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The tradeoff and synergy between ecosystem services in the Grain-for-Green areas in Northern Shaanxi, China

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ABSTRACT

As an important part of the strategy of Western development, the Grain-for-Green Program (GFGP) was initiated to protect the environment and mitigate disasters. Ecosystem services and their dynamics are considered emerging features of ecological quality and the change in direction by many scholars and practitioners. Extending from ecosystem services (ESs) modeling, we propose a simple and feasible framework for quantitatively assessing the benefits and equilibrium of the consequences of the GFGP. Our starting evaluation shows that ESs has changed dramatically in the GFGP area. By fitting pair-wise ESs' spatial concordances at the grid-cell level, we have revealed the tradeoffs between provisioning and regulating services and the synergies between the regulating services. The analysis of the variability of the relationship between ESs on different land cover types clearly identifies the vegetation that has produced exceptionally strong ESs. Our findings suggest that quantifying the interactions between ESs may improve the ecosystem-based management practices and support policy-making to address the challenges of the sustainable use of natural resources. The framework designed for regional-scale analysis can help in clearly understanding the interrelations of ESs and make natural resources related decisions more effective and efficient, although this framework still needs to move beyond these fundamental and illustrative analyses to more fully explain the synergies and tradeoffs.

1. Introduction

Human activities are now widely accepted as the main driver of the Earth's surface transformation (Vitousek, 1997; Foley et al., 2005). One of the world's most ambitious ecosystem conservation set-aside programs is the Grain for Green Program launched in China in 1999 (Uchida et al., 2005; Chen et al., 2009). Studies have shown that the cumulative contributions of GFGP to the ecosystems in China and the world are tremendous (Liu and Diamond, 2005; Liu et al., 2008). Specifically, GFGP has fundamentally improved ecosystem services by increasing vegetation cover, decreasing water surface runoff and soil erosion, and reducing river sediments and nutrient loss to maintain soil fertility (Liu et al., 2002; Ma and Fan, 2005; Li et al., 2006; Long et al., 2006; Xu et al., 2006). The enhancement of the supply of ecosystem services (ESs) has led to declines in many other ESs (Rodríguez et al., 2006; Bennett and Balvanera, 2007), as evidences have emerged that intentional management options that are beneficial for one service may cause a cross-balance that reduce the benefits for other services (D'Amato et al., 2011; Dickie et al., 2011). For example, the purposeful removal of vegetation for cultivation increases soil erosion and overgrazing by animal husbandry causes land cover and soil degradation. Finding out how ESs interactions change as land use and management changes may help avoid unnecessary losses by focusing on finding the most efficient solutions to mitigate the tradeoffs or to enhance synergism and maximize the desirable values (White et al., 2012). Identifying the tradeoffs and synergies among ESS is likely to improve ecosystem-based management practices and strengthen the decision-making processes to achieve specific objectives (Carreno et al., 2012).

To better understand and take advantage of the relationship between ESs, much work has been done to examine how multiple ESs correlate with each other theoretically, from which humans can benefit. Studies have showed that biodiversity conservation

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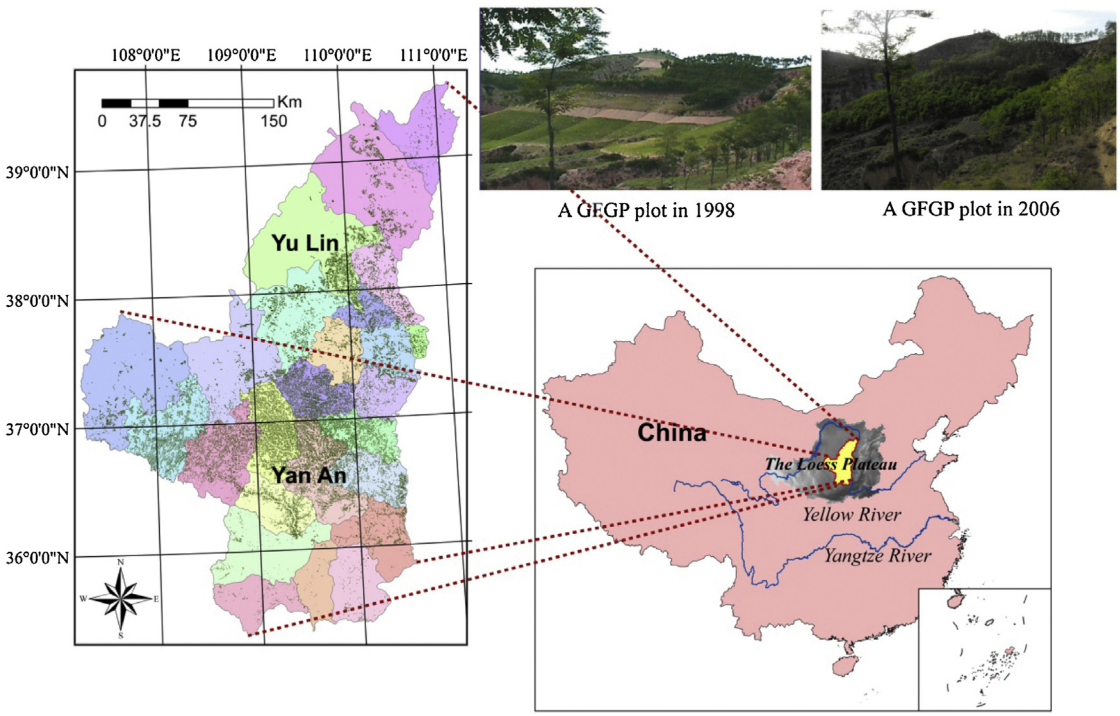

