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Land use optimization based on ecosystem service assessment: A case study in the Yanhe watershed

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ABSTRACT

Regional land use change can significantly change the ecosystem patterns and processes, resulting in changes of ecosystem services supplies. Large-scale ecological restoration programmes have been implemented in China to restore and sustain ecosystem services. We selected the Yanhe watershed on China's Loess Plateau, which has experienced the Grain for Green Programme (GFGP), as study area, and we used specialized models to quantify four ecosystem services (water provision, soil conservation, carbon sequestration, and agricultural production) under land use scenarios relative to actual land use change from 2000 to 2015. These scenarios were set according to slope, land use type and water constraint of the watershed to improve water quantity, carbon sequestration, soil retention, agricultural production, and sub-watershed water sustainability. The results show that from 2000 to 2015, 66% of farmlands converted to grassland, 12% of farmlands converted to forest, and farmland proportion declined from 42.0% to 5.3%, while water provision and agricultural production services declined by 12% and 87%, and soil conservation and carbon sequestration services increased by 13% and 3%. Furthermore, under five specific scenarios that converted all retired farmland to grassland in the water-short area and maintained farmland at 0–10° slope in the water-adequate area, all four ecosystem services improved compared with 2015 levels. By identifying optimized land use scenario of retired farmland, we refined general principles of future analyses and decision making in ecological restoration. Comprehensively analyzing slope, land use type and water constraint of the watershed when choosing land use scenarios for GFGP can effectively resolve trade-offs among multiple ecosystem services and can promote regional sustainable development.

1. Introduction

Ecosystem services are the benefits people obtain from ecosystems and can be categorized into provisioning, regulating, cultural, and supporting types (MA, 2005). Ecosystem services connect natural systems and human society (Costanza et al., 1997; Daily, 1997). People often hope to maximize one or several ecosystem services by land use change (Karp et al., 2013). However, ecosystem services are not independent; the interactions between different ecosystem services are primarily trade-offs and synergies (Bennett et al., 2009). Trade-offs are the situations that one ecosystem service increases with the reduction of another service (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). Synergies are defined as the situations in which two ecosystem services increase or decrease together (Bennett et al., 2009). Multiple ecosystem services should be considered simultaneously to improve land use planning and decision making (de Groot et al., 2010; Fu et al., 2015). Ecosystem service has become mainstream in environmental planning and management (Daily et al., 2009; de Groot et al., 2010; Hu et al., 2014).

Land use change can alter the types, patterns and processes of ecosystem, causing change of ecosystem services (Foley et al., 2005; Ray et al., 2010; Fu et al., 2015). Ecosystem service concepts can be an effective link between science and policy by making the trade-offs more transparent (Costanza et al., 2017). Thus, ecosystem service assessment and trade-offs are widely used in land use policy and management practices (de Groot et al., 2010; Doody et al., 2016; Kennedy et al., 2016). Ecosystem service quantification and trade-off analysis are crucial issues in integrated valuation of ecosystem services for land use

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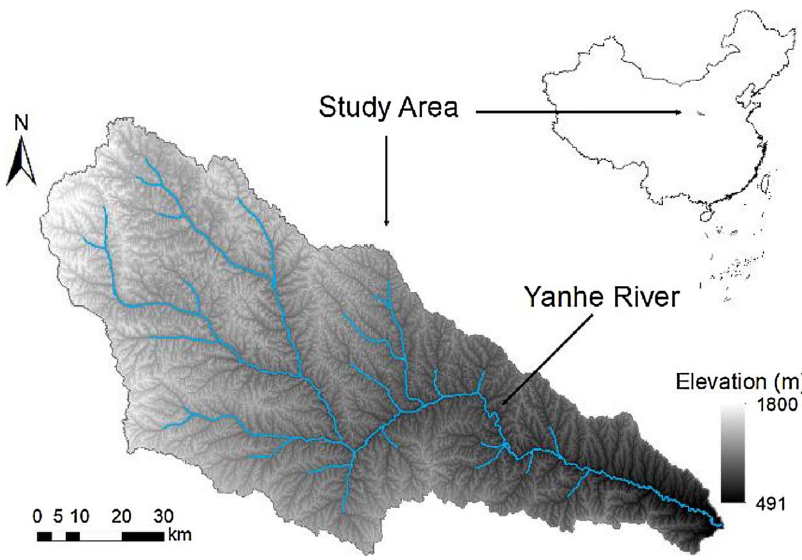

Fig. 1. The location of the Yanhe watershed.

planning, management, and decision making (Mach et al., 2015; Vogdrup-Schmidt et al., 2017; Wang et al., 2017). General spatially explicit ecosystem assessment tools have built the relationship between landscape structure and ecosystem services (Hu et al., 2014) and can be used in studying the land use impacts on a range of ecosystem services and analysis of trade-offs (Zheng et al., 2016a).

