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Research paper

Precipitation does not amplify the efficiency of fencing measures for temperate grassland restoration: A case study in northern China based on remote sensing

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ABSTRACT

Increasing anthropogenic interventions involving utilization and conservation of vegetated ecosystems has attracted considerable attention focused on large-scale assessments of the roles played by human-domination. The effects of specific anthropogenic measures have generally been ignored by large-scale assessments, which has probably resulted in irrational regulations and imprecise understanding of these specific measures. This paper aims to reveal the effect of a grassland restoration measure—fencing in northern China—as well as the spatial patterns of fencing efficiency. Spatially continuous Normalized Difference Vegetation Index (NDVI) data based on remote sensing was used to detect grassland vegetation changes during fencing periods. Using subsequent processes to smooth the impact of precipitation from the current year and by setting thresholds for identifying changed/unchanged NDVI, the spatial vegetation changes were converted into two groups of statistical data: the mean NDVI-increase value in each sample region and the pixel areas with different grassland change types in each sample region. The precipitation lag effect on NDVI increases was assessed by multiple comparison tests, and regions with a significant precipitation lag effect were removed from the fencing effect assessment. Finally, the areas with different grassland change types were related to changes in fenced area using regression analyses under different precipitation gradients. The results indicated that the precipitation lag effect caused by legacy moisture significantly affected the spatio-temporal vegetation changes. By excluding the regions with legacy moisture, the increase in fenced area facilitated an expansion of improved grassland and a reduction in degraded grassland. Fencing efficiency was maximized in the 250–300-mm precipitation zone, where the expansion rate of improved grassland area reached 0.70 ($R^2 = 0.54$, $p < 0.01$). The second-best and least effective zones lay in the mean annual precipitation (MAP) >300-mm and MAP <250 mm zones, respectively. We conclude that a wetter climate does not automatically result in a better fencing effect, and legacy moisture will lead to an overestimation of the fencing effect. A rational fencing implementation should consider the resilience and degradation degree of steppes.

1. Introduction

To improve the sustainability of terrestrial ecosystems for humankind, increasing numbers of anthropogenic utilization and conservation measures have intervened in vegetated ecosystems, altering both their biological material and energy flow. Human-dominated roles are increasing in terrestrial ecosystems (Haberl et al., 2014). Distinguishing and quantifying the large-scale effects of human-induced changes in vegetated ecosystem from those driven by natural factors is crucial for understanding human-dominated roles in ecosystems, and these tasks have received considerable attention from researchers (Haberl et al., 2007; Imhoff et al., 2004; Krausmann et al., 2013; Vitousek et al., 1997). These previous assessments of anthropogenic factors have generally included all human activities, whereas the impact and the efficiency of distinct human factors that are primary factors affecting

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regional ecosystems still lack attention. This neglect is prone to lead to blind expansions of human activities after a measure was deemed effective in one or more sites, the subsequent consequences tend to surpass managers' expectations. This is particularly true for temperate grasslands that have been partly restored by protected-status projects after experiencing serious degradation led by a large increase in livestock populations (Ministry of Agriculture of the People's Republic of China, 2013; Spieles, 2010). This paper aimed to assess the large-scale efficiency of a specific primary anthropogenic measure—fencing—which has been adopted by many countries to promote the restoration of temperate grassland vegetation (Hao et al., 2014; Spieles, 2010).

Fencing grasslands to promote grassland restoration is a controversial intervention because it deprives wild ungulates of mobility and hinders local herdsmen from using their grasslands in traditional nomadic ways. However, by eliminating livestock pressures on grasslands, fencing measures can achieve productivity increases (Barros et al., 2014), biodiversity rehabilitation (Gao et al., 2013; He et al., 2011) and other goals (Deng et al., 2014; Teague et al., 2011) as the fencing duration increases (Firincioglu et al., 2007; Liu et al., 2015).

Fencing was prolifically implemented as part of the 'Returning Grazing Lands to Grasslands' project–which was a part of 'Grain to Green' program of China (Armitage et al., 2012; Wu et al., 2014), and it was a recommendation of China's revised Grassland Law in 2003. According to statistics from the National Animal Husbandry Station of the Agricultural Ministry of China, fencing enclosed 69.8 Mha of grassland in China in 2010, and nearly half (46%) of this fencing was implemented in Inner Mongolia at a cost of approximately 270 million RMB. From 2000–2010, the fenced area increased by 1.7 Mha per year in the Inner Mongolian grasslands; nearly 1/3 of the open grazing grassland was converted to fenced grassland. The total area of other measures (including such measures as improving soil, planting grass and shrubs, and so forth) implemented for the 'Returning Grazing Lands to Grasslands' project amounted to less than 6% of the total grassland area from 2000 to 2010. Moreover, fenced grassland usually overlapped the implementation areas of these other measures.

