

Accepted Manuscript

Rangeland
Ecology & Management

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PII: S1550-7424(14)00002-5
DOI: doi: [10.1016/j.rama.2014.12.001](https://doi.org/10.1016/j.rama.2014.12.001)
Reference: RAMA 1

To appear in: *Rangeland Ecology & Management*

Please cite this article as: Yan, Ruirui, Xin, Xiaoping, Yan, Yuchun, Wang, Xu, Zhang, Baohui, Yang, Guixia, Liu, Shimin, Deng, Yu, Li, Linghao, Impacts of Differing Grazing Rates on Canopy Structure and Species Composition in Hulunber Meadow Steppe, *Rangeland Ecology & Management* (2014), doi: [10.1016/j.rama.2014.12.001](https://doi.org/10.1016/j.rama.2014.12.001)

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Impacts of Differing Grazing Rates on Canopy Structure and Species

Composition in Hulunber Meadow Steppe

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Abstract

In this study, the impacts of cattle grazing with differing grazing rates on species composition, canopy structural traits, standing crop of canopy biomass, and plant species diversity were examined in a meadow steppe of the Hulunber grasslands, Northeastern China. Six stocking-rate treatments (0, 0.23, 0.34, 0.46, 0.69 and 0.92 AU.ha⁻¹) with three replicates were established, and observations were conducted from 2009 to 2011. Our findings demonstrate that short-term grazing substantially altered the species composition and relative dominance, standing crop of aboveground biomass, and canopy structural traits, whereas no significant changes in species diversity and evenness occurred in response to different-rated grazing in this meadow steppe, which has a long-term evolutionary grazing history and high resources availabilities. We found that perennial graminoid significantly decreased, while forbs and annuals increased at the same time, with increasing grazing intensity and duration; canopy height and coverage decreased substantially with increasing stocking rates, whereas significant changes in plant density occurred only at heavy grazing in the second and third year; significant negative linear relations were found between the standing crop of biomass and grazing intensity in each individual year or for three years on average. Significantly highest species richness and canopy dominance occurred only at the intermediate grazing rate in the third year, and intermediate grazing intensity also maintained a highly constant standing crop of canopy biomass in the three years, all being in accordance with the intermediate disturbance hypothesis. Our findings imply that monitoring changes in species composition, canopy traits, and standing crop of biomass in grassland communities can provide important references for assessing current grazing management scenarios and conducting timely adaptive practices to maintain the long-term ability of grassland systems to perform their ecological functions.

Keywords: Cattle herbivory; Canopy biomass; Compensatory growth; Life form; Intermediate grazing effects; Relative dominance of species

INTRODUCTION

Grasslands comprise 30–40% of Earth's land surface, of which about 90% are utilized as grazing lands (Asner et al. 2004). They support the livelihood for over 1 billion people in arid and semiarid areas, primarily through extensive livestock production (FAO 2006). Herbivory by domestic livestock is also a major driver of global vegetation dynamics, biodiversity alteration and biogeochemical cycles (Diaz et al. 2007). It is estimated that as much as 70-80% grasslands have become degraded to some degree worldwide, largely due to overgrazing (MA 2005).

As a major human use practice, livestock grazing substantially influences the structure and functions of grassland ecosystems, by modifying the species composition, richness, canopy traits, and a number of abiotic factors, posing profound impacts on the net primary production (NPP) and its allocation between canopy and belowground (Altesor et al., 2005). In turn, these changes will determine forage availability and quality, thus constraining the stocking number and distribution of domestic animals in grasslands through bottom-up regulation. Within a region, grazing effects are mainly dependent on the current stocking rate, short-term grazing strategies (e.g., rotational vs. continuous) (Briske et al. 2008), and the evolutionary history of grazing of the site (Milchunas and Lauenroth 1993). Whereas the direct impacts of grazing activities on species composition and canopy traits largely depend upon grazing intensity, grazing frequency, the magnitude of grazing period, and livestock species, the relationship between canopy traits and grazing intensity can best be described in terms of relevant changes in response to increasing grazing rate (Ellison 1960; Liu and Li 2006).

Grazing effects on grassland species composition and diversity have been intensely studied in the past decades. Several prevailing hypotheses are used to describe and explain the relationship between grazing intensity and plant diversity as affected by resource availability and evolutionary history of grazing. For example, according to the intermediate disturbance hypothesis, grassland communities at intermediate grazing intensity display the highest diversity of plant species and ANPP, whereas heavy grazing reduces species diversity or richness (Grimes 1973; Huston 1979). Some researchers have observed that bunch grass communities gradually become transformed into dwarf grass communities with increased stocking rate, leading to negative responses of vegetation and degradation of grasslands. In addition, as stocking rate rises, species of high palatability for livestock animals decrease, whilst species of poor palatability increase (Dong et al. 2007), leading to diminished plant and animal production, altering species composition and canopy traits. Milchunas and Lauenroth (1993) noted that changes in species composition increased with increasing productivity and with longer, more intense evolutionary histories of grazing. Contrary to the commonly held view, most experiments show that plant production is equal or greater in continuous compared to rotational grazing, and so is animal production (Briske et al. 2008). Selective livestock grazing and divergent adaptation of plant species and/or groups to changes in abiotic factors (e.g., light, soil water and nutrient availabilities) under different grazing regimes

have been reported to be the major top-down mechanism regulating plant traits and species diversity (Diaz et al. 2007). Grazing alters the flow of energy and the cycling of materials through browsing, trampling, and dung and urine depositions (Hobbs et al. 1996). Therefore, relationships between grazing and canopy traits, species diversity, and primary productivity, are at the core of the current research (Altesor et al. 2005).

The Hulunber grasslands in northeastern China comprise one of the largest areas of natural temperate sub-humid meadow grasslands in the world, covering an area of about 9.97×10^6 km². Large areas have been converted into croplands in the past 50 years, but a large portion of the region still is occupied by natural or semi-natural grasslands for seasonal or continuous cattle and sheep grazing, leading to 50% degradation of the total available grassland area (Kato et al. 1998; Cui et al. 2005; Wang et al. 2008). Therefore, the determination of appropriate stocking rates is one of the most critical and urgent issues underpinning the adaptive management and sustainable development of these precious grasslands (Zhao et al. 2007). The effects of livestock grazing on plant community structure (Altesor et al. 2005; Sala et al. 1986), above- and below ground net primary productivity (Christtansen and Srejcor 1998), species composition and richness (Belsky 1986; Marty 2005), vegetation dynamics (Austin et al. 1981; Briske et al. 2003; Bokdam et al. 2000; Kraaij and Milton 2006), and plant succession (Ellison 1960), have been extensively studied in recent several decades. However, most of these studies were conducted in North American prairie, South American pampas, and Australian savanna, with most of them distinguishing between grazed vs. ungrazed cases (Milchunas and Lauenroth 1993; Briske et al. 2003; Diaz et al. 2007). In contrast, grazing effects in response to different stocking rates (Cooper et al. 2005; Sabine et al. 2007; Ausden et al. 2005) have been much less studied, with the studies of the kind being extremely rare in Northeastern Chinese grasslands (Yan et al. 2010).

In this study, the impacts of cattle grazing with differing grazing rates on species composition, canopy structural traits, standing crop of canopy biomass, and plant species diversity were examined in a meadow steppe of the Hulunber grasslands, Northeastern China. Our objectives were (1) to detect differential changes in species composition and community structure in response to increasing grazing intensity and duration; (2) to discern the relevant mechanisms underpinning these changes and; (3) to evaluate to what extent can grazing influence the stability in canopy structure and species diversity at local and short-term scales.

MATERIALS AND METHODS

Study Site

This study was conducted in the Hulunber Grassland Ecosystem Observation and Research Station, which is located in the center of the Hulunber meadow steppe (N 49°19'349"~49°20'173", E 119°56'521"~119°57'854"), in the

north-eastern region of Inner Mongolia, China. Elevation varies from 666 m to 680 m. The climate is temperate semi-arid continental, with an annual average of 110 frost-free days. Annual mean precipitation ranges from 350 to 400 mm, about 80% of which falls between July and September. Annual mean air temperature is between -5°C \sim -2°C , with maximum monthly mean of 36.17°C in July and minimum of -48.5°C in January. Monthly average temperature and precipitation during 2009–2011 at the study site are shown in Fig. 1. The soil is chernozem or chestnut soil by type. Vegetation is characterized as typical meadow steppe. The dominant species are in the order in importance value of: *Leymus chinensis*, *Stipa baicalensis*, *Carex duriuscula*, *Galium verum*, *Bupleurum scorzonerifolium* and *Filifolium sibiricum*.

