

Article

How Seasonal Grazing Exclusion Affects Grassland Productivity and Plant Community Diversity

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Abstract: The Sanjiang Plain is famous for its concentrated distribution of natural wet grasslands. These wet grasslands are an important source of seasonal pasture or hay in the area. However, changes in community structure and ecosystem function have already occurred in wet grasslands because of overgrazing and climate change, resulting in severe grassland degradation. Exploring a reasonable grazing management strategy is crucial for improving grassland species diversity, increasing grassland productivity, and maintaining sustainable grassland utilization. We investigated the effects of five grazing management (GM) strategies (no grazing through the growing season (CK), spring grazing exclusion (Spr-GE), summer grazing exclusion (Sum-GE), autumn grazing exclusion (Aut-GE), and grazing through the growing season (G)) on the productivity, community composition and structure of wet grasslands in the Sanjiang Plain under three grazing intensities (GI) (light (L), moderate (M), and heavy (H)). Results showed that Spr-GE and Sum-GE were beneficial in increasing total aboveground biomass (AGB), but decreased plant community diversity in Spr-GE due to increased intraspecific and interspecific competition. The exclusion of different seasonal grazings changed the composition of plant communities. At the level of functional groups and dominant species, Spr-GE had a significant effect on most functional groups and dominant species' characteristics, while Aut-GE had little effect on most functional groups and dominant species' characteristics. However, different functional groups and dominant species had different responses to seasonal grazing exclusion. In addition, under M, there were significantly improved grassland total AGB and PF AGB. The results indicated that Spr-GE with M may be an effective livestock-management strategy to protect grassland vegetation and community diversity, as well as to restore degraded grassland.



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Keywords: wet grassland; seasonal grazing exclusion; aboveground biomass; species diversity; grazing management

1. Introduction

China has the third largest grassland area in the world, covering 3.9×10^8 ha, or 41% of China's total terrestrial area [1]. Grassland-based animal husbandry in Northern China provides 33% of goat and sheep meat, 70% of wool, 14% of beef and 10% of milk produced in China [2]. Livestock grazing represents a significant human disturbance in grasslands [3], and plays an important role in grassland ecosystem dynamics [4]. Grazing can positively or negatively affect grassland productivity and plant diversity by altering abiotic aspects of grassland ecosystems [2,5,6]. Moderate grazing may increase spatial heterogeneity by inhibiting the canopy of high-growth dominant species and increasing light availability, promoting the establishment of grazing-tolerant and avoided species, resulting in rapid changes in community composition and increased species diversity [7,8]. However, high-intensity grazing not only directly alters plant community structure and composition (such

as reduction in aboveground biomass) [3,9], but also exacerbates resource pressures on palatable species (i.e., soil water-holding capacity and nutrient availability), reducing plant diversity and community productivity [8,10,11]. In addition, the effects of grazing on plant diversity and productivity also depend on regional differences in soil fertility, water availability, and avoidance or tolerance strategies of plants [8,12] and the management system adopted [13]. For example, previous studies have shown that livestock under continuous grazing regimes frequently reuse heavily grazed patches because of the higher palatability of new young leaves, and that repeated grazing in heavily grazed patches increases grazing pressure and soil compaction and decreases species diversity in these patches [14–16].

With the continuous expansion of animal husbandry in Southwest China, grassland resources are facing great pressure [17]. Studies have shown that 90% of grasslands in China have been degraded to varying degrees, and that the degradation trend continues [18]. Grazing exclusion is considered to be an effective way to prevent the detrimental cycle of grassland degradation and restore grassland ecosystems and soil fertility [19,20], and grazing exclusion has become the main management measure of degraded grassland restoration [21]. However, grazing exclusion is still controversial for grassland species diversity and productivity [22,23]. A large number of studies have shown that grazing exclusion may lead to the decline of species richness and biodiversity in grassland communities [24–27]. For example, grasses are more competitive than other growth forms, and grazing exclusion leads to a decrease in species richness by displacing low-adapted grazing species [28,29]. In fact, the effects of grazing exclusion on grassland species diversity and productivity depend on many factors, such as grassland type [13], grazing exclusion duration [30], grazing exclusion period [28], and climatic conditions [31]. Therefore, specific research on grazing management strategies is essential to restore degraded grassland structure and function and maintain the production of grassland ecosystems.

Seasonal grazing exclusion is a simple and effective strategy to change the composition, characteristics and diversity of grassland communities [32]. Seasonal grazing exclusion not only gives plants the opportunity to recover leaf area, produce seeds, and accumulate reserves [33], but also improves grassland primary productivity and species richness [34,35]. At the same time, seasonal grazing exclusion also reduces the outflow of energy and nutrients from the soil–plant system to consumers (livestock) [36], especially for the more productive and high-quality palatable grasses [37], and increases the decomposition of plant litter and promotes nutrient recycling [38,39]. Secondly, seasonal grazing exclusion limits the trampling of livestock and improves soil properties, thereby increasing water retention and improving vegetation habitat [40]. It is well known that spring is the main growing and flowering period for many annual and perennial grasses in temperate biomes. Spring grazing exclusion can effectively increase the abundance of perennial weeds and promote the growth of annual and grazing sensitive plant species [32,41]. However, most previous studies on grassland exclusion have been grazing exclusions during the growing season, and there is still a gap in the study of seasonal grazing exclusion on grassland productivity and community diversity. Therefore, it is necessary to conduct seasonal grazing exclusion research for appropriate grazing management strategies.

The Sanjiang Plain is known for its concentrated distribution of natural wet grasslands. Wet grasslands are generally more productive than upland grasslands [42–44] and are an important source of seasonal pasture or hay [44–47]. However, because of extreme changes in community structure and ecosystem function of grasslands caused by overgrazing, the degradation of grasslands has occurred [48]. Moreover, with warm and dry climates predicted by climate change models, upland grassland productivity is expected to decrease in the future [49,50], and grazing pressure on wet grasslands may increase [51]. Therefore, it is very important to explore reasonable grazing management strategies to improve grassland species diversity and productivity, and maintain sustainable grassland use. At present, it is not clear how differences in grazing intensity and management strategies affect the maintenance of biodiversity and productivity of the wet grasslands. Therefore,

the main objectives of this paper are to study (1) effects of seasonal grazing exclusion on grassland productivity and community diversity under different grazing intensities, and (2) assess the effect of seasonal grazing exclusion on functional groups and dominant species of plant communities under different grazing intensities.

