Effects of stocking rate on the variability of ecosystem productivity in desert steppe

Zhongwu Wang [A], Shuying Jiao [B], Guodong Han [A], Mengli Zhao [A], Jing Wang [A] and Walter D Willms [C]

[A] College of Ecology and Environmental Science, Inner Mongolia Agricultural University, Hohhot, Inner Mongolia 010018, People's Republic of China
[B] College of Resources and Environment, Shandong Agricultural University, Tai'an, Shandong 271018, People's Republic of China
[C] Agriculture and Agri-Food Canada, PO Box 3000, Lethbridge, Albert T1J 4B1, Canada.
Contact email: zhongwuwang1979@yahoo.com

Abstract. Management practices can increase biodiversity and generate corresponding compensatory effects on biomass production, which may reduce inter-annual variability of productivity in some grassland ecosystems. However, it remains unclear how stocking rate influences variability of ecosystem productivity. Four stocking rates were compared in a completely randomized block experiment in the desert steppe of Inner Mongolia, China: non-grazed control (0 sheep/ha/mo), lightly grazed (LG, 0.15 sheep/ha/mo), moderately grazed (MG, 0.30 sheep/ha/mo) and heavily grazed (HG, 0.45 sheep/ha/mo). Aboveground net primary productivity (ANPP) was measured every August for eight consecutive years (2004-2011). ANPP decreased significantly (P<0.05) with increasing stocking rate. Coefficients of variation for community (CV_{comm}) in LG and MG were lower than in the control and HG treatments. Coefficients of variation for both species (CV_{sp}) and functional groups (CV_{PFG}) showed logarithmic relationships with relative density (P < 0.05). Thus, both stocking rate and annual precipitation significantly affected the biodiversity and stability of desert steppe in terms of interannual variability of ANPP. As in other grazed systems, our results indicate that grazing management can alter dominant species and functional group components within the grassland community.

Keywords: Sheep grazing, aboveground net primary productivity, plant functional group, *Stipa breviflora*, ecosystem stability.

Introduction

Ecosystem stability is defined as the capability of a natural system to return to a steady state through self-regulating mechanisms following an external disturbance. Among the potential factors, grazing is critical since it can maintain grassland health and ensure a flow of ecosystem goods and services. In recent years, the effects of species, plant functional groups (PFGs) and community on aboveground net primary productivity (ANPP) have been used to evaluate ecosystem stability (Tilman 1999; Pfisterer and Schmid 2002; Bai *et al.* 2004; Wang *et al.* 2005). Biodiversity can reduce the variability in productivity of ecosystems due to compensatory effects (Naeem and Li 1997; Tilman 1999). The compensatory growth by remaining species within the functional groups is an important factor contributing to the relationship between diversity and stability. While much progress has been made in understanding the effects of grazing on ecosystem stability, it remains unclear how stocking rate influences compensatory effects and variability of biomass productivity. To address this question, the desert steppe biome was chosen as a model system. Desert steppe accounts for 39% (Angerer *et al.* 2008) of a total 78 million ha of grassland in Inner Mongolia, China (Han *et al.* 2008). New knowledge of the effects of management on ecosystem stability is required to ensure the future conservation of desert steppe.

Methods

Areas of desert steppe biome located in the Siziwang Banner of Inner Mongolia in China (41°46′43.6″N, 111°53′41.7″ E; elevation 1456 m) were used in this study. The region is characterised as having a prototypical continental climate with an average annual precipitation of 193 mm and an average annual temperature of 3.43 °C. A completely randomized block experiment comprising 4 grazing treatments × 3 replicates was established in June 2004. In total, 12 paddocks (4.4 ha each) were fenced and stocked with sheep at rates of 0, 0.15, 0.30 and 0.45 sheep/ha/month for non-grazed exclosure (control, CK), lightly grazed (LG), moderately grazed (MG) and heavily grazed (HG) treatments, respectively. For each year from 2004 to 2011, paddocks were grazed from June 1 to November 30. In each paddock, ten portable cages (1.5 m × 1.5 m) were established for ANPP sampling prior to grazing every year. Above-ground net primary productivity (ANPP) was measured in August by harvesting an area of 1 m^2 inside each cage. All data were analyzed as a completely randomized block design according to the

MIXED procedure analysis of variance (GLM) performed with SAS (SAS Institute 2008).

