



The grazing effects on GPP in Inner and Outer Mongolia grasslands under climate change and divergent grassland use systems

Guo, JP^{1,2}; Shi, CJ³; Zhao, YH²; Li, HX¹; Wang, YD¹; Xing, PF¹; Li, YL¹; Wang, H²; Ma, ZY¹; Zhou, YX¹; Hu, Q⁴; Frank Li, YH^{1,*}

¹ Key Laboratory of Ecology & Resource Use of the Mongolian Plateau, School of Ecology & Environment, Inner Mongolia University, Hohhot, 010021, China; ² School of Public Administration and Law, Northeast Agricultural University, Harbin, 150036, China; ³ Institute of Grassland Research, Chinese Academy of Agricultural Sciences, Hohhot, 010021, China. ⁴ School of Land Science and Technology, China University of Geosciences (Beijing), Beijing, 100083, China

Corresponding author*: Frank Li Y.H., lifyhong@126.com

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Abstract

Global climate change and divergent grassland use systems may lead to divergence and degradation of grassland systems in arid and semi-arid regions. However, the effects of grazing intensity on the gross primary productivity (GPP) of grasslands under climate change and the nomadic versus sedentary grazing systems are still unclear. Here, we investigate the grazing effects on different steppe ecosystems by comparing a ratio index change of nomadic GPP to sedentary GPP (NS) under different grazing intensities. The grassland GPP increased significantly between 2001-2023 across three grazing intensities under nomadic and sedentary grazing systems. The NS index in desert and meadow grasslands increased and then decreased across grazing intensities, with 2012 being the turning point. Surprisingly, the typical grasslands exhibited the opposite characteristics. The impact of differences in grazing systems did not exceed the regulatory role of climatic factors. Random forest analysis revealed that the minimum temperature ratio of the coldest month of nomadic to sedentary sites was the dominant factor influencing the NS index in desert and meadow grasslands. In typical grassland, the precipitation ratio of the warmest quarter of nomadic to sedentary sites is predominantly the NS index. Our study highlights the impact of changing climatic environments on the grassland GPP in the semi-arid region.

Introduction

Grazing reshapes vegetation communities' structure, composition, and function through feeding, urination, trampling, and seed dispersal (Ren *et al.*, 2024). The protection of semi-natural grasslands has relied on the maintenance of traditional nomadic systems for hundreds or even thousands of years (Deng *et al.*, 2023).

The traditional nomadic system is an inheritance that simulates the migratory behavior of wild herbivores. With the development of society and economy, some traditional nomadic grazing methods on common grasslands have gradually been transformed into fenced sedentary grazing on private pastures (Parra *et al.*, 2025). However, to our knowledge, the differences in the impacts of different grazing systems and intensity changes on grassland vegetation communities under the context of climate change remain unclear.

The grasslands of the Mongolian Plateau (MP), a significant portion of the Eurasian continent's temperate grasslands, are primarily found in Mongolia (UM) and China's Inner Mongolia Autonomous Region (IM). They are vital for regional ecological security and the livestock economy. However, the interaction of grazing and climate change has led to severe grassland degradation, posing an urgent challenge for sustainable grassland management in the region. The MP is a complete physical geographical unit. The parts of IM in China and UM have the same climate, biological evolution history, and similar modern climates, soil, and vegetation types. However, human activities driven by changes in land use policies show significant differences in the two countries. In the IM, an extensive sedentary grazing utilization mode has been formed, while in UM, traditional grassland nomadism is still practiced. Although many studies have focused on the impact of the combination of grazing methods, intensities, and climate change on the UM grassland ecosystem, most of them are limited to a single region within IM or UM and focus on the grassland conditions under different land uses. There is a need for comprehensive, cross-border studies to assess the impact of varying grassland utilization systems on vegetation productivity. Understanding these impacts and mechanisms is crucial for restoring degraded grasslands and developing sustainable management practices, ensuring regional ecological security.

