



Ecological and socioeconomic effects of ecological restoration in China's Three Rivers Source Region

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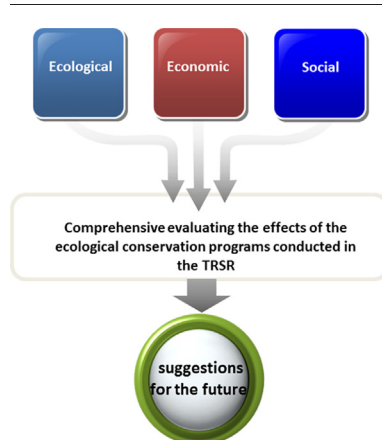
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HIGHLIGHTS

- Grassland degradation has been mitigated.
- The pastoral's livelihoods still mainly rely on the natural resources of grassland.
- Pastoral's cognition plays key effects in the successful implementation of the programs.

GRAPHICAL ABSTRACT



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ABSTRACT

The Three Rivers Source Region, in the central Qinghai-Tibet Plateau, has a sensitive and fragile ecological environment. Adverse changes in climate and human activities have degraded the grassland ecosystems. To mitigate or reverse the degradation, alleviate rural poverty, and stimulate economic development, ecological restoration projects have been implemented. In the present study, our goal was to assess the ecological and socioeconomic effects of these programs based on land-use change, grassland NPP, and household surveys. Household data were collected using structured questionnaires in 11 villages from three counties, with average elevation above 3773 m asl. We found that the grassland degradation had been mitigated, especially after the implementation of ecological restoration programs since 2005 in a regional nature reserve in Qinghai Province. Household income depends strongly on the region's natural resources, so the grassland ecosystems are still at risk of unsustainable use. A household that understood the effects of the ecological restoration programs and had received training to participate in the programs was more willing to participate in future programs. Our findings suggest that for successful restoration, it is essential to help residents of the study area thoroughly understand the ecological restoration programs and learn the restoration techniques before implementation of such programs. This is because the participation of the residents depended strongly on both their income and their satisfaction with the ecological restoration programs.

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1. Introduction

The Three Rivers Source Region lies in the center of the Qinghai-Tibet Plateau. Its name derives from the fact that it includes the headwaters of three of Asia's most important rivers: the Yangtze River, the Yellow River, and the Lancang (Mekong) River (Fang, 2013). The region covers 36.3×10^6 ha, and its average elevation is >4000 m, with snow cover retained at the highest elevations throughout the year (Wang et al., 2017). The region has been called "Asia's water tower" because of the importance of these rivers for the ecological security of China and other countries surrounding the Qinghai-Tibet Plateau (Sun et al., 2012).

Alpine grassland is the plateau's main ecosystem, where it accounts for $>85\%$ of the total area (Ma et al., 2016). However, in recent decades, the ecosystem has experienced increasing degradation and soil erosion in response to changing climatic conditions and increasing human activity (Gao et al., 2009; Cai et al., 2015). The Three Rivers Source Region has a sensitive and fragile ecological environment (Liu et al., 2014). Once the alpine grassland vegetation is disturbed or degraded, it is difficult to restore it to health (Li et al., 2009; Zhang, 2015). Therefore, the region has attracted considerable attention in an effort to find ways to mitigate its grassland degradation and promote sustainable regional development (Liu et al., 2008b).

To protect its fragile ecological environment and ensure the sustainability of the plateau's delivery of ecological services, 22 ecological restoration programs have been implemented since the initiation of the Western China Development Strategy in 2000 (Liu et al., 2008a; Shao et al., 2017). These programs were intended to reduce land degradation, alleviate rural poverty, and stimulate economic development, and have brought dramatic social and ecological changes to the Three Rivers Source Region (Wang et al., 2016). Studies have suggested that these ecological restoration policies have contributed to improvement of the ecosystem services for the whole region. For example, grassland degradation was mitigated in the regional nature reserve: net primary production (NPP) increased by 45%, grassland biomass increased by 24.7%, and runoff, provision of water resources to downstream regions, and water quality improved (Huang et al., 2011; Liu et al., 2014; Zhang et al., 2016). However, the socioeconomic and regional development impacts of these programs have been studied by few researchers. Recent research has shown that China's grassland management policies have generally improved the condition of the grassland ecosystem, but might also have had negative impacts on pastoralist livelihoods, animal husbandry, pastoral society, and even the grassland ecosystem (Li and Li, 2015; Gongbuzeren et al., 2016; Zhao et al., 2017).

