

Heavy grazing led to the decrease of competitive intensity relationships among dominant populations of clustered grasses in a desert steppe

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Abstract

Stipa breviflora (*Stipa breviflora* Griseb.) and *Cleistogenes songorica* (*Cleistogenes songorica* (Roshev.) Ohwi) are two dominant species in the critically important desert steppe of northern China. Under the interference of grazing, the two species will have the phenomenon of plant cluster fragmentation to varying degrees. Therefore, when the two plant populations appear in the same plant community, what changes will happen in the inter-specific relationship during grazing has important guiding significance for its regulation of plant community and function. To study this, we observed populations of wild *S. breviflora* and *C. songorica* in field under a suite of grazing intensities and at a variety of scales. The density changes of dominant species *S. breviflora* and *C. songorica* in desert steppe in Inner Mongolia were studied under four grazing intensities (no grazing, CK, 0 sheep-ha-1-half year-1, light grazing, LG, 0.93 sheep-ha-1-half year-1, moderate grazing, MG, 1.82 sheep-ha-1-half year-1, heavy grazing, HG, 2.71 sheep-ha-1-half year-1) and six scales (5 cm×5 cm, 10 cm×10 cm, 20 cm×20 cm, 25 cm×25 cm, 50 cm×50 cm and 100 cm×100 cm). Results showed that grazing changes the relationship between dominant species. With the increase of grazing intensity, the densities of *S. breviflora* and *C. songorica* increased, and the increase was more obvious with the increase of scale. Under heavy grazing conditions, the dominant populations of clustered grasses in Inner Mongolia desert steppe resisted the interference of high-intensity grazing by reducing inter-specific competition ability (increasing inter-specific affinity).

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Abstract: *Stipa breviflora* (*Stipa breviflora* Griseb.) and *Cleistogenes songorica* (*Cleistogenes songorica* (Roshev.) Ohwi) are two dominant species in the critically important desert steppe of northern China. Under the interference of grazing, the two species will have the phenomenon of plant cluster fragmentation to varying degrees. Therefore, when the two plant populations appear in the same plant community, what changes will happen in the inter-specific relationship during grazing has important guiding significance for

its regulation of plant community and function. To study this, we observed populations of wild *S. breviflora* and *C. songorica* in field under a suite of grazing intensities and at a variety of scales. The density changes of dominant species *S. breviflora* and *C. songorica* in desert steppe in Inner Mongolia were studied under four grazing intensities (no grazing, CK, 0 sheep·ha⁻¹·half year⁻¹, light grazing, LG, 0.93 sheep·ha⁻¹·half year⁻¹, moderate grazing, MG, 1.82 sheep·ha⁻¹·half year⁻¹, heavy grazing, HG, 2.71 sheep·ha⁻¹·half year⁻¹) and six scales (5 cm×5 cm, 10 cm×10 cm, 20 cm×20 cm, 25 cm×25 cm, 50 cm×50 cm and 100 cm×100 cm). Results showed that grazing changes the relationship between dominant species. With the increase of grazing intensity, the densities of *S. breviflora* and *C. songorica* increased, and the increase was more obvious with the increase of scale. Under heavy grazing conditions, the dominant populations of clustered grasses in Inner Mongolia desert steppe resisted the interference of high-intensity grazing by reducing inter-specific competition ability (increasing inter-specific affinity).

Keywords

Grazing intensity, Inter-specific relationship, Jaccard index, Desert steppe, Dominant population

Background

Due to the interference of natural and human factors, the global environment is undergoing changes (Scales, 2005). Understanding how these current and future environmental changes influence plant diversity and community composition is critically important (Moritz and Agudo, 2013; Zhang et al., 2019). There are two common views on this topic. The first is that biodiversity promotes the stability of ecosystems (Cadotte et al., 2012; Weigelt et al., 2008), while the second view generally accepts that the stability of plant communities depends more on changes in inter-specific relationships, and this change in biodiversity depends on environmental changes (Wayne Polley et al., 2007).

