Interactive effects of grazing and climate on grassland vegetation diversity in arid and semi-arid regions

Xiuli Gao[1]

[1]Chinese Research Academy of Environmental Sciences

December 13, 2022

Abstract

In arid and semi-arid regions, grassland vegetation is the most important element in maintaining the basic functions of ecosystems. Plateau in northwestern China is an important hotspot area for the research of grassland ecosystems in the global arid areas, and is facing the dual effects of high -intensity grazing activities and significant climate change. Study the trend of changes in vegetation under the double influence of grassland vegetation is of great significance to environmental management and biodiversity protection in the region. However, the current impact of climate change and human grazing activities on vegetation lacks substantial evidence, and its impact mechanism is currently unclear. We conducted vegetation surveys and analyzed the dual pressure of plant diversity index under the dual pressure of grazing intensity and climate factors to reveal the mechanism of interaction impact on the intensity impact. The results showed that the vegetation was more sensitive to the rainfall during the rainy season, and under the pressure of low grazing, the stability of vegetation should change the stability of precipitation in the rainy season. In addition, precipitation in the rainy season is a more important climatic factors affecting the diversity of vegetation in drought and semi -arid areas. In the warm and dry climate mode, vegetation is more sensitive to grazing interference and more vulnerable to vegetation; in the cold and humid climate mode, the stability (or elastic) of vegetation should be higher. The results of the research provide direct evidence for the interaction between grazing and climate on the interaction of vegetation diversity and stability, and provide a scientific basis for the grazing management and vegetation protection in the arid area.

Introduction

Vegetation communities in arid and semi-arid regions are vulnerable to the effects of global climate change (Peters *et al.,* 2012; Na et al., 2021; Li *et al.,* 2021). Vegetation is the most important condition to maintain the ecosystem function in arid and semi-arid areas. Therefore, it is very important to maintain the diversity and stability of vegetation communities in these areas. (Jin *et al.,*2019). The dry-semi-arid regions in northwestern China have the world's important pasture and the distribution area of the world's important grass ecosystem. Due to the grassland vegetation protection system attributed to the Chinese government, most of these grass ecosystems facing artificial interference are limited to grazing activities. Some studies have pointed out that the climate model in northwestern China has undergone significant warm and humidization changes in recent decades. Therefore, it is necessary to study the mechanism of changes in the diversity of grassland vegetation in the northwest of China and semi -arid regions under the dual pressure of grazing and climate change.

Climate change and grazing are important stressors affecting grassland ecosystem stability (Li *et al.,* 2015; Jiang *et al.,* 2017). Precipitation is almost the only water source for inland grassland. Long-term precipitation changes will lead to obvious succession of vegetation communities, and some arid plants are more sensitive to precipitation changes (Vicente-Serrano *et al.,* 2012). Temperature is also considered to be an important factor affecting vegetation growth and water cycle (Fensholt *et al.,* 2012; Na *et al.,* 2021). In addition, there is an interaction between surface vegetation and local climate. Low temperature, high biomass and high coverage vegetation can maintain a humid climate. The stability of the interaction between vegetation and climate may be weakened by the destruction of vegetation and the rise of temperature caused by external disturbances (Claussen *et al.,* 2013). Overgrazing resulted in the loss of vegetation diversity and the reduction of community stability, resulting in the collapse of grassland ecosystem and promoting desertification。Continuous grazing activity will change the vegetation species composition of grassland, resulting in the disappearance of wet-loving vegetation and the replacement of grassland by drought-tolerant shrubland, resulting in the decline of grassland productivity and pasture carrying capacity (Vicente-Serrano *et al.,* 2012). However, the interaction between climate change and human grazing activities on vegetation is currently unclear (He *et al.,*2022).

In the grassland areas in northwestern China, the local government proposed a series of strict management systems in order to avoid the irreversible damage of vegetation in arid areas. Therefore, in these areas, grazing is a controlled behavior that is constrained, while the effects of climate change on vegetation are uncontrollable and unavoidable. The role of climate in influencing vegetation diversity and maintaining vegetation-climate stability in the context of grazing intensity changes needs to be reexamined. In addition, under the global trend of long-term climate change, the ability of vegetation communities in arid areas to maintain vegetation-climate stability in response to grazing disturbance also needs more understanding. Therefore, the interaction analysis of climate and grazing activities on vegetation is needed to develop more scientific and economic grazing management strategies, and to better understand the impacts of climate change on vegetation in arid areas.

Vegetation survey was carried out on five grasslands with distinct climatic differences in arid and semi-arid regions of northwest China. The relationship between Simpson, Shannon and Pielou index of vegetation and grazing intensity, temperature and precipitation were analyzed. The effects of grazing activities and climate differences on vegetation diversity and stability were discussed. In addition, the variation trends of dominant species and individual height under the dual effects of grazing intensity and climate were analyzed, and the reasons for the interaction were explained from the species structure. Our results contribute to the understanding of vegetation change mechanisms in arid and semi-arid regions in the context of climate change and grazing management system reform.

