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Grazing Effects on Floristic Composition and Above Ground Plant Biomass of the Grasslands in the Northeastern Mongolian Steppes

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ABSTRACT: We describe plant biomass in the grasslands of the Mongolian steppe obtained using a quadrat sampling technique. Four sites were studied in the northeastern Mongolia located between 47°12'N and 47°40'N and 102°22'E and 112°24'E, which were typical grasslands of the steppe. Biomass, carbon and nitrogen content were determined for the plants collected from the grazed and ungarazed stands. With the measurements above, we expect to obtain information on grazing effects on the grasslands and carbon sequestration of the grassland from the air. In order to estimate the biomass without destroying the stands, we derived an equation to describe the relationship between plant biomass and *v*-value using plant height and species coverage within the stand. Estimated plant biomass in the ungrazed and grazed stands ranged between 108.0 g m^{-2} and 13.4 g m^{-2} and between 97.5 g m^{-2} and 14.1 g m^{-2} in late June 2005, respectively. Litter in the ungrazed and grazed stands ranged from 330.3 g m^{-2} to 78.4 g m^{-2} and from 188.0 g m^{-2} to 20.3 g m^{-2}, similarly. Average carbon and nitrogen contents in plants and in litter were 43.0% and 1.9% and 33.7% and 1.4%, respectively. In study sites at Baganuur, the carbon and nitrogen content of plant materials (plant plus litter) was 118.4 g m^{-2} and 4.7 g m^{-2} on 30 June 2005.

Key words: Mongolian steppes, Nitrogen and carbon contents, Plant biomass

INTRODUCTION

The article aims to describe effects of grazing on floristic composition and above-ground plant biomass in a grassland in the northeastern Mongolia.

The Mongolian steppes occupy approximately 150,000 km^2 of the Eurasian grasslands. The grassland ecosystem is characterized by extremely low winter temperatures, an arid climate, and as having human impacts such as grazing pressure. Recently, the grassland ecosystems of Mongolia have come under increased threat of degradation due to overgrazing by livestock (Gunin et al. 1999, Wuyunna et al. 2004, Hiblig and Opp 2005, Sasaki *et al.* 2005, Xie et al. 2007). The Mongolian grasslands are not only having an important in the raising livestock, but also for atmospheric carbon sequestration. Research regarding the proper use of grasslands is therefore important if the sustainability of the grasslands is to be increased.

In order to determine the amount of plant biomass, carbon and nitrogen contained within the Mongolian grassland, we measured the mass of plants in the stands of vegetation using the harvesting method. We also recorded the floristic composition using a quadrat sampling technique in the grazed and ungrazed stands. With the measurements above, we expect to obtain information on grazing effects on the grassland and carbon sequestration of the grassland from the air. Using information on floristic composition of the stand we are able to recognize the extent of regions applicable to a result of biomass study in a selected site. That is to say, the plant biomasses in the stands having similar floristic composition are similar in amount of biomass in each other (Cheng and Nakamura 2006, 2007).

Plant biomass production in a region has been determined using the following four methods: 1. Estimation by meteorological factors, such as temperature, precipitation and solar radiation, 2. Measurement by the eddy covariance technique (Kato et al. 2004), 3. Measurement by the remote sensing technique (Kawamura et al. 2003)

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and 4. Direct measurement of plants for each species within the stands (ecological measurement). In the present study, we employed the fourth technique for determination of biomass.

STUDY SITES AND METHODS

Study Sites

Study sites were selected after conducting surveys of large areas. The study sites were Hotont in Arkhangai Province (47°23'N, 102° 22'E), Baganuur in Ulaanbaatar Province (47°47'N, 108°29'E), Kherlenbayan-Ulaan (KBU) in Khentei Province (47°12'N, 108°41'E) and Tumentsogt in Sukhbaatar province (47°40'N, 112°24'E), which were typical steppe. These sites were located between 921 m and 1,580 m altitude on a gently rolling plain. The stand of KBU had a slant landform in small scale. We considered the KBU site to be a slant landform in the study area. The soil was chestnut soil and the vegetation of the area was typical of the steppe environment, being dominated by the genus of *Stipa.* The grasslands have traditionally been used for grazing. The study was conducted from 29 June to 6 July 2005. The mean growth period of the vegetation was 64 days (60~67 days), with plant growth considered to begin on 1 May.

According to the records of Institute of Meteorology and Hydrology (2005), the mean annual temperature and precipitation are as follows: 2.3℃ and 208.9 mm in Baganuur, 0.7℃ and 181.3 mm in KBU, 1.9℃ and 280 mm in Tumentsogt, and 1.9℃ and 185.9 mm in Hotont. The precipitation occurs primarily in the summer season.

Quadrat sampling was conducted in ungrazed stands enclosed by fences and grazed stands. The constructing dates and scale of the ungrazed stands were 50 m × 50 m in 2003 in Baganuur, 50 m × 50 m in 2002 in KBU, and 100 m × 100 m in 1999 in Tumentsogt. The season of construction the experimental stands was spring for each year. In Hotont, studies were conducted in grazed stands only.