Inter-specific relationships have been widely studied since the 1990s (Aiba et al., 2012; Perkins and Wilson, 2005). Inter-specific relationship indicates the nature of mutual attraction or exclusion between species. Species that are interdependent, competitive and co-evolutionary, and ultimately make the community relatively more stable (Greig-Smith, 1983). Due to external environmental disturbances such as habitat conditions, spatial scales, and plant traits, including grasslands, deserts, and forests, plant inter-specific relationships exhibit different ecological adaptations. The studies of Callaway and Armas showed that the interaction of plants affects population dynamics (Armas and Pugnaire, 2005; Callaway and Walker, 1997). Dominant species control most of the resources. When an ecosystem is disturbed, dominant species will provide short-term stability to the ecosystem (Avolio et al., 2019; Geider et al., 2001). Therefore, if the dominant species are resistant to interference, their communities would have higher resistance (Hillebrand et al., 2008). The stability of plant communities is the manifestation of the interaction between populations in competition or symbiosis, so as to achieve dynamic equilibrium (Levine and HilleRisLambers, 2009). Some studies suggested that the temporal stability of the community increases with the increase of inter-specific competition (Tilman, 1999). In our system, the introduction of an external pressure (grazing) led to extremely unbalanced population development, enhanced dominant position of major species, reduced species diversity, and simplified community composition and function (Armas et al., 2011). But studies have also shown that inter-specific competition makes communities more unstable (Loreau and De Mazancourt, 2013).

Grazing is one example of a selective pressure. Generally, the competitiveness of grassland plants is affected by livestock trampling and selective feeding. Competition among plants heavily grazed by livestock becomes weak as there is increasing top-down pressure from the grazing ‘predator’. When grazing intensity remains constant, competition between plants will eventually stabilize at a specific level (Muller-Scharer, 1991). Studies have shown that grazing leads to changes in relationships between populations, mainly due to changes in the ability of plants to intercept light (Ford and Diggle, 1981; Hay and Hunt, 1989). Many studies have shown that grazing can reduce the competition between plants, and the importance of competition will decrease (McCanny et al., 1990). Other work suggests that despite grazing altering the outcome of competition, it does not influence the importance of competition (Tilman, 2020). Taylor *et al.* indicated that high-intensity grazing disturbance could change the competition and coexistence among species (Taylor

et al., 1997). Therefore, it is of great significance to explore the effect of grazing intensity on the inter-specific relationship of plant populations (Brooker et al., 2008; Yin et al., 2019).

Due to the harsh environment of arid climate and poor soil, the composition and function of desert grassland ecosystem are relatively fragile (Briske et al., 2015). *Stipa breviflora* and *Cleistogenes songorica* are perennial clumped grasses and dominant species in desert steppe, with the advantages of cold resistance, drought resistance and trampling resistance. Despite observing that both *S. breviflora* and *C. songorica* can break up under the disturbance of grazing (Lv et al., 2020), there remains little research on the inter-specific relationship of dominant grass populations in desert steppe. Therefore, we leveraged an existing long-term grazing experiment to answer three main questions. The first, how does grazing influence the density of each species? The second, how does the increase of grazing intensity change the inter-specific competition between these two species, and does this change vary depending on scale? Finally, we asked, as grazing intensity increases, how does the competitive ability of different dominant species change?

Materials and methods

Study site

Populations of *S. breviflora* and *C. songorica* were identified in Siziwang, Inner Mongolia (41°46'43.6"N, 111deg53'41.7"E, elevation 1456m). The region has a temperate continental arid and semi-arid climate, and is characterized by significant inter and inter-annual variability of hydrothermal conditions (Wang et al., 2011). The average annual precipitation is 223 mm, and 80% of the annual precipitation is concentrated in May to September. The main soil type is light chestnut soil (Chinese classification) or calcic Kastanozems (FAO soil classification). The soil texture is sandy loam, and the desert steppe in this region is dominated by *S. breviflora*, *Artemisia frigida* and *C. songorica*. The composition of plant species is relatively simple, with average vegetation height of 8 cm and a canopy cover ranging from 17% to 20%.

