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Changes in multiple ecosystem services between 2000 and 2013 and their driving factors in the Grazing Withdrawal Program, China

Haiyan Zhang[a,b,1], Jiangwen Fan[a,*], Wei Cao[a], Huaping Zhong[a], Warwick Harris[c], Guoli Gong[d], Yaxian Zhang[a,b]

[a] Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Landcare Research, P.O. Box 69040, Lincoln 7640, New Zealand
[d] Shanxi Institute of Energy, Jinzhong 030600, China

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A B S T R A C T

Quantitative assessment of ecosystem services in the Grazing Withdrawal Program (GWP) of China is required to understand the effectiveness of environmental protection programs and the sustainability of grassland ecosystems. This study focused on quantitative assessment of changes of key ecosystem services and their driving factors in the GWP from 2000 to 2013. Based on widely used biophysical models, including the GLOPEM-CEVSA model, the precipitation storage method, Integrated Valuation of Ecosystem Services and Trade-Offs (InVEST), Revised Wind Erosion Equation (RWEQ) and Underground Productivity Model (UPM), this study integrated multi-source data to analyze dynamic changes of regulating services, including carbon sequestration, water regulation, sand fixation and soil retention, and the provisioning service of grassland yield. For the GWP area during 2000–2013, the ecosystem pattern remained relatively stable and multiple ecosystem services showed overall improvement but there were local deteriorations. For the 14 years net primary productivity (NPP) and grassland yield (GY) increased substantially. Water regulation in forest, grassland and wetland/water body ecosystems improved slightly. The soil conservation function of the entire ecosystem was slightly enhanced with soil retention showing an increasing spatial homogenization and wind erosion having a decreasing tendency. Ecological restoration and reconstruction efforts and climate change helped to improve ecosystem services. Increases in both temperature and precipitation and ecological rehabilitation had a positive effect on vegetation restoration related to a marked increase of vegetation coverage. Increase in annual precipitation increased rainfall related erosion but also assisted water regulation. Reduction in wind speed effectively lowered the occurrence of wind erosion. Vegetation restoration directly increased NPP and GY, and was conducive to water regulation and soil conservation. However, grassland degradation still continued in local areas. Ecological programs applied to the grasslands of China should be continued. Adopting adaptive management approaches that facilitate the synergy of multiple ecosystem services are required to maximize their benefit to the people of China.

1. Introduction

Natural grassland, the largest terrestrial ecosystem in China, has an area of 3.92 million km^2 occupying approximately 41.7% of the country's territory (Fan et al., 2008; Huang et al., 2016). There are three distinct and typical geographic regions in China: the temperate steppe of the northern arid region (48%), the alpine grasslands of the Tibetan plateau at very high elevations (35%), and the tropical – subtropical grassland of the southern humid region (17%) (Liao and Jia, 1996). For the Earth's largest developing country, grassland is the foundation for the rapid and healthy development of animal husbandry. Importantly, grassland also functions as the vital green ecological protective screen for China and even more extensively for Asia. Grasslands play a key role in providing a variety of ecosystem services, including livestock products, water regulation, soil conservation, carbon sequestration, and biodiversity maintenance (Chen et al., 2017; Huang et al., 2013; Yu et al., 2005). Structural and service changes of grassland ecosystems directly or indirectly affect

* Corresponding author at: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A, Datun Road, Chaoyang District, Beijing 100101, China.
E-mail addresses: zhanghy.13b@igsnrr.ac.cn (H. Zhang), fanjw@igsnrr.ac.cn (J. Fan), caowei@igsnrr.ac.cn (W. Cao), zhonghp@igsnrr.ac.cn (H. Zhong), harriswda@gmail.com (W. Harris), gongguoli00@163.com (G. Gong), zhangyx.15b@igsnrr.ac.cn (Y. Zhang).
[1] Institute of Geographic Sciences and Natural Resources Research (Room 3702), Chinese Academy of Sciences, 11A, Datun Road, Chaoyang District, Beijing 100101, China.

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the ecological and social environments essential for human survival and development.

The situation of China's current grassland ecological environment is grim. About 90% of the total grassland area of China has suffered various degrees of degradation since the 1980s. At the end of 2002, the area of deteriorated grassland had reached 135 million ha, and was still increasing at the annual rate of 2 million ha. Kawanabe et al. (1998) reported that during the past 40–50 years degraded grassland covered one-third of the area of north-eastern China and Inner Mongolia. Zhou et al. (2005), in field investigations of alpine meadows in the source region of the Yangtze and Yellow Rivers, estimated that the area had approximately 357×10^4 ha of degraded grassland, of which 21% was heavily degraded. Grasslands degradation results in serious ecosystem structure deterioration and ecosystem services recession, e.g. land desertification, lake shrinkage, wetland degradation, soil erosion, loss of carbon sinks, and more frequent occurrence of sand storms (Han et al., 2018). Degradation was primarily attributed to the integrated effects of highly intensive anthropogenic activities and accelerated climate changes (Yang et al., 2016, Liu et al., 2018). Climatic variations damaging grasslands mainly included global warming (Yu et al., 2012), changing seasonal precipitation patterns causing droughts and floods (John et al., 2013), and wind caused sand erosion (Wang et al., 2006). The negative aspects of human activities mainly include long-term overgrazing (Harris, 2010) and cropland expansion and intensive use (Ren et al., 2016). The Chinese government, as well as many environmental specialists, have generally realized the seriousness of grassland degradation in that it endangers regional ecosystem services and functions (Wang et al., 2017a,b). This degradation results in deterioration of the quality of vegetation and soils, weakening self-restoration functions, losing ecosystem services, and causing property damage (Ouyang et al., 2016).

