Floristic Composition, Grazing Effects and Above-ground Plant Biomass in the Hulunbeier Grasslands of Inner Mongolia, China

Kawada, Kiyokazu[1†], Mayu Kurosu[2], Yunxiang Cheng[2‡], Tsagaanbandi Tsendeekhuu[3],
Wuyunna[4], Toru Nakamura[2] and Ichiroku Hayashi[5*]

[1]National Institute for Agro-Environmental Sciences, 313 Kannon-dai, Tsukuba, Ibaraki, Japan

[2]Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki, Japan

[3]Department of Botany, Faculty of Biology, National University of Mongolia, P. O. Box 767, Ulaanbaatar 46, Mongolia

[4]Department of Environmental Engineering, College of Life Science, Dalian Nationalities University

[5]173-5 Kosato, Ueda, Nagano, Japan, 386-0005

ABSTRACT: In order to assess the effect of grazing on grasslands using floristic composition, we studied the floristic composition and plant biomass of steppe vegetation in Hulunbeier, Inner Mongolia. The dominant species of the grasslands were *Stipa krylovii, Stipa grandis* and *Leymus chinensis*. Floristic composition changed according to grazing pressure, being light, heavy and moderate. Under heavy grazing conditions, the importance value of *P. acaulis, C. korshinskyi* and *Cleistogenes squarrosa* increased in the plant community. These species were indicators of heavily grazed stand. Plant biomass of the stands ranged within 11.6 g m^{-2} and 63.5 g m^{-2} and 69.5 g m^{-2} and 166.2 g m^{-2} to the west and east of Lake Hulun, respectively. These values are equivalent to ca. 450∼1,000 kg of atmospheric carbon per hector, which is retained within the stand during the summer season.

Key words: Floristic composition, Grassland, Inner Mongolia, Plant biomass

INTRODUCTION

The grasslands in eastern Inner Mongolia are located in the interior of Eurasian continent. Although land use in the area has historically been nomadic, there has been a shift among the nomadic people in the region toward permanent settlement. This shift in land use has had a marked impact on the grassland ecosystem of the region (Burensain 2001).

The relatively low population density in Hulunbeier has meant that, compared to other regions in Inner Mongolia, the grasslands in Hulunbeier have been reasonably well conserved (Zhou et al. 1995). Precipitation on the Hulunbeier grasslands increases from west to east because eastern Hulunbeier, which covered by forest steppe, is adjacent to the Da Hinggan Ling mountain range (Liu et al. 1994). Since floristic composition and plant biomass are markedly affected by precipitation, we examined the effects of grazing intensity on the grasslands in Hulunbeier from west to east in areas with different precipitation.

We have conducted an ecological study on the Mongolian steppe to determine how these grasslands could be utilized in a sustainable manner (Hayashi et al. 1988). Numerous studies have been conducted to date on degradation of the grassland in Xilingole, Keerqin sand-land and Hulunbeier in Inner Mongolia and Kazakhstan (Hayashi et al. 1988, 2006, 2008, Nakamura et al. 1988, Kawanabe et al. 1998, Wuyunna et al. 1999). In this study, we undertook a preliminary study on floristic composition and plant biomass of the grassland in the region. Floristic composition of the plant community indicates the stand quality under the environments of climatic change and human activities (Nakamura et al. 2000, Yiruhan et al. 2001).

The findings of the study could be applied to assessing the impact of both environmental conditions and grazing pressure on differences in floristic composition and plant biomass.
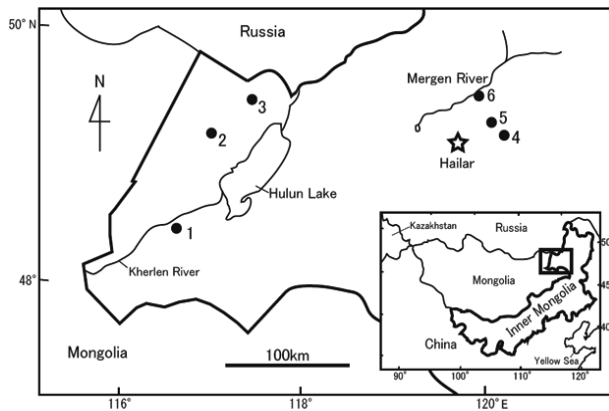
STUDY SITES AND METHODS

Study Sites

The study sites in Hulunbeier were located at a latitude of 48° 29'∼49° 34' N and a longitude of 116° 35'∼120° 12' E. We selected three study sites to the west of Lake Hulun side and three sites including three study stands of Ewenke Somu to the east of the lake (Fig. 1). At each site, samples were taken in areas consi-

---

1. Saihantala Somu, 2. Dalai Somu, 3. Aoerjin pasture in Manchuria,
4. Hake pasture in Hailar, 5. Xiertala pasture in Hailar, 6. Ewenke Somu

Fig. 1. Locations of study sites in Hulunbeier, Inner Mongolia. 1. Saihantala Somu, 2. Dalai Some, 3. Aoerjin pasture in Manchuria, 4. Hake pasture in Hailar, 5. Xiertala pasture in Hailar, 6. Ewenke Somu.

dered to be homogenous with respect to physiognomy. Measurements were carried out in an intensively grazed, lightly grazed and moderately grazed stands, which were assessed depending on vegetation coverage and plant height of the stands. In addition, we also collected data from a stand that was used for mowing to the east of the lake.