Experimental design

To quantitatively test the effects of grazing intensity on the desert steppe ecosystem, twelve adjacent plots were established at a grazing experiment site in 2004. These treatments were arranged in a randomized complete block design, which included four grazing intensity treatments with three replicates ($n = 3$) of each treatment (see Fig. 1). The grazing intensities were identified as no grazing CK (0 sheep*ha⁻¹*half year⁻¹), light grazing LG (0.93 sheep*ha⁻¹*half year⁻¹), moderate grazing MG (1.82 sheep*ha⁻¹*half year⁻¹) and heavy grazing HG (2.71 sheep*ha⁻¹*half year⁻¹). Since 2004, the annual seasonal grazing period is from the beginning of June to the end of November, and is predominantly 2-year-old Mongolian sheep grazing. The daily grazing schedule was from 6:00 am to 6:00 pm. Water and salt were provided freely.

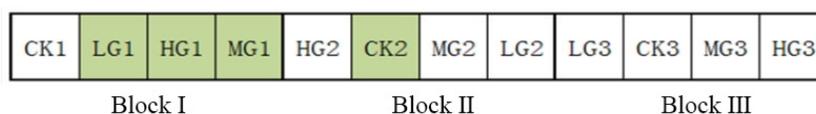


Fig. 1 Schematic diagram of the grazing experiment treatments. Dark color treatments indicate sampled treatments. The grazing experiment treatments (each ca. 4.4 ha) were arranged in a randomized complete block design, which included four grazing intensity treatments with three repeats at each grazing intensity.

Vegetation sampling

Within each randomized block of different grazing intensities, a representative sample plot with the same terrain (5 m×5 m) was selected. The origin of the coordinate in each sample is defined as the upper left corner of the sample. Within this sample plot, a 1 m×1 m sample frame was placed 25 times in turn, and the precise spatial position of *S. breviflora* and *C. songorica* in the sample is determined by the tape. In this fashion we measured the population density of *S. breviflora* and *C. songorica* on 15 August 2019.

Data analysis

The population density of *S. breviflora* and *C. songorica* were tested for homogeneity of variance ($P < 0.05$), and they all obeyed normal distribution. A generalized linear model (GLM) was used to test the effect of grazing intensity on the density of *S. breviflora* and *C. songorica*. A Duncan test (Levene homogeneity test) was used to identify significant pairwise relationships among the different grazing treatments. By using several quadrats, we could also identify how sampling size may have influenced our results. To that end, we split the sample size of 5 m×5 m into 5 cm×5 cm, 10 cm×10 cm, 20 cm×20 cm, 25 cm×25 cm, 50 cm×50 cm and 100 cm×100 cm. Data was square-root transformed to meet a normal distribution, and variance analysis was used to compare the density changes of *S. breviflora* and *C. songorica* under different grazing intensities and across these increasing spatial scales. The bidirectional GLM method was used to test the effects of grazing intensity and spatial scale on the density of *S. breviflora* and *C. songorica*, and the generalized linear model was used to test the effect of spatial scale on the density of *S. breviflora* and *C. songorica*. In order to analyze the synergistic change of density with scale of *S. breviflora* and *C. songorica* in different grazing intensities, the scatter diagram of density of *S. breviflora* and *C. songorica* in different grazing intensities was drawn, and the linear fitting (using MS data) was carried out (r^2 represents the determination coefficient). The analysis of variance was performed using SAS 9.4 (SAS Institute Inc.), and a threshold of $P < 0.05$ level was used to assay significant relationships. Assembly process and graphics rendering are completed in Sigmaplot 14.0 (Systat Software, 2011).