Treatments

This grazing experiment facilities with five stocking rates and one control plot were established in 2009. Stocking rates were set as 0, 0.23, 0.34, 0.46, 0.69 and 0.92 AU/ha, referred to as G0.00, G0.23, G0.34, G0.46, G0.69 and G0.92, respectively, where 1AU= 500 kg of adult cattle), with three replicates for each stocking rate, each replicate occupying a 5 ha paddock, so that in total there were 18 plots randomly distributed over an homogeneous total area of 90 ha. We grazed 0, 2, 3, 4, 6 and 8 head of 250–300 kg young cattle, respectively, in each replicate plot of the six stocking rate treatments, with a total of 69 head of cattle grazing overall. Continuous grazing lasted for 120 days annually between June and October, starting from 2009 to 2011. The grazing cattle were kept in the grazing plots day and night, and their drinking water was supplied from outside water source. The experimental layout is shown in Fig. 2. Before fenced, the site had been under long-term cattle or sheep free ranging. A baseline measurement was conducted prior to field treatments in the summer of 2008 with a 50 meter transect in each plot to investigate vegetation and soil traits.

Field Measurements and Calculations

Five $1 \times 1 \text{ m}^2$ quadrats were randomly located in each grazing plot at peak biomass period (early August, such that ANPP can be estimated) in 2009, 2010 and 2011, respectively. Within each quadrat, the species composition and canopy height and cover of each species were measured. A 50 cm * 50 cm point frame with 100 cross hairs using a grid was used to measure coverage; plant natural height was measured by multipoint method with a ruler and averaged. Density of individuals or bunches was acquired by counting at each quadrat. The canopy was then clipped at ground level and separated for each species or life-form group. Biomass was oven dried for 48 h at 65°C to constant weight. The plant species importance value (IV), and four indices of plant diversity were calculated as follows.

$$\text{IV} = (\text{RH} + \text{RD} + \text{RC}) / 3$$

where RH stands for relative height, RD for relative density and RC for relative coverage of no. i species among the total s species, which were calculated by:

$$RH = (H_i / \sum_{i=1}^s H_i)$$

$$RD = (D_i / \sum_{i=1}^s D_i)$$

$$RC = (C_i / \sum_{i=1}^s C_i)$$

The plant species richness index (R) was calculated using the Margalef index (Margalef 1963):

$$R = \frac{(s - 1)}{\ln N},$$

where N is the number of individual plants in the population and s is the number of species.

The plant species diversity index (H) was calculated using the Shannon-Wiener index (Shannon and Weaver 1949):

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

where P_i is the proportion of all individual plants in the sample that belongs to species i .

The plant dominance index was calculated using the Simpson index (Simpson 1949):

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

The plant evenness index was calculated using the Pielou index (Pielou 1966):

$$J = \frac{-H}{\ln(s)}$$

Statistical Analysis

The data were analyzed with ANOVA, using the MIXED procedure from SAS (SAS Institute Inc., 2005), with the grazing treatment as a fixed effect and the replicate as a random effect. The replicate-treatment effect was used as the measure of experimental error, with the assumption that replicates within each treatment were independent of one another. Results for all variables were considered significant if P values were less than or equal to 0.05.

RESULTS

Canopy and Soil Traits Prior to Treatments

Canopy and soil traits prior to treatments are given in table 1. On average, peak above-ground biomass ranged between 800-850 kg.hm⁻², canopy cover averaged 36-42%, with an average canopy height of 7-9 cm. Soil total

nitrogen content varied between 3.73 and 4.08 g.kg⁻¹, and that of soil organic carbon was 36.37-39.52 g.kg⁻¹ at the surface soil layer. The ratio of aboveground to underground biomass was around 8.85-10.88%. There was no significant difference in canopy and soil traits at plot scale, indicating the site being in homogeneous context as compared among plots or areas to be assigned to different grazing rates within the whole experimental site.

Changes in Species Composition

Changes in the important values (IVs) for individual species and for perennial grasses, annual grasses, legumes, as well as for forbs and others are shown in Appendix 1 and Fig. 3, respectively. During the three years of grazing, the species composition changed greatly across the different grazing treatments. The Importance Value of perennial grasses under G0.00 showed a slight upward trend, with an increase of 6.92% from 2009 to 2011, in stark contrast with the obvious downward trend under the two heavy grazing treatments G0.69 and G0.92 (decreases of 35.38% and 42.04%, respectively), whereas no significant changes occurred at the two light grazing rates (G0.23, G0.34), with decreases of 3.34%, and 4.88%, respectively. The intermediate grazing (G0.46) showed marginally negative effects on the IV of perennial grasses, with a decrease of 19.08%. On the contrary to perennial grasses, the Importance values for forbs under heavy grazing rates (defined as before and the same throughout) increased markedly (29.36% and 67.34%, respectively), whereas those for light and intermediate grazing rates showed slight downward trajectory (decreases of 4.55%, 8.90%, and 9.29% for G0.23, G0.34, and G0.46, respectively), in contrast to the marginally significant upward trend under G0.00 (an increase of 15.41%). Our findings demonstrate that the Importance Values for the previously most dominant perennial grasses such as *L. chinensis* and *S. baicalensis* decreased gradually with increasing stocking rate, whereas those for unpalatable forbs, such as *C. duriuscula*, *A. frigida*, *P. bifurca* and *P. acaulis*, all increased (see Fig. 3 and data in Appendix 1). With the increase of stocking rates from G0.00 to G0.92, annual plants gained more importance in the community. It can be noticed that with increase in grazing time, the most dominant species *L. chinensis*, a perennial grass, has been gradually replaced at light grazing, but rapidly at heavy grazing, by *S. baicalensis* and two other forbs (see appendix 1).

Changes in Canopy Structure Traits

Cattle grazing at each stocking rate resulted in apparent reduction in the total canopy height for each grazing year, and the effects tended to increase with grazing year (Fig.4A). By comparing the extent and significance to which canopy height was reduced in each year, three categories of grazing intensity could be roughly divided, i.e., light (G0.23 and G0.34), intermediate (G0.46) and heavy grazing (G0.69 and G0.92), exactly as the case for grazing rate-induced species

composition changes found in the last section. When three years of data were averaged, a highly significant negative relationship was detected between canopy height and grazing rate (Fig.5A1). It can be seen that canopy height at control and light grazing rates (G0.00, G0.23, G0.34) displayed an upward trend with continued grazing (increases of 44.47%, 21.19% and 19.04% respectively in 2011 compared with 2009. In contrast, extremely minor change (only 0.35% increase) was detected at the intermediate grazing rate (G0.46) among the years, whereas apparent downward trends in canopy height were observed under heavy grazing (G0.69 and G0.92), which showed decreases by 31.56% and 44.40%, respectively from 2009 to 2011.

Decreasing trends in canopy coverage with increasing stocking rate were found in each of the three years (Fig.4B). However, the extent and significance to which canopy was reduced differed greatly, and appeared to increase with year. Again, a highly significant negative relationship was detected between canopy coverage and grazing rate (Fig.5B1). It can be seen that less significant changes occurred in 2009, with no significant differences existed between no grazing and light grazing rates and among one another of the heavy grazing rates, in stark contrast to those of 2010 and 2011. Unlike the case for canopy height, the intermediate grazing (G0.46) effect on canopy coverage was most apparent only in the third grazing year. In addition, canopy coverage at control and light grazing remained relatively constant with year, whereas an “U-shaped” pattern between canopy coverage and grazing year was found for the rest grazing rates. The responses of plant density to grazing were quite different to canopy height and coverage. It can be seen that no significant changes occurred among all the treatments in the first grazing year; whereas marginal differences occurred between no grazing and all the grazing treatments in the second and third year, no significant differences were detected between one another of the grazing treatments (Fig.4C). Although decreasing trend of plant density with increasing grazing rate for each grazing year (Fig.4C), as well as a significant negative relationship for three years averaged, were found, respectively, the R^2 value is lower and the slope of the regression line is less precipitous (Fig.5C1), indicating that grazing intensity was less influential on plant density than on canopy height and coverage. Fig. 4C shows also an “U-shaped” pattern with increasing grazing year for both the control and the various grazing rates.

