



Integrating ecosystem services into effectiveness assessment of ecological restoration program in northern China's arid areas: Insights from the Beijing-Tianjin Sandstorm Source Region



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ARTICLE INFO

Keywords:

Beijing–Tianjin Sandstorm Source Region (BTSSR), China
Ecological rehabilitation
Climate variability
Ecosystem service
Synergy

ABSTRACT

The Beijing–Tianjin Sandstorm Source Region (BTSSR) is the main sandstorm source area in northern China, which plays a crucial role in ecological safety and sustainable development of Beijing and the neighbouring areas. As a result of climate change, ecological restoration and anthropogenic activities, the ecosystem in the BTSSR has experienced substantial changes over the recent decades. The main objective of this study is to quantify the dominant ecosystem services from 2000 to 2010, based upon observations and biophysical models. Furthermore, we investigated the role of climatic variability and ecological restoration program in vegetation activity and ecosystem services. Although the slight increase, both in precipitation and temperature during 2000–2010 and despite the implemented ecological rehabilitation, several drought events offset the ecological rehabilitation program. During 2000–2010, both the overall soil conservation and hydrological regulation functions were slightly enhanced. The carbon sequestration remained stable and food production has sharply increased. The increasing rainfall erosivity has intensified water erosion, whereas the reduction in wind speed weakened wind erosion and thereby reduced the sandstorm events. Vegetation restoration induced by the climatic variability and ecological program has also played a positive role in soil conservation and hydrological regulation enhancement. The spatial correlation analysis indicated the synergies between multiple regulating ecosystem services. Moreover, a synergy between food yield and vegetation carbon sequestration (biomass production) has been identified as well. The experience of ecological rehabilitation and ecosystem change in the BTSSR has exemplified the ecological conservation should take climatic variability into account, and facilitate the synergies on multiple ecosystem services in order to maximize the ecosystem's benefits to human well-being.

1. Introduction

Ecosystems generate a wide range of services, which are collectively known as the ecosystem services and are important for the well-being of human society (Nelson et al., 2009). Over the past few decades, ecosystem services are one of the central issues in the field of sustainable development and natural resources management research (Dearing et al., 2012). Remarkable progress has been achieved towards the understanding of ecosystem services importance and their associated economic profits (NRC, 2005). There are several underlying drivers for ecosystem service change, which can be summed up as natural and

human factors, including policy, economy, technology, and other biophysical conditions (Lü et al., 2012). As a consequence of economic development and population growth, more than half of the worldwide ecosystem has degraded in the last 50 years (MA, 2005). In China, rapid urbanization, farmland expansion, deforestation, reclamation, and other human activities has induced severe environmental degradation on national scale. This degradation in its turn, triggered severe ecological challenges, such as forest degradation, air and soil pollution, water scarcity, desertification, biodiversity loss (SFA, 2010).

Land cover changes induced by anthropogenic and natural factors (i.e., climatic changes) are widely recognized as two major drivers

