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# Grassland conservation programs, vegetation rehabilitation and spatial dependency in Inner Mongolia, China

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ABSTRACT

Three nationwide grassland conservation programs have been implemented in Inner Mongolia since 2000. All aim to relieve grazing pressure, hence to reverse the grassland degradation trend. The different timings and spatial configurations of these programs present an unusual setting of quasi-natural policy experiment for exploring their effectiveness and interactions with other drivers on a regional scale. In this paper, a spatial panel model was developed to examine the effects of the programs on vegetation rehabilitation, meanwhile to detect the spatial interdependent relationship among grassland management units occurring in the process of program implementation. The methodology used a panel dataset of SPOT-VEGETATION NDVI data, multi-station surface meteorological observations, and socio-economic statistics across 88 counties from 2000 to 2013. The modeling results suggested that these programs in general significantly facilitated grassland vegetation rehabilitation. Enrollment in the Beijing–Tianjin Wind/Sand Source Control Program and in the Grazing Withdrawal Program was predicted to increase the normalized difference vegetation index (NDVI) value by an amount equivalent to the effects of 136 mm and 56 mm additional annual precipitation, respectively. The positive and significant coefficient of spatial lag term indicated that there was a synergistic relationship in the vegetation variations of neighboring counties, and a unit increase in the weighted sum of all neighboring counties' NDVI values could approximately increase a target county's NDVI value by 0.2, after controlling for other factors' effects. Certain spatial spillover mechanisms may function to generate this effect, such as benign competition, mutual cooperation and coordination, or sharing of successful experiences among neighboring counties in carrying out the programs. Nevertheless, the actual mechanisms need to be confirmed by field surveys in future studies.



## 1. Introduction

Grassland degradation is of critical concern worldwide because grasslands occupy nearly 40% of the Earth's land surface and support the livelihoods of more than 1 billion people, mostly in the developing world (Millennium Ecosystem Assessment, 2005). The term "grassland degradation" is often referred to as a process in which grassland productivity decreases and ecosystem conditions deteriorate, including fragmentation of grass coverage, reduction in soil fertility, soil compaction, declines in the percentage of high quality forages, and encroachments of deserts (Feng et al., 2009; Li et al., 2013). Adopting grazing pressure relief as the dominant strategy, many conservation initiatives have been established around the world, aiming to reverse the degradation trend, facilitate the sustainable development of vast pastoral regions and enhance their adaptive capacity to climate change (Van Andel and Aronson, 2012). However, few attempts have been made to systematically evaluate the effectiveness of these initiatives (Pullin and Bajomi, 2008; Birch et al., 2010). This study intends to fill this knowledge gap by evaluating the effects of three government-funded conservation programs implemented in Inner Mongolia since 2000 on the vegetation cover condition, thereby examining the effectiveness of grazing pressure relief and its interactions with other drivers.

Grassland degradation is especially serious in Inner Mongolia, which has 78 million ha grassland, accounting for 21.7% of China's total grassland area, and is recognized as the largest of the country's five major pastoral regions (Ellis, 1992). As of 2000, approximately 90% of Inner Mongolia's natural grassland was degraded to some extent (Jiang et al., 2006; Akiyama and Kawamura, 2007). Acknowledged as an important ecological network providing a variety of

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ecosystem services for northern China, such as soil and water conservation, carbon sequestration, repository of genetic resources etc. (Xu et al., 2009; Wu et al., 2015), grassland degradation of this magnitude can be responsible for several regional, and even global, environmental problems (Sheng et al., 2000; Yang et al., 2010), of which the most prominent is the frequent occurrence of severe sand storms and dust storms across northern China in recent decades, especially around Beijing and adjacent regions (Ye et al., 2000; Han, 2004; Tan and Li, 2015). Moreover, such degradation can also directly affect the livelihood of millions of people, especially indigenous ethnic Mongolians who have lived in the region for generations (Waldron et al., 2010).

Three nationwide major grassland conservation programs have been carried out in this region since 2000, namely the Beijing–Tianjin Wind/Sand Source Control Program (hereafter, BTWSSC) since 2001, the Grazing Withdrawal Program (hereafter, GW) since 2003, and the Ecological Subsidy and Award System (hereafter ESAS) since 2011. The objectives, durations, ranges and major measures taken of each program were summarized in Section 2.2. Nevertheless, the basic logic underlying the three programs was that overgrazing is the fundamental cause of grassland degradation (Li and Li, 2016). Therefore, the major counter-measures to restore the grassland vegetation condition are grazing pressure relief by year-round or seasonal grazing cessation, rotational grazing and achieving a forage-livestock balance (Miao et al., 2015). The different timings and spatial configurations of the programs present an unusual setting of quasi-natural policy experiment. It is very interesting and promising to explore the impacts of those programs and other drivers, which is what we intend to accomplish in this study.