2. Materials and Methods

2.1. Site Description

The experimental area is located in Baoqing County, Shuangyashan City, Heilongjiang Province, China (45°47'8" N–46°35'55" N; 131°14'16" E–133°29'48" E), altitude 300–400 m. The region has a cold temperate continental monsoon climate. The average annual temperature is 2.3–2.4 °C, and winters are long and dry. The average temperature in January is –21 to –18 °C, and the annual extreme minimum temperature is –37.2 °C. The summer is warm and rainy, and the average temperature in July is 21 to 22 °C, and the annual extreme maximum temperature is 37.2 °C. The annual accumulated temperature 2500–2700 °C, and the frost-free period is 140–150 days. The average annual precipitation is 551.5 mm, and 75–85% of it is concentrated in June to October. The average annual sunshine volume is 2059 h, and the average annual wind speed is 2.5 m/s. The soil type is marsh meadow soil. The grassland types in the experimental area were peat meadows. The dominant species was *Deyeuxia angustifolia* (Kom.) Chang comb. Nov., and the main companion species were *Carex lasiocarpa* and *Carex pseudo-curaica*.

2.2. Experimental Design

In June 2010, a completely randomized block design was used with three grazing intensities (GI): light grazing (L), moderate grazing (M), and heavy grazing (H). Five grazing management (GM) strategies were used: no grazing through the growing season (CK), spring grazing exclusion (Spr-GE), summer grazing exclusion (Sum-GE), autumn grazing exclusion (Aut-GE), and grazing through the growing season (G) (Table 1). One cow with a body weight of 454 kg was considered as one animal unit (AU) based on the American Grassland Management Association in 1997. The four stocking rates were: CK: 0 AU•hm^{−1}•month^{−1}, LG: 0.6 AU•hm^{−1}•month^{−1}, MG: 1.0 AU•hm^{−1}•month^{−1} and HG: 1.4 AU•hm^{−1}•month^{−1}. To avoid the effects of livestock numbers on feed intake and feeding times and on soil trampling, we varied the area of each experimental area to ensure that the number of animals in each experimental area was approximately the same during grazing. Therefore, the test areas of CK, L, M and H were 0.25 hm², 3.56 hm², 2.13 hm² and 1.53 hm², respectively (Figure 1). In the center of the grazing area with different stocking rates, the grazing exclusion area (25 m²) was set up, and the fixed position was mobile. That is, the grazing exclusion plots in spring moved to the summer position in summer, and then moved to the autumn position in autumn. Local cross beef cattle (local ♀+ Simmental ♂) (18–20 months of age) were selected for the grazing experiment. The grazing season is from June to September each year from 6 a.m. to 7 p.m. After grazing, the animals are driven out of the grazing area and into the pens without feed or water. After two days in captivity, the animals once again enter the grazing area. Grazing began in 2010 and continued for three years. The plot had not been grazed or mowed for five years prior to our experiment.

Table 1. Experimental design of seasonal grazing exclusion.

GM	Grazing Exclusion Period	Grazing Period
CK	5.15–9.25	
Spr-GE	5.15–6.24	6.25–9.25
Sum-GE	6.25–8.4	5.15–6.24 8.5–9.25
Aut-GE	8.5–9.25	5.15–8.4
G		5.15–9.25

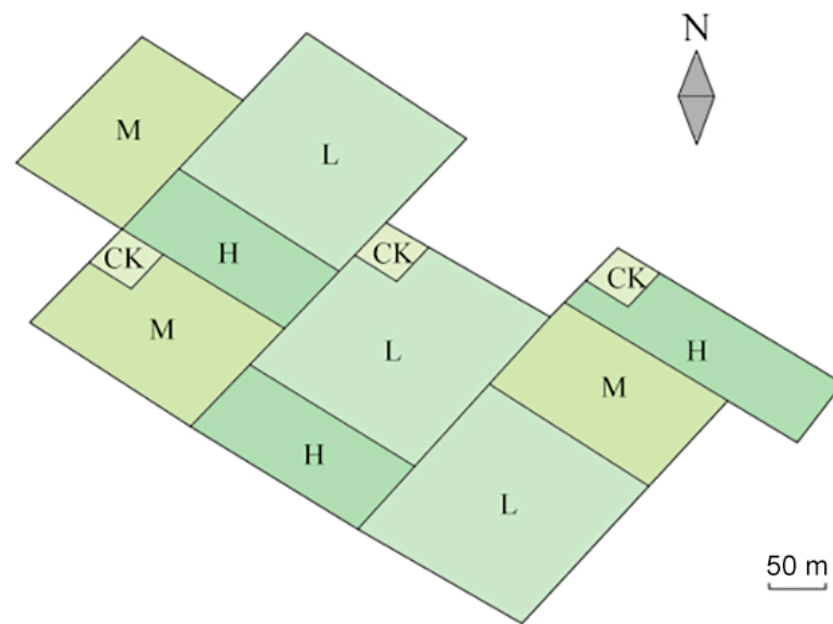


Figure 1. Map of the experimental field (“L” means light grazing, “M” means moderate grazing, “H” means heavy grazing, “CK” means no grazing through the growing season).

2.3. Sampling and Measurements

During the study period, all experimental data were measured in August of each year. When measuring plant data, three $1 \times 1 \text{ m}^2$ quadrats were randomly arranged in each experimental area, and the distance from the edge was at least 1 m to avoid edge effects. We divided the plant community into four functional groups: PG (perennial grasses), PS (perennial sedges), PF (perennial forbs), and ABH (annual and biennial herbs). After the litter was removed, the cover, height and density of the individual plants in each square were determined, then trimmed to the ground and placed in marked paper bags by species. They were then dried at 65°C for 48 h and weighed to obtain aboveground biomass (AGB). Species richness was estimated from the number of species on the quadrat scale. Margalef’s richness index was calculated as follows:

$$R_1 = \frac{S - 1}{\ln N}$$

where N is the total number of individuals of all species, and S is the number of species. The Shannon-Wiener-Index was calculated as follows:

$$H' = -\sum P_i \ln P_i \quad (1)$$

where P_i is the proportion of individual species i representing the relative density of plant species (species density/total density for all species $\times 100$). Pielou’s index was calculated as follows:

$$JP = -\frac{\sum P_i \ln P_i}{\ln S} = \frac{H'}{\ln S}$$

The Simpson diversity index was calculated as follows:

$$D = 1 - \sum (P_i)^2$$

Importance value was calculated as follows:

$$\text{Importance value (\%)} = (\text{Relative density} + \text{Relative coverage} + \text{Relative biomass})/3$$

$$\text{Relative density} = \text{Number of individuals of a plant species} / \text{Number of individuals of all plant species} \times 100\%$$

Relative coverage = Coverage of a plant species/Sum of coverage of all plant species \times 100%

Relative biomass = Biomass of a plant species/Sum of biomass of all plant species \times 100%

2.4. Statistical Analysis

All statistical analyses were performed in R 4.1.2 [52]. Statistical significance was defined at the 95% confidence level ($\alpha = 0.05$). The “lmer” function in “nlme” package was used to establish mixed-effect modeling [53], and the restricted maximum likelihood method was used to estimate the parameters. Years (Y), GI and GM were included as fixed effects and repeated measures were included as random effects. Mixed-effect modeling was used to analyze the effects of different Y, GI and GM and their interactions on the total AGB, plant community diversity, different plant functional groups and dominant species AGB, cover, height and density. We use the Shapiro-Wilk test to test whether the residuals of all analyses were normally distributed. For data that did not satisfy the normal distribution, we used log10 to transform. After the main effect or interaction effect was significant, our “emmeans” package [54] conducted a post hoc test or a simple main effect test. After the simple main effect was significant, the simple effect was tested. TukeyHSD was then used to compare the differences between the means. The “lm” function was used for general linear regression to analyze the relationship between total AGB and species number in each quadrat. To assess differences in plant community composition, we analyzed plant importance values using principal co-ordinate analysis (PCoA). Based on the “vegan” package [55], the Bray-Curtis distance matrix between different squares was calculated, the similarity of 999 permutations (ANOSIM) was analyzed, and the differences in plant community composition in different squares were visualized by PCoA. Significance of the permanova statistic R was tested using 999 permutations of the distance matrix of quadrats.