To study the inter-specific association of *S. breviflora* and *C. songorica* in desert steppe, the plot of 5 m×5 m was regarded as a plant community in this study. We used the Jaccard index to evaluate the strength and direction of inter-specific plant relationships (Guo et al., 2014). The Jaccard index is negatively correlated with competitiveness, and positively correlated with affinity. The calculation formula of Jaccard index is:

$$CJ = j / (a + b + j)$$

In the formula, CJ is the Jaccard index; j is the number of small quadrats with *S. breviflora* and *C. songorica*; a is the number of small quadrats with only *S. breviflora* and without *C. songorica*; b is the number of small quadrats with only *C. songorica* and without *S. breviflora*. By repeating this analysis across the various spatial scales (ranging from 5 cm×5 cm to 100 cm×100 cm), we could evaluate if the strength and direction of these inter-specific relationship was impacted by sampling size.

Results

Effects of grazing intensity and scale on population density of

Stipa breviflora

Grazing intensity, spatial scale and their interaction significantly affected the density of *S. breviflora* population (Table 1, $P < 0.05$). The F value of spatial scale factors on *S. breviflora* density was larger ($F = 306.81$), indicating that the response of *S. breviflora* density to spatial scale factors was more obvious than that of grazing intensity.

The changes of *S. breviflora* population density under different grazing intensities and spatial scales are shown in Fig. 2. The density of *S. breviflora* increased with the increase of grazing intensity (Fig. 2A), and we observed significant pairwise differences between CK and LG, CK and MG, CK and HG ($P < 0.05$), which also indicated that the density of *S. breviflora* was different in LG treatment, that is, the phenomenon of plant cluster fragmentation. Although there was no significant difference between the LG, MG and HG treatments we did observe a general trend of increasing density. The error extension lines between each treatment were long, indicating that the distribution of *S. breviflora* was highly variable within each treatment. The density of *S. breviflora* increased exponentially with the increase of spatial scale (Fig. 2B). Except for 5 cm×5 cm and 10 cm×10 cm, 20 cm×20 cm and 50 cm×50 cm, there were significant differences between the two spatial scales ($P < 0.05$). In fact, there is an exponential correlation between density and spatial scale of *S. breviflora* (density of *S. breviflora* = $0.5314 + 0.0112 \times \exp(1.4160 \times \text{spatial scale of } S. breviflora)$, $r^2 = 0.9995$).

Table1 Variance analysis results for the *Stipa breviflora* population

Source	df	SS	MS	F Value	P Value
Model	8	139.63	17.45	193.94	<.0001
Grazing intensity	3	1.58	0.53	5.83	0.0076
Scale	5	138.06	27.61	306.81	<.0001
Error	15	1.35	0.09		
Corrected Total	23	140.98			

Fig. 2 Population density difference diagrams of *Stipa breviflora* at different grazing intensities and scales. Mean values ($\pm SD$; $n = 24$) of density. Different lowercase letters indicate that grand means differ significantly between the grazing treatments ($P < 0.05$). (1) 5 cm \times 5 cm; (2) 10 cm \times 10 cm; (3) 20 cm \times 20 cm; (4) 25 cm \times 25 cm; (5) 50 cm \times 50 cm; (6) 100 cm \times 100 cm.

Effects of grazing intensity and scale on population density of

Cleistogenes songorica

Grazing intensity, spatial scale and their interaction had significant effects on the density of *C. songorica* population (Table 2, $P < 0.05$). The F value of spatial scale factor was larger ($F = 374.19$), which indicated that the response of density to spatial scale factor was more sensitive than that of grazing intensity.

