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ORIGINAL ARTICLE

Phytosociological study of steppe vegetation in Mongolia

Yunxiang Cheng[1], Tsagaanbandiin Tsendeekhuu[2], Naidan Narantuya[3] and Toru Nakamura[1]

1 Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
2 Department of Botany, Faculty of Biology, National University of Mongolia, Ulaanbaatar, Mongolia
3 Institute of Botany, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

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Correspondence
Cheng Yunxiang, Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8572, Japan.
Email: yxchenge@yahoo.co.jp

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Abstract

Using phytosociological methods, vegetation data were collected from 144 stands in seven areas across approximately 800 km, covering a large proportion of the east–west axis of the Mongolian steppe. Detrended correspondence analysis (DCA) was used to identify trends within the complete set of vegetation data from all 144 stands. We recognized four phytosociological plant communities and seven lower units, among which three of the communities (the *Stipa baicalensis–Agropyron cristatum*, *Stipa grandis–Achnatherum sibiricum* and *Chamaerhodos erecta–Artemisia scoparia* communities) may be considered valuable additions to the current classification system of Mongolian steppe by Hilbig (1995). Three lower units of the *Stipa krylovii–Cleistogennes squarrosa* community were identical with associations described by Hilbig (1990), which named typical sub-association of *Cymbario dahuricae–Stipetum krylovii*, *Cymbario dahuricae–Stipetum krylovii* and *Amygdalo pedunculatae–Spriaeetum aquilegifolia*. The present floristic composition of the community types, which showed a high density of unpalatable species, suggests that intensive grazing has become a widespread problem across the entire Mongolian steppe. On the other hand, the first ordination axis of DCA was associated with land used for cultivation. The stands abandoned over 10 years had high scores on the first axis.

Introduction

Mongolia occupies an area of 1.6 million km^2 in Central Asia, comprising mountains, steppe and desert. The climate of most of the country is arid or semiarid. For more than 2000 years, human societies in Mongolia had been sustained by traditional, nomadic activities. However, the modes of production have been transformed since 1990, following the transition to a free-market economy (Bayasgalan *et al.* 2000; Chuluun & Ojima 2001). Livestock numbers have increased dramatically, from approximately 24.7 million heads in 1989 to approximately 33.6 million in 1999 (National Statistical Office – Mongolia 2003). Consequently, grassland ecosystems have been severely affected by overgrazing (Jigjidsuren & Johnson 2003), and more than 70% of the pastureland, which covers approximately 97.4% of Mongolia, is reported to have been degraded (United Nations Development Programme 2000). In addition, since the 1960s, increasing amounts of land have been caused under cultivation for wheat and fodder, and in 1990, 1.34 million ha were cultivated. This cultivation has caused severe surface soil losses as a result of wind erosion. A survey of arable land conducted from 1990–1993 found that 46.5% of the land examined was affected by erosion (Staalduinen & Werger 2005). Consequently, since the 1990s, cultivation has ceased in some areas (National Statistical Office – Mongolia 2003). Degradation of the soil and vegetation of abandoned croplands are further problems that are seriously affecting the steppe (Staalduinen & Werger 2005).

These changes are adversely affecting the entire steppe ecosystems (Ho 2001), and the changes in the abundance and composition of the vegetation are amongst the most important indicators of steppe degradation (Tong *et al.* 2004). Thus, there are particularly urgent needs to determine the species composition of vegetation in the Mongolian steppe, the extent of degradation and the effects of overgrazing and cultivation so that management measures can be developed to protect the ecosystems from degradation. Unfortunately, relatively little is known about the vegetation composition and dynamics of these ecosystems in a large-scale area. Of the three national-scale classifications of Mongolia's vegetation (Yunatov 1950; Ulziikhutag 1989; Hilbig 1995), only Hilbig (1995) was written in English and readily available to an international audience. His study, however, mainly concentrated on the west of Mongolian areas and thus failed to cover the whole steppe vegetation zone. Particularly, there is still a paucity of basic information about the vegetation that was present before the transition to a market economy, and the subsequent changes. On the other hand, we found no field studies that examined the cultivation influences on the composition of steppe vegetation in Mongolia. With a view to determine the species composition more comprehensively than has been previously attempted, we collected vegetation data in a more broad area of steppe zone and analyzed them using the Braun-Blanquet method (Braun-Blanquet 1964) in combination with a numerical technique (detrended correspondence analysis [DCA]). In this study, our specific objectives were: (i) to classify and describe plant communities of the Mongolian steppe including grazing area and abandoned croplands; and (ii) to assess the various impacts of environmental factors and human activities (grazing pressure and cultivation).

Materials and methods

Study areas

The study was carried out in seven areas (around the villages of Tumentsogt, Shandiin-Hooloi, Kherlenbayan-Ulaan and Baganuur, Hustai National Park, Hotont village and Chenkher) across approximately 800 km, covering a large proportion of the east–west axis of the Mongolian steppe (Figure 1). These areas were chosen as the ones considered representative for all steppe habitat types after being observed. General information of the study sites is presented in Table 1. At the Tumentsogt, Kherlenbayan-Ulaan and Baganuur study sites, quadrats were placed both in free-grazing and enclosed plots (ungrazed plots) to assess grazing impact. These enclosed stands were 100 m × 100 m at Tumentsogt, 170 m × 200 m at Kherlenbayan-Ulaan-1, 50 m × 50 m at Baganuur and Kherlenbayan-Ulaan-2, which had been enclosed for 6, 3, 3 and 3 years from grazing, respectively. To assess the impact of cultivation activities on vegetation, surveys were carried out in Shandiin-Hooloi-2, Kherlenbayan-Ulaan-3 and Chenkher lands where cultivation ceased 12, 14 and 14 years ago, respectively, then keeping grazing up till now.