3. Results

3.1. Total Aboveground Biomass

During the experiment, GM and GM-GI interactions had a significant effect on total AGB ($p < 0.05$), while Y and the interactions of GM, GI, and Y had no effect on total AGB (Table 2). Under L, there was no significant difference in total AGB among different GM ($p > 0.05$). Under M, Sum-GE had the most significant increase in total AGB. The total AGB of Sum-GE-M increased by 108.64% and 30.60% compared with G and CK, respectively. Under H, the total AGB increased most significantly in spring. Compared with G, it increased by 47.98%, and compared with CK, it only decreased by -2.95% (Figure 2).

Table 2. Analysis of variance for effects of grazing management, grazing intensity, year (Y) and their interactive effects on plant diversity, productivity, properties of functional groups and dominant species. “****” means $p < 0.001$; “***” means $p < 0.01$; “*” means $p < 0.05$.

Effects		Y	GM	GI	Y \times GM	Y \times GI	GM \times GI	Y \times GM \times GI
Plant diversity	Margalef’s index	0.696	<0.001 ***	0.073	0.045 *	0.901	0.353	0.697
	Simpson diversity	0.816	0.021 *	0.866	0.220	0.929	0.247	0.994
	Shannon-Wiener- Index	0.654	0.175	0.158	0.959	0.162	0.397	0.546
	Pielou’s index	0.895	0.001 **	0.034 *	0.212	0.899	0.772	0.962
Plant β diversity	Bray-Curtis	<0.001 ***	<0.001 ***	0.783	0.001 ***	0.328	0.362	0.223
Species number	Species number (taxaS)	0.530	<0.001 ***	0.207	0.035 *	0.955	0.423	0.686
Total ABG	Total ABG	0.524	0.027 *	0.927	0.267	0.973	0.031 *	0.157
Functional group cover	ABH cover	0.930	0.455	0.607	0.459	0.694	0.050 *	0.057
	PG cover	0.8967	<0.001 ***	0.500	0.146	0.686	0.031*	0.281
	PS cover	0.990	0.427	0.438	0.693	0.702	0.960	0.951
	PF cover	0.884	0.078	0.082	0.523	0.776	0.202	0.516
Functional group AGB	ABH AGB	0.691	0.278	0.284	0.997	0.716	0.346	0.521
	PG AGB	0.948	0.075	0.105	0.811	0.856	0.250	0.356
	PS AGB	1.000	0.454	0.372	0.678	0.761	0.329	0.547
	PF AGB	0.653	0.325	0.039 *	0.557	0.425	0.062	0.427

Table 2. Cont.

Effects		Y	GM	GI	Y × GM	Y × GI	GM × GI	Y × GM × GI
Functional group density	ABH density	0.998	0.601	0.536	0.799	0.481	0.679	0.554
	PG density	0.981	0.091	0.749	0.270	0.998	0.180	0.284
	PS density	0.814	0.182	0.142	0.510	0.287	0.927	0.971
	PF density	0.824	0.011 *	0.260	0.226	0.234	0.249	0.337
Functional group height	ABH height	0.922	0.038 *	0.079	0.144	0.805	0.282	0.387
	PG height	0.489	<0.001 ***	0.005 **	0.167	0.204	0.404	0.3867
	PS height	0.920	0.035 *	0.320	0.269	0.408	0.635	0.736
	PF height	0.765	<0.001 ***	0.002 *	0.094	0.164	0.404	0.781
Dominant species cover	<i>D. angustifolia</i> cover	0.909	0.821	0.672	0.975	0.815	0.436	0.591
	<i>S. brachyotus</i> cover	0.796	0.004 **	0.015 *	0.516	0.406	0.320	0.703
	<i>T. ohwianum</i> cover	0.891	0.037 *	0.023 *	0.611	0.665	0.123	0.403
	<i>S. radians</i> cover	0.992	<0.001 ***	0.022 *	0.119	0.320	0.109	0.114
Dominant species AGB	<i>D. angustifolia</i> AGB	0.927	0.146	0.092	0.892	0.861	0.207	0.306
	<i>S. brachyotus</i> AGB	0.523	0.175	0.328	0.884	0.521	0.162	0.253
	<i>T. ohwianum</i> AGB	0.803	0.583	0.441	0.660	0.776	0.340	0.590
	<i>S. radians</i> AGB	0.996	<0.001 ***	<0.001 ***	0.375	0.087	<0.001 ***	0.109
Dominant species density	<i>D. angustifolia</i> density	0.762	0.523	0.964	0.648	0.965	0.110	0.455
	<i>S. brachyotus</i> density	0.758	0.006 **	0.035 *	0.434	0.452	0.303	0.803
	<i>T. ohwianum</i> density	0.904	0.003 **	0.232	0.173	0.957	0.494	0.518
	<i>S. radians</i> density	0.798	0.063	0.075	0.230	0.409	0.012 *	0.074
Dominant species height	<i>D. angustifolia</i> height	0.914	0.213	0.141	0.652	0.316	0.063	0.245
	<i>S. brachyotus</i> height	0.484	0.181	0.163	0.361	0.685	0.477	0.714
	<i>T. ohwianum</i> height	0.459	0.029 *	0.224	0.064	0.939	0.651	0.798
	<i>S. radians</i> height	0.864	<0.001 ***	<0.001 ***	0.248	0.123	0.002 **	0.033 *