Fig. 1. Location and appearance of the Grain for Green plots in Northern Shaanxi.

protects the substantial collateral flows of services like carbon sequestration, water provision, and grassland production (Chan et al., 2006). Likewise, a spatially explicit examination of the performance of biodiversity conservation and ESs showed only a small tradeoff among ESs during their development (Nelson et al., 2009). The preservation of ecosystems services has proven to have positive effects on habitats and species conservation status on a European scale with statistical models playing an important role in Maes et al.'s (2012) study. By extending spatially explicit tradeoff analyses from economic value based on marine spatial planning, White et al. (2012) developed a policy window method to indicate sector value flows and prevalent spatial conflicts over marine ESs. For quantitatively accessing the consequences of different forest management options in terms of benefits and tradeoffs among multiple objectives, an ecosystem functional framework is now available (Bradford and D'Amato, 2012).

As quantification and evaluation were conducted intensively and thoroughly for specific cases and experimental analysis, other important factors, including the temporal and spatial scales, the data availability, and the applicable models should be taken into account in the assessment of ESs interactions. Identifying tradeoffs and synergies at one point in time and space would bring incorrect assumptions about the mechanisms behind these relationships and hence managing them would likely be ineffective (Bennett et al., 2009). Human management of ecosystems may cause a mutual conversion between tradeoffs and synergies that arise as the spatial scales move up, bringing about desirable or undesirable outcomes (Heal, 2000; Balvanera et al., 2001). Addressing these challenges requires accounting for mainstream ESs spatio-temporally at different scales during LULC changes (McNally et al., 2011; Dymond et al., 2012). Along with the growing recognition of integrating ESs into ecosystem-based management decisions, spatial patterns of ESs across landscapes should be more broadly explored (Egoh et al., 2008; Tallis et al., 2009). However, policy makers are still limited in implementing practical measures for managing ESs (Dickie et al., 2011) lacking straightforward, user-friendly approaches for characterizing the individual and combined synergies and tradeoffs of multiple objectives explicitly or transparently (Bradford and D'Amato, 2012).

Considering the limitations of the current studies on ESs interactions, we propose a framework to provide a relatively simple and transparent method for creating spatially-explicit simulations of ESs relations under LULC conversion scenarios. Ecological benefits and ecosystem services have been improved after years of efforts by converting sloping croplands to forests or grasslands, putting the scientific grounds for studying ESs interactions on a large-scale. Our overall goal is to identify tradeoffs and synergies between ESs and examine how they are balanced with land cover changes. We quantified carbon sequestration, surface runoff, evapo-transpiration, soil conservation, and their interactions for GFGP area in Northern Shaanxi, to create relatively quick projections of numerous categorical data for distribution. Spatial concordances between multiple ESs were then evaluated by aligning geographic and statistic methods to reveal the balancing mechanism of ESs interactions. The work's specific objectives include (i) quantifying the ESs applied to regionally validate the models, (ii) identifying land cover transition areas from 2000 to 2008 (Loring et al., 2008) to provide an spatially explicit statistical basis for elucidating synergies and tradeoffs between ESs at the grid cell-level, and (iii) illustrating ESs variations in the processes of improving the eco-environment. We conclude by discussing the implications for management and decision-making.

2. Materials and methods

2.1. Study area

Located in the northern part of Shaanxi Province, China (35°21′ N–39°34′ N, 107°28′ E–111°15′ E), the core GFGP area (Fig. 1) covers an area of 7923 km^2 with an elevation ranging from 411 to 1911 m. The region is in the middle of the Loess Plateau which is characterized by typical Loess hills and gullies and dominated by a semi-arid continental monsoon climate. Annual average temperature varies from about 6.5 °C in the north to 12.5 °C in the south, and annual