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Effects of excluding grazing on the vegetation and soils of degraded sparse-elm grassland in the Horqin Sandy Land, China

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ABSTRACT

Livestock grazing is a crucial cause of vegetation degradation and desertification in sandy lands. The sparse-elm grassland of Horqin Sandy Land, China has suffered severe degradation of biodiversity and ecosystem services. Management to exclude grazing is often necessary for ecological restoration, especially in arid and semi-arid regions. We report effects on vegetation and soils in a 10-year experiment to exclude livestock, completely or seasonally, in comparison with a continuously grazed area in Horqin. Complete exclusion of grazing and restriction of grazing to summer both led to significantly increased plant cover and density relative to the grazed control. Species richness increased, reflected in higher Shannon-Wiener indices; only complete exclusion increased the Simpson diversity index, whereas Pielou evenness was significantly lowest under seasonal grazing. Exclosure treatments were also associated with improved soil texture, and increased water retention, available nitrogen, total nitrogen, total carbon and total phosphorus. Soil pH and C/N ratio were highest under the seasonal grazing regime. The results indicated that exclosure management indeed improved biodiversity and ecosystem services in an erosion-prone region. Although total exclosure was most effective in restoration of degraded sparse-elm grassland, seasonal grazing management was highly beneficial and represented a good compromise with resource utilization and economic development.

1. Introduction

As the most widely distributed and largest terrestrial ecosystem, grasslands are highly susceptible to human activities, especially long-term, continuous livestock grazing (White et al., 2000; Molles, 2008). In arid and semi-arid regions, 73% of grassland ecosystems have suffered some degree of degradation (Foley et al., 2005; Bai et al., 2012). As a result, intense and increasing interest has been focused on changes in vegetation and soil physicochemical properties in response to grazing. Numerous studies have reported effects on vegetation cover, species diversity and land productivity (Wu et al., 2009; Schönbach et al., 2010; Deléglise et al., 2011; Su et al., 2015). Other studies have drawn attention to modifications in nutrient availability and destruction of topsoil structure by livestock grazing and trampling (Wienhold et al., 2001; Su et al., 2005; Pei et al., 2008; Li et al., 2011; Miao et al., 2014). Both vegetation degradation and soil deterioration have direct influences on ecological function and ecosystem services, and are thus a threat to socio-economic and cultural development (Jeddi and Chaieb, 2010; Zhang et al., 2011).

Various measures have been implemented to limit further degradation and enhance ecosystem recovery. The most fundamental and economical approach to restoration involves management to exclude livestock and their damaging activities, taking advantage of the natural resilience of ecosystems to achieve recovery (Frank et al., 2014; Su et al., 2015). Indeed, previous studies have confirmed the value of grazing exclusion without any additional measures in the successful restoration of natural vegetation in moderately degraded areas, and also reported improved nutrient availability and water conservation (Jeddi and Chaieb, 2010; Deléglise et al., 2011; Wang et al., 2016). Whether this straightforward approach would be successful in

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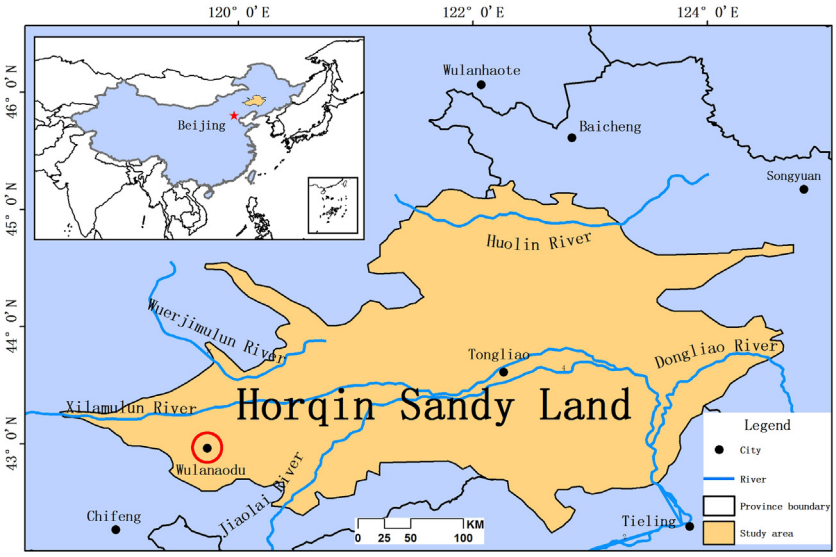

Fig. 1. The geographic location of study area in Horqin Sandy Land, China.

such severely degraded grassland is not known, there having been very few quantitative studies, despite the growing appreciation of increasingly serious desertification and socio-economic losses.