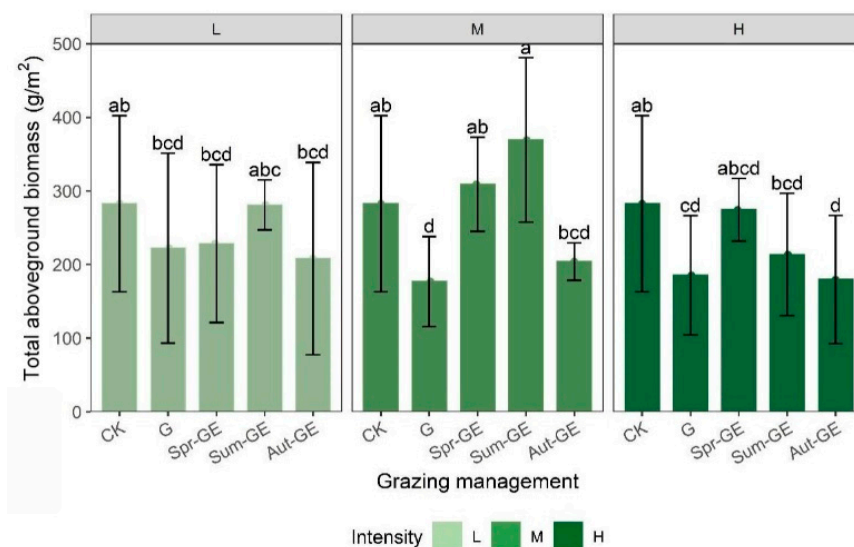


Figure 2. Differences in responses of aboveground biomass to grazing intensities and grazing management. Different lowercase letters indicate significant differences between grazing treatments ($p < 0.05$). “CK” means no to graze through the growing season, “G” means grazing through the growing season, “Spr-GE” means spring exclusion, “Sum-GE” means summer exclusion, and “Aut-GE” means autumn exclusion. “L” means light grazing, “M” means moderate grazing, and “H” means heavy grazing.

3.2. Species Diversity and Composition

GM and Y-GM interactions had a significant impact on Margalef’s richness index, GM had a significant impact on Simpson diversity, and GM and GI had a significant impact on Pielou’s index. The interaction of Y, GM and GI had no significant effect on the diversity index (Table 2). Compared with CK, seasonal grazing exclusion increased Margalef’s richness index, with the smallest increase in Spr-GE, but seasonal grazing Margalef’s richness index was lower than G. As the years of the study increased, Margalef’s richness index decreased in Aut-GE and increased in Sum-GE (Figure 3). Compared with CK, Sum-GE and Aut-GE increased Simpson diversity, while Spr-GE Simpson diversity was not significantly different from CK. There was no significant difference in Simpson diversity

between Sum-GE, Aut-GE and G (Figure 3). Pielou's index was decreased in Spr-GE, and there was no significant difference in Pielou's index between different GI (Figure 3).

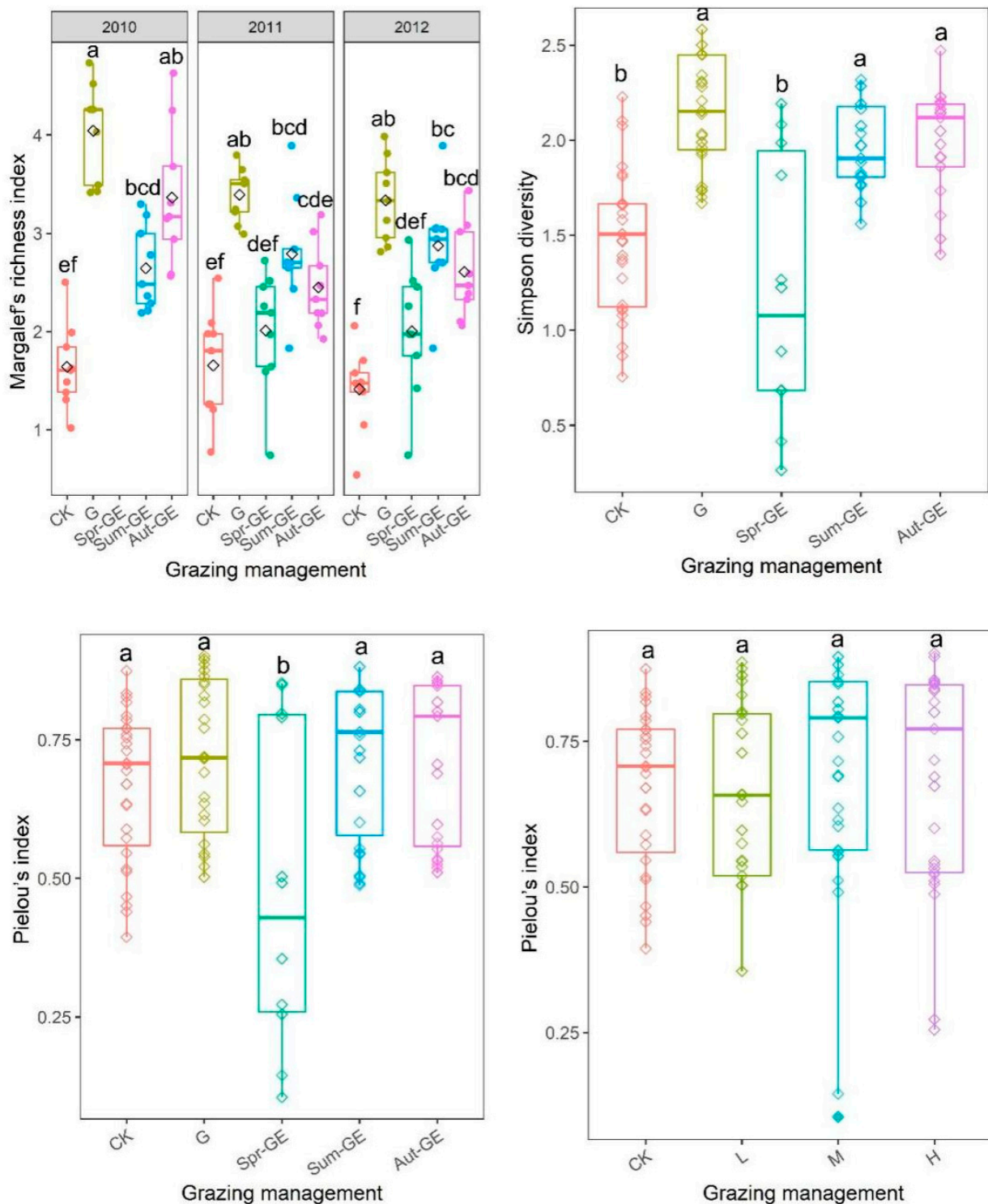


Figure 3. Species diversity under different grazing intensities, grazing management and years. The boxplots show the Margalef's index of different grazing management under different years, Simpson diversity index of different grazing managements, and Pielou's index of different grazing managements and different grazing intensities, with mean (square), median (thin line), quartile and data ranges. The letters of the box plot represent significant differences.

GM and Y-GM interactions had a significant effect on the number of species in each quadrat (Table 2). In addition, linear regression was used to analyze the relationship between the species number in each quadrat and total AGB. With the increase in experimental years, the relationship between the species number and total AGB changed from negative to positive (Figure 4).