Results

Effect of stocking rate on ANPP

Stocking rate had a significant impact on mean ANPP across the eight years of the experiment. Mean ANPP was 867 kg DM/ha in the control treatment, 665 kg DM/ha in the light stocking treatment, and 475 kg DM/ha in the heavy stocking rate treatment. The effect of stocking rate was generally consistent across the eight years of the experiment (Fig. 1).

Effect of stocking rate and year on plant functional groups

Shrubs and semi-shrubs (SS) constituted the highest percentage of ANPP of all of the PFGs (41.8%). Perennial bunchgrasses (PB) constituted the second highest PFG with 37.6% of ANPP. The heavy stocking rate treatment significantly decreased SS components and increased PB components in the plant community (P<0.05). Moreover, there were significant negative correlations between SS and PB as well as SS and perennial rhizome (P<0.05). The same significant negative correlations were also found between PB and AB as well as between SS and AB (P< 0.05) (Table1).

Coefficients of variation

The CV in community (CV_{comm}) was lower in the LG (72.0) and MG (70.6) treatment than in the control (78.0) and HG (74.3) treatments. The CV_{PFGs} in HG treatment (209.2) was higher than the other stocking rate treatments (CK, 160.2, LG, 160.0 and MG, 183.9). The CV in ANPP at the individual species level (CV_{sp}) ranged from 75.6% to 1676.3%. Species with higher relative biomass tended to have lower CV_{sp}. The relationship between CV_{sp} and the species rank is shown in Figure 2. The slope of the relationship was greater for the heavy stocking rate treatment compared to other stocking rates (Fig. 2).

There was a significant negative logarithmic relationship between relative species density and CV_{sp}, also between relative density and CV in ANPP at the functional group level (CV_{PFG}, P<0.05) (Fig. 3).

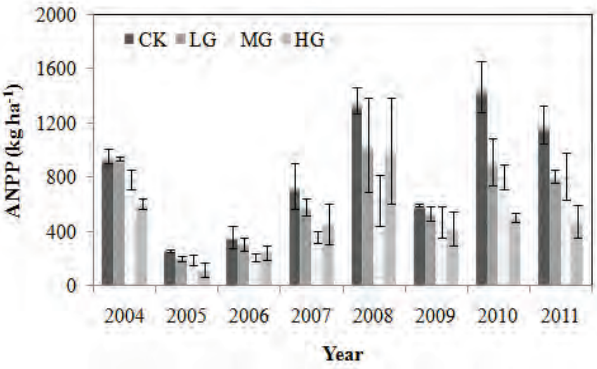

Figure 1. Annual net primary productivity (ANPP) of desert steppe in Inner Mongolia under different stocking rates of sheep over eight years. CK = control, 0 sheep/ha; LG = light grazing, 0.15 sheep/ha/month; MG = moderate grazing, 0.30 sheep/ha/month; HG = heavy grazing, 0.45 sheep/ha/month.

Table 1. Pearson correlation coefficients for percentage contribution to total biomass of different plant functional groups in vegetation of the desert steppe in Inner Mongolia.

	PB[1]	PR	SS	PF	AB
PB	1	-0.473**	-0.453**	-0.283	-0.436*
PR		1	0.496**	-0.029	-0.064
SS			1	-0.201	-0.551**
PF				1	0.149
AB					1

[1] PB perennial bunchgrass; PR perennial rhizome grass, PF perennial forbs, SS shrubs and semi-shrubs; AB annuals and biennials. * P<0.05; ** P<0.01

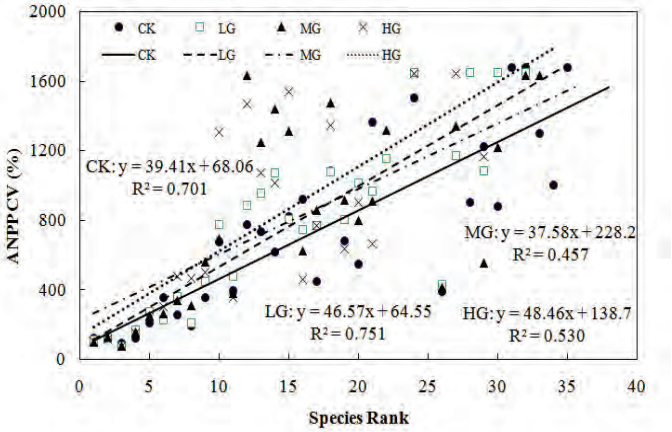

Figure 2. Coefficients of variation (CV) in ANPP at species-level against relative density-based species rank.