Study sites were selected after a preliminary survey of areas considered to be representative of the steppe environment in Hulunbeier, and were located at Saihantala Somu (Saihantala), Dalai Somu (Dalai), Aoerjin pasture in Manchuria (Aoerjin), Ewenke Somu (Ewenke 1, 2, 3), Xiertala pasture (Xiertala) in Hailar and Hake pasture in Hailar (Hake) (Fig. 2). In Ewenke around the Mergen Ri-

(a) Saihantala Somu   (b) Aoerjin pasture in Manchuria

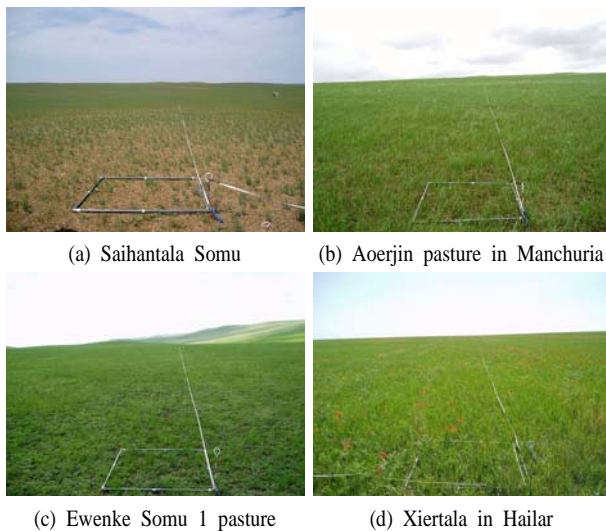(c) Ewenke Somu 1 pasture   (d) Xiertala in Hailar

Fig. 2. Landscape of study stands.

ver, three stands were studied along a gradient of pressure of grazing. Assessing the coverage of vegetation and floristic composition of the stands, the stands were designated as having been subjected to heavy, moderate and light grazing, which varied in response to their distance from the Mergen River which was used by livestock as a water source. Table 1 shows the characteristics of each of the study sites including location, precipitation and mean annual temperature. The stands were situated on a gently rolling plain ranging in altitude between 600 m and 749 m above sea level. The flora of the stands was considered typical for the steppe environment and was dominated by species belonging to the genus *Stipa*. The stands were used for livestock grazing and the soil type at the sites consisted of ksatanozem and chernozem soils. The mean annual temperatures and precipitation at these sites ranged between 0.9℃ and 225.4 mm at Saihantala and 0.2℃ and 317.0 mm in Hailar (Institute of Meteorology and Hydrology of Inner Mongolia 2006). The monthly change in temperature and precipitation in Hailar is shown in Fig. 3. The climatic regime of the region is favorable for plant growth because most of the rainfall occurs in summer. The study was conducted from 1 to 19 July 2006.

METHODS

We measured plant height and coverage for each species in five to ten 1 m^2 quadrats at intervals of 10 m along two transects set 10 m apart. After recording the species in the quadrat, we measured the height of the highest plant and the coverage of each species. Coverage was measured using the Penfound-Howard method modified by Numata (1987). Numata's summed dominance ratio (SDR) was determined from the measurements of plant height, coverage and occurrence frequency (Hayashi et al. 2006).

We obtained biomass data using direct measurements and an estimation technique using a numerical model. The aboveground plant biomass of the stands was determined by clipping the individual plants at the base and then assigning their species. Litter, including standing litter, in the stand was also collected. The aboveground plant biomass for each species was then weighed after drying for 24 hours in an oven at 80℃. In order to estimate the plant biomass in the stand without clipping plants, we determined the *v*-value proposed by Kawada et al. (2005). The *v*-value is derived by multiplying plant height (cm) by the coverage evaluated using Penfound-Howard-Numata criteria; the unit of the *v*-value is cm^3. In calculation, the coverage mentioned above was converted as follows: 4: 8,800 cm^2, 3: 6,300 cm^2, 2: 3,800 cm^2, 1:1,600 cm^2, 0.2: 300 cm^2 and 0.04: 50 cm^2 (Numata 1987). We derived an equation to show the relationship between plant biomass and the *v*-value. Using the equation we were able to estimate the plant biomass of

Table 1. Summarized information for the studied sites in the grasslands in Inner Mongolia

Study site number	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Study site	Saihantala Somu	Dalai Somu	Aoerjin pasture in Manchuria	Hake pasture in Hailar	Xiertala pasture in Hailar	Ewenke Somu 1	Ewenke Somu 2	Ewenke Somu 3
Latitude	48° 29' 24.9"	49° 14' 35.8"	49° 31' 16.5"	49° 15' 15.9"	49° 17' 39.5"	49° 34' 34.0"	49° 34' 25.1"	49° 34' 11.8"
Longitude	116° 35' 14.6"	116° 55' 26.6"	117° 20' 31.2"	120° 12' 50.6"	119° 58' 12.2"	119° 55' 38.1"	119° 55' 56.9"	119° 55' 43.0"
Altitude (m)	600	734	749	645	720	653	702	661.5
Slope (°)	4	0	3	13	0	6	4	3
Direction	NE	−	NW	NW	−	SW	SE	NW
Annual mean Temperature (℃)	0.9	0.4	0.4	0.2	0.2	0.2	0.2	0.2
Annual precipitation (mm)	225.4	196.6	196.6	317.0	317.0	317.0	317.0	317.0
Soil type	Kastanozem	Kastanozem	Kastanozem	Chernozem	Kastanozem	Kastanozem	Kastanozem	Kastanozem
Soil hardness (mm)	16.4	18.8	14.4	17.2	15.4	18.8	18.6	18.4
Soil moisture (%)	11.4	8.5	17.3	16.8	22.5	16.0	14.0	12.1
Date	02-Jul-10	03-Jul-10	05-Jul-10	09-Jul-10	13-Jul-10	17-Jul-10	19-Jul-10	20-Jul-10
Vegetation cover (%)	29.0	58.1	76.1	93.8	84.8	77.8	76.7	93.9
Source material	Loess	Loess	Loess	Loess	Loess	Loess	Loess	Loess
Dominant species	*Allium polyrhizum*	*Stipa krylovii*	*Leymus chinensis*	*L. chinensis*	*L. chinensis*	*S. krylovii*	*S. krylovii*	*S. krylovii*

*Temperature and prepicitation (2001∼2005) provided by the Institute of Meteorology and Hydrology of Inner Mongolia.
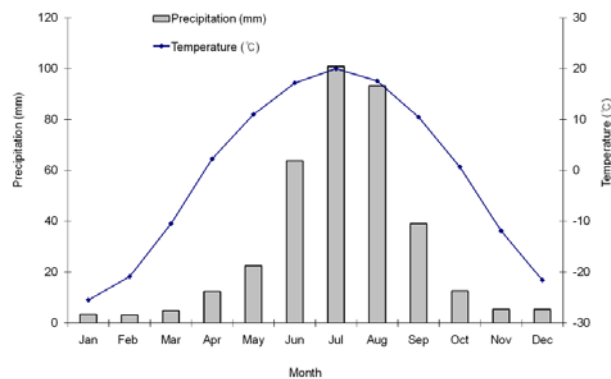

Fig. 3. Monthly change in temperature and precipitation in Hailar.

the stand without destroying the stands.

