Effects of Different Grazing Management Regimes on Plant Community Characteristics in Xinjiang Mountain Grasslands (Postprint)

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Abstract

This study, based on 10-year plant community observation data from the National Mountain Grassland Monitoring Station in Barkol County, investigated the effects of long-term different grazing management regimes (long-term grazing exclusion M0, winter grazing M1, and year-round grazing M2) on plant community characteristic values, plant diversity, and the relationship between diversity and aboveground biomass in Xinjiang mountain grasslands. The results indicated that: M0, M1, and M2 had no significant effect on the importance value of the dominant species Stipa glareosa; M1 and M2 increased the importance values of the non-dominant species and grassland degradation indicator species Achnatherum splendens and Achnatherum inebrians; with increasing grazing intensity, community height, coverage, density, aboveground biomass, and their response ratios decreased significantly; the Shannon-Wiener diversity index, Simpson dominance index, and Pielou evenness index showed no significant differences among grazing treatments, but the Margalef richness index increased significantly with grazing intensity; in the M0 treatment, aboveground biomass was negatively correlated with the Simpson dominance index, Shannon-Wiener diversity index, and Pielou evenness index, while in the M1 treatment, aboveground biomass was negatively correlated with the Margalef richness index. With increasing treatment duration, long-term grazing exclusion favored the restoration of degraded grasslands, improved community characteristic values, and to some extent enhanced grassland productivity and maintained community stability; grazing affected resource redistribution in the ecosystem, leading to increased species diversity, but under year-round grazing management, grassland degradation was exacerbated.

Full Text

Preamble

Effects of Different Grazing Management Regimes on Plant Community Characteristics in Xinjiang Mountain Grasslands

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Abstract: This study investigates the effects of long-term different grazing management regimes (long-term enclosure, winter grazing, and year-round grazing) on plant community characteristics, species diversity, and the relationship between diversity and aboveground biomass in Xinjiang mountain grasslands, based on observational data from a national mountain grassland monitoring station in Barkol County. The results demonstrate that different grazing managements exert no significant influence on the importance value of the dominant species *Stipa glareosa*, but increase the importance values of non-dominant species and degradation indicator species such as *Neotrinia splendens* and *Achnatherum inebrians*. With increasing grazing intensity, community height, coverage, density, aboveground biomass, and their response ratios decline significantly. The Shannon-Wiener diversity index, Simpson dominance index, and Pielou evenness index show no significant differences across grazing treatments, while the Margalef richness index increases significantly with grazing intensity. Under enclosure management, aboveground biomass is negatively correlated with Simpson dominance, Shannon-Wiener diversity, and Pielou evenness indices. Under winter grazing management, aboveground biomass is negatively correlated with the Margalef richness index. As treatment duration increases, long-term enclosure facilitates the restoration of degraded grasslands, enhances community characteristic values, and benefits grassland productivity improvement and community stability maintenance to a certain extent. Grazing affects resource redistribution within ecosystems, leading to increased species diversity, but year-round grazing management intensifies grassland degradation.

Keywords: grazing management; mountain grassland; community characteristics; sustainable development; species diversity; Xinjiang

Grasslands constitute one of the most important terrestrial ecosystems, covering approximately two-fifths of the Earth' s land surface. China' s grassland ecosystems represent a crucial component of the temperate grassland ecosystems across the Eurasian continent, playing significant roles in biodiversity conservation, ecological maintenance, and pastoral development. Xinjiang' s natural

grasslands are rich in resources, ranking among China' s five major pastoral regions and serving as vital ecological components of the region. These grasslands not only form the material foundation for economic development in pastoral areas but also constitute an important green ecological barrier in northwestern China. Mountain grasslands possess unique geographical conditions, species composition, community structure, and functions, forming important ecological protection barriers while creating distinctive cultural and natural landscapes. Vegetation types in mountain grasslands include desert steppe, alpine steppe, mountain meadow, and alpine shrubland. Due to poor soil fertility and scarce precipitation, desert steppes exhibit simple species composition but rich life-form diversity. Under the combined impacts of human disturbance and climate change, Xinjiang' s grassland ecosystems have suffered severe damage with continuously declining productivity. Issues such as grassland degradation and insufficient ecological compensation not only constrain economic development in pastoral areas but also threaten national ecological security.