Methods

Study site

We selected five grassland pastures located in northwest China, namely Duo lun (DL), Er er duo si (EE), Hai La er (HL), Sha po tou (SP), Wu lan aodu (WA). The pastures chosen were far from urban industrial areas and had little human activity other than grazing. Climatic conditions are reflected by four indicators: dry season temperature (DT), dry season precipitation (DP), rainy season temperature (RT) and rainy season precipitation (RP). DL (DT=0.1 , RT=4.69 , DP=118.8 mm, RP=306.7 mm), EE (DT= 4.78 , RT=8.88 , DP=98.3 mm, RP=280.1 mm), HL (DT= 5.77 , RT=9.94 , DP=40.1 mm, RP=104.5 mm), SP (DT= 7.37 , RT=11.01 , DP=62.5 mm, RP=139.8 mm), WA (DT=5.77 , RT=9.94 , DP=40.1 mm, RP=104.5 mm). In the pasture, different grazing intensity locations were selected to set the quadrat. Grazing intensity was divided according to dry season vegetation cover (DVC) and rainy season vegetation cover (RVC). The control group (grazing intensity 0, DVC> 60%, RVC> 70%) and four gradients of different grazing intensities, namely 1 (45%<DVC<60%、55%<RVC<70%), 2 (30%<DVC<45%、40%<RVC<55%), 3 (15%<DVC<30%、20%<RVC<40%), and 4 (DVC<15%、RVC<20%). Plant species were identified and counted in five replicate quadrats for each grazing intensity at each site.

Interactive influence analysis

The seasonal differences of vegetation diversity (Simpson, Shannon, Pielou index of vegetation community) and the effects of temperature and precipitation on vegetation diversity were analyzed according to linear correlation. Linear correlation was used to analyze the effect of grazing on vegetation diversity. The differences in the relationship between vegetation diversity and temperature and precipitation were compared under different grazing gradients, and the differences in the relationship between vegetation diversity and grazing intensity were compared under different temperature and precipitation. Using NMDS analysis and three -dimensional curved interpolation fitting to reproduce and deeply analyze the interaction between climate factor and grazing on the diversity of vegetation. Linear correlation analysis will ignore some special changes trends, and the three -dimensional curved surface can more specifically display the local changes in the state variable with the pressure variable. Linear correlation analysis is drawn with Origin software, and the three -dimensional curved interpolation fitting is drawn with the cubic method in MATLAB. In addition, according to the changes of the interaction effects of the interaction effects under the dual gradient of the main advantage and the height of the plant and the height of the plant.

The calculation of Simpson, Shannon-Weiner, and Pielou indices

The Simpson and Shannon-Weiner indices are both comprehensive indices of richness and evenness, but the Simpson index is more sensitive to species evenness, and the Shannon-Weiner index is more sensitive to species richness (Xu et al., 2011). These indices are usually used together to comprehensively evaluate species diversity (Heip et al., 1998). The Simpson index is calculated as

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

where S is the number of tree species and P_i is the proportion of the number of individuals of species i relative to the total number of individuals in the community. The Shannon-Weiner index is calculated as

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

where the meaning of the above parameters is the same as that of formula (1). The Pielou index describes the evenness of the individual number distribution among species in an ecosystem and is calculated as

$J = H/\mathrm{lnS}$ (3)

where H is the Shannon-Weiner index and S is the number of species.

The calculation of pairwise dissimilarity

In order to compare the pairwise dissimilarity of species composition between each grazing gradients with control grazing gradient for study sites, we adopted Bray-Curtis Index method. We also use the same method to calculate the pairwise dissimilarity of environment conditions between study sites based on the precipitation and temperature of each sample sites in dry season and rainy season.

We visualized community turnover of different grazing gradients sites with Non-Metric Multidimensional Scaling (NMDS) based on a Bray–Curtis similarity matrix of species abundance data.

Results

Diversity index calculation results and analysis of variance

The Simpson index analysis results show that compared with the control group sample, the test group showed a decline in the overall decline (Table 1) as the test group increased, and the differences between different gradients were significantly (Table 2). The differences between different research sites are significant, but the differences between seasons are not significant, and the laws of different research sites on gradients are different. Simpson of DL and HL showed a trend of first decreasing and then increasing on the grazing gradient, Simpson of EE showed an overall decreasing trend on the grazing gradient, Simpson of WA showed an overall fluctuating trend on the grazing gradient, and Simpson of SP showed an increasing trend on the grazing gradient, especially in the rainy season. Shannon index analysis showed that Shannon of WA showed the maximum value, while Shannon of SP showed the minimum value. In the study of grazing gradient, Shannon's change characteristics were consistent with Simpson's, that is, diversity index showed a significant negative correlation with grazing time, but the difference between seasons was not significant, and different research sites had different change rules on grazing gradient. For Simpson and Shannon indices, the interaction between the study site and grazing gradient, the study site and seasonal factor, and the seasonal factor and grazing gradient were all significant. In addition, the Pielou index of sites fluctuated across grazing gradients, but the differences between gradients were significant, while the differences between seasons were not significant. For Pielou index, the interaction between site and grazing gradient and seasonal factors and grazing gradient were significant. The interaction of the three factors of the study site, grazing gradient and seasonal factors had significant effects on the three diversity indexes.

Table1 Simpson, Shannon and Pielou index of each study sites along grazing gradients for dry season and rainy season. DL (Duo lun), EE (Er er duo si), HL (Hai La er), SP (Sha po tou), WA (Wu lan aodu).