In studying the plant biomass of the grassland, we adopted following procedure: 1. The floristic composition of each stand was compared with a floristically homogeneous stand, (What classified was the stand using the floristic composition). 2. In classified stands, quadrat sampling and statistical analysis was undertaken. 3. The mean weight and variance of plant biomass per unit area was calculated with five replications (Huang et al. 2004).

The soil hardness and soil water content were measured using a Yamanaka-type penetrometer (Fujiwara Scientific Company) and a TDR (Time Domain Reflex) soil water meter (Fujiwara Scientific Company) with five replications.

RESULTS

Sample Size

Sample size versus cumulative percentage of newly recorded species in successive increases in the number of quadrats in the Mergen River stands is shown in Fig. 4. As shown in the figure, five quadrats were sufficient for including 95% of the species in the stand. The results were similar to those observed at the five other study sites.

Floristic Composition of the Stands

The floristic composition of the stands is given in Table 2 with Numata's summed dominance ratio (SDR). The stands were dominated by *S. krylovii* and *L. chinensis*. The total number of species
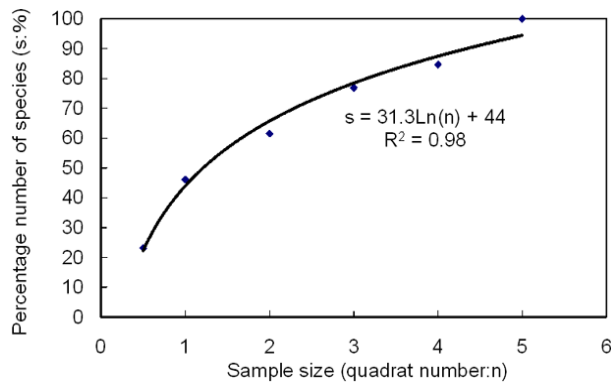
Fig. 4. Sample size versus cumulative percentage of newly recorded species in successively increasing number of quadrats.

at the eight sites was 99 including four unidentified species. The species recorded in all stands are shown in lines 1 to 6 in the table. The dominant species was *S. krylovii* and the stand included *L. chinensis*, *Allium tenuissimum*, *Carex korshinskyi*, *Cleistogenes squarrosa*, *Potentilla bifurca* and *Sibbaldia adpressa*. The species recorded exclusively in Saihantala (SHT) were *Allium polyrhizum*, *Euphorbia humifusa* and *Artemisia pectinata* listed in lines 12 to 14. The Saihantala site was the driest and most heavily grazed of all the study sites. *Allium bidentatum*, *Agropyron cristatum* and *Artemisia frigida* were recorded in Dalai (DL) and Ewenke (EWK). The species recorded in the stands from Dalai to Hake are listed in lines 15 to 24 of the table, while species distributed to the east of Ewenke are listed in lines 25 to 27 in the table. Species specific to each stand were listed in lines 28 to 59 and species with a random distribution at study sites are listed below line 60. The stands in Saihantala were dominated by *A. polyrhizum*, with 17 other species occurring in ten 1 m^2 quadrats. The mean plant height and coverage at this study site was 6.5 cm and 29%. *A. bidentatum*, *A. cristatum* and *A. frigida* were not recorded, although these species were observed in other stands.

The stands in Dalai were dominated by *S. krylovii* and *L. chinensis*, with *Chenopodium acuminatum* having a high ranking and *Caragana microphylla* being specific to the stand. The important species of the stands in Aoerjin were *L. chinensis, S. krylovii* and *C. korshinskyi,* all of which had high SDR values. In addition, *Bupleurum scorzonerifolium*, *A. anisopodium*, *Chenopodium aristatum* and *S. grandis* were observed in high frequency; the latter two species were only recorded in the stands at Aoerjin. In the three stands (Ewenke 1, Ewenke 2, and Ewenke 3) near the Mergen River, the dominant species was *S. krylovii*, with *Potentilla acaulis, Melilotoides ruthenica* and *Amblynotus rupestris*. The Ewenke-1 stand, which was closest to the river, was dominated by *P. acaulis* and *S. krylovii*, which formed two vertical layers in the stand. In

the Ewenke 2 and Ewenke 3 stands, *S. krylovii* was dominant and the SDR of *P. acaulis* was not high compared to the heavily grazed stands. The stand Ewenke 3 was lightly grazed and *S. krylovii* was dominant, with *A. cristatum*, *Poa pratensis* and *L. chinensis* also present. In the stands at Xiertala and Hake, *L. chinensis* was the dominant species. Many species characteristic of the forest steppe were recorded. In Xiertala, 47 species, the largest number of species recorded at any of the study sites, were recorded in six 1 m^2 quadrats. Mean vegetation height and coverage were 17.0 cm and 85%. *Pulsatilla tenuiloba*, *B. scorzonerifolium*, *P. pratensis*, *S. krylovii* and *C. korshinskyi* were high ranking species, and *L. pumilum* and *Veronica incana* were unique to the stand.