Methods

The study area, situated in the central MP, encompasses desert, typical, and meadow grasslands in the IM and UM regions. July–August 2023, we identified 18 paired fenced experimental areas, which have been enclosed for 10 to 60 years, across these grassland types. Within a 30 km radius of each fenced plot, we established 36 additional paired experimental areas with varying grazing intensities, including light and heavy grazing under different methods (traditional nomadic grazing in UM and free grazing within fenced paddocks in IM). These 54 experimental areas served as the basis for a 4 km² buffer zone, which was used to analyze MODIS GPP data for each site in 2001–2023 (Fig. 1). The RFM method was used to analyze the driving mechanisms of the differences in GPP under different climatic conditions and grassland utilization patterns.

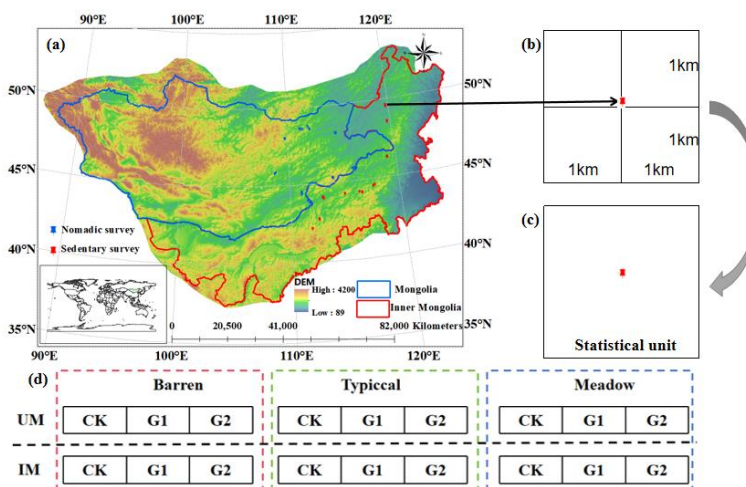


Fig. 1 Study area and experimental design. CK: Fenced, G1: Medium Grazing, G2: Heavy Grazing.

Results

Moderate grazing promotes the increase of vegetation GPP

From 2001 to 2023, the vegetation GPP in the fenced, lightly grazed, and heavily grazed experimental areas all showed a significant increasing trend (Fig. 2(a-c)). Under both the traditional nomadic grazing and fenced grazing systems, the typical grasslands and meadow grasslands are both applicable to the "Intermediate Disturbance Hypothesis" (IDH). The average value of vegetation GPP from 2001 to 2023 was the highest under light grazing, followed by the fenced and ungrazed grasslands, and finally the heavily grazed plots. Regardless of the grazing system, the vegetation GPP of the desert was more suitable for the Dynamic Disequilibrium Hypothesis (DDH).