Response of Canopy Biomass to Grazing

The above-ground standing crop of biomass was also substantially affected by different stocking rates (Fig.4D). Cattle grazing at each stocking rate resulted in apparent reduction in the total canopy biomass mainly in the second and third year and under intermediate and heavy grazing, whereas no significant effect was found at light grazing rates in the first and second years, much like the case for grazing rate-induced changes in canopy height. Whereas the effects of light and intermediate grazing remained comparatively constant with grazing year, those of heavy grazing increased

substantially with grazing duration. When three years of data were averaged, a highly significant negative relationship was detected between canopy biomass and grazing rate (Fig.5D1). Extremely minor change was detected at the intermediate grazing rate (G0.46) among the years, indicating some degree of intermediate grazing effects.

Changes in Species Richness and Evenness

Plant diversity and its responses to different grazing intensities, as indicated by changes in the richness index, the diversity index, the dominance index and the evenness index are shown in Fig. 6A-D. No significant differences in species richness or dominance indices were found between the control and any grazing rate in each grazing year, except those between control and the intermediate grazing rate (G0.46) in 2011, indicating consistent responses of the two indices to grazing and apparent intermediate grazing effects. No significant differences in the diversity and evenness index were detected among any treatments, except that between the control and either G0.34 or G0.92 in 2010. When three grazing years were averaged, typical bell-shaped curves in the four indices with grazing intensity were established, which can be significantly described by an up-concave quadratic equation, with grazing explaining over 80% of the variances of the four indices (Fig. 5 A2 - D2).

DISCUSSION

Species Composition and Dominance

Grazing substantially altered the species composition and relative dominance in this meadow steppe in our study area. Our findings show that perennial graminoid significantly decreased, while forbs and other annuals increased at the same time, which is consistent with the results reported in the typical steppe (Wang and Li 1993) and desert steppe (Zhang et al. 2007) of temperate China. Similar results have also been found in north American prairies (Henebry 2003), pampas of South America (Ausden et al. 2005), and Australian and African savannas (Austin et al. 1981). Selective grazing should be the major reason for the short-term changes in species composition (Kraaij & Milton 2006). In this study, the decline of *L. chinensis*, the constructive species, a perennial graminoid and the most favourite and high-quality forage plant was mainly caused by preferential selective grazing of cattle, while rapid increases in *C. duriuscula*, *P. bifurca*, *P. acaulis* and *A. frigida*. were mainly because their unpalatability, as reported by Wang and Li (1993). This selective-grazing induced mechanism is characterized and corroborated by the linear trends between the dominance of these species in community and grazing intensity (Appendix 1). Life forms, due to their different morphologic characters and reproductive style, respond to grazing differently (Briske

and Richards 1995). For example, annuals and forbs have the advantage over other life forms in that they occupy the gaps among tussocks caused by trampling or at urine or dung patches more easily, showing the maximum dominance at heavy grazing plots but minor changes under light grazing, such as *Artemisia spp.* and *Potentilla spp.* Dense bunch grasses such as *Stipa spp.* and *Achnatherum sibiricum* are much more tolerant to grazing than loose bunch grasses, but being less resilient from long-term heavy grazing than the latter (Cingolani et al. 2005). Therefore, *Stipa spp.* remained constant at various grazing rates, whereas the small loose bunch grasses such as *Cleistogenes squarrosa*, *Agropyron cristatum*, *Koeleria.crista* and *xerophytic carex* were at their maximum dominance at intermediate grazing rate (Appendix 1), and declined markedly at heavy grazing rates as observed in our study, being consistent with previous studies (Markus and Sonja 2002; Marty 2005; Josh et al. 2004). This is because appropriate grazing can enhance regrowth and regeneration of loose bunch grasses by fragmenting tussocks, mature deposition, removing standing dead plant tissues, stimulating soil water and nutrient cycles (Wang et al. 2001; Zhang et al. 2007). It should be noted that the effects of long-term grazing on species composition would differ from the short-term ones as reported in this study, which depend more on the site-specific changes in abiotic conditions and evolutionary history of grazing, resilience ability, and resources availabilities as indirectly affected by grazing at different spatiotemporal scales (Cingolani et al. 2005). Changes in dominant species are more sensitive to varying ecosystem-environmental variables than to varying grazing variables, and decreases are more likely among bunch grasses than other life-forms and more likely among perennials than annuals (Milchunas and Lauenroth 1993).

Canopy Traits

Our findings have demonstrated substantial decreases in canopy height and coverage with increasing stocking rates, but minor changes in plant density at light grazing or significant decreases only at heavy grazing, which are in line with a number of previous studies (Noy-meir et al 1993; Belsky et al 1996; Wang et al 1998; Christtansen and Srejecor 1998; Liu et al. 1999, 2002; Zhang et al. 2000),

Effects of grazing on canopy height depend largely on the magnitude of palatable species with erect and high-statured individuals. Because they are more frequently grazed than species with decumbent canopy architectures by cattle. Significant negative responses of canopy height at light and intermediate grazing rates were mainly associated with preferential cattle foraging of perennial grasses such as *L. chinensis*, *K.crista*, and *P. sphondylodes* characterized by erect architectures of high stature, whereas further decreases in canopy height at heavy grazing rates were related to the additional cattle herbivory and trampling of forbs. On the other hand, canopy height determines light availability

and radiation quality to ground, whereby changes in canopy height would markedly influence understory species composition and dominance via exclusive competition or changes in radiation quality as an environmental signal capable of regulating tiller recruitment in grasses (Briske and Richards 1995), leading to feedback impacts on canopy height. Generally speaking, herbivory favours the growth and expansion of short-statured or creeping plants, causing decreases in canopy height. This assumption can appropriately explain the linear dominance increase in *A. frigida* and concurrent decrease in canopy height with increasing grazing rate, mainly because this species is not palatable until late autumn in addition to its typical decumbent growth characteristics. Our findings show that intermediate grazing generally maintained highly constant canopy height among the three years, supporting the intermediate disturbance-stability relation hypothesis (Cingolani et al. 2005).

Counter to the situation for canopy height, canopy cover is more dependent on the dominance of species with decumbent architectures. In this study, marginally significant changes in canopy coverage at various grazing rates in the first grazing year suggest that grazing impacted more on the erect plants and loose bunch grasses, rendering minor effects on the canopy coverage. With grazing duration increasing in the second and third year, coverage of decumbent species such as *Carex* species and *A. frigida* began to be affected by grazing, especially by heavy grazing, probably to a minor extent by foraging, but to a larger extent by trampling, deposition of dung, wallowing and other physical activities, as we observed in the field. Canopy cover is closely associated with site heterogeneity and habitat fragmentation at local scales in response to livestock grazing (Bokdam and Gleichman 2000; Cooper et al. 2005). A number of studies pointed to that canopy coverage change in response to grazing is highly morphologically-based, with grazing-tolerant species such as dense bunch grasses were less sensitive to grazing, rendering plant species-specific coverage changes.

No significant changes in plant density among all the treatments were found in the first year, suggesting that plant density is less sensitive or of time-lag to grazing compared to canopy height and coverage, which is highly consistent with previous studies (Sala et al. 1986; Altesor et al. 2005; Yan et al. 2010). In contrast, significant decreases in plant density in response to grazing in the latter two years were mainly related to dramatic reductions in rhizomatous plants such as *L. chinensis* and loose bunch grasses such as *K. crista*, *P. sphondylodes* and *Agropyron cristatum*. On the one hand, expansion of rhizome would be greatly suppressed by grazing defoliation due to decreased allocation of carbohydrate from canopy to roots, leading to significant reduction in individual plant density of rhizomatous plants. On the other hand, grazing reduces tiller numbers and total basal area on a per unit basis for loose bunch grasses due to their higher locations of meristem buds on plants which are extremely susceptible to herbivory. Whereas heavy grazing led to slight increases in plant density than at intermediate grazing in our study, which presumably was a result of

tussock fragmentation for dense bunch grasses caused by cattle trampling. Briske et al (1995) noted that the most remarkable modification induced by grazing in bunchgrass populations is the reduction in individual plant basal areas and increases in total plant density.