Grazing, the primary mode of utilization for natural grasslands in China' s pastoral regions, represents a behavior where livestock freely forage on grasslands and constitutes a direct factor affecting grassland plant communities. Grazing increases spatial heterogeneity in resource distribution and enhances species diversity while promoting species equity by eliminating competitive advantages. Moderate grazing can increase grassland species diversity; however, overgrazing affects the sustainable development of natural grassland ecosystems. At the community level, grazing induces significant changes in grassland vegetation quantitative characteristics, particularly as livestock' s selective foraging alters the relative dominance and resource utilization capacity of plants. Livestock grazing and trampling directly affect grassland morphological characteristics, net primary productivity, and community structure. Under specific natural conditions, different grazing regimes lead to variations in plant community characteristics. The effects of grazing on ecosystem structure and function have long been central issues in ecological research, yet few studies have examined how mountain grassland community structure and function in western inland arid and semi-arid regions respond to long-term different grazing management regimes. Therefore, investigating the response mechanisms of mountain grassland community structure and function to different grazing management practices is crucial for rational grazing in pastoral areas.

Since 2004, Xinjiang has successively implemented projects such as "Returning Grazing to Grassland" and grassland ecological compensation reward policies in pastoral and semi-pastoral counties, allowing natural grasslands to recover. However, the lag in herders' understanding of these policies and the effects of project implementation have inadvertently increased pressure on peripheral natural grasslands, leading to a new round of grassland degradation. Determining what grazing systems and management models should be adopted to scientifically and rationally utilize grasslands has become an important issue facing the government today. Therefore, this study takes the mountain grassland on the northern slope of the Tianshan Mountains in Xinjiang as the research object.

By analyzing the effects of different grazing management methods on mountain grassland plant community characteristics, it helps to understand the patterns of community characteristic changes and the internal mechanisms of functional group responses to grazing during long-term succession in Xinjiang mountain grasslands, providing a reference for the implementation of future grassland ecological compensation and reward projects.

1.1 Study Area Overview

Barkol Kazakh Autonomous County is located on the alluvial plain at the eastern section of the Tianshan Mountains. The climate is characterized as continental alpine, with cold winters, cool summers, and a brief warm season. The average annual precipitation is approximately 200 mm, and the mean annual temperature is 1.8°C. The average annual sunshine duration is 2,500 hours. The experimental site is situated at a national fixed monitoring point for mountain grassland on an alluvial fan [Figure 1: see original paper]. The geographical coordinates are 92°45 44.4 E, 43°34 53.2 N, at an elevation of 1,680 m. The soil type is primarily chestnut soil, and the vegetation type is *Stipa glareosa*-dominated temperate desert steppe with uniform species distribution. The main dominant species include *Stipa glareosa* and *Convolvulus ammannii*, while associated species comprise *Allium polyrhizum*, *Heteropappus hispidus*, *Neotrinia splendens*, *Potentilla chinensis*, and *Achnatherum inebrians*. Climate data for the study area during sampling years are presented in Table 1.

1.2 Experimental Design

In 2012, based on vegetation distribution patterns within the study area, regions with relatively uniform vegetation distribution were selected for baseline vegetation characterization. Three grazing regimes were established from east to west: long-term enclosure since 2004 (permanent grazing prohibition, M0), traditional winter utilization (winter grazing, M1), and year-round free grazing (year-round grazing, M2). The permanent grazing prohibition treatment occupied an area of 66.7 hm^2, while both winter grazing and year-round grazing treatments covered 200 hm^2 each. Winter grazing refers to no grazing during the growing season (May–October) but grazing during the non-growing season (November–April). Year-round grazing allowed continuous grazing throughout all seasons with livestock including cattle, sheep, and horses. Both the permanent enclosure and winter grazing areas were fenced, with the permanent enclosure zone experiencing no human disturbance. Monitoring commenced in 2013 with annual measurements during the peak growing season. This study conducted statistical analyses using data from 2013, 2017, and 2022 (data from the peak growth period).

1.3 Data Collection

During the peak growing season (July–August) from 2013 to 2022, three 1 m × 1 m quadrats were randomly established in each plot for ground surveys. The main survey indicators included plant species composition, species-specific density, species-specific height, species-specific coverage, and species-specific aboveground biomass. Species composition and density were determined through visual estimation, while plant height was measured using a ruler. Aboveground biomass was collected via the harvest method: plants were clipped at ground level, placed in kraft paper envelopes, transported to the laboratory, oven-dried at 105°C for 30 minutes to deactivate enzymes, then dried to constant weight. Dried plant material was weighed using a 0.001 g precision electronic balance to record biomass for each species. Total aboveground biomass was calculated from species-specific biomass values and expressed as dry weight per unit area (g/m^2).