In the stand at Hake, 44 species were recorded in six quadrats of 1 m^2 and vegetation coverage was 94%. The mean vegetation height was 25.3 cm, which was the highest at any of the study sites. The dominant species was *L. chinensis* and *S. centauroides*, *B. inermis*, *Galium verum*, *Thalictrum squarrosum* and *C. pediformis* were all present with high SDR. *S. krylovii* had a relatively low SDR value.

In the Hulunbeier grasslands, *S. krylovii* and *L. chinensis* were the dominant species with the latter species increasing in light grazing stands. In stands subjected to under more severe and heavy grazing pressure, *S. krylovii and L. chinensis* was gradually replaced by *P. acaulis* and *A. polyrhizum.*

Floristic Composition of Heavily and Lightly Grazed Stands at the Mergen River Site

The floristic composition of the Mergen River stands exposed to light and heavy grazing is given in Table 3. In the lightly grazed stand, 39 species including three unidentified species were recorded in the five 1 m^2 quadrats. The stand was dominated by *S. krylovii* and included *L. chinensis*, *A. cristatum* and *P. pratensis,* the height and coverage of which were 30.3~50.4 cm and 94%, respectively. In the heavily grazed stand, 25 species were recorded in the ten 1 m^2 quadrats dominated by *S. krylovii.* The plant height of the dominant species and vegetation coverage were 40.2 cm and 78 %, and coverage by *P. acaulis* was large. The soil hardness and soil water contents were 18.4 mm and 12.1% in Ewenke 3 and 18.8 mm and 16.0% in Ewenke 1, respectively. The difference between water content at the sites was significant (Student *t*-test, <0.05). The mean height of the highest *S. krylovii* plants was 50.4 cm in the lightly grazed stand and 40.2 cm in the heavily grazed stand. The plant heights of *L. chinensis*, *A. cristatum* and *P. pratensis* in the lightly grazed stand at Ewenke 3 were 10 cm higher than the heights of the heavily grazed stand. The SDR of the above-mentioned species and *A. frigida* and *A. tenuissimum* decreased in response to grazing. Conversely, the SDRs of *P. acaulis, S. adpressa, S. centauroides, Silene repens* and *A. rupestris* all increased with grazing intensity.

Table 2. General floristic composition of the Hulunbeier grasslands

		Summed dominance ratio (SDR)							
	Species	Saihantala	Dalai	Aoerjin	Ewenke 1	Ewenke 2	Ewenke 3	Xiertala	Hake
1	*Stipa krylovii*	38.6	100.0	81.9	79.4	100.0	100.0	60.3	14.8
2	*Leymus chinensis*	48.5	89.4	100.0	47.2	30.7	59.2	100.0	97.0
3	*Allium tenuissimum*	14.5	55.4	52.7	18.3	38.8	38.0	42.8	17.9
4	*Carex korshinskyi*	71.3	48.3	68.1	41.8	50.2	44.1	63.7	48.7
5	*Cleistogenes squarrosa*	8.2	25.6	55.6	41.3	44.6	46.3	39.4	24.3
6	*Potentilla bifurca*	30.7	13.6	17.0	30.6	12.4	41.0	14.1	41.0
7	*Sibbaldia adpressa*	12.2	3.9	20.6	33.2	37.5	22.2	12.5	
8	*Salsola collina*	41.1	28.4	48.6				5.9	
9	*Chenopodium acuminatum*	15.4	70.4	42.5		20.5			14.2
10	*Caragana stenophylla*	26.4	14.3						
11	*Asparagus dauricus*	21.6	5.1						
12	*Allium polyrhizum*	100.0							
13	*Euphorbia humifusa*	36.7							
14	*Artemisia pectinata*	13.9							
15	*Allium bidentatum*		43.6	48.4	38.0	41.0	43.9	37.8	7.9
16	*Agropyron cristatum*		5.4	40.9	42.0	45.6	59.0	9.7	37.7
17	*Artemisia frigida*		4.6	37.4	3.6	47.5	49.7	40.9	15.5
18	*Bupleurum scorzonerifolium*		4.5	58.2		19.4	17.4	67.8	20.8
19	*Potentilla verticillaris*		4.0	42.1	7.5		7.7	19.6	20.7
20	*Melilotoides ruthenica*		7.7	16.9	40.0	39.5	44.8		
21	*Koeleria cristata*			39.9	26.9	12.4	40.4	48.3	22.8
22	*Potentilla acaulis*			11.9	69.9	39.2	46.9	29.9	6.8
23	*Serratula centauroides*			37.1	40.1	37.6	7.8		76.1
24	*Poa pratensis*			9.3	5.0		53.7	64.1	51.6
25	*Silene repens*				31.4	26.1	7.8	24.1	6.4
26	*Iris tigridia*				41.9	39.4	42.0	39.7	
27	*Amblynotus rupestris*				31.6	12.9	7.5		
28	*Caragana microphylla*		47.1	5.0					
29	*Saussurea salicifolia*		22.5	11.0					
30	*Haplophyllum dauricum*		9.4	11.6					
31	*Euphorbia esula*		4.9	27.3					
32	*Ptilotrichum tenuifolium*		4.3	21.4					
33	*Chenopodium aristatum*			59.6					
34	*Stipa grandis*			44.9					
35	*Festuca dahurica*			22.3					
36	*Silene jenisseensis*			16.3					
37	*Taraxacum dissectum*			11.9					
38	*Filifolium sibiricum*			11.0					
39	*Potentilla betonicaefolia*			9.9					
40	*Artemisia tanacetifolia*						16.8		
41	*Thymus serphyllum* var. *asiaticus*						7.4		
42	*Veronica incana*							43.5	
43	*Senecio kirilovii*							37.2	
44	*Vicia cracca*							28.3	
45	*Achnatherum sibiricum*							9.7	
46	*Artemisia dracunculus*							9.3	
47	*Sanguisorba officinalis*							8.3	
48	*Polygala tenuifolia*							7.9	
49	*Astragalus adsurgens*							7.7	
50	*Adenophora coronopifolia*							6.9	

Table 2. Continued.