In the face of the rapid grassland degeneration, since 2000 the Chinese government at the national scale has implemented a series of ecological programs and policy measures to reverse the degradation trend and to enhance ecosystem services. The most important of these programs are the Grain for Green Project (GGP), the Beijing-Tianjin Wind/Sand Source Control Program (BTWSSCP), the Grazing Withdrawal Program (GWP) and the Ecological Subsidy and Award System (ESAS). Of the grassland ecological rehabilitation programs, the GWP has involved the most investment, has the largest scale, has had the most remarkable effect, and has been of most benefit to Chinese herdsmen. According to the grassland survey report of Ministry of Environmental Protection of the Peoples Republic of China, by 2013 the cumulative total investment of the GWP exceeded 20 billion RMB. Particularly, by 2013 the total area of fenced grasslands had increased to 64.48 million ha. However, assessment of the effectiveness of these ecological programs have been varied and controversial. Some experts consider that the program measures have relieved grazing pressure to bring about recovery of vegetation (Bao and Zhang, 2015; Xing et al., 2005), have improved ecological conditions and have achieved the efficient and sustainable utilization (Xu et al., 2007; Zhang et al., 2016). Conversely, other experts argue that fencing natural grassland has fragmented ecosystems to increase their vulnerability to environmental change (Li and Huntsinger, 2011), long-term grazing exclusion has disturbed the original livestock-forage interaction to adversely affect rangeland quality (Gu and Li, 2013), and that the programs will ultimately result in reduction of animal husbandry and decrease the livelihood of herdsmen (Ho, 2009; Wang, 2009). These opinions are based on the dynamic monitoring of a few indicators in specific areas and mainly involved field experiments and household surveys (Gongbuzeren et al., 2015). Further, the effectiveness of these projects and information on the dynamics of China's grassland are mainly on a large scale derived from official reports and statistics. Some previous studies have used remote sensing data, but have been of short duration. Comprehensive research at the national level to analyze the long-term effectiveness of GWP and to accurately assess the multiple services of China's grassland ecosystem is lacking. How to effectively evaluate the ecological effects and incorporate ecosystem service changes into policy making and planning have become urgent problems for China to solve.

Deeper understanding of the multiple ecosystem services in the GWP is of great importance for the planning and management of grasslands. By the definition of the Millennium Ecosystem Assessment (2005), ecosystem services mean the benefits gained by humans from various ecosystems, and consist of supporting service, provisioning service, regulating service, cultural service, and their interaction. Based on an overall analysis of characteristics of grassland ecosystems for the independence and quantification among different ecosystem services, data availability, practicability of the method and spatial scale, this study focused on some key and dominant ecosystem services. As grasslands significantly influence regional and global carbon balances, carbon sequestration is the first consideration. As the study area has the headwaters of several large Asian rivers, we included water regulation in the assessment. As soil loss by wind and water erosion is also serious in the study area, we assessed the sand fixation and soil retention services of the ecosystem. And, as grassland yield relates to livestock production and the livelihood of herders, it is included. Therefore, we focused on quantifying spatial-temporal changes of regulating service (carbon sequestration, water regulation, sand fixation, soil retention) and provisioning service (grassland yield) in the GWP.

The objectives of this study are for the GWP areas during the period of 2000–2013 to (1) quantitatively examine ecosystem pattern changes; (2) accurately and quantitatively evaluate changes of multiple regulating services (carbon sequestration, water conservation, sand fixation and soil retention) and one provisioning service (grassland yield) through ecological restoration programs and climate variability; and (3) assess the effectiveness of the GWP. Findings from the study are discussed with reference to the policies and practical implications of eco-environmental changes, and also to provide a reference and guide for grassland ecological protection policy-making and planning.

2. Materials and methods

2.1. Study area

Since 2003, the GWP has covered nearly 200 counties in Inner Mongolia, Xinjiang, Qinghai, Tibet, Sichuan, Yunnan, Gansu, Ningxia Provinces and the Xinjiang Production and Construction Corp (some counties have not been considered because their implementation scopes are too small and their implementation periods too short) (Fig. 1a) (Zhang et al., 2016). The total area is 319.21 million ha, accounting for about 33% of China's territory. Due to the lack of the precise scope of the GWP implementation, we use only the demonstration counties as the study area. The area includes arid, semi-arid and alpine regions with eighteen grassland types, varying from Alpine steppe to Alpine meadow, Temperate desert, Temperate steppe, Temperate meadow-steppe etc. The raising and breeding of livestock in the study area has more than 250 kinds, mainly involving sheep, goats, cattle, buffalo, horses, donkeys, mules, and camels. Grassland based animal husbandry is the major income source of local herdsmen and accounts for more than 80% of the per capita net income of rural residents. However, by 2000 more than half of the natural grasslands in the study area were degraded to some extent (He et al., 2005; Jiang et al., 2006; Xu et al. 2007).

Many management practices have been implemented for the purposes of restoring degraded grassland, protecting natural pasture and promoting sustainable development of the region's grassland resources. A first step to relieve grazing pressure was to construct fences. Grazing prohibition, rotation or rest were implemented within the fenced grasslands. The government provided subsidies to implement these grassland management practices to realize grassland ecological protection. From these subsidies, from 2005 allowances to local herdsmen families on the Tibetan Plateau were increased by approximately 375