Simpson	Grazing intensity	DL dry	DL rain	EE dry	EE Rain	HL dry	HL rain	SP dry	SP rain	WA dry
	0	0.63(0.16)	0.72(0.1)	0.75(0.06)	0.8(0.03)	0.81(0.04)	0.85(0.02)	0.7(0.07)	0.35(0.15)	0.79(0.07)
	1	0.69(0.03)	0.67(0.07)	0.64(0.05)	0.75(0.05)	0.6(0.09)	0.55(0.12)	0.64(0.08)	0.26(0.24)	0.64(0.21)
	2	0.43(0.14)	0.29(0.15)	0.64(0.11)	0.43(0.07)	0.25(0.11)	0.6(0.15)	0.37(0.16)	0.77(0.03)	0.43(0.18)
	3	0.27(0.06)	0.49(0.15)	0.41(0.12)	0.67(0.05)	0.33(0.17)	0.31(0.18)	0.57(0.03)	0.73(0.04)	0.48(0.16)
	4	0.66(0.04)	0.51(0.17)	0.34(0.06)	0.33(0.13)	0.47(0.13)	0.46(0.07)	0.57(0.16)	0.57(0.14)	0.54(0.07)
Shannon	0	1.23(0.32)	1.54(0.36)	1.59(0.19)	1.78(0.13)	1.88(0.15)	2.04(0.1)	1.47(0.17)	0.62(0.24)	2(0.26)
	1	1.4(0.1)	1.23(0.23)	1.18(0.18)	1.65(0.17)	1.08(0.18)	1.01(0.3)	1.26(0.22)	0.52(0.46)	1.38(0.56)
	2	0.77(0.22)	0.53(0.18)	1.13(0.29)	0.87(0.13)	0.57(0.24)	1.18(0.36)	0.66(0.26)	1.57(0.11)	0.83(0.33)
	3	0.52(0.11)	0.91(0.27)	0.67(0.15)	1.21(0.16)	0.59(0.27)	0.58(0.32)	1.11(0.04)	1.41(0.14)	0.81(0.26)
	4	1.25(0.09)	0.84(0.34)	0.57(0.1)	0.56(0.23)	0.81(0.24)	0.69(0.14)	1.12(0.35)	0.95(0.33)	1.02(0.12)
Pielou	0	0.72(0.13)	0.82(0.1)	0.86(0.04)	0.88(0.04)	0.87(0.03)	0.89(0.03)	0.78(0.08)	0.62(0.18)	0.78(0.1)
	1	0.77(0.04)	0.84(0.06)	0.84(0.04)	0.81(0.05)	0.78(0.07)	0.66(0.14)	0.77(0.08)	0.4(0.25)	0.74(0.15)
	2	0.63(0.14)	0.53(0.3)	0.9(0.09)	0.57(0.07)	0.35(0.09)	0.76(0.15)	0.55(0.15)	0.91(0.04)	0.58(0.14)
	3	0.44(0.07)	0.65(0.14)	0.61(0.13)	0.9(0.1)	0.6(0.17)	0.48(0.23)	0.71(0.04)	0.88(0.07)	0.78(0.15)
	4	0.83(0.07)	0.86(0.15)	0.67(0.17)	0.65(0.16)	0.73(0.13)	0.9(0.09)	0.7(0.13)	0.91(0.05)	0.71(0.06)

Table 2 Three way ANOVAS of Simpson, Shannon and Pielou index of each study sites along grazing gradients for dry season and rainy season.

	dependent variable	df	mean square	F	Sig.
site	Shannon	5	0.549	9.806	0.00
	Pilou	5	0.055	3.547	0.00
	Simpson	5	0.087	6.881	0.00
degradation	Shannon	5	3.839	68.535	0.00
	Pilou	5	0.11	7.143	0.00
	Simpson	5	0.446	35.423	0.00
season	Shannon	1	0.117	2.09	0.15
	Pilou	1	0.058	3.765	0.05
	Simpson	1	0.018	1.466	0.23
site * degradation	Shannon	22	0.794	14.184	0.00
	Pilou	22	0.095	6.168	0.00
	Simpson	22	0.128	10.12	0.00
site * season	Shannon	4	0.266	4.756	0.00
	Pilou	4	0.016	1.008	0.40
	Simpson	4	0.046	3.62	0.01
degradation * season	Shannon	5	0.599	10.695	0.00
	Pilou	5	0.057	3.722	0.00
	Simpson	5	0.12	9.517	0.00
site * degradation * season	Shannon	16	0.419	7.475	0.00
	Pilou	16	0.11	7.14	0.00

	Simpson	16	0.094	7.426	0.00

Effects of climatic factors on vegetation diversity

The linear fitting plot (Figure 1A-F) reflects the trend of vegetation diversity index with temperature increase from control group (0) to high grazing intensity (3). In the dry season, the three vegetation diversity almost had no significant change with the increase of DT at medium and low grazing intensity (0, 1, and 2). At high grazing intensity (3, 4), the three indices were positively correlated with DT. In the rainy season, the three indexes of the control group (0) were negatively correlated with RT. In the low and high grazing intensity (1 and 4) groups, Simpson and Shannon indices had no significant change with the increase of RT, while Pielou index was negatively correlated with RT. Under moderate grazing intensity (2, 3), the three diversity indices were positively correlated with RT. The linear fitting plot (Figure 1G-L) analysis from the control group (0) to the high grazing intensity (3) group showed that the vegetation diversity index in the rainy season changed from an upward trend to a downward trend with the increase of RP. In the high grazing intensity (3) group, the diversity index was inversely proportional to precipitation in both dry and rainy seasons, and the variation trend was different from that under other grazing pressures. In the dry season, when the grazing intensity was 0, 1, 2, and 4, the variation range of diversity index with the increase of DP was small. In the rainy season, at low grazing intensity (0, 1), the three diversity indexes were positively correlated with RP, but at medium and high grazing intensity (2, 3), the three diversity indexes decreased with the increase of RP.