Throughout Mongolia the climate is extremely continental, and the precipitation is low (ranging 181.3–280.4 mm year^{-1} at the study sites; mean values for 1995–2004, according to data provided by the Institute of Meteorology and Hydrology of Mongolia). The soils at all sites examined in this study are typical Kastanozems (Hilbig 1995; Dordschgotov 2003; Asano *et al.* 2007), and the natural vegetation at the sites is dominated by feather grass of the genus *Stipa* and wormwood (*Artemisia*) species, typical of steppe vegetation on such soils (Walter 1973). The landscape at the sites also has marked similarities to the steppe in Ukraine and Kazakhstan (Cheng & Nakamura 2006, 2007), notably in the scarcity of trees (which are unable to tolerate the conditions) and the importance of grasses in the vegetation (Walter 1973; Coupland 1992) (Figure 2). All of these features are characteristic of the steppe that covers vast areas of Mongolia, particularly the central and eastern regions.

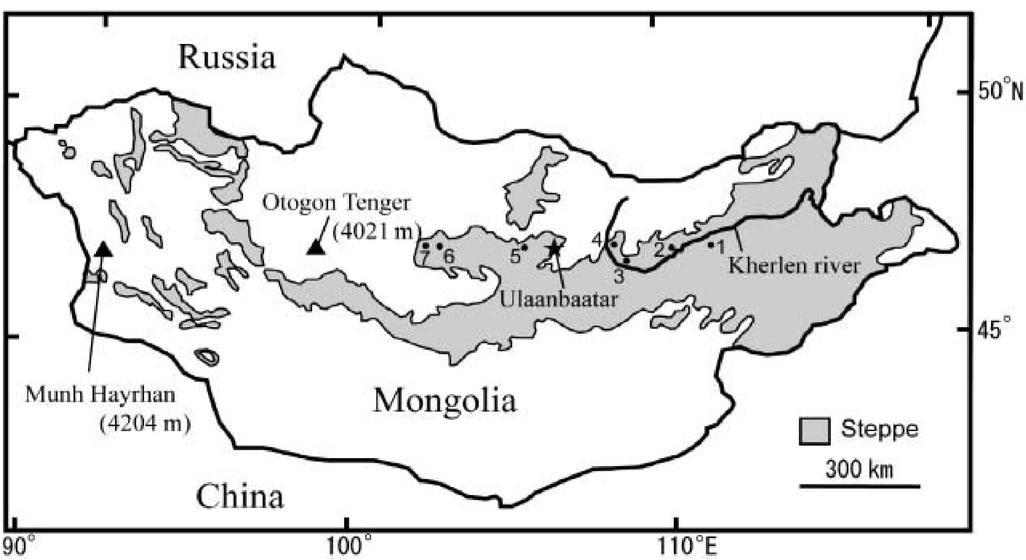

Figure 1 Map of the study area and the seven study sites: 1. Tumentsogt; 2. Shandiin-Hooloi; 3. Kherlenbayan-Ulaan; 4. Baganuur; 5. Hustai National Park; 6. Hotont; 7. Chenkher.

Table 1 Summary of the environmental data for the study sites

Study site	Subsite	Location		Altitude (m a.s.l.)	Mean air temperature (°C)*	Precipitation (mm)*	No. of quadrats	Land utilization history	Vegetation type
1. TMT		47°40′N	112°24′E	936–944	1.9	280.4	10	Free grazing	Ii
		47°40′N	112°24′E	997–1004	1.9	280.4	8	Enclosed for 6 years	Ii
2. SDH									
	SDH-1	47°31′N	110°56′E	1046–1084	−0.3	225.3	18	Free grazing	Iii-d
	SDH-2	47°27′N	110°53′E	1019–1046	−0.3	225.3	7	Abandoned field for 12 years	Iii-d; iv-e
3. KBU									
	KBU-1	47°12′N	108°44′E	1282–1283	0.7	181.3	5	Free grazing	Iii-b
		47°12′N	108°44′E	1253–1281	0.7	181.3	10	Enclosed for 3 years	Iii-b; iii-d
		47°12′N	108°44′E	1279–1280	0.7	181.3	5	Verges beside tracks	Iv-e;
	KBU-2	47°13′N	108°44′E	1345–1369	0.7	181.3	8	Free grazing	Iii-c
		47°13′N	108°44′E	1352–1364	0.7	181.3	7	Enclosed for 3 years	Iii-c
	KBU-3	47°12′N	108°41′E	1265–1290	0.7	181.3	11	Abandoned field for 14 years	Iv-g
4. BGN		47°40′N	108°29′E	1370–1418	−2.3	208.9	10	Free grazing	I
		47°40′N	108°29′E	1396–1427	−2.3	208.9	10	Enclosed for 3 years	I
5. HNP		47°39′N	105°58′E	1308–1415	0.2	270.0	10	Free grazing	Iii-b
6. HTT		47°23′N	102°22′E	1575–1644	1.9	185.9	15	Free grazing	Iii-a
7. CK		47°26′N	101°56′E	1556–1562	1.9	185.9	10	Abandoned field for 14 years	Iv-f

*Mean annual air temperature and annual precipitation obtained from the Institute of Meteorology & Hydrology of Mongolia (1995–2004). BGN, Baganuur; CK, Chenkher; HNP, Hustai National Park; HTT: Hotont; KBU, Kherlenbayan Ulaan; SDH, Shandiin-Hooloi; TMT, Tumentsogt.