The Horqin Sandy Land, located in the southeast of the Mongolian plateau, is in the semi-arid agro-pastoral transition zone of northern China (Jiang et al., 2003; Tang et al., 2014). Sparse-elm grassland constitutes the main original landscape, which is characterized by either isolated or (more often) groups of the sandy elm tree (*Ulmus pumila* var. *sabulosa*), and well developed grass-shrub vegetation. This community structure has proved to have the greatest stability and best adaptability to sandy soil in these arid and semi-arid regions (Li et al., 2004; Yuan et al., 2012). Horqin Sandy Land represents a traditional Mongolian landscape, where stock grazing has provided the main source of income for herdsmen since ancient times (Katoh et al., 1998; Chang et al., 2003). However, intensive human disturbance from excessive grazing, over-cultivation and gathering of firewood has become increasingly pronounced under the influence of settlement and warfare since the early 20th century (Cao et al., 2008; Miao et al., 2014). The local population has increased four-fold over the past 40 years and most herdsmen, lacking formal education, have little a wareness of environmental protection (Chang et al., 2003). Furthermore, the drive for economic benefit has increased stocking rates dramatically to 3.5–4.5 sheep units ha^{-1}, or nearly three times higher than the local recommended livestock capacity (1.5 sheep units ha^{-1}) since the household contract responsibility system, which advocated that village lands should be allocated to individual households, started in the 1980s (Liu and Diamond, 2005; Han et al., 2008). Overgrazing has induced serious land desertification and has had a catastrophic influence on local productivity and life (Jiang et al., 2003). The average above-ground drybiomass has been only 60–200 g m^{-2} over the past few decades. Consequently, herdsmen have had the expense of purchasing extra grass from other places for livestock feeding through the long winter (Yang and Dong, 2010; Jiang et al., 2011).

In order to redress the balance between the pastoralists' profits and ecosystem services, major top-down exclosure projects "Returning Grazing Land to Protected Grassland" and "Ecological Migration" have been carried out by the Chinese government in this region since the beginning of 21st century (Liu and Diamond, 2005; Reynolds et al., 2007). However, because of the relatively limited remaining area of sparse-elm grassland, it has attracted little attention, with few quantitative studies of the impact on either vegetation or soil properties after exclosure management. Therefore, the specific objectives of our experiments were to examine the effects of exclosure measures on vegetation characteristics and soil properties in the degraded sparse-elm grassland of Horqin Sandy Land, in order to provide strategies for supporting restoration and utilization of degraded grassland ecosystems in this region.

2. Material and methods

2.1. Experimental area

The experiment was conducted in Baiyanhwa (a name meaning 'beautiful and prosperous flat' in Mongolian) near the Wulanaodu Desertification Experimental Station of the Institute of Applied Ecology, Chinese Academy of Sciences (43°02′N,119°39′E, 480 m a.s.l). It was located in the degraded sparse-elm grassland within the western Horqin Sandy Land in Wengniute Banner, China (Fig. 1). This area is characterized by a temperate continental climate, with a mean annual temperature of 7.3 °C and mean annual precipitation of 318 mm from 1980 to 2014 (Liu et al., 2014). Nearly 70% of the rainfall is concentrated between June and August in the growing season (Fig. 2). Annual average wind speed is 4.4 m s^{-1}; the windy season is from March to June (Liu et al., 2012b; Miao et al., 2014). The soils are classified as Orthi-sandic Entisols according to the FAO- UNESCO soil taxonomy classification system. They are highly susceptible to wind erosion because of their coarse texture and loose structure (Cao et al., 2008). Sparse-elm grassland alternates with gentle undulating lowlands to constitute the main landscape, which is regarded as the traditional pasture. There are also gentle undulating dunes with inter-dunal lowlands, and small areas of grassland with good water availability that are reclaimed for planting crops in the growing season. The indigenous species of tree is the sandy elm, *Ulmus pumila* var. *sabulosa*; other important species include the shrub *Caragana microphylla* and annual and perennial herbs, such as *Chenodium acuminatum*, *Artemisia scoparia* and *Carex duriuscula*.

2.2. Experimental design

Historically, the experimental area once belonged to a people's commune (a Chinese village government that carried out collective economics before the 1980s) and had undergone moderate grazing