	Species	Summed dominance ratio (SDR)							
		Saihantala	Dalai	Aoerjin	Ewenke 1	Ewenke 2	Ewenke 3	Xiertala	Hake
51	*Bromus inermis*								71.5
52	*Polygonum divaricatum*								39.4
53	*Vicia amoena*								31.6
54	*Stipa baicalensis*								20.2
55	*Polygonum convolvulus*								15.9
56	*Hemerocallis minor*								7.9
57	*Taraxacum mongolicum*								6.3
58	*Lappula ledowskii*								6.1
59	*Viola variegata*								5.9
60	*Scorzonera austriaca*	10.4	23.9	27.3			25.5	37.1	21.6
61	*Pulsatilla tenuiloba*			13.8			24.2	72.1	30.5
62	*Allium anisopodium*		5.7	57.0		13.5		9.0	
63	*Artemisia scoparia*					7.6	10.2	32.6	20.8
64	*Oxytropis myriophylla*			4.6			16.8	47.8	
65	*Heteropappus altaicus*				8.0		16.3	6.3	
66	*Astragalus melilotoides*			24.7				32.1	7.9
67	*Thalictrum squarrosum*			15.2				15.5	60.4
68	*Convolvulus ammannii*	18.9	37.7			26.8			
69	*Oxytropis hirta*		8.2		18.8	6.5			
70	*Cymbaria dahurica*		5.0	11.3				38.5	
71	*Galium verum*						24.2	46.2	62.9
72	*Schizonepeta multifida*						8.3	38.9	20.3
73	*Allium ramosum*	43.4		34.6					
74	*Saposhnikovia divaricata*			14.8				40.7	
75	*Iris lactea* var. *chinensis*			13.7					32.0
76	*Clematis hexapetala*			4.9					8.3
77	*Astragalus galactites*			21.5					6.3
78	*Thermopsis lanceolata*		8.1						6.7
79	*Potentilla tanacetifolia*						7.7		8.4
80	*Plantago depressa*						7.8		6.7
81	*Carex pediformis*							7.9	46.2
82	*Dianthus chinensis*							14.1	17.8
83	*Lilium pumilum*							51.0	10.9
84	*Adenophora stenanthina*							20.1	9.4
85	*Adenophora crispata*							17.7	6.3
86	*Chenopodium album*				3.8				
87	*Iris tenuifolia*		12.5						
88	*Taraxacum* sp.				13.9	17.5	7.3	23.6	
89	*Astragalus* sp.						7.3		
90	*Plantago* sp.				3.5	11.7			
91	*Oxytropis* sp.				7.3			33.9	
92	*Ixeris* sp.						15.9		
93	*Juncus* sp.						9.3		
94	*Chenopodium* sp.					12.4			
95	*Silene* sp.						8.2		
96	Unidentified species 1							6.3	
97	Unidentified species 2						9.0		
98	Unidentified species 3						7.9		
99	Unidentified species 4						8.1		
	Number of species	17	29	43	25	26	39	47	44

Table 3. Floristic composition of the light grazed and heavy grazed stands in Mergen River (MR3 and MR1) with SDR, mean height (H:cm) and mean cover (C)

Species	Light grazed stand (MR3)			Heavy grazed stand (MR1)		
	SDR	H	C*	SDR	H	C
Stipa krylovii	100.0	50.4	3.80	79.4	40.2	1.40
Leymus chinensis	59.2	32.2	0.52	47.2	16.0	0.07
Agropyron cristatum	59.0	34.0	0.36	42.0	9.6	0.09
Poa pratensis	53.7	30.3	0.04	5.0	20.0	0.04
Artemisia frigida	49.7	14.0	0.81	3.6	3.0	0.04
Potentilla acaulis	46.9	3.6	1.28	69.9	3.9	3.60
Cleistogenes squarrosa	46.3	14.9	0.36	41.3	7.1	0.23
Melilotoides ruthenica	44.8	13.4	0.30	40.0	6.2	0.17
Carex korshinskyi	44.1	14.0	0.17	41.8	9.7	0.06
Allium bidentatum	43.9	15.4	0.04	38.0	10.3	0.04
Iris tigridia	42.0	12.6	0.04	41.9	10.0	0.04
Potentilla bifurca	41.0	9.8	0.14	30.6	5.5	0.04
Koeleria cristata	40.4	9.8	0.07	26.9	5.7	0.04
Allium tenuissimum	38.0	20.9	0.04	18.3	14.8	0.04
Scorzonera austriaca	25.5	13.3	0.04			
Galium verum	24.2	10.0	0.04			
Pulsatila tenuiloba	24.2	10.0	0.04			
Sibbaldia adpressa	22.2	5.0	0.04	33.2	3.7	0.06
Bupleurum scorzonerifolium	17.4	14.8	0.04			
Artemisia tanacetifolia	16.8	10.5	0.20			
Oxytropis myriophylla	16.8	12.5	0.04			
Heteropappus altaicus	16.3	10.5	0.04	8.0	7.5	0.04
Ixeris sp.	15.9	9.0	0.04			
Artemisia scoparia	10.2	26.0	0.04			
Juncus sp.	9.3	19.0	0.04			
Schizonepeta multifida	8.3	10.0	0.20			
Silene sp.	8.2	11.0	0.04			
Serratula centauroides	7.8	8.0	0.04	40.1	7.1	0.10
Silene repens	7.8	8.0	0.04	31.4	5.9	0.12
Plantago depressa	7.8	8.0	0.04			
Potentilla verticillaris	7.7	7.5	0.04	7.5	4.5	0.04
Potentilla tanacetifolia	7.7	7.0	0.04			
Amblynotus rupestris	7.5	6.0	0.04	31.6	5.6	0.16
Thymus serphyllum var. *asiaticus*	7.4	5.0	0.04			
Taraxacum sp.	7.3	4.0	0.04	13.9	1.1	0.04
Astragalus sp.	7.3	4.0	0.04			
Oxytropis hirta				18.8	4.3	0.07
Oxytropis sp.				7.3	3.5	0.04
Chenopodium album				3.8	5.0	0.04
Plantago sp.				3.5	1.5	0.04
Unidentified species 1	9.0	17.0	0.04			
Unidentified species 3	8.1	10.0	0.04			
Unidentified species 2	7.9	9.0	0.04			
Number of species	39			25		

*Mean cover is evaluated as 4: > 75%, 3 : 74~50%, 2 : 49~25%, 1 : 24~5%, 0.2 : 4~1%, 0.04 : < 0.9%

The relative SDR of *C. squarrosa*, *C. korshinskyi, and Allium bidentatum* also increased by grazing.