Figure 2 Landscape of the *Stipa grandis–Achnatherum sibiricum* community in Tumentsogt site, dominated mainly by *Leymus chinensis, S. grandis and A. sibiricum*.

Vegetation survey

The vegetation was surveyed in 144 quadrats, ranging in size from 1.0–4.0 m^2; the areas sampled were relatively homogeneous and contained representative vegetation communities. The smallest area that should be sampled at each site was determined by the concept of species-area curve. Surveys were conducted during July and August 2005, according to the phytosociological methods of Braun-Blanquet (1964). The species composition of each stand was recorded, using Braun-Blanquet's cover-abundance scale, and plant communities were classified on the basis of their differential species (Braun-Blanquet 1964; Mueller-Dombois & Ellenberg 1974). At each quadrat, the altitude, direction and inclination of slope, maximum plant height and the extent of vegetation cover were recorded. Soil hardness in each quadrat was measured by Yamanaka type penetrometer. Nomenclature follows Grubov (1982). The plant life forms were classified according to Ma (1989, 1990, 1993, 1994, 1998).

Statistical analysis

Detrended correspondence analysis (Hill 1979) was used to identify trends within the complete set of vegetation data from all 144 stands. Ordination diagrams were plotted for the first and second axes; in all cases these had considerably higher eigenvalues than the lower order axes. Mann–Whitney's *U*-test was used to test for statistically significant differences in plant height, total vegetation cover and soil hardness of each quadrat between free-grazing plots and enclosed plots of each site (Tumentsogt, Baganuur, Kherlenbayan-Ulaan-1 and Kherlenbayan-Ulaan-2).

Results

Phytosociological description

The areas of Mongolian steppe examined were dominated by feather grass of the genus *Stipa*. *Cleistogenes squarrosa*, *Artemisia* *frigida*, *Agropyron cristatum*, *Koeleria cristata* and *Carex duriuscula* were also common. Four main phytosociological plant communities were identified: *Stipa baicalensis–A. cristatum*, *Stipa grandis–Achnatherum sibiricum*, *Stipa krylovii–C. squarrosa* and *Chamaerhodos erecta–Artemisia scoparia* (Table 2). Further, the *S. krylovii–C. squarrosa* community was divided into four lower units: the *Artemisia glauca* lower unit; the *Artemisia adamsii* lower unit; the *Corispermum mongolicum* lower unit; and the typical lower unit. The *C. erecta–A. scoparia* community was divided into three lower units: the *C. squarrosa* lower unit; the *Elymus repens* lower unit; and the typical lower unit.

Stipa baicalensis–Agropyron cristatum community

The characteristic species of this community are *S. baicalensis, Veronica incana*, *Medicago falcata* and *Alyssum lenense*. It was found on mountain slopes at altitudes between 1370–1427 m a.s.l. The community was found in 20 localities, including 10 from free-grazing plots and 10 from enclosed plots, in the Baganuur site near the river Kherlen. Although species composition did not change clearly between free-grazing plots and plots enclosed from grazing for 3 years, the cover of *C. duriuscula* in the community increases near water resources, indicating that areas near sources of water have been intensively grazed (Hilbig 1995). The sites for this community are located in ecotone areas between mountain steppe and forest steppe (Hilbig 1995). The stony and rocky soils favor the dominant shrub species *Caragana pygmaea*, and the differential species *A. lenense*, while the differential species *S. baicalensis* and *V. incana* are usually present in mountain steppe vegetation (Ma 1989, 1990, 1993, 1994). We found no trees at these sites. The characteristics of the species mentioned indicate that the community belongs to a stony mountain steppe vegetation type. The community does not fit clearly into any of the steppe communities described by Hilbig (1990). Thus, we consider it to be a distinct vegetation type.

Stipa grandis–Achnatherum sibiricum community

This community is characterized by *S. grandis*, *A. sibiricum*, *Polygonum divaricatum*, *Ptilotrichum elongatum*, *Schizonepeta multifida* and *Saposhnikovia divaricata*. The community was recognized from 18 quadrats, all of which placed in Tumentsogt, which was on a relatively flat plain at altitudes ranging 936–1004 m a.s.l. In terms of general species composition, the community type does not fit clearly into any of the steppe communities listed by Hilbig (1995), but it closely resembles the *Anemarrhenetosum asphodeloides* sub-association of the *S. grandis–Artemisia commutata* association described by Nakamura *et al*. (1988) on the steppe of Inner Mongolia. In this study, *S. grandis–A. sibiricum* community was found in Undurhaan province (the most easterly of the study sites, Figure 1), which are beyond Hilbig's (1995) study areas and near the steppe of Inner Mongolia. The findings suggest that the *S. grandis–A. sibiricum* community may be a distinct vegetation type in Mongolia, but similar with Inner Mongolian type due to geographic distribution. In addition, the site is distant enough from villages and rivers for grazing to not be very intense.

Stipa krylovii–Cleistogenes squarrosa community

The community is mainly characterized by the species *S. krylovii*, *Caragana stenophylla* and *Saussurea salicifolia*. In this survey, the *S. krylovii–C. squarrosa* community was recognized at 78 localities in four sites, being the most widespread of those identified in our study. Within this community, four lower units were recognized.