Methods

We measured plant height and species coverage at five points within a 1-m^2 quadrat, in quadrats at 10 m intervals 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 using the Penfound-Howard method modified by Numata (1987). Numata's summed dominance ratio (SDR) was determined from the measures of plant height, coverage and frequency of occurrence. The aboveground plant biomass of the stands was determined by clipping the individual plant at the base and then assigning their species. Any litter in the stand, including standing litter, was collected. Aboveground plant biomass for each species was then weighed after drying for 24 hours in an oven at 80℃.

In order to estimate plant biomass in stand without the need for destructive sampling, we determined the *v*-value as proposed by Kawada et al. (2006). The *v*-value is a product of plant height (cm) and coverage of population of the species, which is evaluated using the criteria of Penfound-Howard-Numata (Numata 1987). The unit of measurement for the *v*-value is cm^3. To calculate in the same unit, the coverage of population of the species 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. We derived an equation of the relationship between the *v*-value and plant biomass. Using the equation, we are able to estimate the plant biomass of the stand without destructive sampling. In this study, we calculated the average biomass of five stands for each study site. The Student's t-test was used to calculate the correlation coefficient of the measured biomass values and those estimated using the equation. The difference between plant biomass in the grazed and ungrazed stands was then assessed using the Mann-Whitney U test.

In order to obtain preliminary information on weight ratio of above and below ground biomasses, we collected plants of *Artemisia scoparia* including the below ground parts of plant.

The nitrogen and carbon contents were determined using a Shimazu C-N analyzer. Carbon and nitrogen measurements were conducted in triplicate.

RESULTS

Dry : Fresh Weight Ratio of Plant Materials

The ratio of dry and fresh weights of the plants recorded at each study site are shown in Table 1. The mean ratio of dry weight to fresh weight of plants was 0.48. The figures varied among species, ranging from 0.81 in *Caragana stenophylla* to 0.14 in *Schizonepeta* 0.48 steppe plants in Inner Mongolia was 0.43. The fresh weight, dry weight and water content of the plant biomass from the stands are shown in Table 2. For the ungrazed stand in Baganuur, the fresh weight, dry weight and water content of plant biomass was 250.3 g m^{-2}, 133.8 g m^{-2} and 136.5 g m^{-2}, respectively. In this region, circa 1.4 tons of water per hectare was available for livestock by grazing the plants. In the grazed stands, fresh and dry biomasses were 167.5 g m^{-2} and 73.7 g m^{-2}, respectively. The water content in the stands studied ranged between 41.5 % and 56.0%.

Relationship between Aboveground Biomass and *v*-values

The spatial distribution of plant biomass in grasslands is not homogenous. Consequently, in order to accurately estimate grassland biomass, it is necessary to harvest plants from numerous points

Table 1. Ratio of dry weight to fresh weight of plant materials in the Mongolian steppes