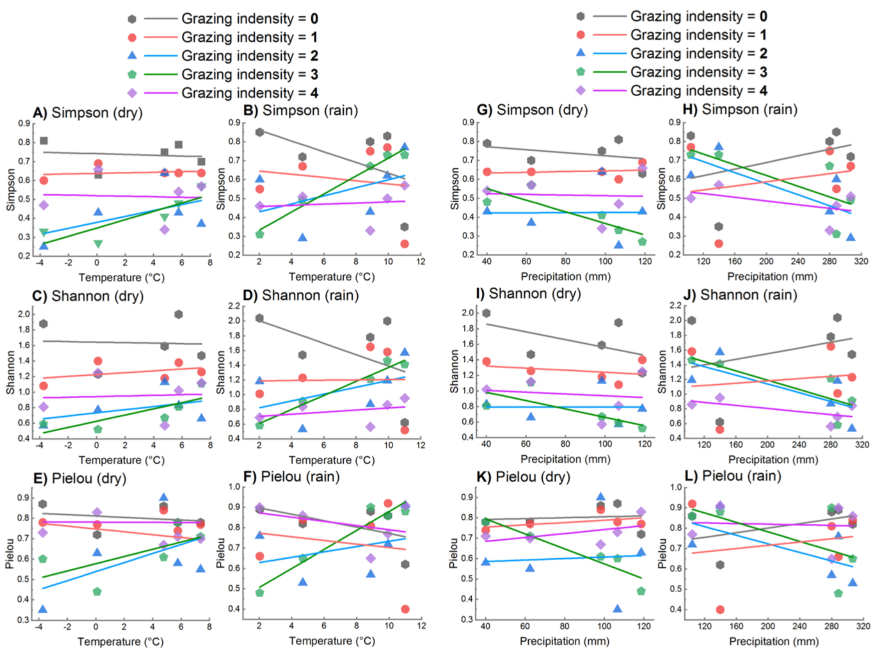

Figure 1 Linear fitting diagram of vegetation diversity index with temperature and precipitation under different grazing intensities. A-F is the linear fitting diagram of the diversity index of the three plantboards and the annual average temperature in the dry season/rainy season, and G-L is the linear fitting diagram of the diversity index of the three plantboards and the annual average precipitation in the dry season/rainy season.

Effects of grazing on vegetation diversity

The linear fitting analysis of the vegetation diversity index and grazing gradient in different sites showed that the diversity index of five sites in the dry season and four sites in the rainy season (except for SP) were inversely proportional to grazing intensity (Figure 2), indicating that vegetation diversity was generally lost in the dry season under grazing pressure. The slope of Pielou index is lower than that of Simpson and Shannon. In addition, the relationship between diversity and grazing pressure was different between sites and seasons (Figure 2). Among them, DL (DT=0.1 , RT=4.69 , DP=118.8 mm, RP=306.7 mm) in wet and cold climate had the lowest slope with the increase of grazing pressure in both dry and rainy seasons. SP (DT= 7.37 , RT=11.01 , DP=62.5 mm, RP=139.8 mm) belongs to the warm-dry climate type, and the relationship between vegetation diversity index and grazing intensity is obvious seasonality, which is inversely proportional in the dry season and directly proportional in the rainy season.

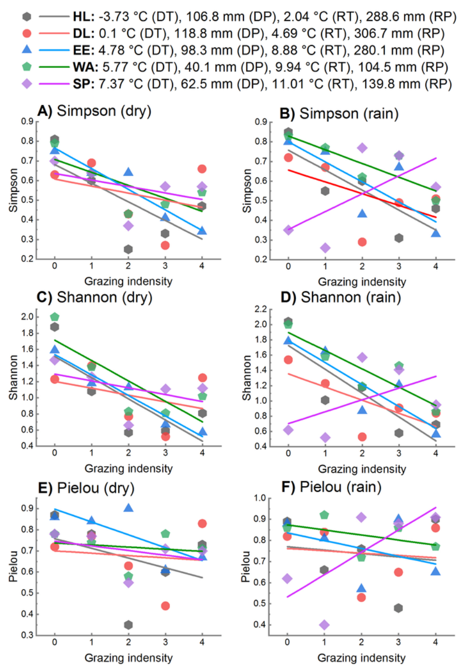

Figure 2 Linear fitting plots of vegetation diversity index and grazing gradient in different locations. A, C, and E are the linear fitting plots of Simpson, Shannon, Pielou index and grazing gradient in the dry season, and B, D, and F are the linear fitting plots of Simpson, Shannon, Pielou index and grazing gradient in the rainy season.

Interaction of grazing and climatic factors on vegetation diversity

Axis 1 in the NMDS figure represents the climate gradient and axis 2 represents the grazing gradient. Plant community composition was significantly different under different grazing gradients. Vegetation composition of grazing gradient 1 was mainly concentrated in the first and second quadrants in different research sites, and mainly distributed along axis 1. Grazing gradients 2-4 were mainly distributed along axis 2, concentrated in the third and fourth quadrants. Compared with the rainy season, the plant community composition under different grazing gradients at different study sites was more similar in the dry season. In the dry season, the species composition of WA (DT=5.77, RT=9.94, DP=40.1mm, RP=104.5mm) was significantly different from that of other sites, and the species composition of other sites showed high similarity. However, on the whole, the differences in species composition under the grazing gradient in the dry season were significantly lower than those in the rainy season (Figure 4).