The changes of population density under different grazing intensities and spatial scales were shown in Fig. 3. The density of *C. songorica* increased with the increase of grazing intensity (Fig. 3A), and there were significant differences between CK and HG, LG and HG, MG and HG ($P < 0.05$), which also indicated that the density difference of *C. songorica* only appeared in HG, implying that the heavy grazing did induce fragmentation of the plant habitat. Heavy grazing led to a significant increase in the density of *C. songorica*. Although there was no significant difference in the density among CK, LG and MG treatments, there was still a trend of density increase with the increase of grazing intensity. The error extension lines between each treatment were long, indicating that *C. songorica* distribution was highly variable between treatments. The density of *C. songorica* increased exponentially as the scale of our sampling increased (Fig. 3B). Except for 5 cm \times 5 cm and 10 cm \times 10 cm, 20 cm \times 20 cm and 50 cm \times 50 cm, there were significant differences between the other spatial scales ($P < 0.05$). In fact, there is an exponential correlation between density and spatial scale of *C. songorica* (density of *C. songorica* = $0.1412 + 0.0026 \times \exp(1.4189 \times \text{spatial scale of } C. \text{ songorica})$, $r^2 = 0.9994$).

Table 2 Variance analysis results of the *Cleistogenes songorica* population

Source	df	SS	MS	F Value	P Value
Model	8	33.42	4.18	236.2	<.0001
Grazing intensity	3	0.33	0.11	6.21	0.0059
Scale	5	33.09	6.62	374.19	<.0001
Error	15	0.27	0.02		
Corrected Total	23	33.69			

Fig. 3 Population density difference diagrams of *Cleistogenes songorica* at different grazing intensities and spatial scales. Mean values ($\pm SD$; $n = 24$) of density. Different lowercase letters indicate that grand means differ significantly between the grazing treatments ($P < 0.05$). (1) 5 cm \times 5 cm; (2) 10 cm \times 10 cm; (3) 20 cm \times 20 cm; (4) 25 cm \times 25 cm; (5) 50 cm \times 50 cm; (6) 100 cm \times 100 cm.

Inter-specific association between *Stipa breviflora* and *Cleistogenes songorica* populations

It can be seen from the Jaccard index (Table 3) of *S. breviflora* and *C. songorica* populations that the value of Jaccard index under grazing treatment was greater than that under non-grazing treatment at different scales, indicating that grazing does increase the inter-specific affinity of *S. breviflora* and *C. songorica*.

When comparing two sites under the same grazing intensity, we observed that the value of the Jaccard index increased as our sampling sized increased, implying an increase in the inter-specific affinity. At the spatial scale of 5 cm×5 cm, the Jaccard index showed a strong inter-specific competition between *S. breviflora* and *C. songorica* . At the spatial scale of 100 cm×100 cm, we observed the highest compatibility between *S. breviflora* and *C. songorica* under grazing. At this scale, it appears that grazing intensity has little effect the relationship between these grass species. With the increase of grazing intensity, the inter-specific affinity between the two species increased. Notably, we observed that the influence of grazing on inter-specific affinity was greatest at the smallest sampling resolution, and generally decreased as sampling resolution was increasingly coarse. In summary, grazing increased the inter-specific relationship affinity (competitive ability decreased) between *S. breviflora* and *C. songorica* in order to resist grazing disturbance, and this affinity was particularly prominent in large scale.

Table 3 Jaccard index of *Stipa breviflora* and *Cleistogenes songorica* populations

Grazing intensity	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6
CK	0.0111	0.0545	0.2588	0.3194	0.7653	0.9200
LG	0.0190	0.0803	0.3108	0.4692	0.9100	1.0000
MG	0.0243	0.0797	0.3440	0.4722	0.8600	1.0000
HG	0.0297	0.1151	0.4027	0.5342	0.8900	1.0000

Abbreviations: (1) 5 cm×5 cm; (2) 10 cm×10 cm; (3) 20 cm×20 cm; (4) 25 cm×25 cm; (5) 50 cm×50 cm; (6) 100 cm×100 cm.