Considering the importance of the ecological restoration's impacts on the region's socioeconomic and ecological characteristics, it is essential to more comprehensively understand the long-term ecological and socioeconomic impacts of these programs. Multidisciplinary research will be important because it will help to reveal the relationships among the policies and their impacts (Cobbinah et al., 2014; Sauvé et al., 2015). To provide the necessary information, we combined ecological and socioeconomic techniques to study the impacts of the ecological restoration on the environment and regional development. We selected three villages in the upper reaches of the Yellow River, which lies within the Three Rivers Source Region, for a case study. We obtained land-use data, NPP estimates, responses to household questionnaires, and government statistical data. Our specific goals were to (1) analyze the changes in land-use patterns and NPP to reveal the ecological impacts of the ecological restoration programs; (2) analyze how the ecological restoration policies have affected rural incomes and the employment structure at a household level; and (3) analyze the impact of the programs on the region's traditional pastoral society in terms of their participation in the ecological restoration activities, satisfaction with their new lives, and the opportunities for skills training. Our results provide a more comprehensive picture of the impact of the ecological restoration programs in the study area, and suggest policy implications for decision-makers.

2. Methodology

2.1. Study area

The Three Rivers Source Region is on the Qinghai-Tibetan Plateau, which is known as "Earth's Third Pole" because of its elevation and frigid climate. Because of its ecological significance and vulnerable environment, the region has been defined as one of China's important ecological function zones; as a result, $>50\%$ of the total area is protected against development and in an additional 33% of the area, only limited development is permitted. The grassland that local livelihoods rely on accounts for $>60\%$ of the area.

We included three counties from the study area in our study: Maduo, Maqin, and Jiuzhi counties in the Guoluo Autonomous Prefecture of Qinghai Province (Fig. 1). The study area has an average elevation of 3773 m above sea level (asl). In 2015, 72.3% of the study area (3,887,200 ha) was covered by alpine grasslands, followed by unused land (16.6%), forest (6.0%), cropland (1.1%), bodies of water (3.9%), and built-up land (0.1%). The vegetation's growing season is from the end of March to August (Zhang, 2015). The study area is characterized by alpine, windy, and semi-arid to semi-moist climate conditions, with an annual average temperature ranging from to, with monthly means ranging from -5.6 °C in January to 7.8 °C in July and annual precipitation ranging between 262 mm and 773 mm.

About 90% of the total population in the three counties belongs to the Tibetan ethnic group. The rural population accounts for about 75% of the total, and the per capita disposable incomes of rural residents in Maduo, Jiuzhi, and Maqin counties average 4606, 4065, and 6083 Chinese yuan (CNY, at 1 USD = 6.5 CNY on 15 January 2018). These represent 58.1, 51.2, and 76.7%, respectively, of the average level of 7933 CNY for Qinghai Province (GAPBS, 2016; HAPBS, 2016; QPBS and NBSSOQ, 2016a, b). Traditional animal grazing has been practiced in the region for centuries, with the main animals being yak (*Bos grunniens*) and Tibetan sheep (*Ovis ammon*), which are suitable for grazing in the alpine grassland. Table 1 summarizes the characteristics of the three counties and key data.

2.2. Research methods and data

2.2.1. Land-use change

To characterize the spatial and temporal patterns of land use change across China, the Chinese Academy of Sciences initiated a nationwide land use project in the late 1990s (Liu et al., 2003). We adopted the land-use datasets generated by this study (2000, 2005, 2010 and 2015; 30-m resolution), which we obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (<http://www.resdc.cn/>). We used that data to determine the land-use change from 2000 to 2015 using a spatial analysis tool, ArcGIS 10.2 (<http://www.esri.com/software/arcgis>). According to the land cover classification system for National Land Cover Database, the land cover was categorized into six types: cropland, forest, grassland, body of water, unused land, and built-up land, which included urban areas (Liu et al., 2003). According to the analysis by Liu et al. (2003), the accuracy of the cropland area determined from the land-use dataset was 94.9%, whereas that of the built-up area had the highest accuracy, at 96.3%. The accuracy for forest and grassland was 90.1 and 88.1%, respectively. The land use change was calculated as follows:

$$R_U = \frac{U_a - U_b}{U_b} \times 100\% \quad (1)$$

where R_U (%) is the land use change from 2000 to 2015, U_a (ha) is the area of a given land use in 2015 and U_b (ha) is the area of the same type of land use in 2000.

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