2 Data Processing

This study employed two-way ANOVA to analyze the effects of different grazing management regimes, grazing duration, and their interactions on species importance values (IV), community characteristic values (height, coverage, density, aboveground biomass) and their response ratios, and biodiversity indices (Shannon-Wiener diversity index H , Margalef richness index D, Pielou evenness index J, Simpson dominance index D). When significant differences were detected among treatments, one-way ANOVA and Duncan' s multiple comparison tests were used to examine differences in species importance values, community characteristic values, and their response ratios across grazing management regimes and years. All data were expressed as mean ± standard error (SE), with $P < 0.05$ considered statistically significant. Linear regression analysis was used to examine relationships between aboveground biomass and species diversity indices. Data were organized using Excel 2019, statistically analyzed using SPSS 26.0, and visualized using Origin 2017 software.

2.1 Species Importance Value Calculation

The importance value (IV) for each species was calculated as:

$$IV = \frac{Hr + Dr + Cr}{3}$$

where IV is the importance value, Hr is relative height, Dr is relative density, and Cr is relative coverage.

2.2 Diversity Index Calculation

The Shannon-Wiener diversity index (H), Pielou evenness index (J), Margalef richness index (D), and Simpson dominance index (D) were calculated as follows:

Shannon-Wiener diversity index:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

Pielou evenness index:

$$J = \frac{H'}{\ln S}$$

Margalef richness index:

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

Simpson dominance index:

$$D = 1 - \sum_{i=1}^{S} P_i^2$$

where P_i is the importance value of the i-th species in the quadrat, S is the number of species in the quadrat, and N is the total number of individuals.

2.3 Response Ratio Calculation

The response ratio (RR) was calculated as:

$$RR = \ln\left(\frac{X_F}{X_N}\right)$$

where RR is the response ratio, X_F is the community characteristic value under different grazing management regimes, and X_N is the community characteristic value under long-term enclosure management in 2013.

3.1 Changes in Importance Values of Main Species Under Different Grazing Management Regimes

Changes in importance values of various species under different grazing management regimes are presented in Table 3. Dominant species primarily comprised *Stipa glareosa*, while degradation indicator species included *Heteropappus hispidus*, *Neotrinia splendens*, and *Achnatherum inebrians*. Significant differences in importance values were observed among treatments ($P < 0.05$). With increasing treatment duration, the importance value of the dominant species

Stipa glareosa showed no significant changes across different grazing management regimes. Under long-term enclosure (M0), the importance value of *Convolvulus ammannii* increased significantly, while those of *Heteropappus hispidus*, *Allium polyrhizum*, and *Neotrinia splendens* decreased significantly ($P < 0.05$). Under winter grazing (M1), the importance value of *Convolvulus ammannii* increased significantly, while that of *Heteropappus hispidus* decreased significantly ($P < 0.05$). Under year-round grazing (M2), only the importance value of *Allium polyrhizum* decreased significantly ($P < 0.05$). In 2013, significant differences in *Achnatherum inebrians* importance values existed among treatments. In 2017, significant differences were found for *Convolvulus ammannii*, *Allium polyrhizum*, and *Achnatherum inebrians*. In 2022, significant differences occurred for *Heteropappus hispidus* and *Neotrinia splendens*. The importance value of *Achnatherum inebrians* under M0 was significantly lower than under M1 and M2 ($P < 0.05$), with no other significant differences among treatments.

3.2 Changes in Community Characteristic Values Under Different Grazing Management Regimes

Two-way ANOVA results indicated that grazing management regime, grazing duration, and their interaction all significantly affected community characteristic values. Aboveground biomass differed significantly among treatments across all years ($P < 0.05$), showing an increasing trend with treatment duration. Aboveground biomass in 2022 was significantly higher than in 2013 and 2017 across all treatments. Community height under different treatments was significantly higher in M0 than in M1 and M2 ($P < 0.05$), while M1 height was significantly higher than M2. Community coverage in M0 was significantly higher than in M1 and M2, and M1 coverage was significantly higher than M2. Community density in M0 was significantly lower than in M1 and M2 ($P < 0.05$), while M1 density was significantly higher than M2.