Standing Crop of Biomass

Significant negative linear relations were found between the standing crop of biomass and grazing intensity in each individual year or for three years on average. Other studies have also observed substantial decreases in canopy biomass as well as in above-ground plant production in response to livestock grazing (Altesor et al. 2005). In effect, standing crop of canopy biomass (SCB) is a product of plant production minus concurrent livestock consumption on an annual basis. Therefore, a comparison of the difference in SCB between no-grazing and each grazing rate with grazing duration would be extremely conducive for discerning the effects of grazing on plant growth and canopy reestablishment and the relevant underlying mechanisms. It can be noticed (Fig. 4D) that the impact of light grazing became significant only at the third grazing year and showed a progressively enlarged difference in SCB between no grazing and grazing, indicating that the grazing impact in the first year was mainly on the whole-plant growth of current year due to direct defoliation. A lack of significant changes in SCB in the first two years under light grazing also indicates that compensatory growth of these species in the current year might have played a role large enough in offset for the herbivory loss (Belsky 1986). Many studies show initial increases in plant growth with grazing under conditions of long evolutionary history, low consumption, and few years of treatment (Milchunas and Lauenroth 1993), as is the case in our study. Given the fact that livestock consumption was presumably constant due to fixed number of cattle at each grazing rate among grazing years, the marginally significant decreasing trajectory at light grazing and significant dramatic decreasing trends at heavy grazing of SCB in contrast to an slightly increasing trend of peak SCB at the control with grazing duration indicate that total canopy net primary production had decreased substantially with increasing grazing duration, due to a reduction in the canopy photosynthetic capacity as a result of dominance increases in species of low whole-plant photosynthesis such as dense bunchgrasses and decumbent species, reduced regrowth and recruitment of palatable species, such as rhizomatous and loose bunch grasses, as well as abiotic modifications unfavourable for canopy reestablishment, in response to direct livestock defoliation, selective browsing, trampling, wallowing, and dung and urine depositions, as noted by Briske et al (1995) and Hobbs et al (1996). It is noteworthy that intermediate grazing maintained highly constant differences in SCB with no-grazing, displaying two parallel trajectories of inter-annual SCP dynamics (Fig. 4D), suggesting that grazing at this intensity rendered minimum effects on the community NPP but maximum positive effects on the community stability, supporting the intermediate disturbance-stability relation hypothesis (Cingolani et al. 2005). Milchunas and Lauenroth (1993) noted

that percentage differences in ANPP between grazed and ungrazed treatments were more sensitive to varying environmental factors than to varying grazing variables.

Plant Community Diversity

Plant species diversity offers insights into community composition, and is an important index in revealing the relationships between communities and the environment. The results of the present study indicate that significant changes (increases) occurred in species richness and total canopy dominance only at the intermediate grazing rate and in the third year (Fig. 5), being consistent with a number of previous studies (Altesor et al. 2005; Cingolani et al. 2005) and in support of Connell's (1978) intermediate disturbance hypothesis. In the un-grazed plots of our study, litter accumulation, exclusive competition of bunch grasses for other species, as well as tussock expansion and preoccupation of available gaps made it difficult for more species to get inhabited and regenerate (Oba et al. 2001). In contrast, moderate-grazing led to more heterogeneous habitat, providing diverse gaps for more species to settle down; with increase in stocking rates, only grazing-tolerant or -avoiding species can exist, leading to diminished species richness (Briske and Richards 1995). In addition, under excessive grazing, edible forage species in the community would be over-consumed, leading to a decline in their regeneration ability as noted by Li (1993) and Yang (1999). Huston (1979) argued that native grassland ecosystems often contain only a small number of more competitive species, while moderate grazing leads to multi-species coexistence. Zhao and Sun (2000) observed that under an optimal grazing intensity, species diversity increased, forage species became abundant, and species richness reached maximum in a typical steppe of the same area. Our observation that no significant changes occurred in species evenness under all the grazing rates for each of the three grazing years is inconsistent with many previous study, which might be due to the relatively short duration of our grazing treatment.

IMPLICATIONS

In this study, short-term grazing substantially altered the species composition and relative dominance, standing crop of aboveground biomass, and canopy structural traits, whereas no significant changes in species diversity and evenness occurred in response to different-rated grazing, in this meadow steppe with a long-term evolutionary grazing history and high resources availabilities. Our findings show that perennial graminoids significantly decreased, while forbs and annuals increased at the same time, with increasing grazing intensity and duration; canopy height and coverage decreased substantially with increasing stocking rates, whereas significant changes in plant density occurred only at heavy grazing in the second and third year; significant negative linear relations were found between the standing crop of biomass and grazing intensity in each individual year or for three years on average.

Significantly highest species richness and canopy dominance occurred at the intermediate grazing rate in the third years, and intermediate grazing intensity also maintained a highly constant standing crop of canopy biomass in the three years, being consistent with the intermediate disturbance hypothesis. Our findings imply that monitoring changes in species composition, canopy traits, and standing crop of biomass in grassland communities can provide important references for assessing current grazing management scenarios and conducting timely adaptive practices to maintain the long-term ability of grassland systems to sustain productivity.

ACKNOWLEDGMENTS

We are grateful to many my colleagues with the Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences and the Hulunber Grassland Ecosystem Research Station for assistance with field observations and sample collection. Shimin Liu, Andrew Moore and Shu Zhao made useful comments and English editing on the previous versions of the manuscript. This work was funded by the following projects: International Science and Technology Cooperation Project (2012DFA31290); National Natural Science Foundation of China (41201199); Public sector projects in the Ministry of Agriculture (201003019, 201003061, 200903060, 201303060); National high-tech research and development projects(863) (2012AA102003-4); Major state basic research development program of China (973 Program) (2010CB833502); Basic special funding from the central public welfare scientific research institutes (No. 202-21); Special funding for modern agricultural technology system of the Chinese Ministry of Agriculture.

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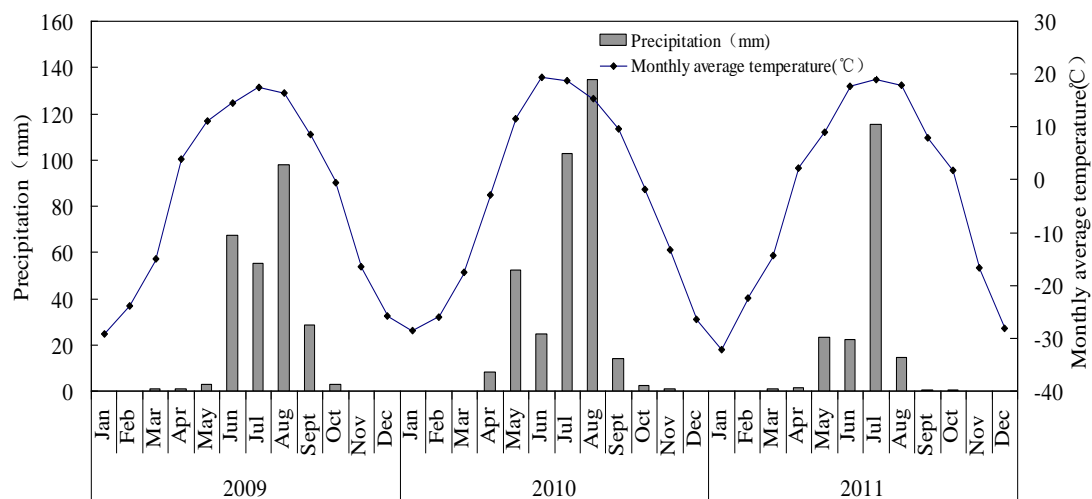


Figure 1. Monthly average temperature and precipitation over selected periods at the experimental site in the meadow steppe of Hulunber, Inner Mongolia