Controversy exists in previous studies about the ecological effects of the programs. Many scholars suggest that grassland conservation programs have had positive impacts on restoring grassland vegetation (Liu et al., 2003; Xing et al., 2005; Shi et al., 2009; Bao and Zhang, 2015); yet, others argue that these programs have generated negative impacts on the larger scale ecosystem (Wang, 2009; Wang and Qiao, 2011; Li and Li, 2016). Researchers who are skeptical about the three conservation programs point out that grazing pressures are shifted to non-program areas (via leakage), thus increasing degradation in non-program regions, and that illegal grazing activities commonly occur in program areas (Wang, 2009; Wang and Qiao, 2011; Li and Li, 2016;). In addition, some scientists believe that long-term grazing exclusion is harmful to vegetation regeneration and is unsustainable (Xue et al., 2010; Gu and Li, 2013; Li and Li, 2016). According to the grazing optimization hypothesis, an appropriate level of grazing intensity is needed to sustain grasslands and can contribute to enhanced biodiversity and primary productivity (McNaughton, 1979). The impact of grazing intensity control on grassland vegetation change still needs to be verified.

Most of the previous studies on the effectiveness of the conservation programs in Inner Mongolia used small-scale data generated from field experiments and household surveys (Li and Li, 2015). The small scale of these studies impeded the discovery of large-scale effects of the programs, and results could not be expanded to regional levels due to spatial heterogeneity. Although some research used large-scale data generated from remote sensing, the time spans of such studies were relatively short (usually 1–2 years); thus, it was difficult to find the long-term effects of the conservation programs, and specifically to find the long-term effects of grazing exclusion. Li et al. (2012) used long-term panel data to empirically analyze the natural and man-made causes to grassland degradation in Xilingol League over the last two decades. However, both fixed-effects and random-effects models of panel data imply an assumption of spatial independence; ignoring the spatial dependency among neighbors could lead to biased estimation (Anselin, 2013).

Spatial externalities play a central role in the recent emergence of "spatial thinking" in mainstream social sciences (Goodchild et al., 2000), driven by a rising awareness that spatial interdependency (or spatial correlation) broadly and inherently exists in social phenomena, such as interdependent behaviors of economic agents, social–economic agglomeration externalities as well as spatial knowledge spillovers. Spatial panel models were developed to take spatial dependency into account by introducing spatial lag error terms or spatial lag dependent variables into normal panel models (Anselin, 2013). These models allow cross-sectional dependence as well as state dependence, and can also enable researchers to control for unknown heterogeneity (Lee and Yu, 2010). Hence, spatial panel data models have a wide range of applications in fields such as agricultural economics (Druska and Horrace, 2004), transportation (Frazier and Kockelman, 2005), public economics (Egger et al., 2005), and demand for goods (Baltagi and Li, 2006). However, the application of such models in land-change science has been relatively slow and almost nonexistent in grassland conservation policy appraisals.

Considering the limitations in previous studies, the goal of this paper is to assess the effects of government conservation programs and other factors on the grassland vegetation cover condition at a large, regional scale, meanwhile to detect the spatial interdependent relationship among grassland management units occurring in the process of program implementation. Specifically, we will investigate the program effects and spatial dependency by building a panel dataset and employing a novel spatial panel model. The panel dataset will consist of the SPOT-VEGETATION NDVI data product, multi-station surface meteorological observations, socio-economic statistical data, as well as the implementation duration and range of major grassland conservation programs across all counties in Inner Mongolia from 2000 to 2013. The spatial panel model pooled with spatial autocorrelations and temporal fixed effects will disentangle the potential spatial interactions embedded in grassland management process and quantify the effects of such factors as climate and demographic change, economic development, and agricultural expansion on the grassland vegetation condition. It is hoped that, with the empirical data and spatial modeling method, this study will improve our knowledge of the effectiveness and spatial spillover effects of government conservation policy, which may help to design and implement policy more effectively, ultimately, to achieve better resource conditions.

The paper is organized as follows. The methodological framework was described in Section 2. Empirical results and detailed discussions were then presented in Sections 3 and 4, respectively. Finally, the implications for policy making and future studies were summarized in Section 5.

## 2. Material and methods

### 2.1. Study area

Inner Mongolia is located in the north of China (97–126°E, 37–53°N), and covers a total land area of 1.18 million km$^2$, most of which belongs to the Mongolian Plateau, with an average altitude of 1000 m (Fig. 1). Geomorphology in the region varies greatly, including several plateaus (Alxa, Bayan Nur, Hulun Buir, Xilingol, and Ulan Qab), mountains (Great Khingan, Helan and Yinshan), plains (Hetao, Liaohe, Nenjiang, and Tumuochuan), and also valleys and basins. There are five major deserts (Badaim Jaran, Bayan Ondor, Qubqi, Tengger, and Ulan Buh) and five major sandlands (Hulun Beir, Hunshandak, Khorchin, Mu Us, and Ujumqin) in this region.