The *A. glauca* lower unit is differentiated by *A. glauca* (wormwood), *Thermopsis lanceolata*, *Allium bidentatum*, *Cymbaria dahuricae*, *Gallium verum* and *Stellera chamaejasme*. This lower unit was found in the Hotont site, which is characterized by gently rolling hills with an altitudinal range of 1575–1644 m. The vegetation cover ranges 35–65%. Although the lower unit is similar, in some respects, to the *C. dahuricae–S. krylovii* association described by Hilbig (1990), species avoided by cattle such as *A. glauca*, *T. lanceolata* and *S. chamaejasme* were found in great abundance (Hilbig 1995), suggesting that the *A. glauca* lower unit is characteristic of overgrazing.

The *A. adamsii* lower unit is differentiated by *A. adamsii*, *Convolvulus ammannii* and *Kochia prostrata*. It was found mainly in the Kherlenbayan-Ulaan-1 subsite near the river Kherlen, and the Hustai site near the Tuul river, both of which range in altitude 1021–1403 m a.s.l. Due to the proximity of watercourses, the sites of this lower unit are intensively grazed by livestock. Overgrazing has led to degradation of vegetation cover (which was as low as 5% in several stands), increased erosion and the spread of resilient species, *C. duriuscula* and *C. squarrosa* in particular (Hilbig 1995; Wallis *et al*. 1996). In this study, *C. ammannii* and *A. frigida* were also found at high densities. The *A. adamsii* lower unit was also described by Hilbig and Knapp (1983) and Hilbig (1990) as a typical sub-association of the *C. dahuricae–S. krylovii* and by Wallis de Vries *et al*. (1996) as the *A. adamsii–S. krylovii* community.

The *C. mongolicum* lower unit was found on south-facing slopes with stony and rocky soils in the Kherlenbayan-Ulaan-2 subsite, where the altitudinal range was 1345–1369 m. The lower unit is differentiated by *C. mongolicum*, *Asparagus dahuricus*, *Lespedeza dahurica* and the shrub *Amygdalus pedunculata*. The total vegetation cover is very low (5–40%). Hilbig (1990) described this lower unit as *Amygdalo pedunculatae–Spriaeetum aquilegifolia*. It is considered to be a degraded form of the *Ulmus pumila* bush forest (*Spiraeo aquilegifoliae–Ulumetum pumilae*) (Hilbig & Knapp 1983; Hilbig 1987,

Table 2 Synthesis table of the steppe vegetation in Mongolia

I. *Stipa baicalensis – Agropyron cristatum* community
II. *Stipa grandis – Achnatherum sibiricum* community
III. *Stipa krylovii – Cleistogenes squarrosa* community
  A. *Artemisia glauca* lower unit
  B. *Artemisia adamsii* lower unit
  C. *Corispermum mongolicum* lower unit
  D. Typical lower unit
IV. *Chamaerhodos erecta – Artemisia scoparia* community
  E. *Cleistogenes squarrosa* lower unit
  F. *Elymus repens* lower unit
  G. Typical lower unit

Community type	I	II	III				IV		
			A	B	C	D	E	F	G
Number of stands	20	18	15	18	15	30	7	10	11
Mean of total number of species	18	19	17	12	12	9	8	7	4
Differential species of *Stipa baicalensis – Agropyron cristatum* community									
Stipa baicalensis	V	.	.	.	.	.	.	.	.
Veronica incana	IV	.	.	.	.	.	.	.	.
Medicago falcata	IV	+	.	.	.	II	.	.	.
Alyssum lenense	III	.	.	.	.	.	.	.	.
Spiraea aquilegifolia	II	.	.	.	.	.	.	.	.
Calamagrostis epigejos	II	.	.	.	.	.	.	.	.
Filifolium sibiricum	II	.	.	.	.	.	.	.	.
Differential species of *Stipa grandis – Achnatherum sibiricum* community									
Stipa grandis	r	V	.	.	.	.	.	.	.
Achnatherum sibiricum	.	V	.	.	.	.	.	.	.
Polygonum divaricatum	.	IV	.	.	I	.	.	.	.
Ptilotrichum elongatum	.	III	.	.	.	I	.	.	.
Schizonepeta multifida	.	IV	.	.	.	.	.	+	.
Saposhnikovia divaricata	.	IV	.	.	I	r	I	.	.
Leontopodium leontopodioides	.	II	.	.	.	.	.	.	.
Thalictrum squarrosum	.	II	.	.	.	.	.	.	.
Gypsophila davurica	.	II	.	.	.	.	.	.	.
Artemisia commutata	.	II	.	.	.	.	.	.	.
Astragalus tenuis	.	II	.	.	.	.	.	.	.
Chenopodium acuminatum	.	II	.	.	.	.	.	.	.
Allium mongolicum	.	II	.	.	.	.	.	.	.
Festuca lenensis	.	II	.	.	.	.	.	.	.
Differential species of *Stipa krylovii – Cleistogenes squarrosa* community									
Stipa krylovii	.	.	V	V	V	V	.	+	.
Caragana stenophylla	I	.	III	II	II	II	.	.	.
Saussurea salicifolia	I	I	III	.	V	+	.	.	.
Differential species of *Artemisia glauca* lower unit									
Artemisia glauca	.	.	V	.	.	.	.	.	.
Thermopsis lanceolata	r	.	IV	.	.	.	.	.	.
Allium bidentatum	.	.	V	I	.	.	.	.	.
Cymbaria dahurica	I	.	IV	II	I	r	.	.	.
Galium verum	.	II	III	.	.	r	.	.	.
Thalictrum minus	III	.	II	.	.	.	.	.	.
Stellera chamaejasme	II	.	III	.	.	.	.	.	.
Dianthus chinensis var. versicolor	I	.	II	.	.	.	.	.	.
Oxytropis sp.	.	.	III	.	.	.	.	.	.
Potentilla strigosa	.	.	II	.	.	.	.	.	.
Festuca ovina	.	.	II	.	.	.	.	.	.
Thalictrum alpinum	.	.	II	.	.	.	.	.	.

