 and 3), and a decrease in the tufted- and branched-form species (Table 3). In the AF site, sown grasses seem to have disappeared, because all grasses found in the site have not been used as sown grasses in Inner Mongolia. The values of the Euclid distance between the sites (Table 4) also appear to support the vegetation shift of this direction.

Chen *et al.* (2004) reported indicator species as a criterion of grassland degradation caused by overgrazing in Inner Mongolia. As the degradation progresses, *L. chinensis* and *Stipa grandis*, which are dominant in healthy grasslands and palatable to livestock, decrease, being replaced by *Artemisia frigida* Willd. and *Potentilla acaulis* L. In our survey, *L. chinensis* and *S. baicalensis*, which are most preferred by grazing animals, were less dominant in the grazed grassland (G2 site) as compared to the non-grazed grassland (G1 site). All these shifts appear to be the results of selective feeding and the trampling pressure of livestock (Hayashi 2003).

In this survey, most of the dominant species in the abandoned field and the artificial meadows were scarce in the grassland areas. In addition, all the dominant species except *Sphallerocarpus gracilis* were classified as common weeds in crop fields (according to the "Chinese Colored Weed Illustrated Book"), including the four cosmopolitan weeds *C. album*, *S. viridis*, *A. retroflexus* and *K. scoparia.* In contrast, *A. frigida* and *P. acaulis*, which are common in the most severely degenerated grasslands as a result of grazing (Wuyunna *et al.* 1999; Chen *et al.* 2004), were not observed in this study.

Table 1 Extended Summed Dominance Ratio (E-SDR$_2$) values of the dominant species in the four sites under different land-use conditions

		Site			
Species†	Family	G1	G2	P	AF
Potentilla fragarioides	Rosaceae	67	26	5	
Poa annua	Gramineae	55	84	10	
Cleistogenes squarrosa	Gramineae	47	45		
Saposhnikovia divaricata	Umbelliferae	25	9	5	
Caragana sp.	Leguminosae	16	5		
Potentilla conferta	Rosaceae	8	32		
Melilotus suaveolens	Leguminosae	3	25		5
Phlomis umbrosa	Labiatae		38		
Koeleria cristata	Gramineae		30		
Stipa baicalensis	Gramineae	75	34	42	
Carex sp.	Cyperaceae	53	42	32	
Potentilla nudicaulis	Rosaceae	25	51	15	
Allium ramosum	Liliaceae	25	24	10	
Potentilla multifida	Rosaceae	18	10	12	
Astragalus adsurgens	Leguminosae		42	15	
Corispermum sp.	Chenopodiaceae		15	59	
Cannabis sativa f. *ruderalis*	Moraceae			37	41
Lappula myosotis	Boraginaceae	3		36	5
Artemisia annua	Compositae			35	30
Chenopodium album	Chenopodiaceae		3	34	43
Calystegia hederacea	Convolvulaceae		15	20	33
Plantago depressa	Plantaginacae		3	19	10
Amaranthus retroflexus	Amaranthaceae			5	90
Kochia scoparia	Chenopodiaceae		8	5	77
Setaria viridis	Gramineae				66
Polygonum bungeanum	Polygonaceae				48
Salsola collina	Chenopodiaceae		3	15	17
Sphallerocarpus gracilis	Umbelliferae		3	10	10
Leymus chinensis	Gramineae	88	82	66	11
Artemisia scoparia	Compositae	58	44	47	49
Agropyron cristatum	Gramineae	10	47	34	5
Serratula komarovii	Compositae	8	5	26	5
Potentilla tanacetifolia	Rosaceae	3	5	25	5
Potentilla bifurca	Rosaceae		42	22	30
Others					
Potentilla longifolia	Rosaceae		30	10	
Vicia sp.	Leguminosae		5		21
Bromus inermis	Gramineae		3	10	
Geranium sp.	Geraniaceae		3		30
Portulaca oleracea	Portulacaceae			36	
Polygonum convolvulus	Polygonaceae			10	20
Eragrostis picosa	Gramineae				20

† Species dominant in two or more surveyed sites out of the six (G1, G2, P, AF, M1 and M2) are in the list. The numbers in the same box-frames show high dominance in the ranges of sites: grassland, grassland and path, path and abandoned field, abandoned field, all sites.

Table 2 Number of species† by families in the six sites under different land-use conditions

Family	Site G1 (10)‡	G2 (18)	P (17)	AF (13)	M1 (11)	M2 (10)
Gramineae	5	7	5	4	2	3†
Rosaceae	5	7	9	2	3	2
Compositae	4	4	4	6	3	4
Leguminosae	2	5	1	2	0†	2
Chenopodiaceae	0	4	4	3	5	2
Polygonaceae	0	0	1	3	1	1
Other families	6	16	12	7	5	4
Total	22	43	36	27	19	18

† The number except *Medicago sativa* and *Psathyrostachys juncea*.
‡ The number of families.

Table 3 Annual/perennial ratios and the life (growth) form compositions of grasses in the six sites under different land-use conditions

	Site G1	G2	P	AF	M1	M2
Annual and perennial ratio†						
Annual	23	33	42	59	56	44
Perennial	77	67	58	41	44	56
Growth form ratio‡						
E‡	18	30	36	44	47	39
T	27	21	17	15	11	22
B	27	16	21	6	11	6
Ps	16	10	14	15	13	14
Pr	7	8	4	6	8	8
R	5	9	5	7	5	0
L	0	6	3	7	5	11

† Ratios are expressed as the percentage of total number for each site.
‡ E, erect; T, tufted; B, branched; Ps, pseudo-rosette; Pr, partial rosette; R, rosette; L, liana.

Table 4 Euclid distance values indicating the similarity of vegetation between the four sites under different land-use conditions

Site	G1	G2	P
G2	128.1	–	–
P	157.6	162.2	–
AF	239.8	240.0	190.9

Weed is biologically defined as a species that grows entirely or predominantly in the habitats markedly disturbed by man (Ito 1993). It is therefore understandable that weedy species appeared only in the path and the cultivated fields (AF, M1 and M2 sites) and were dominant in the abandoned fields. Some previous studies reported that weedy species such as *C. album* and *S. viridis* appeared in some particularly heavily grazed grasslands, but they were not dominant (Kawanabe *et al.* 1998; Hayashi 2003). This indicates that disturbances such as trampling and tillage have a stronger impact on grassland vegetation than any overgrazing activities. Zhou (1987) pointed out that once the grassland soil was disturbed it took more than 10 years for the land to revert to an *S. grandis* dominated grassland.

The results of our study showed that trampling and tillage cause a greater change in the vegetation. As the disturbances occurring in the grassland have become more diverse and intensive, the criterion for grassland degradation should be extended to the areas that were disturbed due to human activity where the vegetation mainly comprises weeds. In addition, ecological indicators such as life-form compositions are useful because they are applicable to all types of vegetation.

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