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Do sheep grazing patterns affect ecosystem functioning in steppe grassland ecosystems in Inner Mongolia?

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ABSTRACT

Overgrazing has driven degradation and desertification of semi-arid grasslands in Northern China over recent decades. Selective grazing by sheep influences sward structure by inducing heterogeneous vegetation patterns comprising overgrazed hotspots and areas rejected by grazing sheep. In this study, we examined the effects of grazing intensity (ungrazed, light and heavy grazing in 2008 and 2010) and grazing system (a mixed system involving continuous grazing alternating annually with hay making vs. a continuous system involving continuous utilization of the same area for grazing) on plant biomass distribution and ecosystem functioning after 4 years and 6 years of controlled grazing in a semi-arid steppe of Inner Mongolia, China. The spatial biomass distribution was determined by sward height measurements converted to biomass and afterwards visualized in biomass distribution semivariograms. Within each of the different areas: grazed (i.e., areas frequently grazed by sheep), rejected (i.e., areas largely avoided by grazing sheep) and fenced (i.e., areas from which grazing had been excluded by fencing), plant species and soil parameters were sampled in order to analyze the mechanisms and effects of grazing patterns on ecosystem functioning. The results revealed a more homogeneous biomass distribution in the ungrazed and heavily grazed plots compared to lightly grazed plots, in which heterogeneous biomass distribution patterns included both overgrazed hotspots and rejected areas. The patch vegetation patterns were consistent between years only under light grazing intensity. However, patch vegetation patterns in the continuous system did not necessarily indicate negative effects on grassland ecosystem functioning. Within the 6 years of grazing experiment, it appears that patchy structure rather than homogeneous patterns showed higher biodiversity, significant variations in litter, soil water content and soil temperature and smaller effects on belowground biomass and carbon storage. Therefore, heterogeneous patchy vegetation patterns are likely to moderate grassland recovery and optimize ecosystem functioning by forming resource islands with sufficient water and nutrients in the short run.

1. Introduction

Overgrazing is a major driver of disfunction in grassland ecosystems (Milchunas and Lauenroth, 1993; Pakeman, 2004; Cingolani et al., 2005). It induces environmental and economic problems, such as degradation and reduced livestock production, especially for plant community under semi-arid and arid climatic conditions. Although the effects of overgrazing have been the subject of several studies (Diaz et al., 2001, 2007; Adler et al., 2005; Schonbach et al., 2012), few studies have investigated the influence of animal grazing behavior on plant growth, animal productivity and ecosystem functioning. Grazed areas can be divided into patches resulting from the grazing behavior of animals. These patches can be characterized into frequently-grazed areas with low or even no soil coverage and rejected areas dominated by mature plant

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species. This variable sward structure may change the microenvironment within a paddock (Burke et al., 1998; Aguiar and Sala, 1999). The patchy pattern in the plant community is considered to be the effect of selective grazing (Teague and Dowhower, 2003; Dumont et al., 2012). Forage quality attracts the livestock to stay in their preferred food patches (Dumont et al., 2012) and grazing animals have the ability to retain their memory of specific food plots (Dumont and Petit, 1998). According to previous studies, young plant materials have clearly better nutrient quality than mature plants (Schonbach et al., 2009). Although grazing-induced vegetation variations are well understood, little attention has been drawn to the effects of the behavior of grazing animals on the spatial distribution of vegetation and the consequent effects on plant communities. It is unclear how grazing patterns affect grassland ecosystem functioning. Moreover, there are few findings concerning the appropriate grazing intensity and grazing management for improving grassland productivity and maintaining steppe ecosystem sustainability in Inner Mongolia. Low stocking rate per unit area under continuous grazing is not a normative practice for protecting grassland, since overgrazed hotspots may also occur under light grazing pressure. In addition, the nutrient imbalance resulting from dung and urine patches of herbivores influence heterogeneity in biomass production and species composition (Macdiarmid and Watkin, 1971; Jaramillo and Detling, 1992; Shiyomi et al., 1998). Therefore, more detailed information about the spatial distribution of vegetation is important to understand the complex interaction of vegetation–animal-grazing patterns.

In this study, we examined the effects of grazing intensity and grazing system (continuous grazing alternating annually with hay making vs. continuous utilization of the same area for grazing) on spatial patch pattern, plant biomass distribution and ecosystem functioning in the fourth and sixth year after the start of a grazing experiment in the Xilin River Basin, Inner Mongolia, China (Schonbach et al., 2009). Plant species and soil parameters across three kinds of vegetation patches (grazed, rejected and fenced area) were evaluated to explore the mechanism and effects of grazing patterns on ecosystem functioning. We hypothesize that grazing intensity affects the pattern of grazing, and that patterns persist over time. The objectives of the study were (1) to determine the spatial biomass distribution under different grazing intensities and management systems; (2) to correlate the spatial vegetation patch pattern with plant and soil variables; and (3) to identify links between grazing patterns and ecosystem functioning in steppe grassland ecosystems.