Community type	I	II	III				IV		
			A	B	C	D	E	F	G
Number of stands	20	18	15	18	15	30	7	10	11
Mean of total number of species	18	19	17	12	12	9	8	7	4
Kochia prostrata	r	II	.	III	I	+	.	.	.
Astragalus galactites	r	.	.	II	.	r	I	.	.
Oxytropis myriophylla	.	.	.	II	+	+	.	.	.
Differential species of *Corispermum mongolicum* lower unit									
Corispermum mongolicum	.	.	.	.	V	.	.	.	.
Asparagus dahuricus	.	I	.	.	V	r	.	.	.
Lespedeza dahurica	.	.	.	.	III	.	.	.	.
Amygdalus pedunculata	r	.	.	.	III	.	.	.	.
Polygala sibirica	.	+	+	.	II	.	.	.	.
Differential species of *Chamaerhodos erecta – Artemisia scoparia* community									
Chamaerhodos erecta	.	.	+	+	.	+	IV	IV	V
Artemisia scoparia	.	.	.	.	.	I	I	V	V
Differential species of *Cleistogenes squarrosa* lower unit									
Cleistogenes squarrosa	I	IV	II	V	III	V	V	.	.
Artemisia frigida	IV	V	V	IV	.	III	IV	.	.
Carex duriuscula	IV	III	V	IV	I	III	III	.	.
Poa botryoides	I	III	.	.	.	.	III	.	.
Leymus chinensis	II	IV	V	I	+	III	II	.	.
Ixeris chinensis var. graminifolia	.	.	.	+	.	+	III	.	.
Salsola collina	.	I	.	I	.	II	II	.	.
Differential species of *Elymus repens* lower unit									
Elymus repens	.	.	.	.	.	.	.	III	.
Artemisia sp.	I	.	.	.	.	.	.	IV	.
Cleistogenes kitagawai	.	.	.	.	.	.	.	IV	.
Chenopodium album	.	.	.	.	.	+	.	.	IV
Artemisia tanacetifolia	.	.	.	.	.	.	.	.	III
Companions									
Agropyron cristatum	IV	IV	+	III	IV	II	.	.	.
Koeleria cristata	IV	II	III	I	III	I	I	.	.
Caragana microphylla	II	IV	.	II	I	I	.	.	.
Haplophyllum dahuricum	III	IV	.	III	IV	II	.	.	.
Allium anisopodium	III	I	.	II	III	II	.	.	.
Potentilla bifurca	I	II	IV	III	.	II	III	II	IV
Caragana pygmaea	IV	.	.	II	.	II	.	.	.
Arenaria capillaris	III	.	IV	I	.	r	.	.	.
Sibbaldianthe adpressa	II	I	IV	II	.	+	I	.	.
Serratula centauroides	IV	V	II	+	.	.	.	.	.
Potentilla acaulis	III	IV	.	II	.	.	I	.	+
Iris flavissima	.	.	IV	.	III	.	.	.	.
Ptilotrichum canescens	.	.	III	II	I	+	.	.	.

Table 2 *Continued*

I. *Stipa baicalensis – Agropyron cristatum* community
III. *Stipa krylovii – Cleistogenes squarrosa* community
A. *Artemisia glauca* lower unit
B. *Artemisia adamsii* lower unit
C. *Corispermum mongolicum* lower unit
D. Typical lower unit

II. *Stipa grandis – Achnatherum sibiricum* community
IV. *Chamaerhodos erecta – Artemisia scoparia* community
E. *Cleistogenes squarrosa* lower unit
F. *Elymus repens* lower unit
G. Typical lower unit