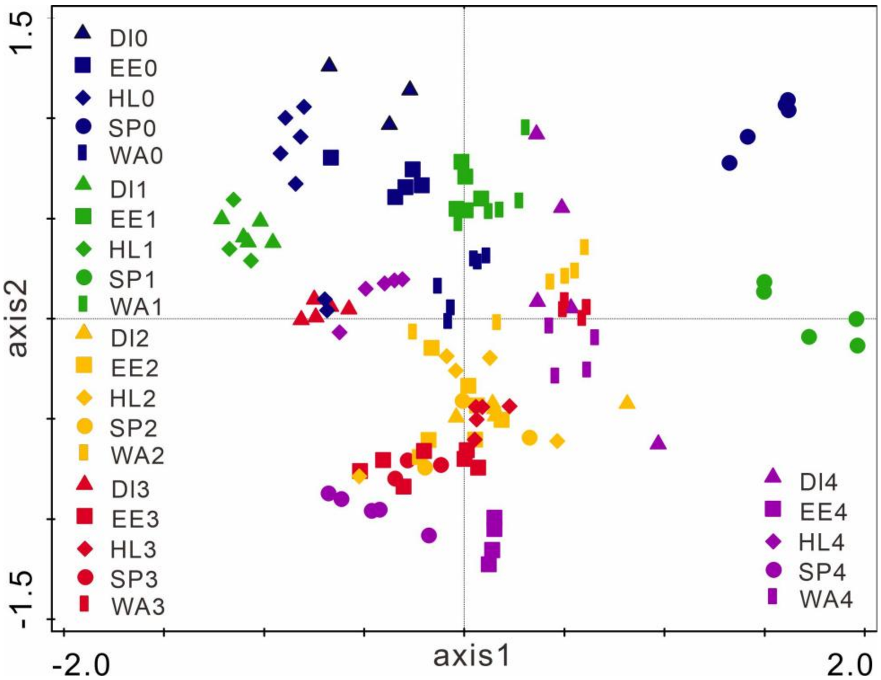

Figure 3 Non-metric multidimensional scaling (NMDS) plots depicting community turnover of different grazing gradients sites of rainy season based on a Bray–Curtis similarity matrix of species abundance data.

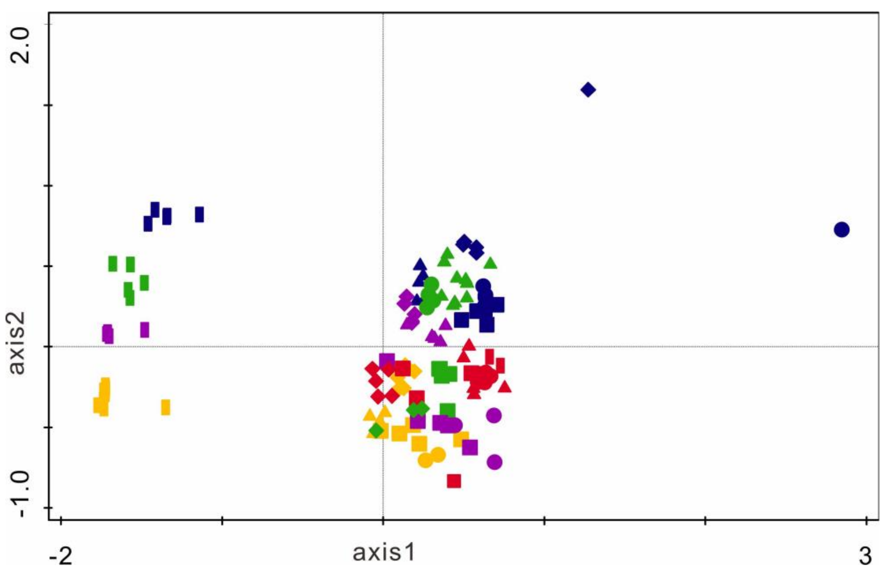

Figure 4 Non-metric multidimensional scaling (NMDS) plots depicting community turnover of different grazing gradients sites of dry season based on a Bray–Curtis similarity matrix of species abundance data.

The contour plots (Figure 5 and Figure 6) clearly show the local variation trend of diversity on the gradient of temperature, precipitation and grazing intensity. Vegetation diversity varied along the temperature and precipitation gradients, and the variation was greater along the precipitation gradients. The fluctuation characteristics of the contour lines showed that the variation range of vegetation diversity on the grazing gradient was greater than that on the temperature and precipitation gradients. In the dry season, vegetation diversity increased slightly with the increase of precipitation, while in the rainy season, vegetation diversity decreased first and then increased with the increase of precipitation.

In the rainy season, the vegetation diversity in DL, HL, EE and WA first decreased with the increase of grazing intensity, reached the lowest level at medium and low grazing intensity (1 or 2), then increased with the increase of grazing intensity, and reached the highest level at high grazing intensity (3), and finally the diversity index decreased again. In SP (DT=7.37 , RT=11.01 , DP=62.5 mm, RP=139.8 mm), vegetation diversity showed a significant increase with the increase of grazing intensity. During the rainy season, Pielou and Simpson indices were higher in high grazing intensity (3 and 4) than in medium grazing intensity (1 and 2), while Shannon index was also at a higher level, but significantly lower than Pielou and Simpson indices.