Discussion

Within the PB and SS functional groups, *Artemisia frigida* was more palatable than *Stipa breviflora* and *Cleistogenes songorica* (unpublished data). Due to its palatability, *A. frigida* received increased grazing pressure with the increase in stocking rate. Perennial bunchgrasses, especially *C. songorica*, are more resistant to grazing (Holechek *et al*. 2004). The negative correlations among PFGs demonstrated the existence of compensatory growth among different PFGs.

Grazing reduced variation in productivity. The CV was higher in all stocking rate treatments than in the control treatment at both species and PFG levels. Productivity from the HG treatment had the highest variation compared to the other stocking rate treatments throughout the study. Compared with the control, MG and HG, LG was most beneficial to the conservation and maintenance of productivity and ecosystem stability because the CV was lowest in this treatment. Both CV_{sp} and CV_{PFG} were negatively correlated with relative density, which is generally consistent with Bai *et al*. (2004). However, the relationship between CV_{PFG} and relative density observed by Bai *et al*. (2004) was linear whereas the relationship between CV_{sp} and ANPP, and between CV_{PFG} and ANPP, in this study was logarithmic. This may indicate that ecosystem stability in the desert steppe is more susceptible to ANPP fluctuation than in other environments. Ecosystem stability consistently increased from species to PFG to the community level, as demonstrated by decreasing CVs for each level. For example, with the variation of precipitation amount and timing, the ANPP CV of individual species ranged from 5.62 % to 387.30%; the PFG CV ranged from

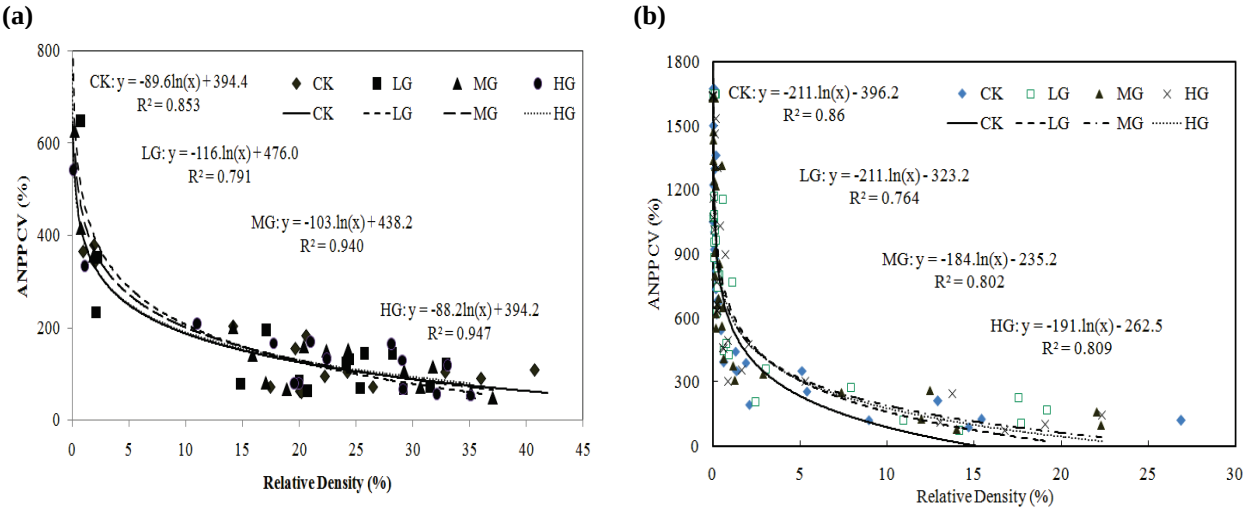

Figure 3. The relationship between (a) relative species density and CV_{PFG}, and (b) relative species density and CV_{sp}.

32.48% to 447.21%; and the community CV ranged from 10.3% to 99.8%. These results generally accord with previous studies. Functional groups have greater resistance to most disturbances (*e.g.*, grazing and fire) than individual species in grassland (Lavorel *et al.* 1999).

Conclusion

ANPP decreased significantly with increasing stocking rate. Ecological compensatory effects existed at different hierarchical levels among species and PFGs. Ecosystem stability increased from species to functional groups to the community level. Grazing dampened variation in inter-annual productivity, thereby increasing ecosystem stability. In desert steppe, long-term studies are required to provide more insights into plant community response and function while also gathering key information for the management and conservation of the grassland resource of Inner Mongolia.

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