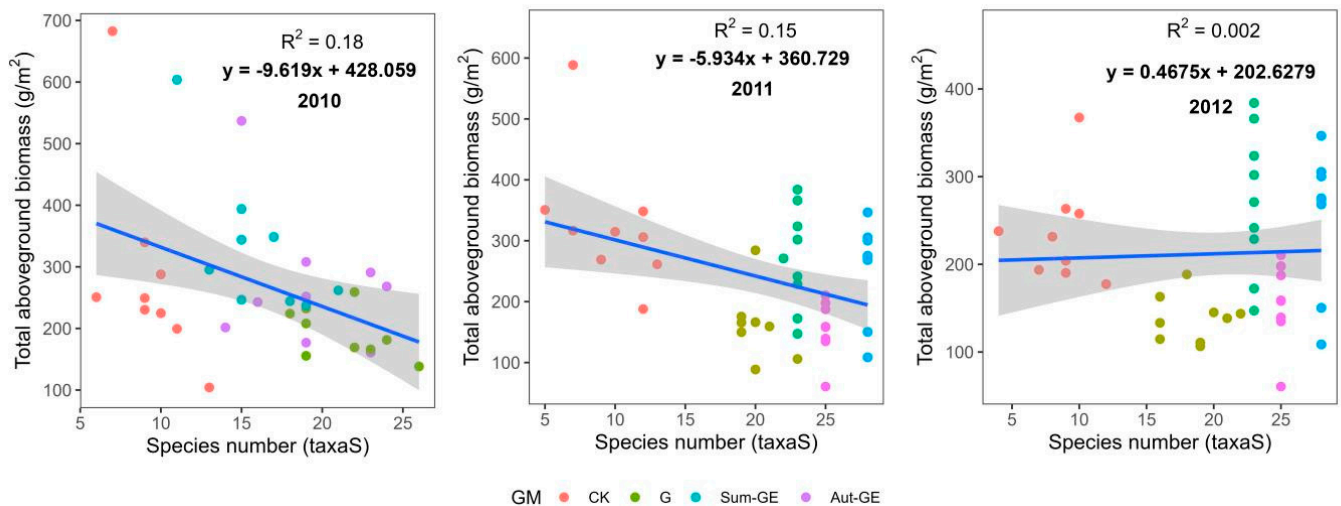


Figure 4. Linear relationship between species diversity (quadrat scale) and total aboveground biomass of different grazing managements in different years.

Y, GM, and Y-GM interaction had significant effects on plant community composition (Table 2). The PCoA analysis explained 61.36%, 71.71% and 73.81% of the variation of plant composition along the first two direction axes in 2010, 2011 and 2012 ($p < 0.001$, $p < 0.001$, $p < 0.001$). Seasonal grazing exclusion, G and CK were significant on both sides. Moreover, with the increase in study years, different seasonal grazing exclusions and G were significantly separated, indicating that the plant community composition of seasonal grazing exclusion, G and CK were different. With the increase in study years, different seasonal grazing exclusions also changed the plant community composition. Plant community composition was different under different seasonal grazing exclusions (Figure 5).

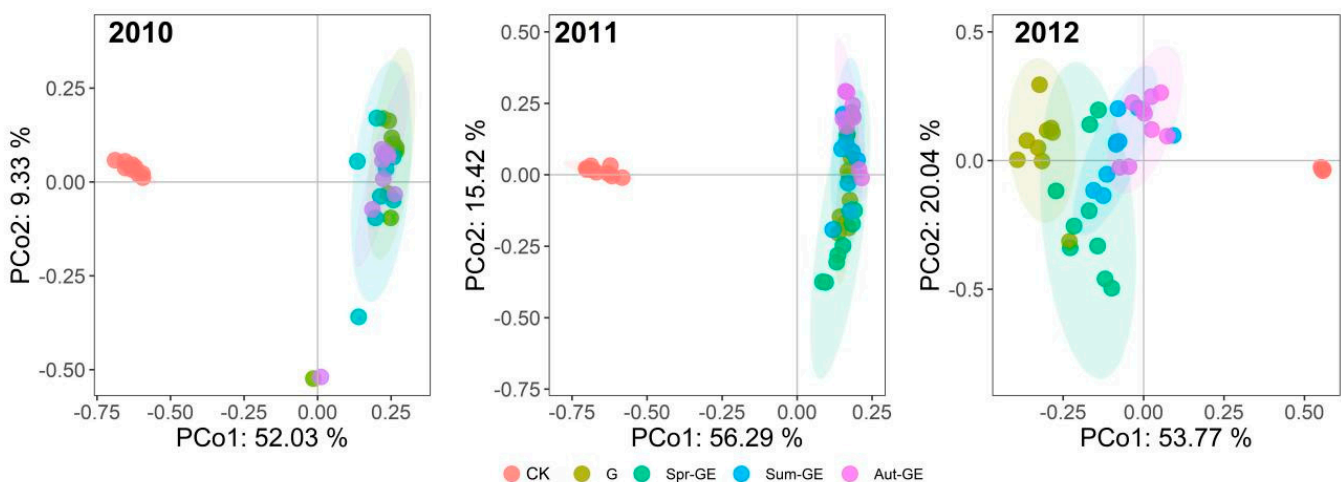


Figure 5. PCoA analysis of plant community composition under different grazing managements and years.

3.3. Properties of Functional Groups and Dominant Species

A total of four dominant species and 42 subordinate species were recorded in the study plots (Table 3). GM-GI interactions had a significant effect on ABH cover, and GM and GM-GI interactions had a significant impact on PG cover (Table 2) ($p < 0.05$). Under L and H, Spr-GE increased ABH cover, and Sum-GE decreased ABH cover under M. There was no significant difference in PG cover under different GM and GI ($p > 0.05$) (Figure 6).

GM had a significant effect on PF AGB ($p < 0.05$) (Table 2). There was no significant difference in PF AGB under different GM ($p > 0.05$) (Figure 6). GM had a significant effect on PF density ($p < 0.05$) (Table 2). Spr-GE significantly increased PF density, and the PF density from Spr-GE to Sum-GE, CK, G, and Aut-GE showed a decreasing trend (Figure 6).

GM had a significant effect on ABH, PG, PS and PF height, GI had a significant effect on PG and PF height ($p < 0.05$), and GM-GI interaction had no effect on the height of each functional group ($p > 0.05$) (Table 2). Spr-GE increased the height of each functional group, while Aut-GE decreased the height of each functional group. The height of each functional group in Spr-GE was higher than that of Sum-GE, Aut-GE and G, and the PS height of Spr-GE was significantly higher than that of CK (Figure 6).