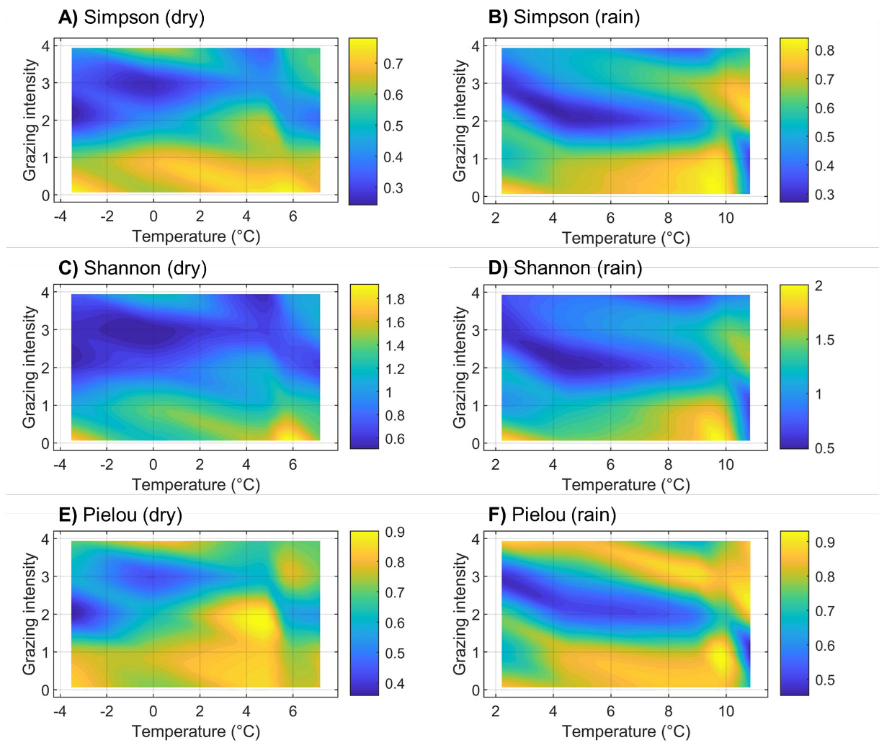

Figure 5 Contour plot of the 3D interpolated surface of plant diversity index (Simpson, Shannon, Pielou) -temperature -grazing intensity. A, C, and E are contours of diversity index-DT - grazing intensity in the dry season, and B, D, and F are contours of diversity index-RT - grazing intensity in the rainy season.

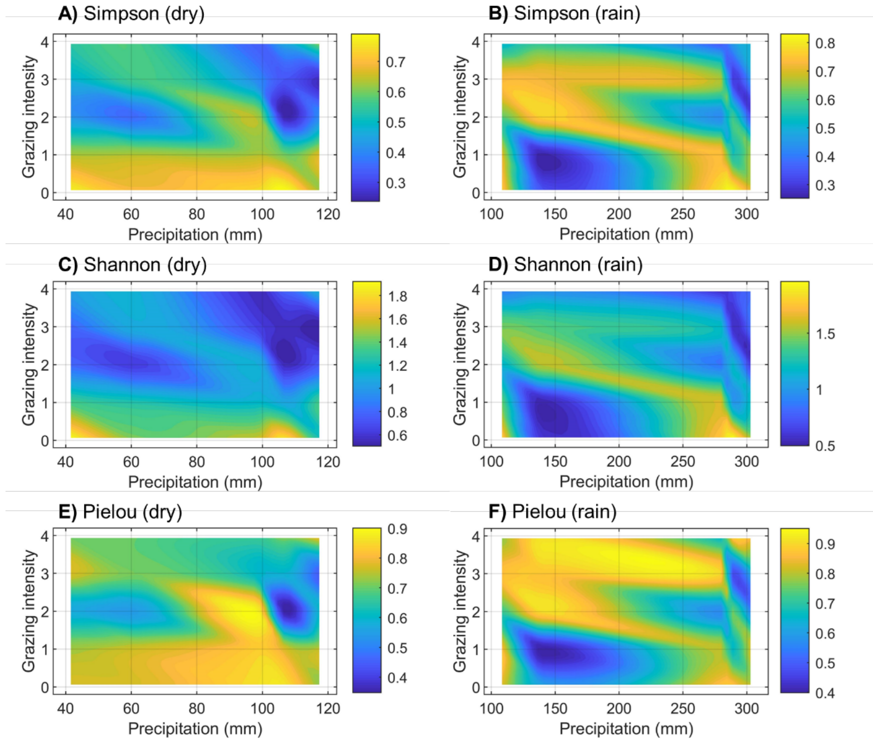

Figure 6 Contour plot of the 3D interpolated surface of plant diversity index (Simpson, Shannon, Pielou) -precipitation and grazing intensity. A, C, and E are contours of diversity index-DP-grazing intensity in the dry season, and B, D, and F are contours of diversity index-RP-grazing intensity in the rainy season.

Effects of grazing and rainy season precipitation on plant species composition

In the surveyed areas, Gramineae is the most dominant species. The results of contour line (Figure 7) showed that the coverage of grasses did not have an obvious relationship with the precipitation in the rainy season, but changed significantly with the increase of grazing intensity, indicating that grazing intensity was an important factor affecting the dominance of grasses. Gramineae showed greater coverage at low grazing intensities, but at high grazing intensities, the coverage of grasses decreased sharply or even disappeared. In the rainy season, HL and DL, which has a large precipitation, the advantages of the grass family have increased rapidly with the intensity of the grazing. Grazing intensity and rainfall in rainy season were important indexes affecting plant height. The grazing intensity was less than 3, and the coverage of low-height plants increased with the increase of precipitation in the rainy season, and reached the maximum when the precipitation was greater than 280mm in the high rainy season. In high grazing intensity, the coverage of plants with low plant height decreased with the increase of rainy season precipitation (Figure 7). The trend of coverage of tall plants was opposite to that of short individual plants.

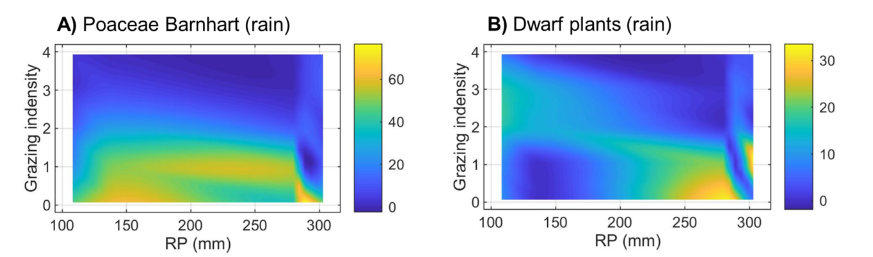

Figure 7. Contour plot of the 3D interpolated surface of plant coverage (grasses and low plant height) -precipitation in rainy season (RP) -grazing intensity.