In this context, Inner Mongolian grasslands were selected as the study area for assessing the large-scale efficiency of the fencing measure. To monitor grassland vegetation changes, the normalized difference vegetation index (NDVI) of remote sensing image was applied, NDVI is closely related to vegetation biomass (Barrachina et al., 2015) and coverage (Lehnert et al., 2015), and it has spatial continuity (Turner et al., 2005). However, two difficulties existed in assessing the large-scale effects of anthropogenic measures on vegetated ecosystems: (1) smoothing the impact of climate on vegetation changes and (2) quantifying the relationship between remote sensing-based vegetation changes and anthropogenic measures. We proposed a solution that combines remote sensing monitoring and ecological analysis approaches. The key to this solution lay in the statistical conversion of remote sensing image data, which includes regional averages of NDVI values and area statistics concerning grassland vegetation changes.

The temporal variability of precipitation had a more significant effect on temperate grassland than did temperature over relatively short timespans and was the dominant climatic factor impacting temperate grassland of north China (Piao et al., 2006). The impact of the temporal variability of precipitation on temperate grassland stems primarily from two factors: the precipitation impact of the current year (Mowll et al., 2015) and the precipitation lag effect (Reichmann et al., 2013). Therefore, we first smoothed the precipitation impact from the current year and then assessed the precipitation lag effect on NDVI using multiple comparison tests. The regions with a significant precipitation lag effect were removed from the subsequent fencing effect assessment. Three types of grassland changes were identified spatially according to NDVI unchanged thresholds. The total area of each type of grassland change was determined statistically for each sample region and, finally, related to fenced area changes by regression analysis. To reach the ultimate goal of determining the spatial patterns from the fencing effect, the relationship between the areas with grassland changes and the fenced area changes were evaluated under different precipitation gradients.

2. Materials and methods

2.1. Study area

The Inner Mongolian Autonomous Region (IMAR) in northern China covers an area of 118 Mha, including 78.8 Mha of natural grasslands and 22.7 Mha of desert area, which account for 66% and 19% of the total area, respectively (Fig. 1). Inner Mongolian grassland is representative of typical Eurasian steppe. The grassland area usable for human activities is approximately 63.59 Mha. The IMAR ranges from 37°24′N to 53°23′N in latitude and from 97°12′E to 126°04′E in longitude. As shown in Fig. 1, this transect exhibits significant spatial variability, and mean annual precipitation (MAP) varies from 50 mm in the northwest to 450 mm in the southeast. Moving from east to west, the steppe type shifts with the decreasing annual precipitation, from meadow steppe (300–450 mm), to typical steppe (250–400 mm), to desert steppe (150–250 mm). According to official statistics (Ministry of Agriculture of the People's Republic of China, 1996), these grassland types respectively constitute 10.95%, 35.12% and 10.68% of the total grassland. Most of the annual rainfall is concentrated between May and September. The primary productivity of the steppe peaks in July and August (Potter et al., 1993; Zhou et al., 2001). The average annual temperature varies from 0 °C to 8 °C. The topography of the study area consists of gently rolling hills and tablelands, with elevation ranging from 700 m in the east to 1500 m in the west.

2.2. Datasets

In 2000, Inner Mongolia covered 87 banners (counties). Grassland fencing data were collected from both early (2000–2002) and later (2009–2011) fencing periods, using individual banners (counties) as units. The official fenced grassland area data from 2010 were provided by the Department of Livestock Production of the Ministry of Agriculture, China. The fenced area of most banners remained the same from 2009 to 2011. The data for a few banners with different fenced areas were acquired from the Inner Mongolian Yearbooks of 2010 and 2012. Due to the lack of official statistics, the early fenced area data for the 2000–2002 period were acquired by compiling published Chinese literature, including the Inner Mongolian Yearbooks of 1999–2003, the local chronicles of 46 banners, 7 articles from the Chinese Academic Journal Network Publishing Database (identified through searches using keywords relating to banner names and pasture or grassland management) and 7 reports from an official website. However; two problems were encountered during data compilation for ten banners. (1) While some published sources reported increases in fenced areas for several successive years they lacked data for the initial fenced area for the corresponding years. Therefore; we adopted the available fenced area from the most recent report (usually in the 1990s) as the initial fenced area and calculated the total fenced area during the early period by summing the initial fenced area and the increased fenced area acquired from the published literature. (2) In the 1990s; other sources reported only the initial fenced area and provided no information regarding increases or decreases in fenced area over subsequent periods. In this case; we assumed that