Species	Dry weight /fresh weight	Species	Dry weight /fresh weight
Achnatherum sibiricum$^{5)}$	0.63	*Haplophyllum dahuricum*$^{1)}$	0.35
Achnatherum sibiricum$^{6)}$	0.55	*Haplophyllum dahuricum*$^{2)}$	0.39
Agropyron cristatum$^{1)}$	0.43	*Haplophyllum dahuricum*$^{3)}$	0.69
Agropyron cristatum$^{2)}$	0.48	*Haplophyllum dahuricum*$^{4)}$	0.60
Agropyron cristatum$^{3)}$	0.64	*Haplophyllum dahuricum*$^{6)}$	0.55
Agropyron cristatum$^{5)}$	0.58	*Iris flavissima*$^{1)}$	0.30
Agropyron cristatum$^{8)}$	0.53	*Iris flavissima*$^{2)}$	0.16
Allium anisopodium$^{3)}$	0.35	*Iris flavissima*$^{4)}$	0.26
Allium anisopodium$^{4)}$	0.29	*Iris flavissima*$^{7)}$	0.83
Allium bidentatum$^{1)}$	0.28	*Koeleria cristata*$^{1)}$	0.40
Allium bidentatum$^{2)}$	0.29	*Koeleria cristata*$^{2)}$	0.43
Allium bidentatum$^{7)}$	0.29	*Koeleria cristata*$^{3)}$	0.77
Allium bidentatum$^{8)}$	0.30	*Koeleria cristata*$^{4)}$	0.64
Alyssum lenense$^{1)}$	0.42	*Koeleria cristata*$^{5)}$	0.65
Alyssum lenense$^{2)}$	0.56	*Koeleria cristata*$^{6)}$	0.74
Arenaria capillaris$^{1)}$	0.52	*Koeleria cristata*$^{8)}$	0.66
Arenaria capillaris$^{8)}$	0.58	*Leymus chinensis*$^{1)}$	0.42
Artemisia frigida$^{5)}$	0.47	*Leymus chinensis*$^{2)}$	0.45
Artemisia frigida$^{6)}$	0.70	*Leymus chinensis*$^{5)}$	0.54
Artemisia frigida$^{7)}$	0.46	*Leymus chinensis*$^{6)}$	0.59
Artemisia frigida$^{8)}$	0.51	*Leymus chinensis*$^{7)}$	0.49
Artemisia glauca$^{7)}$	0.37	*Leymus chinensis*$^{8)}$	0.51
Artemisia glauca$^{8)}$	0.35	*Medicago falcata*$^{1)}$	0.30
Asparagus dahuricus$^{3)}$	0.58	*Medicago falcata*$^{2)}$	0.31
Asparagus dahuricus$^{4)}$	0.43	*Poa botryoides*$^{5)}$	0.54
Bupleurum scorzonerifolia$^{1)}$	0.42	*Polygonum divaricatum*$^{5)}$	0.22
Caragana microphylla$^{4)}$	0.75	*Potentilla acaulis*$^{2)}$	0.29
Caragana microphylla$^{5)}$	0.54	*Potentilla bifurca*$^{8)}$	0.36
Caragana microphylla$^{6)}$	0.66	*Schizonepeta multifida*$^{5)}$	0.14
Caragana stenophylla$^{1)}$	0.50	*Serratula centauroides*$^{1)}$	0.29
Caragana stenophylla$^{2)}$	0.45	*Serratula centauroides*$^{2)}$	0.05
Caragana stenophylla$^{4)}$	0.81	*Serratula centauroides*$^{5)}$	0.35
Carex duriuscula$^{1)}$	0.47	*Serratula centauroides*$^{6)}$	0.77
Carex duriuscula$^{2)}$	0.45	*Sibbaldia adpressa*$^{1)}$	0.52
Carex duriuscula$^{7)}$	0.67	*Sibbaldia adpressa*$^{7)}$	0.60
Carex duriuscula$^{8)}$	0.56	*Sibbaldia adpressa*$^{8)}$	0.54
Carex korshinskyi$^{5)}$	0.76	*Stipa baicalensis*$^{1)}$	0.49
Carex korshinskyi$^{6)}$	0.76	*Stipa baicalensis*$^{2)}$	0.36
Caryopteris mongolica$^{3)}$	0.53	*Stipa grandis*$^{5)}$	0.59
Caryopteris mongolica$^{4)}$	0.55	*Stipa grandis*$^{6)}$	0.58
Cleistogenes squarrosa$^{5)}$	0.61	*Stipa krylovii*$^{3)}$	0.71
Cleistogenes squarrosa$^{6)}$	0.27	*Stipa krylovii*$^{4)}$	0.75
Cleistogenes squarrosa$^{7)}$	0.46	*Stipa krylovii*$^{7)}$	0.61
Convolvulus ammanni $^{3)}$	0.66	*Stipa krylovii*$^{8)}$	0.52
Cymbaria dahurica$^{2)}$	0.23	*Taraxacum* sp. $^{7)}$	0.31
Cymbaria dahurica$^{7)}$	0.45	*Thalictrum squarrosum*$^{5)}$	0.40
Cymbaria dahurica$^{8)}$	0.37	*Tharictrum minus*$^{2)}$	0.55
Echinops gmelinii$^{2)}$	0.27	*Thermopsis lanceolata*$^{8)}$	0.34
Ephedra sinica$^{5)}$	0.41	*Tragopogon trachycarpus*$^{1)}$	0.19
Filifolium sibiricum$^{1)}$	0.25	*Veronica incana*$^{1)}$	0.53
Galium verum$^{8)}$	0.65	*Veronica incana*$^{2)}$	0.38
Mean ratio			0.48

$^{1)}$Baganuur Ungrazed, $^{2)}$Baganuur Grazed, $^{3)}$KBU Ungrazed, $^{4)}$KBU Grazed, $^{5)}$Tumentsogt Ungrazed, $^{6)}$Tumentsogt Grazed, $^{7)}$Hotont-1, $^{8)}$Hotont-2.

Table 2. Fresh and dry weight of plant biomass in the stands in the Mongolian steppes

Sites	Fresh weight (g m^{-2})	Dry weight (g m^{-2})	Water content(%)	Water content (g m^{-2})
Baganuur				
Ungrazed	250.3	113.8	54.5	136.5
Grazed	167.5	73.7	56.0	93.8
KBU				
Ungrazed	51.8	29.4	43.4	22.5
Grazed	24.1	14.1	41.5	10.0
Tumentsogt				
Ungrazed	170.3	83.5	51.0	86.8
Grazed	83.7	48.2	42.4	35.5
Hotont				
Grazed(1)	266.4	126.8	52.4	139.6
Grazed(2)	356.1	160.0	55.1	196.1

within the study site. However, since the clipping and identification of plant specimens in the field is both time and labor intensive, the period over which plant biomass can be harvested is limited. In order to estimate plant biomass without destructive sampling, we derived an equation to describe the relationship between plant biomass and the *v*-value using both plant height and coverage of species population in a stand. Using the ungrazed stand at Baganuur as an example, the relationship between *v*-values (v: 100 × cm^3) and plant biomass (w: g) for each species is given in Fig. 1. The equation describing the relationship is given as:

$$w = 4.8 * \ln(v) - 7.9 \qquad R^2 = 0.89 \tag{1}$$

Table 3 shows the measured and estimated plant biomass values and the *v*-value for each species in the ungrazed stands of the Baganuur study site.