3.3 Response Ratio of Community Characteristic Values Under Different Grazing Management Regimes

Both grazing management regime and grazing duration significantly affected the response ratios of community characteristics, though their interaction only significantly affected height and coverage response ratios. With increasing treatment duration, the response ratios of aboveground biomass and height under all treatments increased significantly ($P < 0.05$). The aboveground biomass and height response ratios under M2 were significantly higher than under M1 ($P < 0.05$), while those under M1 were significantly higher than under M0. The coverage and density response ratios under M0 showed increasing trends with treatment duration ($P < 0.05$). Under M1, coverage and density response ratios initially increased then decreased, while under M2 they showed continuously increasing trends. The coverage response ratio under M2 was significantly higher than under M1, and the density response ratio under M1 was significantly higher than under M0.

3.4 Effects of Different Grazing Management Regimes on Community Diversity Indices

Grazing management regime significantly affected the Margalef richness index, while grazing duration showed no significant effect, though their interaction was significant. With increasing treatment duration, the Margalef richness index under M2 was significantly higher than under M0, while the richness index under M0 was significantly lower than under M1 ($P < 0.05$). No other significant differences were observed among treatments. Grazing management regime, grazing duration, and their interaction had no significant effects on Shannon-Wiener diversity index, Simpson dominance index, or Pielou evenness index [Figure 4: see original paper].

3.5 Changes in Correlation Between Aboveground Biomass and Diversity Indices Under Different Grazing Management Regimes

Under M0 management, community aboveground biomass showed significant negative correlations with Simpson dominance index, Shannon-Wiener diversity index, and Pielou evenness index ($P < 0.05$), with R^2 values of 0.67, 0.65, and 0.66, respectively. Under M1 management, the Margalef richness index was significantly negatively correlated with community aboveground biomass ($P < 0.05$), with $R^2 = 0.71$. Under M2 management, no significant correlations existed between aboveground biomass and diversity indices [Figure 5: see original paper].

4.1 Effects of Different Grazing Management Regimes on Community Characteristics

Community characteristics form the foundation of ecological restoration and reconstruction, representing a comprehensive manifestation of vegetation adaptation to ecosystems. In this study, the response ratio indicates the degree of similarity between treated communities and the initial state under human disturbance. With increasing treatment duration, aboveground biomass and height under long-term enclosure management and their response ratios were significantly greater than those under winter and year-round grazing, consistent with findings from Yao et al. This phenomenon may arise from several mechanisms. First, long-term enclosure effectively reduces grazing pressure on grasslands, providing recovery opportunities for high-quality forage species such as *Stipa glareosa*. Second, under winter and year-round grazing, increased herbivory on palatable dominant species like *Stipa glareosa* reduces photosynthetic leaf area, affecting organic matter accumulation and slowing growth. Additionally, plants adopt prostrate growth forms to avoid herbivory, resulting in reduced height. Furthermore, year-round grazing significantly increased community density response ratio compared to winter grazing, as livestock grazing and trampling altered ecosystem characteristics and species composition. Palatable

tall plants like *Stipa glareosa* were consumed, increasing competitive advantages for short, sparse species such as *Heteropappus hispidus* and reducing inhibition of understory species, thereby creating more resource utilization space and altering community characteristics. Beyond grazing effects, climate variation also influences grassland community characteristics, with temperature and moisture being critical environmental drivers limiting vegetation growth. Research indicates that spring warming promotes plant green-up and subsequent growth, while increased precipitation enhances forage production when thermal conditions are suitable. Our results showed that community characteristics in 2022 were significantly higher than in 2013. Analysis of rainfall and temperature data revealed that although growing-season precipitation was similar between years, the 2022 green-up period (April–May) had favorable hydrothermal conditions that promoted plant recovery and growth, likely representing the primary climatic factor. In contrast, despite 2017 receiving approximately 150 mm of growing-season rainfall, community characteristic values did not exceed those of 2013, possibly because the plots had only been enclosed for a short period, preventing rapid community response and resulting in lower height, coverage, density, and biomass.

