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Exploring spatiotemporal changes in ecosystem-service values and hotspots in China

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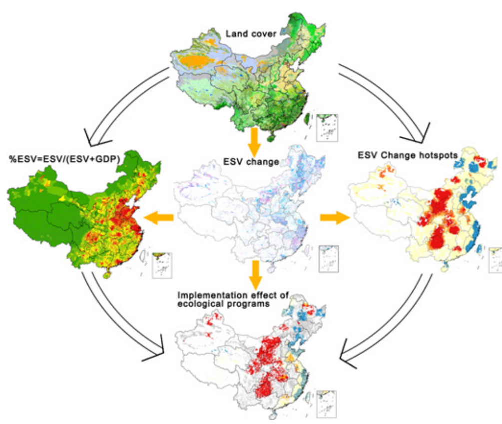
HIGHLIGHTS

- We examine changes in terrestrial ecosystem services values and their hotspots in China.
- The tendency of ecosystems in China to gradually deteriorate.
- The variations in terrestrial ESV change have spatial heterogeneity.
- Ecological conservation programs have a positive ecological effect on China's ecosystems.

GRAPHICAL ABSTRACT



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ABSTRACT

Although ecosystems are valuable, they have been allowed to deteriorate globally in recent decades. However, the spatiotemporal changes in ecosystem-service values (ESVs) and their hotspots in China are not well understood. Here, long-term land-cover data, the spatial analysis method and an econometric analysis model were used to examine these changes. The results indicate that the total terrestrial ESV decreased from US$2398.31 billion in 1990 to US$2347.56 billion in 2010 (converted to 2009 dollar values), which provides strong evidence for the tendency of ecosystems in China to deteriorate over time, albeit slightly. We also found that the changes in ESVs had significant spatial heterogeneity. Our analysis showed that the relationship between ESV and gross domestic product (GDP) is generally negative, but this relationship is not always fixed. The Loess Plateau, Guizhou, Hubei, Henan and Xinjiang continually presented concentrated hotspot areas of ESV changes, whereas coastal regions continually presented concentrated cold-spot areas. Overlap analyses and logistic regressions demonstrate that national ecological programs have clear effects on the improvement of ecosystems but that the effectiveness of different policies varies on spatial and temporal scales. The results of this study will support more effective decision-making around the implementation of ecological conservation policies.

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1. Introduction

Ecosystems provide a multitude of services that are of fundamental significance to humans' well-being, livelihood, health and survival (Costanza et al., 1997, 2014; Millennium Ecosystem Assessment, 2005; TEEB, 2010a, b). The importance of these services has stimulated considerable interest in their conservation. After the seminal work of Costanza et al. (1997), the body of research on methods of estimating, mapping, and quantifying ecosystem services has grown exponentially (Fisher et al., 2009), particularly since the release of the Millennium Ecosystem Assessment (MA; de Groot et al., 2010, 2012), an international study involving over 1300 scientists. The MA provided important evidence of the ongoing degradation of approximately 60% of the world's ecosystems over the past five decades (Millennium Ecosystem Assessment, 2005). The Economics of Ecosystems and Biodiversity (TEEB), an international initiative, further confirmed this global trend of ecosystem deterioration and provided a scientific foundation to help decision makers recognize, demonstrate and capture the values of ecosystems (TEEB, 2010a). Currently, hundreds of projects and groups around the world are generating additional data on ecosystem services and on improving modeling, mapping, valuation, and management techniques stimulated by the aforementioned programs.

Most research on the valuation of ecosystems services is focused on monetizing and estimating explicit ecosystem-service values (ESVs) at a certain point in time (Costanza et al., 1997; Li and Fang, 2014; Sutton and Costanza, 2002). Although temporal changes in ESVs are as important or even more important, monitoring change over a longer time scale has rarely been performed on global, national or regional scales; however, this topic has attracted scholarly attention in recent years (Costanza et al., 2014; Su et al., 2012a). For example, Costanza et al. estimated that the global loss of ESV from 1997 to 2011 caused by land-use changes was $4.3–20.2 trillion/yr (Costanza et al., 2014). Kreuter et al. (2001) and Su et al. (2012b) quantified variations in ESV in response to land-use changes on regional and eco-regional scales. Kreuter et al. (2001) reported a 4% net decline in the estimated annual value of ecosystem services between 1976 and 1991 in San Antonio, the United States. Su et al. (2012b) found that considerable urban expansion led to a loss of 8.5 billion RMB yuan ecosystem-service values per year on average between 1994 and 2003 in the Hang-Jia-Hu eco-region of China. Furthermore, the number of studies on this topic on local scales has grown rapidly (Hu et al., 2008; Li et al., 2007; Zhao et al., 2004). Based on the aforementioned literature, we found that basic benefit transfer (assuming a constant unit value per hectare of a given ecosystem type multiplied by the area of each type to arrive at an aggregate total (Costanza et al., 2014)) is still a simple and easy method of determining ESVs on global and national scales.