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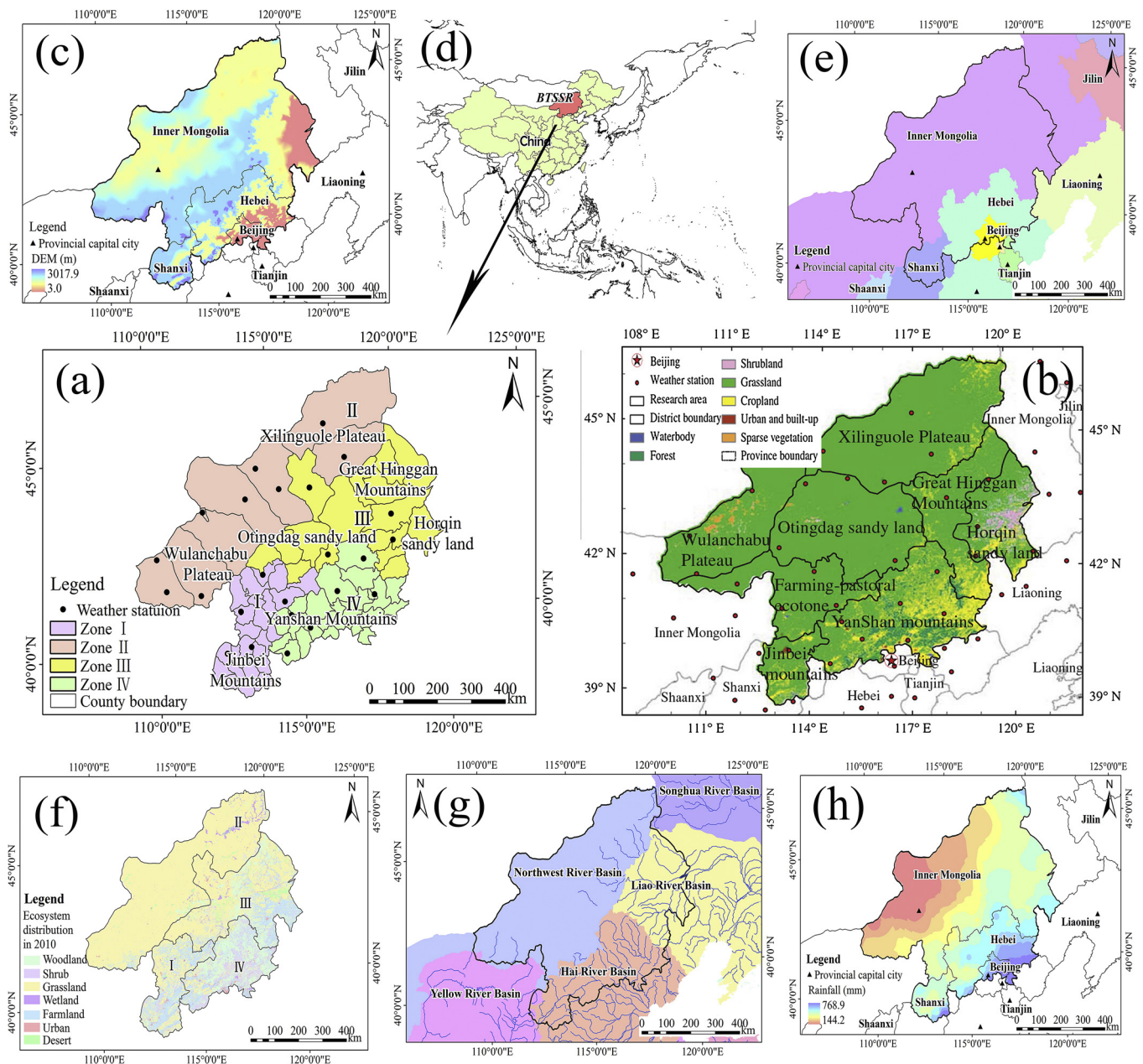


Fig. 1. Locations of research area, weather station, and general description of geographical information: (a) spatial distributions of counties, weather stations, and control areas in the BTSSCP. Zone I: control area of arid desert grassland; Zone II: control area of Otingdag sandy land; Zone III: control area of sandy land in the agro-pastoral transition zone; Zone IV: the Yanshan Mountain water source conservation area, (b) geographical zones distribution (Liu et al., 2013), (c) Digital Elevation Model (DEM), (d) location of BTSSCP in the world map, (e) administrative divisions in the BTSSCP and neighboring areas, (f) ecosystem distribution in 2010, (g) river system distribution, and (h) spatial distribution of years' average rainfall.

influencing the changes in ecosystem and their services (MA, 2005; Nelson et al., 2009). However, the local and global consequences of land cover changes on the ecosystem services and the human society are not clearly understood (Reyers et al., 2009). Effective management of ecosystem services is therefore essential to develop the conservation and land management plans (Kremen, 2005). Furthermore, managing ecosystem services require prior knowledge of their dynamic patterns, status, connections, interactions among the ecosystem structures and functions (MA, 2005). Thereby, a spatially explicit assessment of ecosystem services is critical for making the effective land use and management decisions (Balmford et al., 2002; MA, 2005).

In order to mitigate and adapt to the environmental degradation, in particular for the ecologically fragile regions, a series of ecological restoration programs have been initiated at national and regional scales,

e.g., ‘Grain for Green Program (GFGP)’, ‘Three-North Shelterbelt Program (TNSP)’, ‘Natural Forest Conservation Program (NFCP)’, ‘Sloping Land Conversion Program (SLCP)’, and ‘Beijing-Tianjin Sand Source Control Project (BTSSCP)’ (Yin and Yin, 2010; Zhang, 2012). These programs are mainly focused on local environmental restoration by planting trees in semi-arid and arid regions, by protecting the natural forests and by encouraging afforestation activities (Zhang et al., 2016). However, the effectiveness of these programs is questioned in the previous studies. It has been reported that the implementation of large scale ecological programs had altered the pattern and the quality of the regional ecosystem. Zhang et al. (2016) reported that the multiple ecological programs accelerated the greening trend in northern China and highlighted the importance of human awareness in regional vegetation growth in the conditions of changing climate. Increasing

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