4.2 Effects of Different Grazing Management Regimes on Species Importance Values and Diversity Indices

Importance values reflect the status and role of species within communities, with greater values indicating higher status and larger ecological function. As treatment duration increased, *Stipa glareosa* maintained its dominant position across all grazing management regimes, with its dominance becoming more stable. This demonstrates that the dominant perennial grass *Stipa glareosa* possesses strong adaptive capacity and competitive ability under various grazing intensities, reflecting unique characteristics of temperate desert steppe. As grazing intensity decreased across management regimes, the importance value of *Stipa glareosa* increased, indicating that long-term enclosure strengthens its dominant position and contributes to degraded grassland restoration. Conversely, as grazing intensity increased, the importance value of dominant species declined while degradation indicator species (*Heteropappus hispidus*, *Neotrinia splendens*, and *Achnatherum inebrians*) increased significantly, suggesting that year-round grazing management intensifies community degradation and is unsustainable for mountain grassland development.

Plant diversity indices measure species richness, evenness, dominance, and overall diversity, reflecting the degree of interspecific competition impacts on communities. Our results showed that after treatment implementation, the Margalef richness index under year-round grazing was significantly higher than under long-term enclosure and winter grazing. This may occur because long-term enclosure and winter grazing lack sufficient disturbance, intensifying intraspecific competition and excluding less competitive species from the system. No significant differences were observed in Shannon-Wiener diversity, Simpson dominance, or

Pielou evenness indices across treatments, contradicting the intermediate disturbance hypothesis but aligning with Song et al.' s findings that plant species diversity in temperate typical steppe is unaffected by grazing intensity. This may relate to the stable community structure of *Stipa glareosa*-dominated temperate desert steppe. The complexity of grazing disturbance processes and lack of standardized grazing indicators, combined with limited research on diversity in *Stipa glareosa* desert steppe in Xinjiang, hinder accurate cross-study comparisons.

4.3 Effects of Different Grazing Management Regimes on Correlations Between Aboveground Biomass and Diversity Indices

Investigating relationships between aboveground biomass and diversity indices is crucial for understanding grassland ecosystem structure and function. Previous research has shown that species diversity-biomass relationships can exhibit linear positive correlation, linear negative correlation, hump-shaped, unimodal, or non-significant patterns due to energy, resource, and environmental constraints. In this study, significant negative correlations existed between aboveground biomass and Simpson dominance, Shannon-Wiener diversity, and Pielou evenness indices under long-term enclosure, while winter grazing showed significant negative correlation only between biomass and Margalef richness index. These findings contradict the general assumption of positive diversity-biomass relationships but align with Wang et al.' s research on long-term enclosure effects in alpine steppe and Wang Juan et al.' s study on alpine grassland.

These results may be attributed to the community structure of *Stipa glareosa*-dominated temperate desert steppe, which may represent the fundamental pattern of diversity-biomass responses to different grazing regimes in this grassland type. Alternatively, enclosure and grazing season effects may contribute, as accumulated standing dead material and litter in enclosed plots can limit effective light radiation to understory species, creating strong negative effects that ultimately reduce species diversity. Therefore, when utilizing long-term enclosure for vegetation restoration, the effects of enclosure season should also be considered.

5 Conclusions

1) Different grazing management regimes exert no significant effect on the importance value of *Stipa glareosa*, and its dominant status remains unchanged. Under enclosure management, the importance value of degradation indicator species *Neotrinia splendens* decreases, while under year-round grazing, the importance values of degradation indicator species *Neotrinia splendens* and toxic plant *Achnatherum inebrians* increase, which is detrimental to sustainable mountain grassland utilization.

2) Compared with winter and year-round grazing, enclosure management

significantly improves community characteristic values in Barkol County mountain grasslands, enhancing grassland productivity and maintaining community stability to a certain degree.

3) Among diversity indices, only the Margalef richness index is significantly affected by grazing management, while Shannon-Wiener diversity, Simpson dominance, and Pielou evenness indices show no significant differences. Year-round grazing significantly increases Margalef richness, releasing ecological niches and affecting resource distribution within the ecosystem.

4) Under enclosure management, aboveground biomass shows significant negative correlations with plant diversity indices (Simpson dominance, Shannon-Wiener diversity, and Pielou evenness). Under winter grazing, aboveground biomass is significantly negatively correlated with the Margalef richness index. These patterns indicate that enclosure and winter grazing management regimes favor the growth of a few highly competitive species.

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Note: Figure translations are in progress. See original paper for figures.