Community type	I	II	III				IV		
			A	B	C	D	E	F	G
Number of stands	20	18	15	18	15	30	7	10	11
Mean of total number of species	18	19	17	12	12	9	8	7	4
Differiential species of *Artemisia adamsii* lower unit									
Artemisia adamsii	r	.	.	IV	.	I	III	.	II
Convolvulus ammannii	.	.	.	IV	II	r	.	.	.
Carex korshinskyi	II	I	.	.	.	.	.	II	.
Echinops latifolius	II	.	I	.	.	.	.	.	.
Medicago ruthenica	.	II	.	.	.	+	.	.	.
Artemisia dracunculus	.	.	I	.	.	.	.	.	.
Allium senescens	.	I	.	.	.	.	.	.	.
Rheum undulatum	II	+	.	.	.	.	.	.	.
Silene repens	I	.	I	.	.	r	I	+	.
Astragalus adsurgens	I	II	I	.	.	.	III	II	.
Thermopsis dahurica	+	+	.	.	.	.	.	.	.
Polygonum alopecuroides	II	.	.	.	.	.	.	.	.
Pulsatilla bungeana	II	I	.	.	.	I	.	.	.
Androsace incana	r	.	.	.	.	.	.	.	.
Carex sp.	+	.	.	.	.	.	.	.	.
Bupleurum bicaule	r	II	.	I	II	.	.	.	.
Saxifraga spinulosa	+	.	.	.	.	.	.	.	.
Phlomis tuberosa	r	.	.	.	.	.	.	.	.
Echinops gmelinii	I	.	.	.	.	.	.	.	.
Scabiosa sp.	I	.	.	.	.	.	.	.	.
Orostachys sp.	+	.	.	.	+	.	.	.	.
Sedum aizoon	r	.	.	.	.	.	.	.	.
Scabiosa comosa	+	.	.	.	.	.	.	.	.
Ephedra sinica	I	II	.	.	.	r	.	.	.
Alisma gramineum	r	.	.	.	.	.	.	.	.
Androsace fillformis	r	.	.	.	.	.	.	.	.
Iris sp.	+	.	.	.	+	.	.	.	.
Lappula myosotis	r	.	.	.	.	.	.	II	.
Linum sibiricum	r	.	.	.	.	.	.	.	.
Tragopogon sp.	r	.	.	.	.	.	.	.	.
Arctogeron gramineum	.	.	.	+	.	I	.	.	.
Thymus gobicus	+	+	.	.	.	I	.	.	.
Thalictrum petaloideum	+	.	.	.	.	.	.	.	.
Allium sp.	.	.	.	II	II	r	.	.	.
Achillea asiatica	r	.	.	.	.	.	.	.	.
Orostachys spinosa	I	.	.	.	.	.	.	.	.
Heteropappus hispidus	r	+	.	.	.	r	.	.	.

Community type	I	II	III				IV		
			A	B	C	D	E	F	G
Number of stands	20	18	15	18	15	30	7	10	11
Mean of total number of species	18	19	17	12	12	9	8	7	4
Stellaria dichotoma	.	.	.	II	.	II	II	.	.
Lappula semiglabra	.	I	.	.	.	.	.	.	.
Euphorbia discolor	.	I	.	.	.	.	.	.	.
Astragalus sp.	.	.	.	.	I	r	.	.	.
Potentilla tanacetifolia	.	I	+	I	.	.	I	I	+
Taraxacum leucanthum	.	.	.	.	.	.	I	.	.
Plantago depressa	.	.	.	+	.	r	I	.	.
Potentilla sericea	.	.	.	+	.	r	II	.	I
Dontostemon integrifolius	.	.	.	.	.	.	.	.	+
Potentilla multifida	.	+	.	.	.	r	.	.	.
Orostachys fimbriatus	.	I	.	.	.	.	.	.	.
Potentilla verticillaris	.	+	.	.	.	.	.	.	.
Scorzonera radiata	.	+	.	.	.	.	.	.	.
Spiraea dahurica	.	.	.	.	.	r	.	.	.
Potentilla leucophylla	.	.	.	.	.	r	.	.	.
Heteropappus altaicus	.	.	.	I	.	+	.	II	.
Plantago sp.	.	.	.	.	.	r	.	.	.
Oxytropis ambigua	.	.	.	.	.	+	I	.	.
Potentilla conferta	.	.	I	I	.	+	I	.	.
Achnatherum splendens	.	.	.	.	.	r	.	.	.
Cleistogenes songorica	.	.	.	.	.	.	.	I	.
Astragalus danicus	.	.	.	.	.	.	.	I	.
Taraxacum sp.	.	.	.	.	.	.	.	+	.
Saussurea amara	.	.	.	.	.	.	.	+	.
Polygonum sibiricum	.	.	+	.	.	.	.	+	.
Thalictrum contortum	.	.	I	.	.	.	.	.	.
Pedicularis flava	.	.	+	.	.	.	.	.	.
Inula britannica var. chinensis	.	.	+	.	.	.	.	.	.
Dracocephallum foetidum	.	.	+	.	.	.	.	.	.
Bupleurum sibiricum	.	.	+	.	.	.	.	.	.
Viola sp.	.	.	+	.	.	.	.	.	.
Ranunculus sp.	.	.	+	.	.	.	.	.	.
Poa sibirica	.	.	+	.	.	.	.	.	.
Stipa klemenzii	.	.	.	I	.	.	.	.	.
Iris tigridia	.	.	.	+	.	.	.	.	.
Limonium sp.	.	.	.	.	+	.	.	.	.
Orostachys malacophyllus	.	.	.	.	.	r	.	.	.

Constancy r-V, calculated by the appearance ratio for each species; V, 80.1–100% high constancy; IV, 60.1–80% moderately high constancy; III, 40.1–60% intermediate constancy; II, 20.1–40% low constancy; I, 10.1–20% very low constancy; +, 5.1–10% constancy (rare); r, up to 5% constancy (Braun-Blanquet 1964; Mueller-Dombois and Ellenberg 1974).

1990). However, we did not find *U. pumila*. Wallis de Vries *et al.* (1996) classified this lower unit as *Caryopteris mongholica–Amygdalus pedunculata* shrubland.

Additionally, the typical lower unit is characterized by the absence of the differential species of the other lower units, mentioned above, and was found in the Shandiin-Hooloi site and Kherlenbayan-Ulaan-1 subsite.

Chamaerhodos erecta–Artemisia scoparia community

The characteristic species of this community are the annuals *C. erecta* and *A. scoparia.* The community was found at 28 localities in three sites, all of which are either abandoned fields that had not been cultivated for 12–14 years, or verges beside tracks in the natural steppe. The abandoned fields are currently used for grazing.