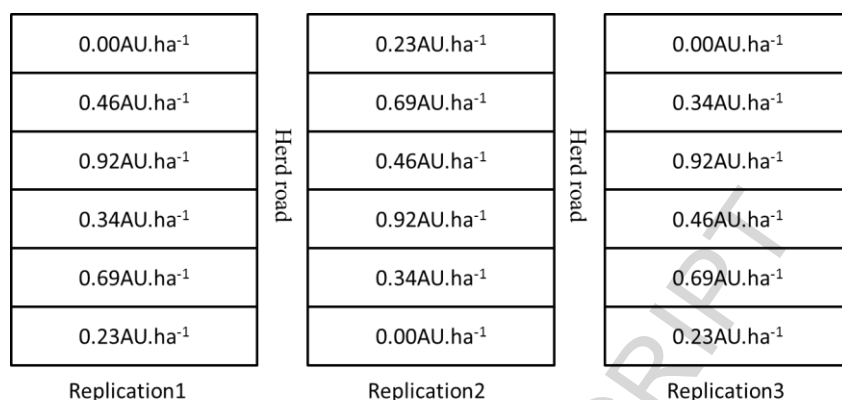


Figure 2. Experimental design diagram of cattle grazing with different stocking rates

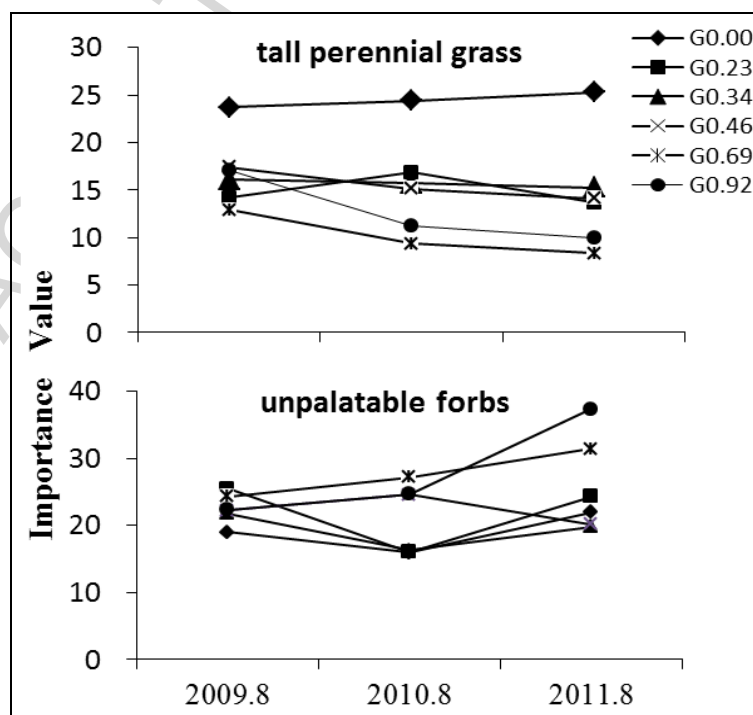


Figure 3. The importance values of perennial grass (*Leymus chinensis* and *Stipa baicalensis*) and unpalatable forbs (*Carex duriuscula*, *Artemisia frigida*, *Potentilla acaulis*, and *Potentilla bifurca*) with grazing year at different grazing stocking rates.

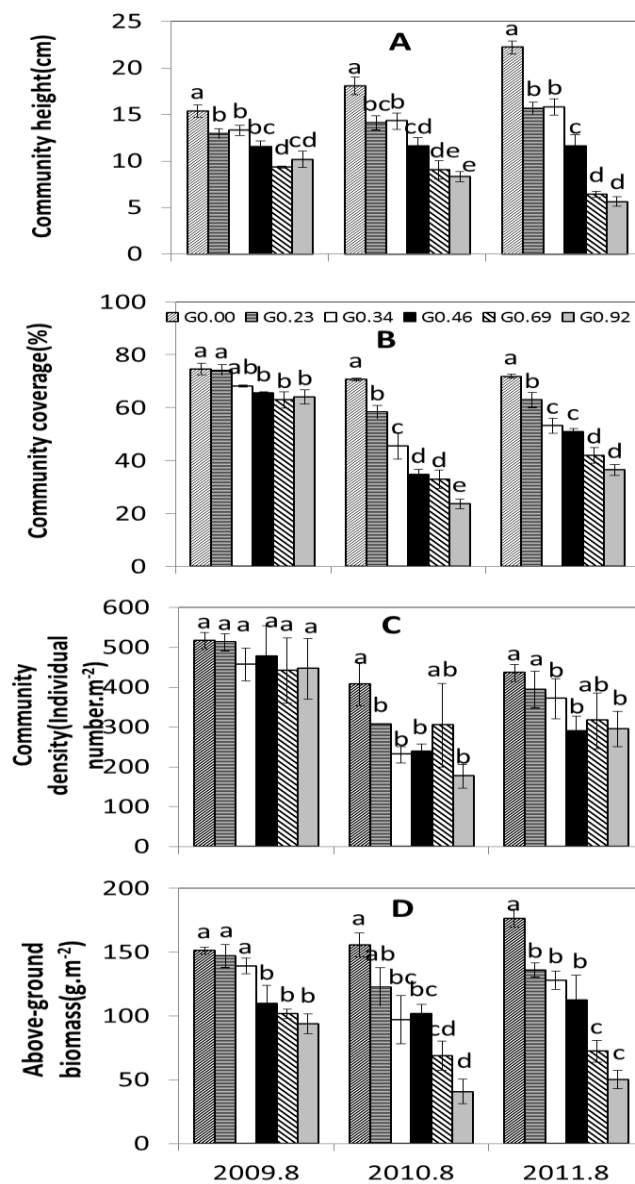


Figure 4. Mean(\pm SE) values for canopy traits at stocking rates in each year, canopy height(A) , canopy coverage(B), community density(C), above-ground biomass(D). Values in a column group share the same lower case letter indicate that they are not significantly different at $P < 0.05$ for the corresponding stocking rates marked with colour.

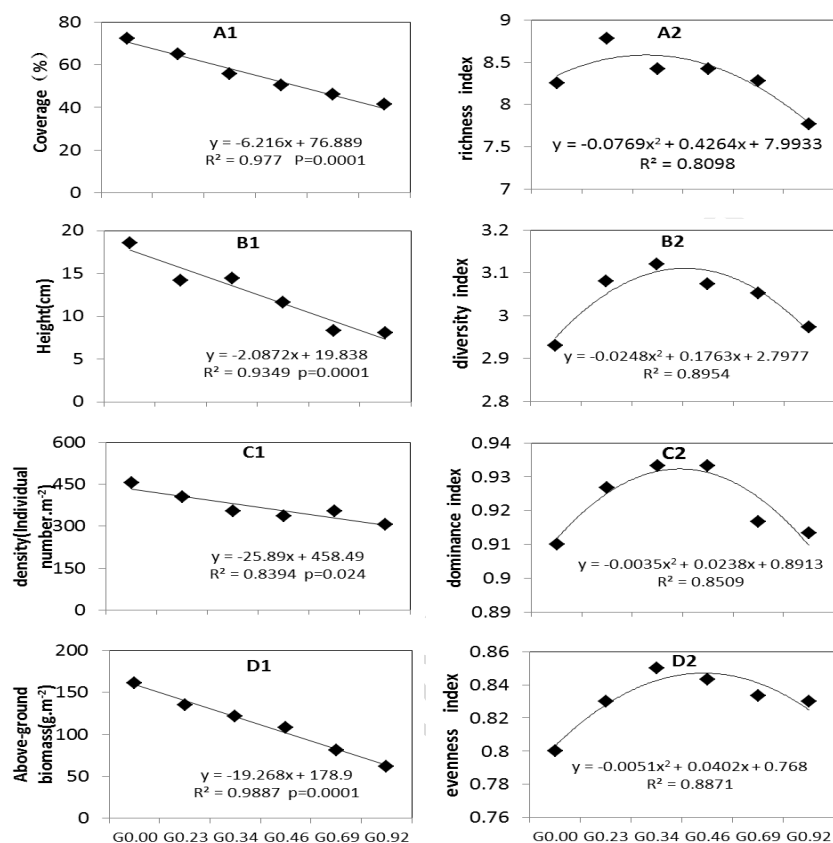


Figure 5. The correlations between canopy traits and stocking rates based on the three-year average, canopy height(A1), canopy coverage (B1), community density(C1), above-ground biomass (D1); and the correlations between species composition traits and stocking rates, richness index (A2), diversity index (B2), dominance index (C2), evenness index (D2).