GM and GI had a significant effect on *S. brachyotus*, *T. ohwianum* and *S. radians* cover ($p < 0.05$), while GM-GI interactions had no significant effect ($p > 0.05$) (Table 2). Spr-GE increased *S. radians* cover, while Sum-GE and Aut-GE decreased *S. radians* cover. Compared to G, Spr-GE and Aut-GE have increased *S. brachyotus* cover, but both were lower than CK. Aut-GE increased *T. ohwianum* cover, Sum-GE decreased *T. ohwianum* cover. From Aut-GE to Spr-GE, G, CK and Sum-GE *T. ohwianum* cover showed a decreasing trend (Figure 7). *S. radians* cover was significantly lower than CK under different GI, and decreased with the increase in GI. *S. brachyotus* cover was significantly lower than CK under different GI, but increased with the increase in GI. There was no significant difference in *T. ohwianum* cover under different GI ($p > 0.05$) (Figure 7).

Table 3. Plant community composition and functional group classification in the study area.

	Plant species	Function Groups	Plant Species	Function Groups
Dominant species	<i>Deyeuxia angustifolia</i> Kom. <i>Sonchus brachyotus</i> DC.	PG PF	<i>Taraxacum ohwianum</i> Kitam. <i>Stellaria radians</i> Linn.	PF PF
Subordinate species	<i>Cirsium setosum</i> (Willd.) Bieb. <i>Artemisia selengensis</i> Turcz. ex Bess. <i>Inula japonica</i> Thunb. <i>Deyeuxia langsdorffii</i> (Link) Trin. <i>Plantago asiatica</i> L. <i>Inula japonica</i> Thunb. <i>Cirsium pendulum</i> Fisch.ex DC. <i>Lagedium sibiricum</i> (L.) Sojak. <i>Chenopodium album</i> L. <i>Artemisia argyi</i> Levl. et Van. <i>Erigeron canadensis</i> L. <i>Echinochloa crus-galli</i> (L.) P. Beauv. <i>Sphallerocarpus gracilis</i> (Bess.) K.-Pol. <i>Arctium lappa</i> L. <i>Ixeridium sonchifolium</i> (Maxim.) Shih. <i>Polygonum aviculare</i> L. <i>Rorippa islandica</i> (Oed.) Borb. <i>Epilobium fastigiatum</i> Nakai <i>Potentilla chinensis</i> Ser. <i>Achillea millefolium</i> L. <i>Spodiopogon sibiricus</i> Trin.	PF PF PF PG PF PF PF PF ABH PF ABH ABH PF ABH ABH ABH ABH PF PF PG	<i>Carex tristachya</i> <i>Geum aleppicum</i> Jacq. <i>Lathyrus quinquenervius</i> (Miq.) Litv. <i>Stachys baicalensis</i> Fisch. ex Benth. <i>Geranium wilfordii</i> Maxim. <i>Artemisia scoparia</i> Waldst. et Kit. <i>Digitaria sanguinalis</i> (L.) Scop. <i>Geranium sibiricum</i> L. <i>Carduus nutans</i> L. <i>Setaria viridis</i> (L.) Beauv. <i>Polygonum lapathifolium</i> L. <i>Sium suave</i> Walt. <i>Viola yedpensis</i> Makino <i>Amaranthus retroflexus</i> L. <i>Poa annua</i> L. <i>Picris hieracioides</i> L. <i>Stachys chinensis</i> Bunge ex Benth. <i>Thalictrum petaloideum</i> L. <i>Equisetum arvense</i> L. <i>Galeopsis bifida</i> Boenn. <i>Roegneria kamoji</i> Ohwi	PS PF PF PF PF ABH ABH ABH PF ABH ABH PF PF ABH ABH PF PF PF PF

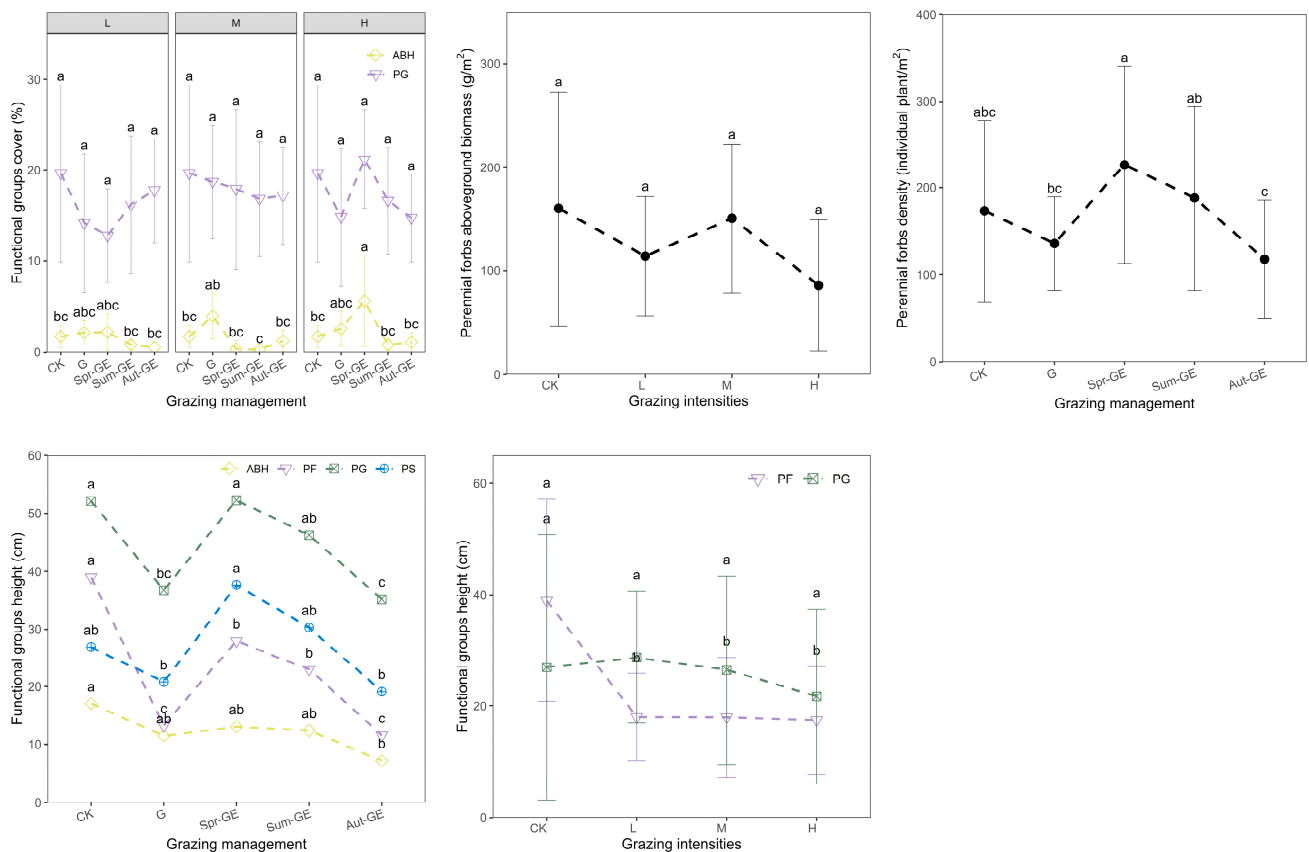


Figure 6. Effects of grazing intensity and grazing management on cover, aboveground biomass, density and height of different functional groups (PG means perennial grasses, PS means perennial sedges, PF means perennial forbs, ABH means annual and biennial herbs). Different letters represent significant differences.

