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Ecosystem change assessment in the Three-river Headwater Region, China: Patterns, causes, and implications

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ABSTRACT

The Three-River Headwater Region (TRHR) is the source of the Yangtze River, Yellow River, and Lancang River, which is significant to fresh water resources in China and Asia. The ecosystem in the TRHR has undergone great changes in recent decades owing to dramatic climate change and tremendous human pressure. This study focused on assessing the ecosystem change in the TRHR from 2005 to 2012, which was indicated by ecosystem pattern, quality, and service. Based on the actual observation records and widely used biophysical models including Revised Universal Soil Loss Equation (RUSLE), Revised Wind Erosion Equation (RWSQ), and Carnegie-Ames-Stanford Approach (CASA) models, this study assessed the ecosystem services including soil conservation, water conservation, carbon sequestration, and species conservation. The climate variability and ecological rehabilitation promoted ecological restoration, which was indicated by vegetation cover, productivity (carbon sequestration), streamflow, and habitat area increase. However, the increasing precipitation intensified water erosion by enhancing rainfall erosivity, and increasing temperature induced glacier melting and permafrost degradation, which posed a threat to the sustainable development of regional environment. The ecosystem change is the combined result of ecological rehabilitation and climate variability, the effectiveness of ecological conservation efforts is uneven, indicated by coexistence of restoration and degradation, and is likely a temporary improvement rather than fundamental change. The experience of ecological rehabilitation and ecosystem change in the TRHR exemplified the ecological conservation should take climate variability into account, and facilitate synergies on multiple ecosystem services in order to maximize human well-being and preserve its natural ecosystems.

1. Introduction

Ecological restoration and conservation have been widely conceived and implemented as important corrective measures against environmental degradation, and they have facilitated sustainability at various scales (Bullock et al., 2011; Allan et al., 2013). Protected areas, which cover approximately 13% of the global land surface, are the dominant form of ecological conservation (Butchart et al., 2012). Because of the widely established protected areas and widely implemented ecological restoration programs, the effectiveness of these conservation and restoration efforts has recently become an attractive research topic with critical management implications (Leverington et al., 2010; Butchart et al., 2012). Consequently, there is an increasing need to quantitatively evaluate both the ecological effects of human socioeconomic development and the effectiveness of ecological conservation and restoration (Yang et al., 2015). As the largest developing nation, China's socioeconomic status continues to rise rapidly, and the country suffers from severe ecological degradation problems (e.g. resource depletion, environmental pollution, and ecological degradation) (Lü et al., 2011; Yang et al., 2015; Wu and Chen, 2015). Therefore, the government has launched several large-scale ecological rehabilitation and conservation programs since late 1970s (Lü et al., 2011; Jiang et al., 2015a,b). Multiple afforestation programs in the northern China include the 'Three North' Shelterbelt Development Program

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(TNSDP), the Beijing–Tianjin Sand Source Control Program (BSSCP), the Nature Forest Conservation Program (NFCP), and the Grain to Green Program (GTGP). These programs focus on local environment restoration by planting trees and grass in semi-arid and arid regions to protect natural ecosystems including forest, wetland, grassland, and desert. Furthermore, China has previously established a protected area system, which manages approximately 15% of the country's territory (He, 2009; Jiang and Wang, 2016). The largest nature reserve in the Qinghai–Tibet Plateau, China is TRHR reserve, which covers 15.2×10^4 km^2 (Shao et al., 2013; Jiang et al., 2016b).

In recent years, several studies have been conducted on the ecosystem change and effectiveness assessment of ecological programs in the TRHR. Shao et al. (2013) investigated the ecological effectiveness of the TRHR Project during 2005–2009 based on actual observations and model simulation results, including vegetation growth improvement, reduction in desertification area, carbon sequestration in both above ground biomass and soil, etc. Previous researches also conducted systematic and comprehensive studies on grassland degradation (Liu et al., 2008), soil and water loss (Shao et al., 2009), soil organic carbon change (Sun et al., 2011), water resources change (Bing et al., 2011; Zhang et al., 2012; Jiang et al., 2015a,b), climate change (Yi et al., 2012a, 2013; Jiang et al., 2016b,c), vegetation cover change (Liu et al., 2014), wetland ecosystem change (Tong et al., 2014) in the TRHR. However, previous research has focused on the changes in ecosystem services that resulted from the implementation of ecological projects (Jiang et al., 2015b, 2016b). Although dynamic monitoring and effectiveness assessments of single and multiple ecological projects have been conducted, few studies have analyzed the causes of ecosystem change and its policy and practical implications. How to incorporate ecosystem changes into policy making and planning have been questioned. In addition, some key ecosystem services of the TRHR, such as sand fixation, species conservation, etc, have not been sufficiently understood. Consequently, an in-depth investigation of ecosystem changes that identifies potential causes is urgently needed, and will have important implications on ongoing and upcoming ecological conservation in the TRHR and neighbouring area.