This community could be further divided into three lower units. The first, described as the *Cleistogenes squarrosa* lower unit, is differentiated by the tussock grass *C. squarrosa*, *A. frigida* (sagebrush), *C. duriuscula*, *Poa botryoides* and *Ixeris chinensis* var. *graminifolia*. This lower unit was found on land in Shandiin-Hooloi-2 that had been abandoned for 12 years and the verges beside tracks in Kherlenbayan-Ulaan-1. The second, the *Elymus repens* lower unit, is differentiated by the rhizomatous grass *E. repens*, along with *Artemisia* sp. and *Cleistogenes kitagawai*, and was found on land that had been abandoned for 14 years in Chenkher. The third, the typical lower unit, is differentiated by the absence of the species mentioned above. This lower unit was recognized in fields of Kherlenbayan-Ulaan-3 that had been abandoned for 14 years. As shown in Table 2, very few species were found here; notable exceptions being the annual weeds *C. erecta*, *A. scoparia*, *Chenopodium album* and the common species *Potentilla bifurca*.

Although Hilbig (1990) described the species composition of arable fields and verges beside tracks, there have been no studies of abandoned fields in Mongolia. Thus, this is probably the first description of the *C. erecta–A. scoparia* community.

Human impacts on the steppe vegetation

Human activities including cultivation and grazing have negatively impacted on the Mongolian steppe. On the one hand, due to the impact of cultivation, the *C. erecta–A. scoparia* community characterized by annual grasses is recognized as a clearly distinct group (Table 2). As shown in Figure 3, the first axis obtained from the DCA has an eigenvalue of 0.687 and represents three groups obviously. In the *C. erecta–A. scoparia* community, the *C. squarrosa* lower unit is fairly close to the group uninfluenced from cultivation. However, the typical lower unit and the *E. repens* lower unit appeared as two isolated groups. These two lower units have high scores and are associated with land used for cultivation,

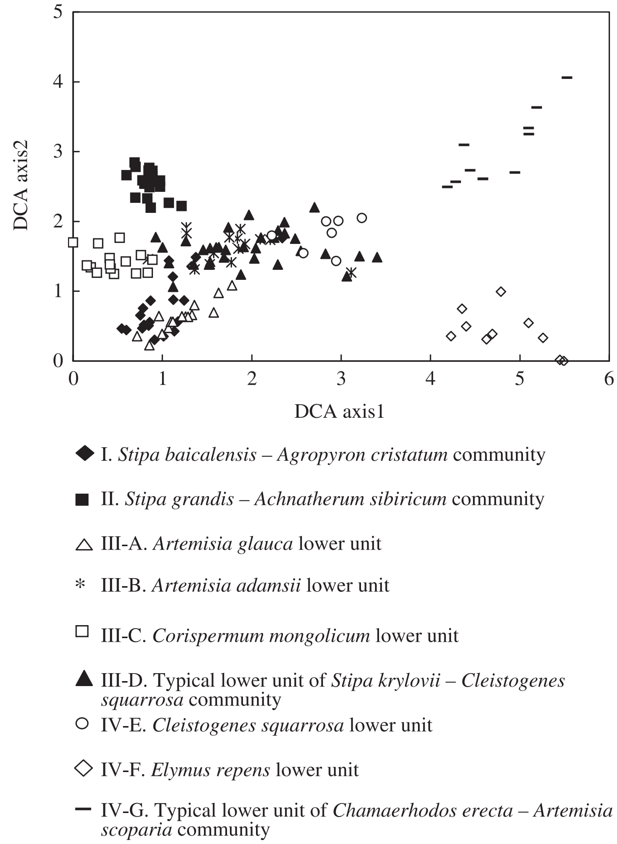

Figure 3 Ordination by detrended correspondence analysis of 144 surveyed stands from the steppe vegetation of Mongolia. Eigenvalue for axis 1 and axis 2 was 0.687 and 0.477, respectively.

as suggested in Table 2. The second axis has an eigenvalue of 0.477 and does not show a clear trend in species composition. On the other hand, the vegetation type is shown same between free-grazing and enclosed plots in each corresponding site (Table 1 and Table 2), which indicates grazing impact is not apparent on floristic composition in this study. However, the total vegetation cover and plant height in the unenclosed plots showed lower than those of the enclosed plots (Mann–Whitney's U-test, $P < 0.01$) (Table 3). Significant differences in soil hardness (Mann–Whitney's U-test, $P < 0.05$) between the enclosed and the unenclosed plots were observed only in the Kherlenbayan-Ulaan-2 study site. The results above indicated that soil hardness had changed obviously in a short enclosed time, while vegetation recovery was apparently showed in vegetation cover and plant height.

Discussion and conclusion

Hilbig (1995) provided the most extensive description of Mongolian plant communities. Fifty-four of these communities were described sufficiently by their habitats, however, further researches have been needed for more

Table 3 Plant height, total vegetation cover and soil hardness of the enclosed and unenclosed plots in each research site

	Study site	Plant height (cm)	Total cover (%)	Soil hardness
TMT	Enclosed for 6 years	50.5 ± 9.1**	67.5 ± 10.8**	11.1 ± 1.7
	Unenclosed	33.5 ± 6.5	45.0 ± 7.5	10.1 ± 1.4
BGN	Enclosed for 3 years	50.6 ± 9.5	81.1 ± 5.7**	15.5 ± 1.7
	Unenclosed	36.5 ± 1.6	52.0 ± 14.0	13.3 ± 2.8
KBU-1	Enclosed for 3 years	38.8 ± 7.8*	63.3 ± 9.4**	14.4 ± 2.3
	Unenclosed	27.5 ± 4.3	7.2 ± 1.9	16.0 ± 1.4
KBU-2	Enclosed for 3 years	31.7 ± 10.7**	34.0 ± 4.9**	12.3 ± 1.4*
	Unenclosed	9.3 ± 1.7	9.8 ± 6.2	15.0 ± 2.1