M and GI and their interactions had significant effects on *S. radians* AGB ($p < 0.001$) (Table 2). *S. radians* AGB was increased in Spr-GE, with the most significant increase under M and higher than CK. Under different GI, *S. radians* AGB showed a decreasing trend from Spr-GE to Sum-GE and Aut-GE (Figure 7).

GM and GI had significant effects on *S. brachyotus* density, GM had significant effects on *T. ohwianum* density, and GT-GI interaction had significant effects on *S. radians* density ($p < 0.05$) (Table 2). The density of *S. brachyotus* decreased with different GI, especially under M. Both seasonal grazing exclusion and G reduced *S. brachyotus* density, most significantly in Spr-GE. Aut-GE significantly increased *T. ohwianum* density, while Spr-GE significantly decreased *T. ohwianum* density. Spr-GE significantly increased *S. radians* density under M and H, and different seasonal grazing exclusions significantly increased *S. radians* density under L (Figure 7).

GM had a significant effect on *T. ohwianum* height, and GM and GI and their interaction had a significant effect on *S. radians* height ($p < 0.05$) (Table 2). Spr-GE significantly increased *T. ohwianum* height, which was significantly higher than CK. Spr-GE increased the height of *S. radians* under L and M, and the height was increased most significantly under M. Under different seasonal grazing exclusions, *S. radians* height decreased from Spr-GE to Sum-GE and Aut-GE (Figure 7).

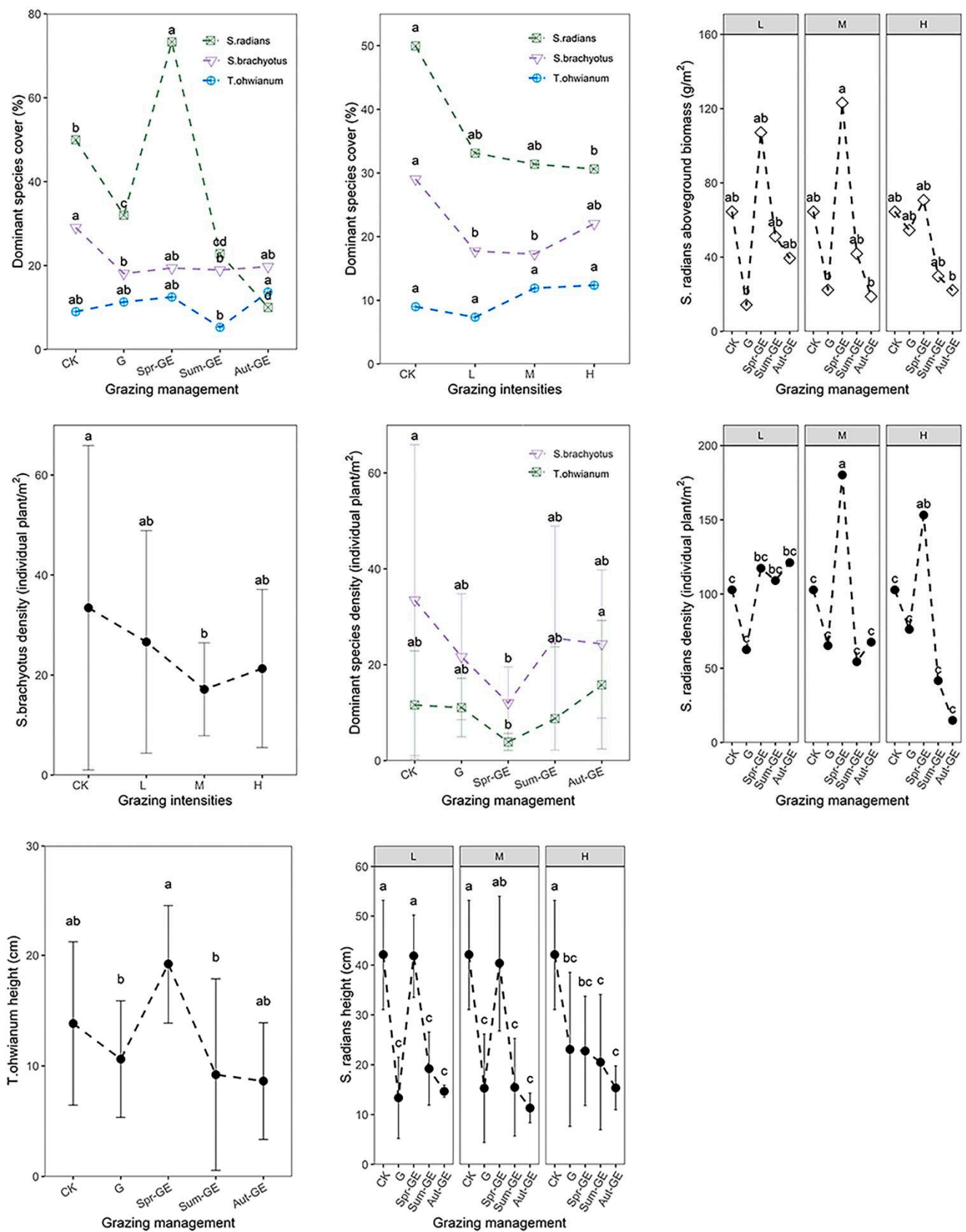


Figure 7. Effects of grazing intensity and grazing management on cover, aboveground biomass, density and height of dominant species. Different letters represent significant differences.

4. Discussion

4.1. Effects of Grazing Management and Grazing Intensity on Total Aboveground Biomass

Primary productivity is one of the most fundamental features of grassland ecosystem functioning, and is often influenced by a variety of abiotic and biotic drivers [56–58]. Some previous studies have shown a hump in the relationship between plant performance characteristics (such as biomass or productivity) and grazing intensity in grassland ecosystems [59,60]. The results of this study confirm this conclusion in that the total AGB of grassland under M is significantly higher than L and M during the same grazing exclusion season. This may be due to the plant compensation effect, where grassland total AGB reaches a maximum at moderate grazing intensity [61].