Although developing a greater understanding of temporal changes in ESVs is important, increasing interest has been focused on determining how ESVs change spatially by identifying 'hotspots' of ecosystem services that are important for biodiversity and provide multiple ecosystem services (Chan et al., 2006; Egoh et al., 2009; Naidoo et al., 2008; Turner et al., 2007). These spatial studies may provide a series of useful tools that can effectively integrate ecosystem services into planned or current conservation programs (Naidoo et al., 2008), assess the effects of implementing ecological policies, and identify priority areas for ecosystem-service management (Egoh et al., 2011). Such information is particularly important to allow for the modification of current ecological conservation planning and policies in a more beneficial and targeted way. However, hotspots of ESV changes on specific spatial scales, particularly global and national scales, are poorly characterized.

The initiation of economic reforms in China in 1978 promoted rapid economic growth, urbanization and industrialization and transformed a population of 1.3 billion people from a largely agrarian society into an industrial economy (He et al., 2014). This rapid development had a significant influence on land use and cover changes (LUCCs) and ESV changes (Liu et al., 2010) and led to an increasingly deteriorating environment in China (Liu et al., 2008). Recent literature has documented the negative effects (e.g., environmental pollution, soil erosion, natural disasters) on ecosystems that are associated with this rapid economic development (Diao et al., 2009; He et al., 2014; Liu et al., 2008). To improve human well-being and to change the deterioration of ecology and the environment, the Chinese government has implemented a number of national programs on ecosystem-service conservation, such as the Key Shelterbelt Construction Program (KSCP), the Natural Forest Conservation Program (NFCP), the Grain to Green Program (GTGP), the Beijing–Tianjin Sandstorm Control Program, the Wildlife Conservation and Nature Reserve Development Program, and the Forest Eco-Compensation Program (Liu et al., 2008). These programs also provide additional opportunities to understand national concerns about ecosystem-service issues.

The availability of land-cover data is a key factor when undertaking a long temporal-scale analysis of ESVs at the national level. However, the limitedness of the available long-term land-cover data for China has increased the difficulty of investigating national change in ESVs (but a land-cover change database during 1990–2010 developed by Chinese Academy of Sciences is an exception). In addition to issues with available data, determining unit values of ecosystem services remains a challenge. Although relevant studies have focused on the dynamic changes in ESVs in China on regional, city or county scales (Fang et al., 2014; Hu et al., 2008; Li et al., 2007, 2010a, b; Wan et al., 2015; Zhao et al., 2004), national investigations are still lacking. However, aggregates of these data to form a national picture can be used to revise national income figures (Costanza et al., 2014). Identifying hotspots of ESV change on a national scale satisfies the requirements for applying dedicated programs and policies. For decision makers, identifying hotspot and cold-spot areas of ESV change is a more practical method of testing the effect of implementing related policies and programs for ecological conservation and adjusting the direction of programs in the future.

In this paper, we investigated the spatiotemporal changes in ESV, examined the relationships between ESV and gross domestic product (GDP), identified hotspot and cold-spot areas of ESV change and tested the effects of implementing ecological conservation programs in China. This analysis was based on long-term continuous land-cover data for China for the period from 1990 to 2010, and it incorporated land-cover data, the TEEB dataset, the Hot Spot Analysis (Getis-Ord Gi*) tool and a logistic regression model.

2. Materials and methods

2.1. Study area and land-cover data

Land-cover data are used to estimate the ESV and to identify the hotspots of ESV change. Land-cover data on a long time scale provide the foundation for studies of ESV change and effective decision-making support for conservation projects. The land-cover dataset (1-km resolution) of used in this paper included five continuous periods (1990–1995, 1995–2000, 2000–2005 and 2005–2010; Fig. 1). It was produced by the Chinese Academy of Sciences (CAS, http://www.geodata.cn/) using an integrated method of the automatic classification method and manual interpretation method for remote-sensing images. Landsat MSS/TM/ETM, the China–Brazil Earth Resources Satellite (CBERS), HJ-1 (a small satellite constellation for environmental and disaster monitoring) and Moderate Resolution Imaging Spectroradiometer (MODIS) remote-sensing images were the primary data sources. Land-cover types were divided into 6 categories and 25 sub-categories. The total accuracy rate of land-cover classification exceeded 80%, as verified by a host of field surveys. This is the newest and most detailed land-cover dataset on the national scale in China (Liu et al., 2003, 2010).