Relationship between Species Rank and SDR

As described above, particular species combinations were observed in particular environmental conditions. Among the species examined, a relationship was observed between rank (*r*) and SDR in a stand. For example, the relationships between rank and SDR in the Manchuria stand is shown in Fig. 5. The relationship can be approximated using the following equation:

$$SDR = 90.5 \exp(-0.06\ r) \tag{1}$$

r: species rank in SDR.

The relationship was observed also in other study sites. The coefficient and exponent for each study site are given in Table 4. The exponents were −0.13 in Saihantala and −0.12 in Dalai and −0.06 in Aoerjin, Xiertala and Hake. The equation for each site was derived from five randomly selected quadrats. The intensively grazed stands were composed of a small number of species and the exponents are small. In the heavily grazed areas, the stands to the west of Lake Hulun had smaller exponents compared to sites in the east, implying that the stands to the west were grazed more intensively than the stands to the east. These empirical findings were corroborated in the field.

The Shannon-Weaver's index is also provided in the same table, and similar values were obtained in both the lightly and heavily grazed stands. The Shannon-Weaver's index was not sensitive to the degree of grazing pressure.

Plant Biomasses in the Stands

The relationship between *v*-value (*v*: × 100 cm^3) and plant biomass (*w*: g) in Aoerjin in Manchuria is shown in Fig. 6. The plant biomass in the stands was estimated using the equation showing the relationship between the *v*-value and plant biomass (Kawada et al. 2005, Hayashi et al. 2006). For example, the relationship between plant biomass (*w*) and *v* value in Aoerjin can be approximated as:
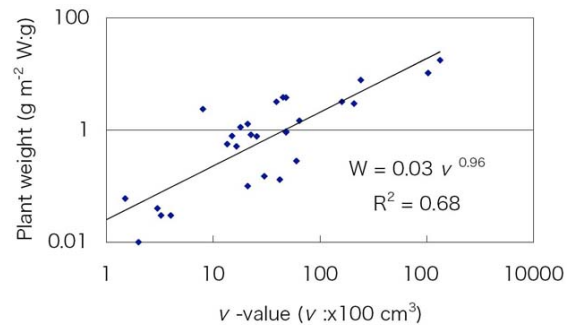
$$w = 0.03\ v^{0.96}\ (R^2 = 0.68) \tag{2}$$

Fig. 5. Relationship between species rank and summed dominance ratio (SDR) for each stand.

Fig. 6. Relationship between *v*-value of the species and plant weight.

Table 4. Coefficient and exponent of the equation SDR = a ∗ exp (b ∗ r), species richness (5 m^{-2}) and Shannon-Weaver's index (H')

		Species richness (5 m^{-2})	Coefficient (a)	Exponent (b)	R^2	H'
West	Saihantala	15	91.0	−0.13	0.90	1.24
	Dalai	24	93.6	−0.12	0.98	1.55
	Aoerjin	43	89.4	−0.06	0.99	2.07
East	Ewenke 1	21	84.0	−0.09	0.82	1.04
	Ewenke 2	24	86.1	−0.10	0.89	0.80
	Ewenke 3	39	76.6	−0.07	0.94	0.94
	Xiertala	47	99.6	−0.06	0.96	2.40
	Hake	43	76.5	−0.06	0.98	2.35

* These equations and species richnesses are calculated by randomly-selected five quadrats.

Once we obtained the coefficient and exponent, we are able to estimate the plant biomass in the stand without the need for destructive sampling in the stand; instead, all that was required was measurements of plant height and coverage. This enabled us to save time and labor measuring plant biomass, which is an important component of field surveys. Using equation (2), the measured and estimated plant biomass from the study sites could be calculated and shown in Table 5. The amount of plant litter and dung in the quadrat are also shown in the Table. The plant biomass values in stands to the west of Lake Hulun were 11.6 g m^{-2} in Saihantala, 28.0 g m^{-2} in Dalai and 63.5 g m^{-2} in Aoerjin. In the stands to the east of the lake, biomass values were 69.5 g m^{-2} in Ewenke-1, 111.2 g m^{-2} in Ewenke 2 and 120.1 g m^{-2} in Xiertala and Hake, values of 136.6 g m^{-2} and 166.2 g m^{-2} were recorded. The difference between measured and estimated values ranged between 1% and 29%. Increased grazing pressure decreased plant biomass within the stand and standard deviation decreased. Plant litter was 172 g m^{-2} in Xiertala, which was the largest of all of the study sites. Amount of livestock dung varied between stands, and was independent of grazing intensity.

To obtain the stand biomass as a whole, we used the relationship between the plant biomass (W) and V (cm^3) value, which is a product of vegetation coverage and plant height in the stand. The V value is separate from the v-value, which is a product of plant height and coverage of plant population for each species. Using the V-value, we were able to estimate stand biomass without measuring the weight of each species in the stand.