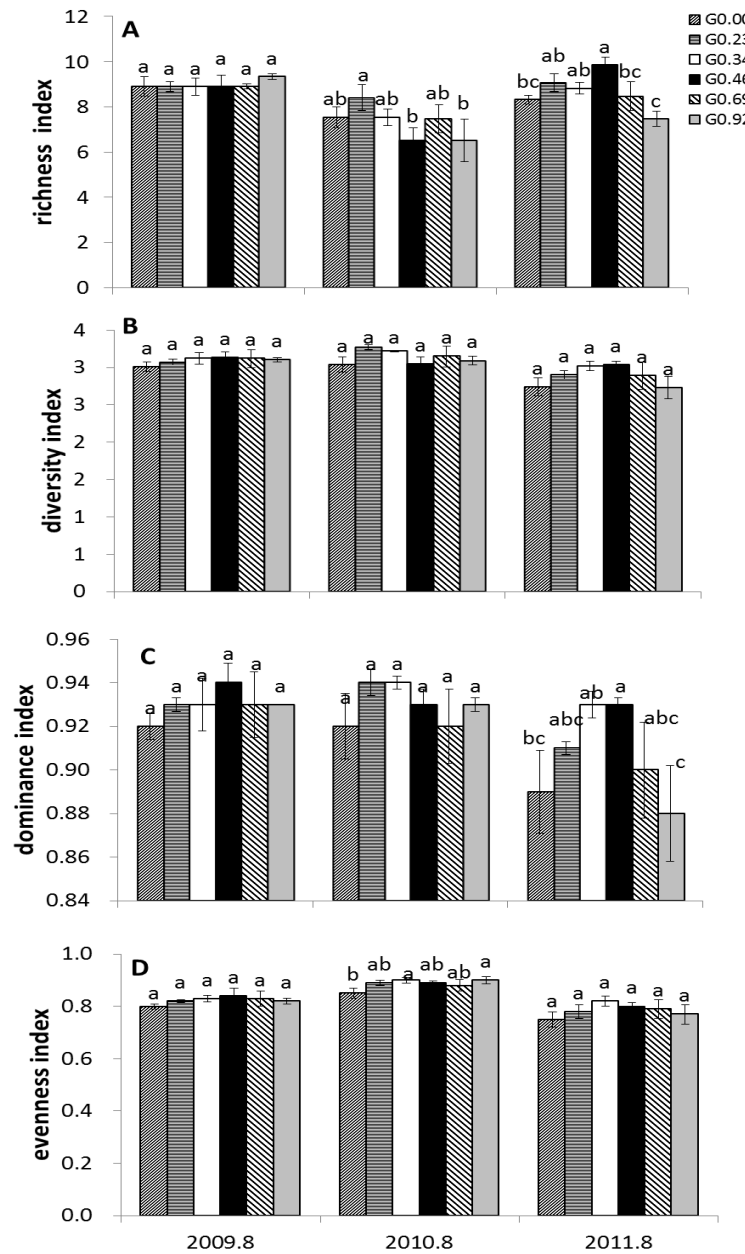


Figure 6. Mean(\pm SE) values of richness index (A), diversity index (B), dominance index (C), and evenness index (D) at different stocking rates in different years. Values in a column group share the same lower case letter indicate that they are not significantly different at $P < 0.05$ for the corresponding stocking rates marked with colour.

Table 1. Canopy and soil traits prior to grazing treatments averaged for plots of each stocking rate

Stocking rate (AU.ha ⁻¹)	Height (cm)	Coverage (%)	Above-ground biomass (g.m ⁻²)	Below-ground biomass (g.m ⁻²)	Soil organic carbon (g.kg ⁻¹)	Soil Total N (g.kg ⁻¹)
G0.00	7.96±0.54a	41.80±3.97a	81.73±8.44a	1389.89±271.51a	36.37±1.69a	3.73±0.12a
G0.23	7.38±0.62a	42.13±8.08a	81.97±13.65a	1442.14±267.28a	39.52±2.16a	3.87±0.27a
G0.34	8.18±0.85a	40.36±5.03a	85.96±19.08a	1381.10±330.20a	37.834±1.48a	3.87±0.30a
G0.46	7.70±0.53a	42.27±5.39a	81.71±9.95a	1234.95±293.64a	37.94±1.85a	3.87±0.10a
G0.69	7.76±0.61a	37.97±4.40a	77.34±11.02a	1149.47±227.86a	39.33±1.83a	4.02±0.18a
G0.92	7.97±0.66a	36.97±4.42a	74.80±7.32a	1352.64±274.63a	39.09±0.45a	4.08±0.07a

Appendix 1. The importance values of major species under different stocking rates in different years in the Hulunber meadow steppe community

		Species	2009.8						2010.8						2011.8					
			G0.00	G0.23	G0.34	G0.46	G0.69	G0.92	G0.00	G0.23	G0.34	G0.46	G0.69	G0.92	G0.00	G0.23	G0.34	G0.46	G0.69	G0.92
Perennial grass	Rhizome type grass	<i>Leymus chinensis</i>	18.93	9.77	11.69	11.81	8.86	12.06	20.97	13.34	12.12	10.06	5.27	7.23	21.31	8.99	10.76	9.18	4.51	7.04
	Type dense clump of grass	<i>Stipa baicalensis</i>	4.75	4.39	4.38	5.64	4.06	5.04	3.46	3.51	3.75	5.05	4.06	3.99	4.02	4.69	4.53	4.94	3.84	2.87
		<i>Koeleria cristata</i>	4.19	3.91	4.58	4.28	3.54	4.34	2.16	2.37	2.32	2.46	1.66	0.76	1.81	2.39	2.91	3.61	2.78	3.35
		<i>Cleistogenes squarrosa</i>	2.93	5.67	4.97	3.67	4.82	3.68	1.24	1.76	2.39	1.79	2.39	2.34	2.27	7.57	3.76	3.84	3.96	6.12
		<i>Festuca ovina</i>								0.61					0.13	0.02				
		<i>total IV</i>	11.87	13.97	13.86	13.59	12.42	13.06	6.76	8.22	8.44	9.26	8.11	7.09	8.23	14.67	11.22	12.39	10.52	12.34
	Hydrophobic type plexus grass	<i>Poa sphondylodes</i>	1.04	0.75	1.15	0.98	0.85	1.45	1.45	3.2	2.73	1.62	1.24	1.67	2.07	2.45	3.25	3.26	0.12	0.39
		<i>Achnatherum sibiricum</i>	0.73	0.18	0.31	0.89	0.67	0.44		0.36		0.68	0.85		0.16	0.09	1.06	0.62	0.48	
		<i>Agropyron cristatum</i>	0.03	0.43	1.26	0.44	0.93	0.1	1.93	1.73	3.22	1.69		0.14	0.77	0.69	2.33	0.38	0.25	
		<i>Hierochloe glabra</i>									0.57					0.14	0.14	0.12	2.41	
		<i>Bromus inermis</i>	—	—	—	—	—	—	—	—	0.26	—	—	—	—	—	—	—	—	—
		<i>total IV</i>	1.77	1.36	2.72	2.23	2.49	1.99	3.35	5.09	6.78	3.99	2.09	1.81	3.37	3.37	6.78	4.38	3.26	0.39
Annual grass		<i>Helictotrichon schellianum</i>	0.33	0.36	0.30	0.35	0.32	0.63	0.5			0.37			0.07	0.23	0.19	0.11	0.11	0.02
Perennial Forb	<i>Carex duriuscula</i>	13.59	16.79	15.27	15.77	16.98	15.89	11.94	11.85	12.43	19.22	20.94	17.84	18.47	19.23	15.29	14.28	21.12	27.73	
	<i>Artemisia laciniata</i>	7.03	7.55	5.96	6.97	7.42	8.32	5.98	6.18	5.38	4.72	4.97	5.98	6.63	9.76	9.27	11.27	9.67	7.87	
	<i>Pulsatilla turczaninovi</i>	5.86	6.46	6.26	6.63	7.36	6.97	5.73	6.57	7.55	5.39	7.46	6.03	6.07	7.83	6.18	8.03	8.94	7.15	
	<i>Serratula centauroides</i>	4.87	4.28	5.38	5.48	5.37	4.92	3.46	2.86	4.27	3.67	3.65	5.51	2.98	3.53	3.57	4.48	4.38	5.04	
	<i>Iris ventricosa</i>	4.37	4.78	3.98	2.98	3.03	3.03	3.36	2.96	2.77	2.93	3.32	2.43	3.98	3.93	4.13	3.38	2.44	1.08	
	<i>Allium tenuissimum</i>	2.85	1.91	2.47	2.52	1.55	2.55	0.67	1.04	0.09	1.61.3	1.31.6	1.31.6	1.05	0.91	1.54	1.77	1.56	2.12	
		5.51	7.72	7.25	5.55	5.55	5.55	7.74	4.69	6.95	9.53	5.33	3.36	5.51	1.47	4.76	7.67	6.67	2.12	