The *v*-value of the stands was 1.9725×10^5 cm^3 in the ungrazed stand. Measured and estimated aboveground plant biomass were 113.8 g m^{-2} and 117.3 g m^{-2}. The equations of the relationship in Baganuule, KBU, Tumentsogt and Hotont are shown in Table 4. Using these equations, we estimated plant biomass at the study sites. These equations were shown to be significant by the Student's *t*-test.

The relationships given in Table 4 are approximated with the functions of linear in KBU and Tumentsogt, the logarithmic in Baganuur, KBU and Tumentsogt and the power in Baganuur. The cause of difference among the stands remains to be elucidated in future though it is speculated that the difference suggests the difference of stand structure for each site.

Testing the Applicability of the Equations

In order to test the applicability of the equations, we compared the measured and estimated values of plant biomass in the stands studied (Table 5). For Baganuur, the measured and estimated values were 113.8 g m^{-2} and 108.0 g m^{-2} in the ungrazed stand and 97.5 g m^{-2} and 73.7 g m^{-2} in the grazed stand, giving a difference of 5% and 32%. The differences between the measured and estimated values were within 16% in grazed and 21% in ungrazed at Tumensogt and 19% in grazed stand in Hotont, respectively.

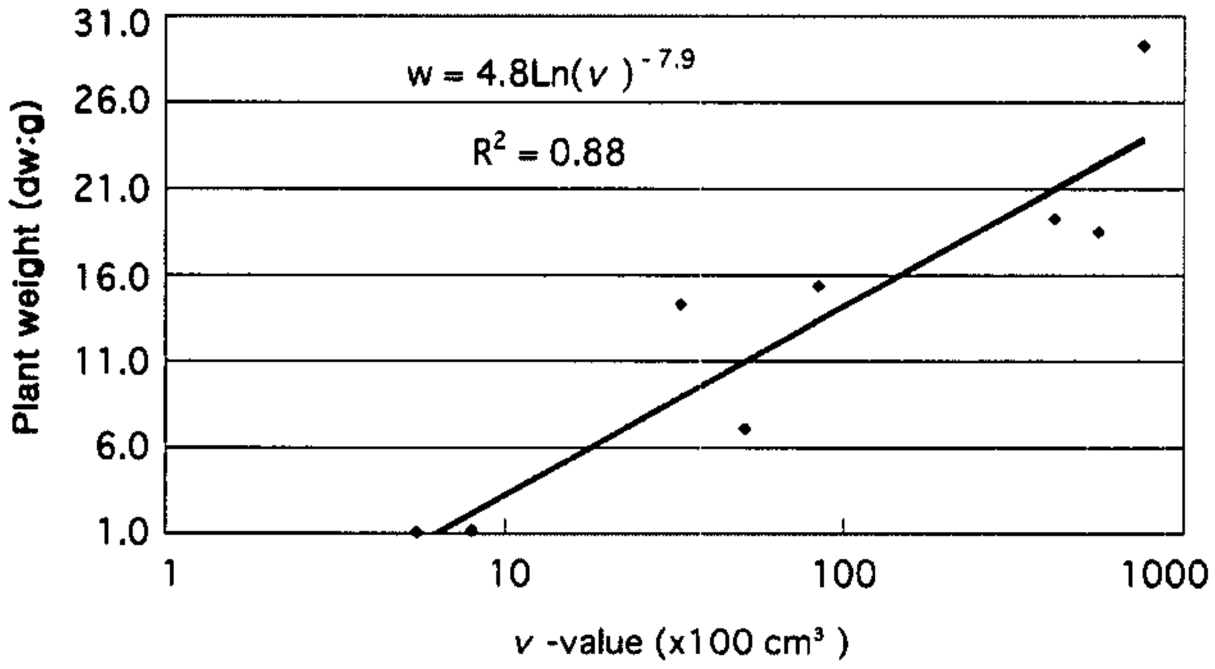

Fig. 1. Relationship between the *v*-value and plant dry weight in the ungrazed stand in Baganuur.