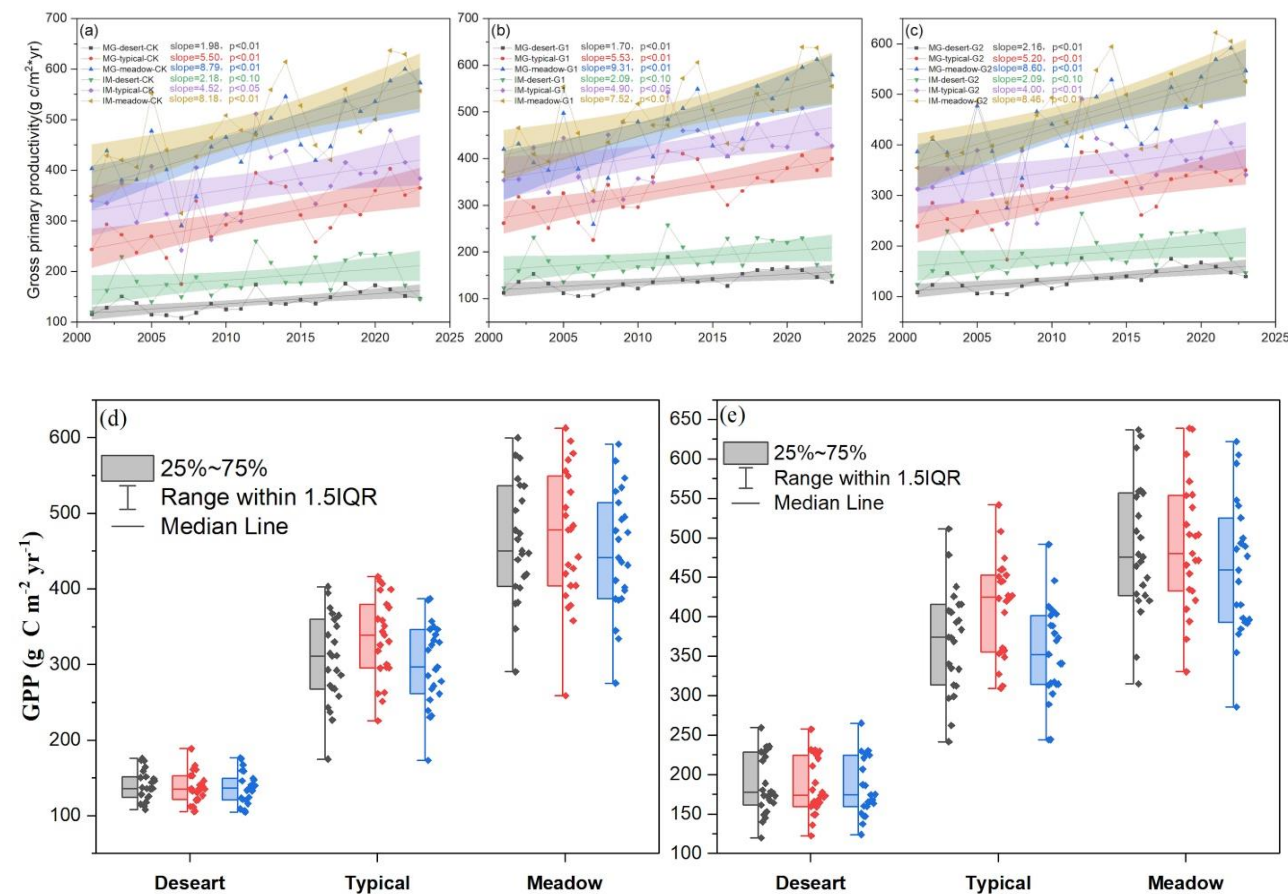


Fig. 2 Vegetation GPP changes along the grazing gradient under different grazing systems in 2001-2023.

Climate Impacts on Vegetation Surpass the Effects of Grazing Regimes

In 2001-2023, the ratio changes of vegetation GPP in the nomadic vs sedentary grazing systems in the enclosed and grazed experimental zones across desert grasslands and meadow grasslands both exhibited a pattern of initial decline followed by an increase, predominantly driven by the minimum temperatures during the coldest months. However, the ratio changes of vegetation GPP in the fenced experimental areas of typical grasslands showed a trend of increasing and then decreasing, which was mainly regulated by the average temperature in the warm season. The impact of differences in grazing systems did not exceed the regulatory role of climatic factors. Under the traditional nomadic system, the trend of the ratio change of

GPP of vegetation under light and heavy grazing to that under free grazing within fenced paddocks was consistent with the trend under the fenced state. However, under the influence of grazing factors, the regulatory factors became the variability of temperature (for desert and meadow grasslands) and the rainfall in the warm season (for typical grasslands)