	Species	2009.8						2010.8						2011.8					
		G0. 00	G0. 23	G0. 34	G0. 46	G0. 69	G0. 92	G0. 00	G0. 23	G0. 34	G0. 46	G0. 69	G0. 92	G0. 00	G0. 23	G0. 34	G0. 46	G0. 69	G0. 92
	<i>Thalictrum.sguarrosum</i>	2.5	3.8	3.6	3.0	3.3	3.3	1.6	3.8	3.0	3.8	2.5	3.8	3.2	3.8	4.6	2.3	3.1	2.0
	<i>Allium.ramosum</i>	1.9	2.7	2.1	3.0	1.3	2.1	1.7	1.9	2.1	2.4	2.0	4.0	0.9	0.6	1.3	1.8	1.9	1.7
	<i>Galium.verum</i>	2	6	1.6	1.5	1.5	1.7	1.3	0.9	1.6	2.2	1.1	2.4	1.4	2.7	1.9	2	1.5	1.8
	<i>Potentilla bifurca</i>	1.8	0.6	0.8	0.8	1.9	1.5	1.8	1.6	0.9	1.8	2.5	2.4	1.4	2.1	1.6	2.4	2.1	1.6
	<i>Scorzonera divaricata</i>	4	4	9	4	8	6	5	9	9	2	2	2	7	4	4	2.4	2	8
	<i>Allium.bidentatum</i>	1.7	0.8	1.0	0.5	0.8	0.4	1.9	2	1.3	2	5	8	1.2	1.4	0.7	0.7	1.2	1.5
	<i>Carex pediformis</i>	2	1.9	2.1	2.4	1.4	1.3	1.5	1.9	1.6	1.7	1.2	1.9	1.4	1	0.9	0.7	1.0	0.1
	<i>Artemisia.frigida</i>	6	8	6	6	5	1.3	6	1.9	4	4	8	6	1	1	4	4	7	8
	<i>Potentilla verticillaris</i>	1.3	5.0	1.6	2.6	2.6	2.5	1.0	1.7	3.0	5.3	3.5	3.6	5.3	2.9	5.0	5.9	3.4	2.2
	<i>Saposhnikoria divaricata</i>	6	4	8	2	6	9	8	7	9	3	3	3	2	1	1	4	9	7
	<i>Potentilla acaulis</i>	1.3	2.1	3.1	2.2	2	1.4	1.5	1.8	1.9	2.4	2.6	2.9	1.7	2.2	2.5	2.6	5	5.9
	<i>Bupleurum scorzonrifolium</i>	5	5	7	7	2	3	4	1.8	5	1	2	8	1	2.2	9	1	5	5.9
	<i>Thalictrum petaloideum</i>	1.2	0.9	1.7	0.9	1.1	1.2	1.1	1.1	1.2	0.7	1.3	0.7	1.1	0.9	0.7	0.7	1.3	1.3
	<i>Lilium brownii var. viridulum</i>	3	5	1	8	9	1.2	1	5	2	4	3	4	6	7	1	7	8	1.3
	<i>Schizonepeta multifida</i>	1.0	0.8	0.7	0.7	0.6	0.8	0.7	1.1	1.1	1.1	1.4	1.4	0.0	0.7	0.2	0.8	3.1	2.0
	<i>Iris tigridia</i>	8	3	4	2	8	4	0.6	2	5	5	3	5	0.3	2	9	8	9	2
	<i>Potentilla tanacetifolia</i>	0.8	0.9	1.6	0.6	1.1	0.8	1.2	2.0	1.8	0.8	1.8	1.4	1.1	0.4	2.5	0.4	0.7	0.7
	<i>Heteropappus altaicus</i>	5	8	6	9	9	9	1	3	2	2	7	7	1.1	7	2.5	0.4	1	9
	<i>Euphorbia Esula Linn.</i>	0.7	0.4	0.1	0.8	1.1	0.4	0.3	1.0	0.5	1.0	1.0	4	0.2	0.3	0.3	0.7	0.2	0.1
	<i>Adenophora stenophylla</i>	2	2	7	1	5	9	2	2	9	9	4	4	4	5	6	3	9	4
	<i>Tephrosieris kirlowii</i>	0.7	0.3	0.1	0.3	0.3	1.5	0.3	0.5	0.5	0.5	0.5	0.5	0.2	0.6	0.4	0.5	0.8	0.4
	<i>Sibbaldia adpressa</i>	0.6	1.0	0.8	0.9	1.3	1.0	0.4	1.6	1.6	2.1	1.9	1.0	0.2	0.6	0.4	0.5	0.8	0.4
	<i>Clematis hexapetla</i>	7	2	6	5	6	6	9	4	3	2	1	7	0.0	0.0	0.2	0.2	0.2	0.0
	<i>Taraxacum mongolicum</i>	0.5	0.8	0.7	0.2	0.8	0.3	1.9	1.0	1.0	0.6	1.5	2.0	9	9	5	2	1	9
	<i>Artemisia dracunculus</i>	6	3	4	9	1	1	5	2	9	2	9	3	0.8	1.0	0.4	0.7	0.7	0.3
	<i>Dianthus chinensis</i>	0.4	0.0	0.1	0.2	0.1	0.3	0.0	0.6	1.4	0.5	0.6	0.6	2	2	4	5	6	7
	<i>Sanguisorba officinalis</i>	1	3	5	3	1	2	3	9	8	7	2	2	0.4	0.1	0.4	0.0	0.0	0.0
	<i>Veronica incana</i>	0.3	0.3	0.4	0.3	0.4	0.0	0.8	1.2	0.5	1.0	1.6	7	0.4	0.1	0.4	0.0	0.0	0.0
	<i>Thesium longifolium</i>	4	7	4	4	3	8	7	4	5	7	7	7	0.4	4	5	6	6	7
	<i>Orostachys fimbriatus</i>	0.3	0.1	0.1	0.1	0.1	0.0	0.3	0.4	0.3	0.4	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Allium condensatum</i>	0.3	1.3	0.8	1.9	1.4	1.2	2.2	1.2	2.2	1.6	1.3	2.0	2.2	1.7	0.8	1.6	1.2	1.4
	<i>Leontopodium leontopodioides</i>	2	7	6	2	8	9	1	5	9	2	2	2	7	2	6	7	3	5
	<i>Potentilla conferta Bunge</i>	0.2	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.2	0.0
	<i>Artemisia commutata</i>	4	5	8	0.1	2	6	5	0.1	0.6	0.6	0.7	0.5	2	5	1	5	4	3
	<i>Sedum aizoon</i>	0.2	0.6	0.5	0.4	0.4	0.1	0.1	0.6	0.6	0.7	0.5	0.5	0.0	0.4	0.1	0.3	0.1	0.1
	<i>Thlaspi eochleariforme</i>	2	4	2	1	2	8	7	5	2	3	6	6	4	3	5	7	2	2
	<i>Silene conoidea</i>	0.1	0.4	0.6	0.1	0.3	0.4	1.3	1.4	0.5	0.6	1.5	1.4	0.7	0.5	1.0	0.6	0.1	0.1
	<i>Artemisia gmelinii</i>	4	1	1	1	8	8	1.3	1.4	1	4	8	6	0.7	5	5	9	8	8
	<i>total IV</i>	0.1	0.2	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.4	0.8	2.1
	<i>Dimorphostemon micranthus</i>	3	0.3	0.4	0.7	0.9	1.7	1.1	0.8	0.6	0.3	0.3	0.3	0.0	0.3	0.5	0.3	3	5
	<i>Ixeris polyccephala</i>	3	9	2	4	8	2	7	7	5	7	7	7	5	3	3	0.3	0.3	0.3
	<i>Chenopodium glaucum</i>	0.1	0.1	0.3	0.3	0.4	0.1	0.7	1.0	0.6	1.2	0.7	0.7	0.0	0.0	0.1	0.1	0.0	0.0
	<i>Chenopodium aristatum</i>	8	1	6	5	4	6	1	1	1	5	5	5	7	4	1	7	2	2
	<i>Chenopodium chinensis</i>	0.0	0.3	0.2	0.1	0.0	0.0	0.4	0.5	0.5	1	0.8	0.8	0.1	0.1	0.1	0.1	0.3	0.3
	<i>Lepidium apetalum</i>	9	3	2	7	8	8	7	7	0.5	1	2	2	1	2	2	0.3	0.0	0.0
	<i>Plantago depressa</i>	0.2	0.8	0.2	1.4	0.1	0.7	0.1	0.3	0.5	1.2	0.4	0.8	0.0	0.1	0.0	0.0	0.0	0.0
	<i>total IV</i>	62.	70.	65.	66.	70.	66.	59.	62.	65.	70.	75.	77.	63.	69.	66.	70.	78.	77.
	<i>total IV</i>	24	57	85	47	81	15	21	87	11	98	26	84	6	45	9	5	84	25
Annual forb	<i>Dimorphostemon micranthus</i>	0.6	1.0	0.9	1.3	0.3	0.3				0.1				0.0	0.0	0.0	0.0	0.0
	<i>Ixeris polyccephala</i>	2	6	1	4	9	7				9				1	1	4	2	2
	<i>Chenopodium glaucum</i>	0.1	0.0	0.0	0.0	0.2	0.2	0.3			0.3			0.0	0.0	0.2	0.0	0.1	0.1
	<i>Chenopodium aristatum</i>	8	6	5	5	5	5	1						1	2	1	3	9	9
	<i>Chenopodium chinensis</i>	0.1			0.1	0.0	0.3		0.0	0.2		0.4							
	<i>Lepidium apetalum</i>	0.0			1	6	1		3			6							
	<i>Plantago depressa</i>	3																	
	<i>total IV</i>	0.0	0.0	0.3	0.3	0.4	0.0									0.0	0.0	0.1	0.1
	<i>total IV</i>	4					5									1	1	4	4
	<i>total IV</i>																		