Variance of Plant Biomass and Spatial Distribution in Grasslands

We examined the variance among estimated plant biomass at the Baganuur site in Table 6. In the ungrazed stand, plant biomass from

Table 3. Measured and estimated plant biomasses and *v*-value of the ungrazed stand in Baganuur

Species	Plant biomass (g m^{-2})		
	Measured biomass	Estimated biomass	*v*-value (×100 cm^3)
Koeleria cristata	29.3	23.9	760
Agropyron cristatum	19.3	21.0	416
Stipa baicalensis	18.5	22.5	560
Caragana stenophylla	15.4	13.4	84
Carex duriuscula	14.3	8.9	33
Haplophyllum dahuricum	7.1	11.0	51
Filifolium sibiricum	3.8		
Arenaria capillaris	1.2	2.1	8
Allium bidentatum	1.1	0.3	6
Serratula centauroides	0.6	2.6	9
Potentilla bifurca	0.5	0.0	4
Alyssum lenense	0.4	0.0	4
Leymus chinensis	0.3	5.1	15
Veronica incana	0.3		
Bupleurum scorzonerifolium	0.3		
Iris flavissima	0.2		
Medicago falcata	0.1	0.7	6
Tragopogon trachycarpus	0.1		
Caragana pygmaea		5.8	17.5
Unidentified species	1.0		
Total (g m^{-2})	113.8	117.3	
Litter (g m^{-2})	221.9		
Gross total (g m^{-2})	335.7		
v-value (× 100 cm^3)			1972.50

five quadrats varied from 97.6 g m^{-2} to 117.3 g m^{-2} (mean: standard error; 107.9 ± 7.0 g m^{-2}). In the grazed stand, the biomass weight varied from 60.7 g m^{-2} to 140.3 g m^{-2} (97.5 ± 29 g m^{-2}). The result shows that the spatial distribution of the biomass in the grassland is heterogeneity. Given the need for the collection of multiple samples due to the natural heterogeneity of plant biomass, future studies of grassland biomass should increase the number of samples analyzed.

Estimated Plant Biomass at Study Sites

Using the equations given in Table 4 the plant biomasses in the study sits were estimated. Estimated plant biomass and measured plant litter are shown in Table 7. In Baganuur, the mean biomass produced in the 60 days from the beginning of the growing season in ungrazed and grazed stands were 107.9 g m^{-2} and 97.5 g m^{-2}; the difference of 10.5 g m^{-2} was not significant by the Mann-Whitney U test. The growth of plants in the grazed stand may be accelerated by grazing activity of livestock and also due to fertilization by excreta of the livestock. The mass of litter in the un-

Table 4. Equations of relationship between the v-value (cm^3) and biomass (w;g) for the stands

	Equations	R^2	n	p
Baganule				
Ungrazed	$w = 4.80 \ln(v) - 7.90$	0.89	13	0.001*
Grazed	$w = 0.15(v)^{0.88}$	0.82	16	0.001*
KBU				
Ungrazed	$w = 0.90 \ln(v) - 0.50$	0.55	8	0.05*
Grazed	$w = 0.20 \ln(v) + 0.92$	0.01	8	n.s.
Tumentsogt				
Ungrazed	$w = 0.02v + 1.18$	0.87	13	0.001*
Grazed	$w = 3.25 \ln(v) - 3.93$	0.76	11	0.001*
Hotont				
Grazed	$w = 0.03v + 1.66$	0.96	25	0.001*

n: sample size.

Table 5. The measured and estimated plant biomasses in the stands

Sites	Plant biomass (g m^{-2})		
	Measured (a)	Estimated (b)	(a)−(b)/(a)
Baganuur			
Ungrazed	113.8	108.0	0.05
Grazed	73.7	97.5	−0.32
Tumentsogt			
Ungrazed	83.5	70.3	0.16
Grazed	48.2	58.3	−0.21
Hotont			
Grazed	143.4	116.7	0.19

Table 6. Variation of plant biomasses among five quadrats of the stands in Baganuur

Sample number	Plant biomass (g m^{-2})	
	Ungrazed stand (a)	Grazed stand (b)
1	117.3	60.7
2	113.0	71.0
3	103.4	112.9
4	108.4	140.3
5	97.6	102.7
Mean ± s.e.	107.9 ± 7	97.5 ± 29

s.e. : standard error.

Table 7. Estimated plant biomass and measured litter in the stands in Baganuur, KBU, Tumentsogt and Hotont

Stands	Mean biomass±s.e. (g m^{-2})	Litter (g m^{-2})
Baganuur		
Ungrazed (a)	107.9±0.7	221.9
Grazed (b)	97.5±28.8	22.7
(a)−(b)	10.5	199.2
KBU		
Ungrazed (a)	13.4±2.2	78.4
Grazed (b)	14.1*	27.8
(a)−(b)		50.6
Tumentsogt		
Ungrazed (a)	72.6	330.3
Grazed (b)	58.6±4.0	188.0
(a)−(b)	14.0	142.3
Hotont		
Grazed	121.8	20.3

* Measured value.

grazed and the grazed stands was 221.9 g m^{-2} and 22.7 g m^{-2}, respectively, with the difference of 199.2 g m^{-2} considered to be that consumed by livestock. As shown in Table 7, plant and litter biomass in the ungrazed and grazed stands at Tumentsogt were 70.3 g m^{-2} and 330.3 g m^{-2}, and 58.2 g m^{-2} and 188.0 g m^{-2}. Livestock grazed the aboveground plant litter as well as living plants. The difference of living plant biomass was not significant by the Mann-Whitney U test. In Tumentsogt, the amount of litter was 257.7 g m^{-2} more than the living plant biomass and the difference in plant litter the between ungrazed and grazed stands, considered reflect the amount grazed by livestock, was 142.3 g m^{-2}. By way of comparison, the plant biomass and amount of litter in the grazed stand in Hotont were 115.8 g m^{-2} and 20.3 g m^{-2}, respectively.