As shown in Fig. 7, this relationship could be approximated using the following equation:

$$W = 0.1\ V + 10.38 \qquad R^2 = 0.91 \qquad (3)$$

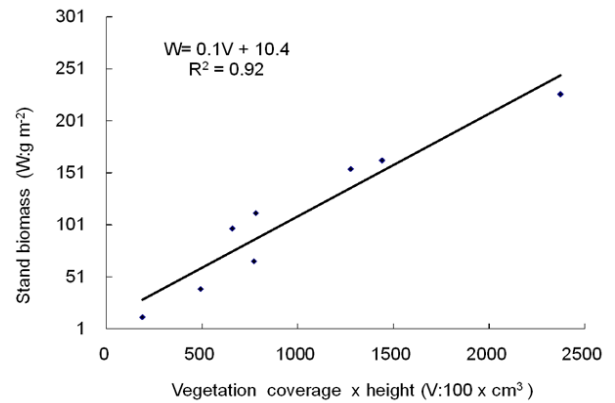where W (g): plant biomass of a stand, V (cm^3): product of the

Fig. 7. Relationship between the product of height and coverage (V: cm^3) and plant biomass (W: g m^{-2}) for each stand.

highest plant height and vegetation coverage.

Using equation (3), we were able to collect considerable amounts of data in the field, because time for measuring labor of biomass is saved. The plant biomass values estimated using equation (3) were 29.1 g m^{-2} in Saihantala, 59.6 g m^{-2} in Dalai, 87.5 g m^{-2} in Aoerjin, 247.6. g m^{-2} in Hake, 154.5 g m^{-2} in Xiertala, 76.2 g m^{-2} in Ewenke 1, 85.6 g m^{-2} in Ewenke 2 and 138.0 g m^{-2} in Ewenke 3.

DISCUSSION AND CONCLUSION

We described the floristic composition and biomass of stands in heavily and lightly grazed stands of grassland in Hulunbeier, Inner Mongolia. Even under the same stocking rates, stand quality was observed to vary between stands under different physical conditions such as precipitation and soil. Stand condition is thus determined by a combination of both physical and anthropological factors (Nakamura et al. 2000, Hilbig and Opp 2005). In this study, we

Table 5. The measured and estimated plant biomasses in the stands with standard deviation (S.D.)

		Plant biomass (g m^{-2})				Litter (g m^{-2})	Dung (g m^{-2})
		Measured (a)	Estimated (b)	S.D.	(a)−(b) / (a)		
West	Saihantala	12.3	11.6	2.5	0.05	3.8	8.7
	Dalai	39.2	28.0	7.0	0.29	17.8	29.6
	Aoerjin	65.9	63.5	11.8	0.04	31.4	26.6
East	Ewenke 1	97.4	69.5	14.9	0.29	16.4	9.2
	Ewenke 2	112.2	111.2	27.9	0.01	33.1	16.4
	Ewenke 3	154.7	120.1	15.9	0.22	100.4	4.1
	Xiertala	162.8	136.6	24.9	0.16	172.1	2.4
	Hake	226.5	166.2	65.9	0.27	64.0	5.6

used the floristic composition, which is thought an integrated indicator of physical and biological factors as criteria for assessing grazing intensity. However, these criteria vary depending on climatic conditions. For example, vegetation coverage is sparse in dryer areas such as areas without grazing in the vicinity of the Gobi desert (Sasaki et al. 2005). Therefore, the above-mentioned criteria can only be applied to stands subjected to the same climatic conditions. In addition, use of these criteria requires that we compare stands subjected to grazing with grazing-free stands.

The steppes in the Hulunbeier region vary from forested and meadow steppe to dry steppe from east to west according to precipitation. The amount of precipitation also affects species dominance, which changes from *L. chinensis* and *S. grandis* in the forest steppe/meadow steppe to *S. krylovii* in the dry steppe (Liu et al. 1994). It is necessary, therefore, to establish conserved sites to protect the natural steppe vegetation from grazing in each area. By protecting the natural vegetation from grazing, we will be able to evaluate whether grazing and whether sustainable use of the grasslands has been implemented.

In Saihantala, dominant species of the stand has been altered by grazing from *S. krylovii,* which is a dominant in Hulunbeier grasslands, to *Allium polyrhizum.* By comparing the floristic composition of stands to a protected stand, we are able to predict that the dominant species, *L. chinensis*, will be replaced by *S. krylovii* in the Mergen River stands under lightly grazed condition. However, in Xilingole, Inner Mongolia, *S. krylovii* has increased due to grazing in the grasslands (Nakamura et al. 1998, 2000, Wuyunna et al. 2004). This means that reaction of floristic composition to grazing intensity varies according to physical environmental conditions.

In these stands, grazing was observed to affect the growth-form spectrum in the stand (Nakamura et al. 2000). *P. acaulis*, which is classified as a prostrate-type species in the growth-form classification of plants, increased in heavily grazed stands. *C. squarrosa* and *C. korshinskyi* also increased in response to increased grazing pressure on the Hulunbeier steppe.

The situation on the grasslands was not only influenced by grazing intensity and precipitation, but also by cultivation on the steppes. For example, *B. inermis*, a species characteristic of arable land, occurred in stands which formed by soil deposits transported by wind from croplands elsewhere (Kawada and Nakamura 2003); the stand in Hake, in which *B. inermis* was observed, was surrounded by croplands.

Plant biomass is produced by the plant community, which is determined by physical and anthropological environmental conditions (Chi et al. 1986). In Hulunbeier, to the east of Lake Hulun, the biomass of plant masses measured 111.2 g m^{-2} in Ewenke 2 and 166.2 g m^{-2} in Hake, which is equivalent to 1～2 t ha^{-1} obtained

in Xilingole, Inner Mongolia (Xiao et al. 1996, Okamoto et al. 2000, Yiruhan et al. 2001). Liu et al. (1994) reported that the plant biomass in the Hulunbeier grasslands measured 156.8 g m^{-2} in *S. krylovii - C. squarrosa* stands 266.3 g m^{-2} in the *S. krylovii - L. chinensis* stands, which corroborated the findings of our study. Taken together, these findings indicate that the grassland ecosystems hold ca. 450～1,000 kg of atmospheric carbon per hector in summer. In addition, the steppe ecosystem is characterized as having a large amount of plant litter (Li et al. 2008). In Xiertala, the amount of plant litter measured 172 g m^{-2}, which is greater than that of living plants in the stand. This value is equivalent to 580 kg per hector of atmospheric carbon sequestrated from the atmosphere in the summer period. A portion of the plant litter is expected to be retained as soil organic matter after respiration by soil organisms. If grassland desertification occurs in the steppe region, the sequestrating mechanism of the grassland ecosystems will be lost.