Values are mean ± standard deviation. *$P < 0.05$; **$P < 0.01$ by Mann–Whitney's *U*-test. BGN, Baganuur; KBU, Kherlenbayan Ulaan; TMT, Tumentsogt.

complete classification of the Mongolian steppe. In addition, vegetation composition may have been changed greatly by the effects of overgrazing and cultivation even in the same area with the passage of time. In this study, we recognized four phytosociological plant communities and seven lower units in the Mongolian steppe, and their description (together with associated observations regarding the impact of human activities) will contribute to a better understanding of the steppe. Three lower units of the *S. krylovii–C. squarrosa* community were identical with associations described by Hilbig (1990), which named the typical sub-association of *C. dahuricae–S. krylovii, C. dahuricae–S. krylovii* and *A. pedunculatae–S. aquilegifolia*. Three of the communities (*S. baicalensis–A. cristatum, S. grandis–A. sibiricum* and *C. erecta–A. scoparia* communities) may be considered valuable additions to the current classification system of Mongolian steppe by Hilbig (1995).

The *S. baicalensis–A. cristatum* community was recognized as the only mountain steppe type in this study. This community does not fit clearly into any of the steppe communities described by Hilbig (1990). Nakamura *et al*. (1988) has classified *S. baicalensis–Carex pediformis* association as a meadow steppe type in Inner Mongolia. We compared the two communities, and found they had little similarity on species composition except for the common character species of *S. baicalensis*. The *S. baicalensis–A. cristatum* community was found in ecotone areas containing mosaics of mountain steppe and forest steppe, thus a unique species composition of the community formed under the peculiar environment.

In addition, the *S. grandis–A. sibiricum* community is tentatively described as a new vegetation type in Mongolian steppe. Its general species composition can be related to the *Poo attenuatae–Stipetum grandis* association described by Hilbig (1995). However, those dominant and character species of the *P. attenuatae–Stipetum grandis* association, such as *S. krylovii, Poa attenuata* and *Carex korshinskyi*, do not or scarcely occur at all in the *S. grandis–A. sibiricum* community. This suggests that the *S. grandis–A. sibiricum* community is a different vegetation type or perhaps present as a new lower unit of the *Poo attenuatae–Stipetum grandis* association.

Degradation caused by livestock grazing is a critical problem, especially near towns and watercourses (Reading *et al*. 2006). The present floristic composition of the community types (Table 2) suggests that intensive grazing has become a widespread problem across the entire Mongolian steppe. This is indicated particularly by the high density of *C. duriuscula* in the mountain steppe of *S. baicalensis–A. cristatum* community. In addition, there are abundant unpalatable species (*A. glauca, T. lanceolata, S. chamaejasme* and *A. adamsii*), resilient monocots (*C. duriuscula* and *C. squarrosa*) and prostrate forbs (*A. adamsii, C. ammannii* and *A. frigida*) in the *S. krylovii–C. squarrosa* community. Although species composition did not change clearly between free-grazing plot and enclosed plot at the same site (Table 2), the vegetation cover and plant height have obviously decreased (Table 3). The result indicated that vegetation characteristic had been influenced seriously by grazing even in a short period.

Previous studies of the Inner Mongolian steppe have identified three main phases of succession in abandoned fields. Annual weeds dominate for the first to third years, after which rhizomatous grasses become dominant over the following 5 years, then tussock grasses become dominant over the next 15 years (Li & Xu 2002; Xu *et al*. 2002). In our study, these phases corresponded to the following lower units: the typical lower unit of the *C. erecta–A. scoparia* community, dominated by the annual species *C. erecta* and *A. scoparia*; the *E. repens* lower unit, dominated by the rhizomatous grass *E. repens*; and the *C. squarrosa* lower unit dominated by tussock grasses, respectively. There were minor differences, however, only in the time since the fields we surveyed were abandoned (12–14 years). In terms of dominant species, the succession phase of the typical and *E. repens* lower unit did not follow the previous studies by Li and Xu (2002) and Xu *et al*. (2002). The findings suggest that grazing has seriously influenced the recovery of vegetation following the cessation of cultivation, and may even have changed the vegetation composition (Xu *et al*. 2002). Probably, succession in the typical and *E. repens* lower unit may have been delayed more than usual.

In arid and semiarid areas, the natural recovery of abandoned land is a long-term ecological process, which can be further delayed or impaired if other intensive disturbances occur (Zambel *et al*. 2000; Li & Xu 2002). All of the three lower units of the *C. erecta–A. scoparia* community were found in fields that had been abandoned for more than 10 years. This finding suggests that the formation of these lower units may be strongly influenced both by the time the land has been abandoned and by grazing activities. In particular, the vegetation recovery of the typical and *E. repens* lower units may have been delayed dramatically. Under these conditions, if the grazing activities continue, the steppe will be in danger of desertification (Zambel *et al*. 2000). Vegetation succession can be accelerated by artificial reseeding soon after fields have been abandoned (Li & Xu 2002). This may be most appropriate in areas of Mongolia suitable for the *C. erecta–A. scoparia* community. In addition, it may also be necessary to erect fences to exclude grazing animals and protect the vegetation.

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