Estimation of Weight Ratio of above and below Ground Biomasses

The relationship between above-ground (Wa) and below ground (Wb) weights in the plant of *Artemisia scoparia* is shown Fig. 2. The relationship is approximated as follows:

$$Wb = 0.21 Wa^{1.20} \tag{2}$$

Using the equation, we are abele to estimate the below ground biomass from the above ground biomass of *Artemisia scoparia.*

Carbon and Nitrogen Content of Plant and Litter

Carbon and nitrogen content of plant material in grazed stand are given in Table 8. Mean carbon and nitrogen content in plants and litter was 43.0% and 1.9% and 33.7% and 1.4%, respectively. In Baganuur, the amount of carbon in the aboveground plant biomass was 43.5 g C m^{-2} (435 kg C ha^{-1}) (Table 9). Total carbon of the stand was 118.4 g C m^{-2}, which included 74.9 g m^{-2} carbon in the litter. This implies that in early July 2005, 1,184 kg of carbon per hectare was held in the plant community as plant biomass and litter. The amount of carbon contained in plant biomass and litter were 31.2 g C m^{-2} and 111.4 g C m^{-2} in Tumentsogt and 51.1 g C m^{-2} and 6.8 g C m^{-2} in Hotont (Table 9). The nitrogen content of plant biomass and litter were 1.6 g N m^{-2} and 3.1 g N m^{-2} in the ungrazed stand in Baganuur (Table 9).

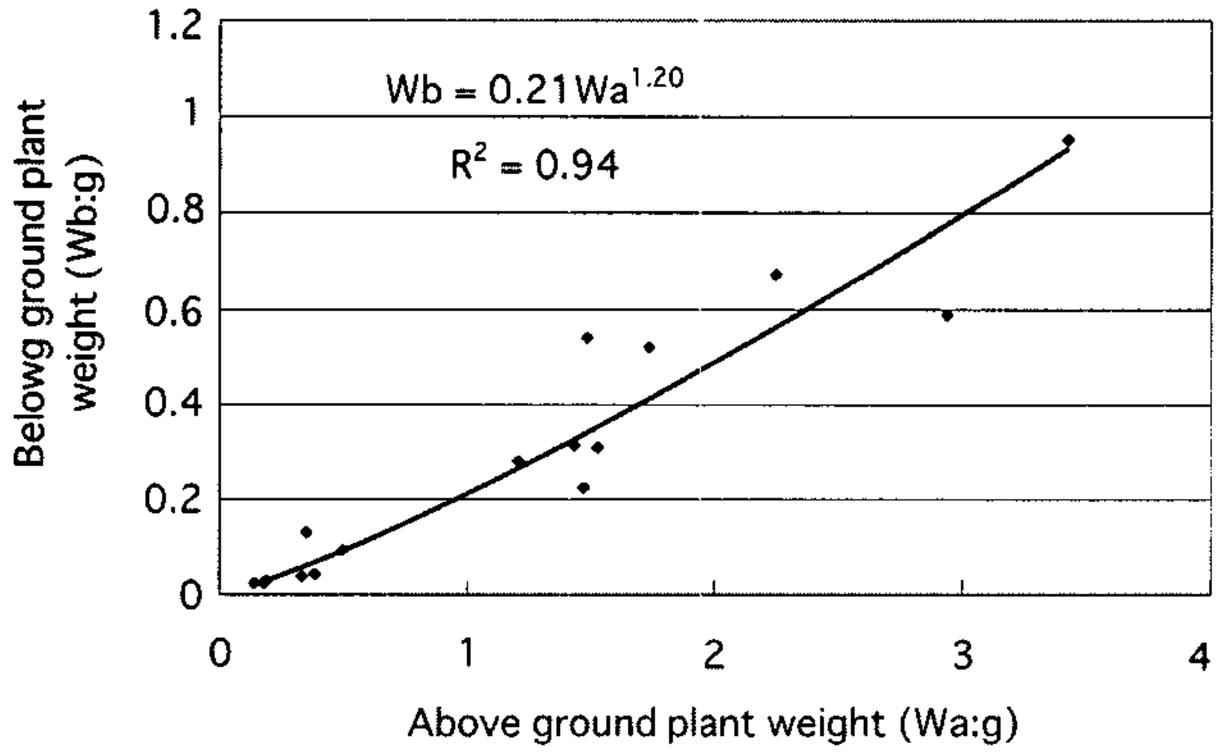

Fig. 2. Relationship between above (Wa) and below (Wb) ground plant weights of *Artemisia scoparia.*

Table 8. Carbon and nitrogen contents in plant materials collected from the Mongolian steppes. (s.e.: standard error)