This study is trying to test main hypotheses as the followings: (1) in the context of climate variability and ecological conservation, ecosystem change in the TRHR presents obvious spatial heterogeneity; (2) the ecosystem change from 2005 to 2012 is jointly influenced by climate variability and ecological conservation, and it is more relevant to climate variability; (3) owing to complex driving forces, the effectiveness of large scale ecological conservation and restoration efforts is uneven in nature reserve and non-nature reserve, indicated by coexistence of ecological restoration and degradation. Based upon above hypothesis, the objectives of this study can be summarized as the followings: (1) to investigate the ecosystem changes including pattern, quality, and service from 2005 to 2012 based upon actual observations and biophysical model simulations; (2) to explore the underlying factors that drive ecosystem changes: natural and human factors; and (3) to discuss the policy and practical implications of ecosystem assessment and to provide a reference for environment policy making and planning.

2. Research area review

The three-rivers headwater region (TRHR) is a nature reserve located in the hinterland of the Qinghai–Tibet Plateau, an important source of fresh water resources in China and Asia (Liu et al., 2008; Shao et al., 2013; Tong et al., 2014; Liu et al., 2014). The TRHR includes 22 counties and has a total area of 39.5×10^4 km^2. The TRHR has a complex terrain, with mountains forming the basic framework of the landscape (Fig. 1). The elevation increases from southeast to northwest, ranging from 1987.5 to 6714.5 m. Owing to its average elevation above 4000 m, the annual average temperature range is −5.6 to 7.8 °C (Yi et al., 2012a), annual rainfall is between 262.2 and 772.8 mm from northwest to southeast (Yi et al., 2013), and annual sunshine hours are between 2300 and 2900. The TRHR has a developed river system with numerous tributaries and plume or fan-shaped structures. The years' average annual runoff is about 500×10^8 m^3 and incorporates 25%, 49%, and 15% of the Yangtze River Basin (YARB), Lancang River Basin (LRB), and Yellow River Basin (YRB) runoffs, respectively. The main land use types in 2010 in the TRHR are grassland, desert, wetland, shrub, and forest, which account for 68.4%, 16.0%, 9.4%, 4.6%, and 0.3%, respectively, the other types account for less than 2%. Alpine meadow and alpine grassland are the dominate types of grassland (Liu et al., 2014). As China's major extensive wetland, TRHR has abundant river, lake, mountain snow, and glacier resources and is known as the world's largest alpine wetland ecosystem (Liu et al., 2008; Zhang et al., 2012; Tong et al., 2014; Liu et al., 2014). Wetlands, glaciers, and permanent mountain ice and snow are not only distinctive ecosystems in the TRHR, but also important water suppliers (Liu et al., 2014; Tong et al., 2014). Soil types vary by altitude and consist of alpine cold desert soil, alpine meadow soil, alpine steppe soil, cinnamon soil, and forest soil, the meadow soil accounts for the largest proportion in the TRHR (Shao et al., 2009; Yi et al., 2012b). The soil in this area has thin depth, coarse texture, poor water conservation capacity, low fertility, which is easy to be eroded and thus induce soil erosion (Liu et al., 2008; Shao et al., 2009; Yi et al., 2012b). The permafrost and seasonal frozen soil distribute widely, which cover more than 75% area (Li et al., 2008). Animal and plant resources are very rich in the TRHR, with 69 species having national key protection status, including 17 level–I protected species and 52 level–II protected species (Shao et al., 2013).

Due to its special geographical location, rich natural resources, and distinguished ecological function, the TRHR is an important nature reserve in the Qinghai–Tibet Plateau, China (Liu et al., 2008; Shao et al., 2013; Tong et al., 2014; Liu et al., 2014). However, due to the region's high altitude and harsh natural conditions, its ecosystem is very fragile. In recent years, the ecosystem has undergone great changes because of climate warming and increasing human activities. For instance, the retreat of glaciers, the rising snow line, grassland degradation, and the decline in water conservation capacity all pose a direct threat to the ecological safety of the TRHR (Liu et al., 2008; Shao et al., 2013; Zhang et al., 2014). Against this background, the state council promulgated and implemented an ecological project entitled by 'Overall Planning of Eco-environment Protection and Construction in the TRHR', commonly called the TRHR Project. The TRHR Project was launched in 2005 and included 18 nature reserves with a total area of 15.2×10^4 km^2 (Shao et al., 2013). The total project investment amounted to 11.8 billion USD, including expenses on returning pasture and farmland to forest, afforestation, comprehensive treatment of soil degradation in 'black soil beach' areas, which is a kind of severely degraded grassland (Liu et al., 2008; Shao et al., 2013), and artificial rainfall enhancement. The project named 'Returning Pasture and Farmland to Forest' accounted for the largest proportion (41%) of the expenditures (Shao et al., 2013). Most projects were completed by 2013 as the budget execution rate reached more than 95%.

3. Data and methodologies

3.1. Data collection and generation

Basic geographic information, remote sensing images, hydrological and meteorological records, soil and vegetation maps,