This study showed that seasonal grazing exclusion had a positive effect on grassland total AGB. This is attributed to the fact that continuous grazing reduces the ability of plants to regenerate [62]. Seasonal grazing exclusion allows individual plants to recover from negative effects, such as defoliation and physical damage to stems and roots, increasing their growth rates by allowing roots to transfer more biomass to the ground [63]. It can also restore physical and chemical environmental changes such as soil compaction, nutrient enrichment and soil organic carbon decline caused by animal husbandry [64,65], increase litter input, and soil nutrient content [66]. The improvement of soil structure and environment in turn promotes the growth and development of vegetation [22,67,68]. Furthermore, the study showed that the total AGB in spring and summer grazing excluded was significantly higher than that in autumn. Spring and summer are the main periods of growth and flowering for many temperate annual and perennial species, during which grazing exclusion may enhance persistence and promote plant growth [38,69]. Leonard and Kirkpatrick (2004) showed that excluding spring grazing increased the number and biomass of grassland plants [70].

4.2. Effects of Grazing Management and Years on Plant Community Diversity and Composition

Plant communities can exhibit higher species diversity in the case of grazing disturbance [71]. Mixed-effect model analysis showed that different GMs had a significant effect on grassland diversity. Grazing exclusion during the growing season (CK) significantly reduced species diversity, while species diversity increased after grazing, and grazing changed plant community composition. Grazing exclusion limits natural resources such as light, water and nutrients, and exacerbates intraspecific and interspecific competition in plant communities [72–75]. However, livestock activities not only directly affect intraspecific and interspecific competition [63,76–79], but also enhance environmental heterogeneity and provide favorable conditions for the survival of subordinate species [80,81]. Seasonal grazing exclusion allows the development of fast-growing, competitive species and promotes adequate flowering, pollination and seed dispersal of high-priority plant species [82,83]. The dominant grasses have a high resource utilization capacity, which inhibits the growth of subordinate species and leads to the decrease in species diversity. Grasses have good palatability, and grazing effectively promotes the growth of fast-growing subordinate species. Seasonal grazing exclusion increased the species number within the plots, and the PF cover and density were also significantly increased.

In addition, species diversity of grazing excluded varied significantly in different seasons, with plant diversity increasing from spring and summer to autumn. To a certain extent, spring grazing exclusion promoted the rapid growth of dominant grasses. However, spring grazing creates more niche for subordinate species, which may be responsible for the lower diversity and differences in species composition in spring grazing excluded. However, the exclusion of grazing in autumn enabled the fruiting plants to complete reproductive growth, increased the variety and capacity of soil seed bank, and ensured high species diversity [84]. Furthermore, we found that species diversity was influenced by GI, supporting the observation that the effects of herbivores on plant diversity depend on regional differences in soil fertility, water availability, and avoidance or tolerance strategies of plant species [8].

The analysis showed that the Y had a significant impact on species diversity. Previous studies have shown that plant diversity also depends on the availability of resources, such as precipitation [85]. The difference between annual precipitation and growing season precipitation during the study period was significant, which may be the reason for the difference in species diversity in different years.

The productivity-diversity relationship is a key relationship between grassland ecosystem function [86]. General linear regression results show that the total AGB had a negative linear relationship with species richness in 2010 and 2011, which is different from the previous positive linear or hump relationship [9,87,88]. This means that there is a competitive relationship between the dominant species and the subordinate species, and the dominant species has a significant negative effect on the subordinate species. The accumulation of AGB in dominant species has a negative impact on species richness. With the biomass accumulation of dominant species, shade increases, which in turn inhibits the growth of subordinate species [89]. As a result, species diversity tends to decrease with increased productivity. Subordinate species play a relatively important role in the positive productivity-diversity relationship [9]. Due to the inhibition of dominant species by grazing and the precipitation during the growing season, the growth of subordinate species was promoted, and the complementary interaction between subordinate species may be responsible for the positive correlation of diversity-total AGB in 2012.

4.3. Effects of Grazing Management and Grazing Intensity on the Properties of Functional Groups and Dominant Species

Species-level responses in the face of environmental fluctuations and grazing disturbances have been shown to provide important insights into changes at community levels [7,90,91]. Our study showed that seasonal grazing exclusion has different effects on the characteristics of functional groups and dominant species. Differences in species characteristics can lead to positive, negative, or nonlinear responses of species to seasonal grazing exclusion, complicating community responses to seasonal grazing exclusion [92]. In this study, Spr-GE had a significant effect on the characteristics of most functional groups and dominant species. With the increase in temperature and moisture conditions in spring, plants end their dormancy state and begin to recover, which is the most important stage for the initial growth of grassland vegetation in a year [93]. Spring grazing exclusion enhanced plant photosynthesis and promoted plant growth by increasing metabolites related to Calvin cycle, chlorophyll content, relative leaf water content and related mineral element content [94]. Furthermore, livestock preferred to eat fresh annuals before perennials [95], so Spr-GE promoted ABH growth and increased ABH cover. Aut-GE had little effect on the characteristics of most functional groups and dominant species, which may be due to the fact that plant nutrients are mainly transported and stored underground in autumn for overwintering. However, different species showed different responses to seasonal grazing exclusion. For example, Spr-GE decreased *S. brachyotus* and *T. ohwianum* density, probably due to interspecific competition and compensatory effects [90,96]. It also suggests that wet grassland dominant species are sensitive to seasonal grazing exclusion.

The effects of GI on the characteristics of functional groups and dominant species were significant. PF AGB was highest under M by stimulating nutrient cycling [97] and supplementing growth after plant defoliation [61]. However, overgrazing greatly limited photosynthetic capacity and function of leaves [12,98]; plants cannot fully compensate for tissue loss, resulting in a decrease in AGB. In addition, livestock tend to eat higher PF first, while perennial root grasses grow fast, can reproduce by tillers, and have strong grazing tolerance [9], which leads to no significant change in PG height and a significant reduction in PF height under different GI. Seasonal grazing has a greater impact on dominant species than continuous grazing [81]. In this study, different GI significantly reduced the coverage and density of *S. radians* and *S. brachyotus*. Li et al. (2016) also showed that the abundances and occurrences of some PF decreased even under low GI [99]. PF have a high nutrient content in their leaves, which makes them very sensitive to grazing [100,101].

5. Conclusions

This study shows that Spr-GE and Sum-GE are beneficial for grassland Total AGB, but Spr-GE reduces plant community diversity due to increased intraspecific and interspecific competition. As grazing exclusion during the growing season promoted the growth of subordinate species, the relationship between plant species richness and community Total AGB changed from negative to positive. Different seasonal grazing exclusions changed plant community composition. In terms of functional groups and dominant species levels, Spr-GE had a significant effect on most functional groups and dominant species characteristics, while Aut-GE had little effect on most functional groups and dominant species characteristics. However, different functional groups and dominant species had different responses to seasonal grazing exclusion, which suggests that different wet grassland functional groups and dominant species are sensitive to seasonal grazing exclusion. In addition, M significantly improved grassland Total AGB and PF AGB. In conclusion, Spr-GE with M may be an effective livestock measure to preserve grassland vegetation diversity and restore degraded grasslands.

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