	Species	2009.8						2010.8						2011.8					
		G0. 00	G0. 23	G0. 34	G0. 46	G0. 69	G0. 92	G0. 00	G0. 23	G0. 34	G0. 46	G0. 69	G0. 92	G0. 00	G0. 23	G0. 34	G0. 46	G0. 69	G0. 92
	<i>total IV</i>	0.9 3	1.1 6	1.2 9	1.9 2	0.9 5	1.1 5	0.3 1	0.0 3	0.2 0.2	0.1 9	0.7 6	0 0	0.0 1	0.0 3	0.0 2	0.2 6	0.1 2	0.3 6
Leguminous	<i>Vicia angustifolia</i>	1.2 7	0.7 9	1.1 9	0.3 1	0.8 2	0.9 9	3 4	2.1 4	2.0 4	1.2 9	0.5 1	0.6 8	0.9 5	0.7 5	0.8 5	0.6 2	0.7 4	0.9 4
	<i>Astragalus adsurgens</i>	0.8 8	0.6 7	1.3 1	0.9 3	1.3 7	0.9 7	1.4 6	1.4 5	1.5 3	1.5 7	0.9 9	2.1 7	1.8 3	1.4 8	2.2 2	1.9 2	1.1 5	0.9 5
	<i>Astragalus melilotoides</i>	0.5 9	0.5 7	0.3 6	0.3 3	0.3 1	0.3 1	0.7 1	2.5 1	1.1 1	1.8 8	0.8 0.8	0.0 5	0.1 4	0.0 3	0.0 3	0.0 3	0.0 1	0.0 1
	<i>Cymbaria dahurica</i>	0.5 0.3	0.5 0.2	0.1 0.4	0.1 0.1	0.5 0.5	0.7 0.7	1.1 1.2	1.1 0.8	0.9 0.5	0.4 0.5	1.1 1.1	0.5 0.3	0.0 0.0	0.1 0.0	0.1 0.4	0.0 0.0	0.0 0.1	0.0 0.2
	<i>Oxytropis myriophylla</i>	0.8 8	0.2 6	0.4 4	0.1 8	0.5 5	0.7 5	1.2 5	0.8 7	0.5 8	0.7 0.7	1.1 5	0.3 1	0.0 2	0.0 8	0.4 9	0.0 9	0.1 1	0.2 1
	<i>Thermopsis lanceolata</i>	0.0 7			0.1 3			0.3 9									0.0 6		
	<i>Gueldenstaedtia verna</i>		0.2 1	0.0 3	0.2 7	0.2 6	0.2 1	0.2 4	0.1 9	0.7 2	0.3 5	0.5 6		0.5 6	0.6 2	0.3 4	0.3 1	0.4 9	0.3 1
	<i>Vicia amoena</i>		0.3 6	0.1 5	0.1 9	0.1 8	0.6 9		0.4 5			0.9 4	0.4 7	0.3 1		0.0 3	0.0 3	0.0 5	
	<i>Melilotoides ruthenica</i>		0.1 3	0.2 7	0.7 7	0.1 7	0.2 3	1.6 6	0.6 4	0.5 8	1.2 4	1 1	1.0 4	0.0 1		0.0 3	0.1 5	0.1 2	0.0 7
	<i>Astragalus galactites</i>																		0.0 1
	<i>total IV</i>	3.6 9	3.3 4	3.8 6	3.5 9	4.1 4	4.7 9	9.4 3	9.8 7	7.4 7	5.6 3	8.1 4	5.9 9	3.7 3	3.2 4	4.1 7	3.2 2	2.6 4	2.5 8
<i>Total No. of species</i>		54	55	54	56	53	54	47	54	50	42	48	41	50	50	52	57	51	45

Figure Captions

Figure 1. Monthly average temperature and precipitation over selected periods at the experimental site in the meadow steppe of Hulunber, Inner Mongolia

Figure 2. Experimental design diagram of cattle grazing with different stocking rates

Figure 3. The importance values of perennial grass (*Leymus chinensis* and *Stipa baicalensis*) and unpalatable forbs (*Carex duriuscula*, *Artemisia frigida*, *Potentilla acaulis*, and *Potentilla bifurca*) with grazing year at different grazing stocking rates.

Figure 4. Mean(\pm SE) values for canopy traits at stocking rates in each year, canopy height(A) , canopy coverage(B), community density(C), above-ground biomass(D). Values in a column group share the same lower case letter indicate that they are not significantly different at $P < 0.05$ for the corresponding stocking rates marked with colour.

Figure 5. The correlations between canopy traits and stocking rates based on the three-year average, canopy height(A1), canopy coverage (B1), community density(C1), above-ground biomass (D1); and the correlations between species composition traits and stocking rates, richness index (A2), diversity index (B2), dominance index (C2), evenness index (D2).

Figure 6. Mean(\pm SE) values of richness index (A), diversity index (B), dominance index (C), and evenness index (D) at different stocking rates in different years. Values in a column group share the same lower case letter indicate that they are not significantly different at $P < 0.05$ for the corresponding stocking rates marked with colour.