Discussion

Dual effects of climatic factors and grazing on vegetation diversity

This study analyzed the interactive effects of grazing and climate on grassland vegetation diversity in arid and semi-arid areas through vegetation survey. The results (Figure 3, Figure 4, Figure 5, and Figure 6) supported that grazing had an impact on seasonal differences in vegetation diversity in arid areas. In general, there was no significant difference in vegetation diversity between rainy season and dry season (P >0.05), which indicated that the effect of seasonal change on vegetation diversity was seasonal but had no significant effect. Survey studies have shown that there is no significant seasonal difference in annual plant growth in arid and semi-arid areas, and some studies have shown that grazing intensity has a significant effect on annual plant germination and growth. Comprehensive analysis of seasonal differences of different grazing intensities and vegetation showed (Figure 5, Figure 6) that seasonal differences of vegetation diversity were the largest in moderate grazing intensities (2 and 3), but smaller in low grazing intensities (0 and 1) and high grazing intensities (4). In addition, NMDS analysis results (Figure 3 and Figure 4) also show seasonal differences.

Grazing activity may change the effect of precipitation on vegetation diversity. Precipitation in rainy season may be the key climatic factor affecting vegetation diversity in arid and semi-arid regions. In arid and semi-arid regions, precipitation, especially during the growing season, is considered a greater limiting factor for vegetation growth than temperature (Bao *et al.,* 2014; Rishmawi et al., 2016). In addition, there were seasonal differences in the impact of precipitation on vegetation diversity in the five regions investigated. The variation characteristics of vegetation diversity on the precipitation gradient in the rainy season were significantly different from those in the dry season, and this difference was particularly prominent at low grazing intensity (0, 1 and 2) (Figure 1 and Figure 6). Low grazing intensity in grassland area means low intervention state, representing the original state of vegetation. The variation of vegetation diversity with precipitation in the rainy season is larger, which means that the difference of vegetation diversity between arid and semi-arid regions may be mainly caused by the difference of precipitation in the rainy season. Vegetation diversity was positively correlated with RP at low grazing intensity (0 and 1), but negatively correlated with RP at medium and high grazing intensity (2 and 3). In arid areas, the relationship between vegetation and water resources will be disturbed by high-intensity grazing activities, and the opposite rule will appear.

The effects of grazing on vegetation diversity were also different under different climate models. Except for SP, the variation trend and amplitude of vegetation diversity under the grazing gradient did not show significant differences between the dry season and the rainy season, indicating that there may be no obvious seasonal difference in the impact of grazing on vegetation diversity (Figure 2). The vegetation diversity of the four regions (HL, DL, EE, WA) decreased with the increase of grazing intensity in both dry and rainy seasons, but the vegetation diversity of SP (desert steppe, warm and dry climate) increased significantly with the increase of grazing intensity in rainy season. At medium and high grazing intensity, the three diversity indexes in the five regions increased with the increase of grazing intensity, and the trend of increasing was most obvious in SP. However, increased diversity does not necessarily mean increased stability of plant communities. The coverage of low-height plants was also proportional to grazing intensity in warm and dry climates and was higher than that in humid climates (Figure 7b). These results indicated that high-intensity grazing in warm and dry climate would significantly weaken the dominance of plants with high plant height and enhance the competitiveness of plants with low plant height, thus increasing the diversity, but the aboveground biomass might decrease accordingly. Our results showed that grazing had a greater impact on the dominant patterns of plant communities under drier and warmer climate patterns.

Mechanism of grazing and climate interaction on vegetation diversity

Grazing and climatic factors have interactive effects on vegetation diversity in arid and semi-arid regions, that is, one driver can change the effect of the other driver on the state variable. We discuss the mechanisms and causes of the discovered interaction effects from the perspective of vegetation community stability. With climate change, grazing may reduce vegetation stability. However, under no grazing and low grazing intensity, vegetation coverage was higher, and surface plants were able to fully reduce water loss due to temperature rise.

Grasslands with higher vegetation coverage have stable water retention capacity and are more resistant to climate change, especially warming. Under the background of high intensity grazing, the surface vegetation is overeaten, the vegetation coverage is greatly reduced, and the water holding capacity of the grassland is reduced. Factors such as soil exposure and temperature increase will accelerate surface water evaporation, reducing the available water for plants. An increase in precipitation does not effectively increase surface water supply to plants. By affecting water supply, high-intensity grazing makes vegetation more sensitive to temperature changes and reduces the stability of vegetation communities.

In addition to the environment, the characteristics of plants are also important internal factors that determine their survival. The survival and anti-interference ability of plant species were different under different climate patterns. For example, in arid climates, high-individual plants were more significantly affected by grazing, indicating that high-individual plants were less resistant to grazing disturbance when the climate was drier. In addition, in humid DL and HL, grasses were more sensitive to grazing. Although the coverage of grasses decreased significantly, the coverage of low-height plants did not decrease, and high-height plants were least affected by grazing in this climate model (Figure 7). The results showed that humid climate was conducive to niche succession among species. Although the number of tall grass plants decreased, other tall plant populations quickly occupied the niche, which reflected the higher stability of plant communities in humid climate. The results show that the increase of precipitation in the rainy season plays a greater role in maintaining vegetation stability, while the role of temperature change is very limited. Moreover, a severely dry climate would weaken the resistance of plant communities to grazing and amplify the negative effects of grazing, while a transition to a wetter climate model would increase the stability of plant communities and make them less susceptible to grazing.