ACKNOWLEDGEMENTS

LITERATURE CITED

Burensain B. 2001. Settlement, village formation and the desertification in Inner Mongolia: a case study of the Horchin Area. Journal of Arid Land Studies 11: 13-22. (in Japanese)

Chi Y, Li Y, Ling Y. 1986. Preliminary research of the quantitative relationship between the plant community aerial biomass and the water, temperature conditions in *Aneurolepidium chinense* steppe community. Research on Grassland Ecosystem 1: 24-37. (in Chinese)

Hayashi I, Kawada K, Akimova A, Nakamura T. 2006. Floristic composition and plant biomass of the grasslands in the vicinity of Pavlodar, Kazakhstan. Grassl Sci 52: 141-149.

Hayashi I, Jiang S, Nakamura T. 1988. Phytomass Production of Grasslands in Xilin River Basin, Xilingol, Inner Mongolia, China. Bull Sugadaira Montane Res Cen 9: 19-31.

HayashiI, Kawada K, Kurosu M, Batjargal A, Tsundeekhuu T, Nakamura T. 2008. Grazing effects on floristic composition and above ground plant biomass of the grasslands in the Northeastern Mongolian steppe. J Ecol Field Biol 31: 115-123.

Hilbig W, Opp C. 2005. The effect of anthropogenic impact on plant and soil cover in Mongolia. Erforsch Boil Ress Mongolei 9: 163-177.

Huang D, Shiyomi M, Chen J, Takahashi S, Hori Y, Yamamuru Y,

Wang Y. 2004. Spatial heterogeneity of vegetation in Inner Mongolia, China. Grassl Sci 50: 319-328.

Institute of Meteorology and Hydrology of Inner Mongolia 2006. Meteorological Data in Hailar, Inner Mongolia, China.

Kawada K, Nakamura T. 2003. Effects of Aeolian sandy soils on the floristic composition of grassland originate from crop field in semi-arid region under the strong wind condition. Journal of Arid Land Studies 13: 173-181. (in Japanese)

Kawada K, Vovk AG, Filatva OV, Araki M, Hayashi I. 2005. Floristic composition and plant biomass production of steppe communities in the vicinity of Kharkiv, Ukraine. Grassl Sci 51: 205-203.

Kawanabe S, Nan Y, Zhang S, Oshida T, Kou Z, Jiang D, Furuta M, Takada-Oikawa N. 1998. A change of vegetation and soil of the desertified grasslands on the process of recovery 2. At the sites of non-saline meadow and saline meadow. Grassl Sci 45: 149-156.

Li Y, Qingtao M, Xueyong Z, Jianyuan C. 2008. Relationship between fresh leaf traits and leaf litter decomposition of 20 plant species in Kerqin sandy land, China. Acta Ecologica Sinica 28: 2486-2492.

Liu X, Wei S, Zhang Y, Hu K, Guo X. 1994. The floristic constitution and vegetational characteristic study in Hulunbeier region. Acta Prataculturae Sinica 3: 32-40. (in Chinese)

Nakamura T, Go T, Li Y H., Hayashi I. 1998. Experimental study on the effects of grazing pressure on the floristic composition of a grassland of Baiyinxile, Xilingole, Inner Mongolia. Veg Sci 15: 139-145.

Nakamura T, Go T, Wuyunna, Hayashi I. 2000. Effects of grazing on the floristic composition of grasslands in Baiyinxile, Xilingole, Inner Mongolia. Grassl Sci 45: 342-350.

Nakamura T, Gong Y, Jiang S. 1988. A preliminary study on the classification of steppe vegetation using Braun-Blanquet's method in some areas of Xilin River Basin in Inner Mongolia. Bull Sugadaira Montane Res Cen 9: 9-17.

Numata M. 1987. Structure of plant community. In: Papers on Plant Ecology. Tokaidaigaku Shuppankai, Kanagawa, pp 50-167. (in Japanese).

Okamoto C, Nakamura M, Kabata K, Wang Y. 2000. Seasonal changes of the aboveground phytomass of a *Stipa baicalensis* community in Northeast China. Grassl Sci 46: 217-222.

Sasaki T, Okayasu T, Takeuchi K, Jamsran U, Jadambaa S. 2005. Patterns of floristic composition under different grazing intensities in Bulgan, South Gobi, Mongolia. Grassl Sci 51: 235-242.

Wuyunna, Cheng Y, Okamoto K, Taniyama I. 2004. Structural changes in steppe vegetation community according to grazing gradient in semiarid regions of Inner Mongolia, China. J JASS 20: 160-167. (in Japanese)

Wuyunna, Nakamura T, Hayashi I. 1999. Species diversity and phytomass of the grasslands in Inner Mongolia, China. Grassl Sci 45: 140-148. (in Japanese)

Xiao X, Jiang S, Wang Y, Ojima DS, Bonham CD. 1996. Temporal variation in aboveground biomass of *Leymus chinensis* steppe from species to community levels in the Xilin River Basin, Inner Mongolia, China. Vegetation 123: 1-12.

Yiruhan, Hayashi I, Nakamura T, Shiyomi M. 2001. Changes in floristic composition of grasslands according to grazing intensity in Inner Mongolia. China Grassl Sci 47: 362-369.

Zhou J, Otsuki K, Kamichika M. 1995. Changes of livestock farming in the Inner Mongolia of China. Journal of Arid Land Studies 5: 71-84. (in Japanese)