Species	Carbon (%)	s.e.	Nitorogen (%)	s.e
*Agropyron cristatum*1)	41.2	3.8	1.5	0.1
*Allium bidentatum*2)	42.4	0.5	2.0	0.1
*Artemisia glauca*2)	44.5	0.2	3.0	0.0
*Carex duriuscula*1)	38.1	0.8	1.4	0.0
*Carex duriuscula*2)	43.3	0.1	1.9	0.0
*Carex korshinskyi*3)	44.2	0.1	1.8	0.0
*Koeleria cristata*1)	37.4	5.1	1.3	0.1
*Koeleria cristata*3)	43.8	0.1	1.8	0.0
*Leymus chinensis*3)	45.0	0.2	2.0	0.0
*Stipa baicalensis*1)	39.7	2.8	1.3	0.1
*Stipa grandis*3)	44.8	1.6	1.7	0.3
*Stipa krylovii*2)	44.7	0.0	2.1	0.1
*Stipa krylovii*4)	44.2	1.1	1.8	0.1
*Achnatherum sibiricum*3)	44.6	2.5	2.1	0.2
Other herb and grass1)	43.7	7.2	1.7	0.3
Other herb and grass4)	45.2	0.9	1.8	0.3
Other herb and grass3)	44.0	0.1	1.9	0.1
Other herb and grass2)	42.4	1.2	2.2	0.1
Mean	43.0	1.6	1.9	0.1
Litter2)	33.7	2.1	1.4	0.0

1)Baganuur, 2)Hotont, 3)Tumentsogt, 4)Kherlenbayan-Ulaan.

DISCUSSION

Plant Biomass

Variance in plant biomass among study stands was large because the spatial distribution of biomass in grassland was heterogeneous. We should, therefore, collect a number of quadrat samples to estimate the amount of biomass in grassland. We derived an equation to estimate the biomass without clipping of plants in the stand, because labor of clipping and identifying species is time consuming.

Table 9. Carbon and nitrogen contents of plants and litter in the stands of the Mongolian steppes

Sites	Carbon (g m^{-2})		Nitorogen (g m^{-2})	
	Plants	Litter	Plants	Litter
Baganuur				
Ungrazed (a)	43.5	74.9	1.6	3.1
Grazed (b)	39.6	7.7	1.4	0.3
(a)−(b)	3.9	67.2	0.1	2.8
KBU				
Ungrazed (a)	6.1	26.4	0.2	1.1
Grazed (b)	6.3	9.4	0.3	0.4
(a)−(b)	−0.3	17.1	0.0	0.7
Tumentsogt				
Ungrazed (a)	31.2	111.4	1.3	4.6
Grazed (b)	25.9	63.4	1.1	2.6
(a)−(b)	5.3	48.0	0.2	2.0
Hotont				
Grazed	51.1	6.8	2.7	0.3

Biomass production is affected by combined environmental factors such as meteorological factors, soils and human activities. Therefore, we are not able to consider the biomass production under separated situation.

The biomasses in the stands varied according to the precipitation and temperature not only among study sites but also between years. Nachinshonhor and Hirose (2002) reported that mean plant biomass was 127 g m^{-2} in an ungrazed stand in Tumentsogt in 1999 and 2001, compared to our results of 70.3 g m^{-2} in the ungrazed stand in Tumentsogt in July 2005. This disparity is thought to be due to the difference in precipitation, with 280.4 mm occurring in 2005 and a mean value of 356.3 mm for 1999 and 2001 in Tumentsogt.

The difference of biomasses between the grazed and ungrazed stands, however, was not significant in statistical analysis (Table7). This suggests some accelerative effects of livestock activity to plant growth in the grazed stand.

In this study the plant biomass was assessed in early July, the time of harvest before the date the maximum biomass occurred in the growing season (biomass at harvest time). The plant biomass continues to increase until late August and is decomposed by soil microorganism after withering. The Mongolian steppe environment was found to have a large amount of plant litter. The litter consisted primarily of withered plants from the current growing season and organic residual litter from the previous year, as well as withered roots and rhizomes, all of which contribute to the organic content of the soil.

Numerous studies have been conducted on plant biomass in the Inner Mongolian and Mongolian steppes (Davazamc 1985, Jiang et al. 1985, Hayashi et al. 1988, Kawamura et al. 2003, Kawamura et al. 2005, Bai et al. 2007). Yiruhan et al. (2001) reported that the average aboveground plant biomass at 23 sites was 198 g m^{-2} with standard deviation of 68 g m^{-2} in the Inner Mongolian grasslands. While Kawamura et al. (2005) obtained plant biomass values of 134.5 g m^{-2} with standard deviation of 75.1 g m^{-2} in the same region using a remote sensing method. Mean plant biomass in the steppe regions of Mongolia and Inner Mongolia appear to be between circa 100 g m^{-2} and 200 g m^{-2} (1 and 2 tons per hectare). Using the eddy covariance method, Kato et al. (2004) reported that the net ecosystem production (NEP) was 153.1 g m^{-2} in a growing season in the Qinghai-Tibetan Plateau, China. The value given by Kato et al. (2004) is equivalent to approximately 356.0 g m^{-2} of biomass including below ground biomass.