2. Material and methods

2.1. Study area

The study site is located in a semi-arid, native grassland of the Xilin River catchment, Inner Mongolia Autonomous Region, P.R. China, near the Inner Mongolia Grassland Ecosystem Research Station (IMGERS 43°38′N, 116°42′E, located at about 1200 m a.s.l.). The investigated typical steppe ecosystem is dominated by the perennial rhizome grass *Leymus chinensis*, and the perennial bunchgrass *Stipa grandis* (Bai et al., 2004). The average temperature in the region is 0.9 °C. Mean annual precipitation is 329 mm (1982–2010), with the highest values in the summer from June to August. The variations of temperature and precipitation during our experimental years are shown in Fig. 1. The annual effect of precipitation was determined by using effective annual precipitation (previous-year September to current-year September) instead of using calendar annual (January to December) sums (Ren et al., 2012). The vegetation period lasts for approximately 150 days from April to September. The predominant soil types of this region are calcic chestnuts and calcic chernozemes, which cover acid volcanic parent rock. Soil texture is highly susceptible to wind erosion because it is dominated by fine-sand loess, mainly derived by deflation (Hoffmann et al., 2008).

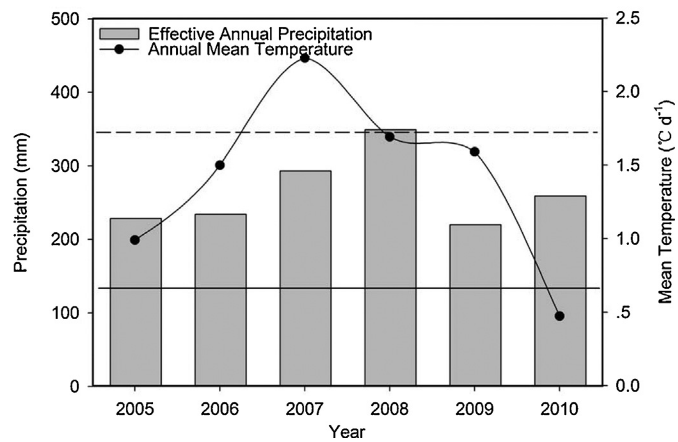

Fig. 1. Effective annual precipitation rates (previous-year September to current-year September) (left *y*-axis) and annual mean temperature (right *y*-axis) from 2005 to 2010. The horizontal dashed line denotes the 20-year (1983–2004) mean effective annual precipitation of 343 mm, and the horizontal solid line denotes the 20-year mean annual temperature of 0.7 °C (Ren et al., 2012).

2.2. Experimental design

A 160 ha sized grazing experiment was established in 2005 and lasted for 6 years. The grazing experiment is described in detail by Schonbach et al. (2011). Until 2003 the area had been heavily used for sheep grazing, after which the grass swards were given a 2-year recovery before the experiment started. The original grazing experimental site covered a total area of 160 ha and was divided into 2-ha paddocks. For the present study, we selected 12 plots, covering a total of 24 ha. The plots were arranged in a split-plot design with two management systems (i.e., continuous grazing vs. mixed grazing system) and three levels of grazing intensity (GI) with two replicates as blocks differing by topographic position (one level block and one sloping block). The continuous grazing system was grazed in each year during the vegetation period (June–September). The mixed grazing system was managed by annual alternations between grazing and hay making. In the present study, the grazing system included ungrazed (GI-0), light (GI-2) and heavy (GI-5) grazing intensity. Stocking rates (i.e. 0, 3.0, and 7.5 sheep/ha) and herbage allowance were used to classify GI (Schonbach et al., 2011, it referred to another set of field experiment). Herbage allowance was calculated as the amount of available aboveground standing biomass for sheep grazing at any point in time during the grazing season (Sollenberger et al., 2005; Schonbach et al., 2011). For the present study, field sampling and measurements were carried out in the fourth (2008) and the sixth year (2010) of the grazing experiment. The fences were set in the beginning of the experiment in 2005. After spatial biomass distribution analysis in 2008, marks were made for all patches. We chose the fences according to the marks we made in 2008. According to the results of spatial biomass distribution, patch vegetation patterns were observed among grazing intensities in different grazing systems. Three types of patches (i.e., grazed (G), rejected (R) and fenced (F) areas) were chosen in both systems in 2008 and in 2010 (Fig. 2), with the fenced area set on part of the grazed area identified from the biomass distribution maps in 2008. Further plant and soil variables were tested under each patch in this system in order to analyze grazing pattern effects.