Conclusion

The main findings were as follows: grazing had an effect on seasonal differences of vegetation diversity in arid areas; under higher grazing pressure, vegetation was more sensitive to the difference of precipitation in rainy season. Under low grazing pressure, the vegetation was more stable in response to precipitation changes in the rainy season. Precipitation in rainy season is a more important climatic factor affecting vegetation diversity in arid and semi-arid regions. Vegetation is more sensitive and vulnerable to grazing disturbance under warm-dry climate model. The stability (or resilience) of vegetation in response to grazing disturbances is higher in cold and wet climate patterns. This study explored the mechanism of the dual effects of grazing and climate factors on vegetation diversity from the perspective of plant community stability, which provided some new insights for the study of vegetation change in arid and semi-arid areas, and also provided valuable evidence for the study of plant community stability. It is important to note that these differences can also be caused by other geographical factors, such as topography, seed banks, and chance events. Therefore, more field investigation and research are needed for verification.

Reference

Claussen M., S. Bathiany, V. Brovkin, and T. Kleinen. 2013. Simulated climate–vegetation interaction in semi-arid regions affected by plant diversity. Nature Geoscience, 6: 954-958.

https://doi.org/10.1038/ngeo1962

Xu Q., F. Zhang, Z.Q. Xu, Y.L. Jia, J.M. gttYou, 2011. Some characteristics of Simpson index and the Shannon-Weiner index and their dilution effect. Pratacultural Science 28 (4), 527-531 (in Chinese with English abstract).

Heip C. H. R., P. M. J. Herman, and K. Soetaert. 1998. Indices of diversity and evenness. Oceanis 24 (4), 61-88.

Rishmawi K., S. D. Prince, and Y. Xue. 2016. Vegetation responses to climate variability in the northern arid to sub-humid zones of Sub-Saharan Africa. Remote Sens, 8(11): 910.

https://doi.org/10.3390/rs8110910

He M., Y. Pan, G. Zhou, K. E. Barry, Y. Fu, and X Zhou. 2022. Grazing and global change factors differentially affect biodiversity - ecosystem functioning relationships in grassland ecosystems. Global Change Biology, 2022, 00: 1-13. *https://doi.org/10.1111/gcb.16305*

Li Z., Y. Chen, W. Li, H. Deng, and G Fang. 2015. Potential impacts of climate change on vegetation dynamics in Central Asia. Journal of Geophysical Research: Atmospheres, 120: 12345-12356.

https://doi.org/10.1002/2015JD023618

Na R. S., L. Na, H. B. Du, H. S. He, Y. Shan, S. W. Zong, L. R. Huang, Y. Yang, and Z. F. Wu. 2021. Vegetation Greenness Variations and Response to Climate Change in the Arid and Semi-Arid Transition Zone of the Mongo-Lian Plateau during 1982-2015. Remote Sensing, 13(20): 4066.

https://doi.org/10.3390/rs13204066

Li C., B. Fu, S. Wang, L. Stringer, Y. Wang, Z. Li, Y. Liu, and W. Zhou. 2021. Drivers and impacts of changes in China's drylands. Nature Reviews Earth & Environment, 2: 858-873.

Peters, G. P., R. M. Andrew, T. Boden, J. G. Canadell, P. Ciais, C. Quéré, G. Marland, M. R. Raupach, and C. Wilson. 2012. The challenge to keep global warming below 2 °C. Nature Climate Change, 3:4-6.

Fensholt, R., T. Langanke, K. Rasmussen, A. Reenberg, S. D. Prince, C. J. Tucker, R. J. Scholes, Q. B. Le, A. Bondeau, and R. Eastman. 2012. Greenness in semi-arid areas across the globe 1981–2007—An Earth Observing Satellite based analysis of trends and drivers. Remote Sensing of Environment, 121: 144-158.

Bao, G., Z. Qin, Y. Bao, Y. Zhou, W. Li, and A. Sanjjav. 2014. NDVI-Based Long-Term Vegetation Dynamics and Its Response to Climatic Change in the Mongolian Plateau. Remote Sensing, 6: 8337-8358.

Jin, Y., J. Li, C. Liu, Y. Liu, Y. Zhang, Q. Song, L. Sha, D. Balasubramanian, A. Chen, and D. Yang. 2019. Precipitation reduction alters herbaceous community structure and composition in a savanna. J. Veg. Sci, 30: 821-831.

Vicente-Serrano, S. M., C. Gouveia, J. J. Camarero, S. Begueria, R. Trigo, J. I. Lopez-Moreno, C. Azorin-Molina, E. Pasho, J. Lorenzo-Lacruz, J. Revuelto, E. Moran-Tejeda, and A. Sanchez-Lorenzo. 2012. Response of vegetation to drought time-scales across global land biomes. Proceedings of the National Academy of Sciences of the United States of America, 110 (1): 52-57.

https://doi.org/10.1073/pnas.1207068110

Jiang, L. L., G. Jiapaer, A. M. Bao, H. Guo, and F. Ndayisaba. 2017. Vegetation dynamics and responses to climate change and human activities in Central Asia. Science of The Total Environment, 599: 967-980.

https://doi.org/10.1016/j.scitotenv.2017.05.012

Acknowledgments

We are grateful to the staff of the field stations for their logistical support during the course of the experiment. This study was supported by The National Basic Research Program (2016YFC0500501).

Author contribution

Xiuli Gao conceived and designed this experiment.

Xiuli Gao analyzed the data and wrote the manuscript.

Conflict of interest

No conflict of interest

Data accessibility statement

All data will be uploaded in a repository once accepted.