The total plant biomass in a stand is taken as the aboveground biomass plus the belowground biomass (roots and rhizomes). The amount of belowground plant biomass in a stand has been observed to vary between studies, because the measurement techniques employed to assess belowground biomass differed between studies. For example, according to Jiang et al. (1985), above- and belowground biomasses per square meter of *Stipa grandis* were 125.5 g and 345.8 g. Similarly, for *Aneulorepidium chinense* (*Leymus chinensis*) these values were 142.0 g and 616.1 g, respectively. In the same study, the ratios of aboveground biomass to belowground biomass were 2.76 and 4.34, respectively. Hayashi et al. (1988) reported the relationship between aboveground biomass (T: g) and belowground biomass (R: g) using the data of Li et al. (1988) in a stand in Inner Mongolia as: $R = 113.3\exp(0.0076T)$. However, the measured belowground biomass of Jiang et al. (1985) was larger than that predicted by the equation. Davazamc (1985) reported that the belowground plant biomass of *Stipa krylovii* stand in Mongolia was 2,500 g m^{-2}, which was 23 times larger than that of the aboveground biomass.

According to Fig. 2, the weight ratio of the below ground to above ground was estimated 2.9 for *Artemisa scoparia* with plant weight of 200 g. In present study, by adopting the ratio of 2.76 of Jiang et al. (1985), the estimated belowground biomass in the ungrazed stand in Baganuur was 257.5 g m^{-2}, while the total plant biomass in the ungrazed and grazed stands was 365.5 g m^{-2} and 335.2 g m^{-2} in Baganuur on 30 June 2005. In the mature stand in a steady state, the belowground biomass produced in a growing season is totally decomposed during the subsequent fall and winter after withering. If the roots and rhizomes survive in this period, the belowground biomass continues to increase and occupies the belowground space with roots and rhizomes for several years. The rest of the biomass is retained in the soil as organic matter during the fall and winter. In Mongolia, withered roots, rhizomes and litter are thought to constitute a major component of soil organic matter because decomposition is limited by low temperature and arid climate.

Amount of Carbon and Nitrogen in the Stands

The carbon in plant biomass and plant litter were sequestrated from the atmosphere during growing season in this study sites. This carbon contained within the plant material contributes to the carbon sink of the grassland ecosystem. The amount of carbon in the plants of the ungrazed grasslands in Baganuur, KBU and Tumentsogt was 435 kg ha^{-1}, 61 kg ha^{-1} and 312 kg ha^{-1} in early July 2005, respectively (Table 9). In the grazed stands, the amount of carbon was 396 kg ha^{-1} in Baganuur, 63 kg ha^{-1} in KBU and 259 kg ha^{-1} in Tumentsogt. Approximately 90% percent of the carbon in this aboveground plant biomass would have been accumulated in the 60-day growing season if plant was considered to start on 1 May in the year of the study. Approximately 10% of the carbon supplies from storage organs are produced in the preceding growing season (Hayashi 2003). The carbon contained in the plant litter of ungrazed and grazed stands in Baganuur was 749 kg ha^{-2} and 77 kg ha^{-2}, respectively. Almost all of the carbon in the litter was sequestrated from atmosphere in the preceding year.

Chen et al. (1985) reported that the nitrogen content of *Artemisia frigida*, *Stipa grandis* and *Stipa baicalensis* in Inner Mongolian grasslands was 2.7%, 1.6% and 1.3%, respectively, which is similar to the findings presented in this study. We were able to determine the amount of nitrogen in a plant community by converting the nitrogen content for each species to the plant biomass in the stand. For example, in the ungrazed stand in Baganuur, the plant community contained 1.6 g m^{-2} of nitrogen (Table 9). Some of the nitrogen contained in these plants is transferred to livestock, making the nitrogen dynamics in the ecosystems of this region. The grassland ecosystems in Mongolia are thus important for the raising of livestock and the conservation of environments, including the sequestration of the atmospheric carbon.

Numerous biomass or carbon budget measurements have been undertaken in ecosystems using physical methods such as remote sensing and the eddy covariance methods (Kawamura et al. 2003, Kato et al. 2004). However, although these techniques can be used to generate much physical data and characterize the carbon budgets of these ecosystems, they cannot be employed to restore damaged ecosystems. Conversely, ecological approach, such as that on the floristic composition shown in Table 3, can be used to restore damaged ecosystems. Because, we can rehabilitate the damaged stand using suitable plant species with information on floristic composition of the stands, which indicates the stand characteristics such as temperature, precipitation and soil properties (Hayashi 1996). Since plant succession can be used to predict changes in species and biomass dynamics in the stands subjected to grazing (Wang 1992, Wuyunna et al. 1999, Nakamura et al. 2000, Hayashi 2003, Kawada et al. 2006, Cheng and Nakamura 2007), then it is likely that the theory can be applied to determining which species are well suited for use in rehabilitation or to restore degraded grasslands.

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