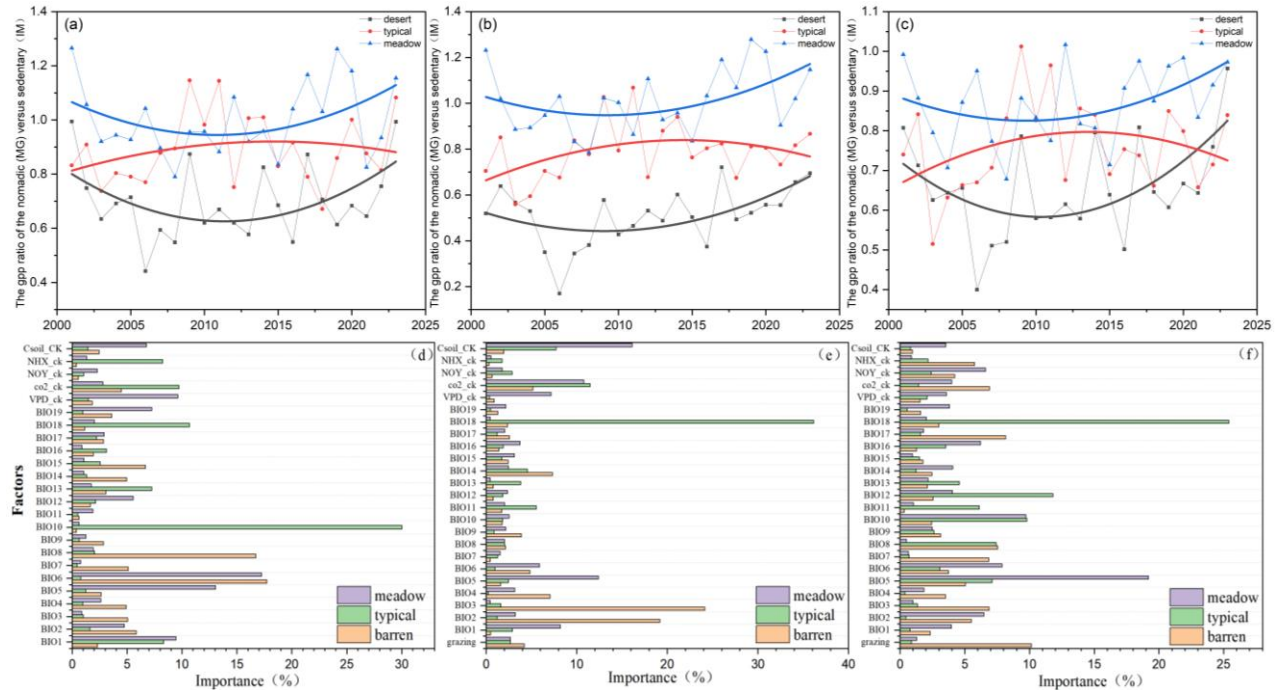


Fig.3 The differential changes in vegetation GPP under different grazing systems in 2001-2023 and their driving factors. (a), (b), (c) and (d), (e), (f) represent the grazing gradients of CK, G1, and G2 respectively.

Discussion

Grazing practices and climate change influence vegetation community productivity, with temperature variability being a key driver of GPP changes across different grazing systems. The IDH applies to the vegetation in the typical grassland areas and meadow areas that are semi-arid and semi-humid (Vidaller *et al.*, 2022). Whether under the traditional nomadic system or the sedentary grazing system, medium grazing will promote the vegetation productivity of the typical grasslands and meadow grasslands; while heavy grazing will reduce the vegetation productivity of the typical and meadow grasslands (Parra *et al.*, 2025). Desert vegetation GPP is highly unstable under any grazing system (Deng *et al.*, 2023; Palmer *et al.*, 2016). In fenced areas, the productivity difference between nomadic and sedentary grazing systems is primarily controlled by the annual minimum temperature, whereas under grazing conditions, it is influenced by temperature variability. Thus, controlling grazing intensity in desert areas and implementing moderate grazing in typical and meadow grasslands is crucial to restoring productivity. Additionally, strict policies to reduce greenhouse gas emissions and temperature variability are essential for mitigating extreme climate events and enhancing regional vegetation productivity.

Acknowledgments

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References

- Deng L, Shangguan Z, Bell SM *et al.* (2023). Carbon in Chinese grasslands: meta-analysis and theory of grazing effects. *Carbon Research* **2**, 19.
- Parra SA, Ramos-Font ME, Buisson E *et al.* (2025). How transhumance and pastoral commons shape plant community structure and composition. *Rangeland Ecology & Management* **98**, 269–282.
- Ren H, Xie J, Ke Y, Yu Q, Lkhagva A & Liu M (2024). Moderate grazing weakens legacy effects of grazing history on primary productivity and biodiversity in a meadow grassland. *Agriculture, Ecosystems & Environment* **362**, 108825.
- Vidaller C, Malik C & Dutoit T (2022). Grazing intensity gradient inherited from traditional herding still explains mediterranean grassland characteristics despite current land-use changes. *Agriculture, Ecosystems & Environment* **338**, 108085.
- Palmer MA, Zedler JB, Falk DA (2016) *Ecological Theory and Restoration Ecology*. In: Palmer MA, Zedler JB, Falk DA (eds) *Foundations of Restoration Ecology*. Island Press, Washington, DC.