Synergistic changes in the density of *Stipa breviflora* and *Cleistogenes songorica* with scale at different grazing intensities

The co-variation of the densities of *S. breviflora* and *C. songorica* with scales under different grazing intensities was shown on Fig. 4. No matter how the grazing intensity changes, there is a significant positive correlation between the densities of the two plant populations ($P < 0.05$). Under different grazing intensities, there was a linear correlation between the density of *S. breviflora* and *C. songorica* . In CK, the correlation is density of *C. songorica* = 0.2623×density of *S. breviflora* , $r^2 = 1.0000$. In LG, the correlation is density of *C. songorica* = 0.0223+0.2331×density of *S. breviflora* , $r^2 = 0.9999$. In MG, the correlation is density of *C. songorica* = 0.2213×density of *S. breviflora* , $r^2 = 1.0000$. In HG, the correlation is density of *C. songorica* = 0.0201+0.2492×density of *S. breviflora* , $r^2 = 1.0000$. The determination coefficients were all close to 1, indicating that under different grazing intensities, the fitting between the densities of *S. breviflora* and *C. songorica* a was excellent.

As grazing intensity increased, we observed an increase of density of *S. breviflora* and a compensatory decrease in the density of *C. songorica* decreased. We interpreted these results as proof of the competitive advantage of *S. breviflora* . We observed, however, that the difference in competitive ability was reduced as grazing intensity increased, suggesting that the increasing top down grazing pressure alleviated competition between species, indicating that in the three treatments, the competitiveness of *S. breviflora* was higher than that of *C. songorica* , until HG treatment, compared with the first three treatments, the competitiveness of *C. songorica* increased, and the competitiveness of *S. breviflora* decreased. It can also be seen from Fig. 3 that compared with other three treatments, the increase of *C. songorica* density in HG treatment was the largest. According to the intercept of this linear relationship, the value of LG treatment was 0.0223, and the value of HG treatment was 0.0201, indicating that the linear relationship between *S. breviflora* and *C. songorica* will be affected by the initial density of *S. breviflora* in LG and HG treatments. However, in HG treatment, due to the competitiveness of *C. songorica* has improved, the impact of initial density of *S. breviflora* will be reduced.

Fig. 4 The relationship between the density of *Stipa breviflora* and the density of *Cleistogenes songorica*

under different grazing intensities. CK, no grazing; LG, light grazing; MG, moderate grazing; and HG, heavy grazing.

Discussion

When the external environment changes, dominant species can choose different strategies to maintain growth, survival and fecundity (Liu et al., 2016). New biomass, for example, is allocated to leaves and roots, or to organs such as stolons, rhizomes and seeds to improve plant access to resources (Drenovsky et al., 2008; Hermans et al., 2006). *S. breviflora* and *C. songorica* are the dominant species in desert steppe, and have obvious control effect on the formation of community composition and community environment in the desert steppe. Perhaps due to the strong grazing resistance of these two species, we did observe increases in density as grazing increased (Fig. 2-3). We also found that a broader sampling method (sampling a 100 cm×100 cm quadrat compared to a 5 cm×5 cm plot) resulted in increases in plant density. This phenomenon may be related to the random walking, trampling and foraging behaviors of grazing livestock (Limb et al., 2010; Lin et al., 2010). As the grazing resistant *S. breviflora* and *C. songorica* are gramineous plants that can quickly absorb nitrogen and regenerate from their grazed meristem, which may also be one of the reasons for their increased density even under heavy grazing (Stampfli et al., 2018).

It should also be noted that *S. breviflora* and *C. songorica* are perennial clumpy grass, but the difference is that *S. breviflora* is dense clumpy grass, and the tillering node is located on the ground, which is easily affected by grazing behavior, resulting in the fragmentation of plant clusters. *C. songorica* is sparse clumpy grass, and the tillering node is located underground. Because of this, simple grazing behavior does not change the number of plant clusters, which may explain why the plant communities appeared to fragment early in *S. breviflora* (the LG treatment), but not in the *C. songorica* species until grazing intensity was sufficiently high (the HG treatment) (An and Li, 2015; Lv et al., 2019; Salt and Mayes, 1991). This physiological difference may also explain why we observed the competitive advantage of *C. songorica* in HG region (Fig. 4). In this experiment, with the increase of grazing intensity, the linear relationship between *S. breviflora* and *C. songorica* was also affected by the initial density of *S. breviflora* (intercept of regression line in Fig. 4). The shift of the regression line on the longitudinal axis and the increase of the regression slope will lead to the relationship between the two become more complex.

The formation of plant population relationships is closely related to the environmental conditions of the community (Wang et al., 2015). Grazing may alter the availability of environmental resources in communities and ultimately alter interactions between species (Liu et al., 2000). In this study, with the increase of grazing intensity and spatial scale, the inter-specific relationship affinity between *S. breviflora* and *C. songorica* increased, and the inter-specific competition ability decreased. This is consistent with the results of Soltani et al., which suggest that long-term grazing generally reduces competition between dominant species (Soltani et al., 2020). The increasing affinity of the two may be interpreted as a tolerance or resistance to grazing disturbance (Levine and HilleRisLambers, 2009). It should also be noted that at the scales of 10 cm×10 cm and 50 cm×50 cm, the inter-specific affinity of *S. breviflora* and *C. songorica* in the LG treatment was higher than that of CK and MG, which implies the existence of a critical point where scale influence inter-specific relationship transformation. It also raises questions about the potential biases induced by different sampling regimes, something which should be considered for studies in the future.

The change in inter-specific association can also be explained by the ecological compensation effect caused by grazing. In the absence of grazing, the limiting factor of population growth is natural resources, and the ability of a given species to access resources induces/produces competition. In the *S. breviflora* desert steppe, grazing could lead to niche differentiation in the ecosystem, which could be directly reflected by the ecological compensation effect between species. This ecological compensation effect changed the resource utilization mode of species (Fock and Kraus, 2016; Liu, 2019). When grazed, the community is exposed to a new pressure the top down influence of livestock feeding and trampling (Levine and HilleRisLambers, 2009). The pressure gradient hypothesis also points out that competition plays a major role in the natural environment. When the interference exceeds a certain limit, the inter-specific interaction between plants will decrease (Bertness and Callaway, 1994; Wan et al., 2011). Therefore, in this experiment, heavy grazing

led to the decrease of inter-specific competition ability of dominant grass populations in desert steppe. In summary, in order to better explore the changes in inter-specific relationships of plant populations under grazing disturbance, specific analysis should be carried out in combination with habitat conditions, plant physiological and biochemical characteristics, and the internal mechanism of plant populations should be explored.

Conclusions

The conclusion of this study is that the inter-specific relationship of dominant grass species is not only affected by grazing intensity, but also by initial population density and sampling scale. There are three results. First, the increase of grazing intensity generally increased the density of *S. breviflora* and *C. songorica* populations in a Inner Mongolian desert steppe. We also noted that this relationship was particularly sensitive to spatial scale, and observed that ‘density’ increased with the increase of our sampling scale (moving from 5 cm×5 cm to 100 cm×100 cm sampling quadrats). Secondly, with the increase of grazing intensity, the affinity of *S. breviflora* and *C. songorica* increased greatly at the small scale, though this affinity was not obvious when observing the entire plot, further suggesting that sampling size may induce bias in these measurements. Finally, with the increase of grazing intensity, the competition between *S. breviflora* and *C. songorica* increased first and then decreased, that is, heavy grazing led to the decrease of inter-specific competition between the two species. Inter-specific relationship is the basis for exploring the stability and evolution of plant communities. The change of inter-specific relationship of dominant grass species in desert steppe may further affect the stability and sustainability of grassland ecosystem, and our observations provide a theoretical basis for formulating reasonable and scientific grazing practices in *S. breviflora* desert steppe.

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Author contributions

Study design: Guodong Han, Zhongwu Wang. Sampling: Zihan Wang, Chen Chen. Analyses: Shijie Lv, Hongmei Liu. Data interpretation & discussion: Shijie Lv, Zihan Wang, Zhongwu Wang, Zhiguo Li. All authors contributed to the writing and critical evaluation of the manuscript.

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Availability of data and materials

The original contributions presented in the study are included in the article/Supporting Information.

Declaration of competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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