Estimating the response of multiple ecosystem services to land use changes and establishing a sustainable balance between multiple uses of different ecosystem services have emerged as a new research field (Fu et al., 2015; Ruckelshaus et al., 2015). Recent research covered various fields, such as agriculture (Bateman et al., 2013; Lorencová et al., 2013), urbanization (Song et al., 2015; Delphin et al., 2016), ecological restoration (Jiang et al., 2017; Wang et al., 2017), and water conservation (Zheng et al., 2016a). The research areas include mountains (Wang et al., 2017), plateau (Feng et al., 2013; Jiang et al., 2017), wetlands (Mach et al., 2015), drylands (Quintas-Soriano et al., 2016), and islands (Zhao et al., 2004). Previous studies indicated that increase in agricultural areas, urbanization, and other factors will lead to reduction in carbon storage, water quality, and biodiversity (Bateman et al., 2013; Fu et al., 2017b). The interaction of multiple ecosystem services, the spatial flow of ecosystem services, and the integration and optimization of ecosystem services can provide enabling conditions for regional ecosystem management (Fu et al., 2015).

Several countries have implemented large-scale ecological restoration projects to improve regional ecosystem services (Zheng et al., 2014). The Grain for Green Programme (GFGP) in China is the largest ecological restoration project ever implemented in developing countries (Wang et al., 2015). GFGP of the Loess Plateau in China has been implemented since 1999 to control soil and water loss (Chen et al., 2007). Previous studies suggested that GFGP has changed various ecosystem services of the Loess Plateau. Vegetation coverage of the Loess Plateau has obviously increased (Lu et al., 2012), and the sediment retention service and carbon sequestration service have been enhanced (Fu et al., 2011; Feng et al., 2013). However, vegetation expansion in water-limited areas creates potentially conflicting demands for water between the ecosystem and humans (Menz et al., 2013). Feng and Fu calculated the minimum water demand for maintaining socio-economic activities across the Loess Plateau ($17 \pm 2\,\mathrm{mm\,yr^{-1}}$), and confirmed that re-vegetation in the Loess Plateau is approaching sustainable water resource limits (Feng et al., 2016). It is necessary to balance each ecosystem service by determining the region's vegetation capacity and its spatial distribution for the sustainable development of the socio-ecological system of the Loess Plateau (Fu et al., 2017a).

We selected the Yanhe watershed in the Loess Plateau as the study area. Previous studies of ecosystem services in this area mainly focused on the quantification, variation, and spatial pattern of several ecosystem services (Su et al., 2012; Su and Fu, 2013), trade-offs of multiple ecosystem services and their influencing factors (Zheng et al., 2014; Feng et al., 2017; Hou et al., 2017; Li et al., 2017), hotspot identification of trade-off between ecosystem services (Zheng et al., 2016b), and developing spatial assessment and optimization tool for regional ecosystem services (SAORES) (Hu et al., 2014). These studies developed applicable methods to explore the relationships between ecosystem services and driving factors over time. However, studies regarding how to minimize the trade-offs between ecosystem services in the Yanhe watershed are still rare, integrated assessment and optimization of multiple ecosystem services has become a challenging task.

The primary objectives of our study were to understand how land use changes affect ecosystem services in the Yanhe watershed and to identify an optimized land use scenario of retired farmland by assessing ecosystem services of set scenarios. We used specialized models to assess water provision, soil conservation, carbon sequestration, and agricultural production of the Yanhe watershed in 2000, 2015 and under set scenarios. The optimized land use scenario was designed to improve ecosystem service supplies compared with the 2015 land use pattern, and the number of sub-watersheds that meet the minimum water demand ($17 \pm 2\,\mathrm{mm\,yr^{-1}}$) should exceed the 2015 level. By identifying optimized land use scenario of retired farmland, we want to refine general principles of appropriately deploying and using land resources for future GFGP in the Loess Plateau or other ecological restoration in areas with similar social and biophysical conditions to the Yanhe watershed, and promote regional sustainable development.

2. Methods

2.1. Study area

The Yanhe watershed (36°21′–37°19′ N, 108°38′–110°29′ E) is located in northern Shaanxi province in China, the middle part of the Loess Plateau (Fig. 1). The Yanhe River is a first-order tributary of the Yellow River. With an area of 7725 $\mathrm{km^2}$, the Yanhe watershed has a semiarid continental climate. Mean annual precipitation of this region is 495 mm concentrated in July–September, and mean annual temperature varies from 8.8 to 10.2 (Su et al., 2012). The elevation varies from 495 to 1795 m. Major land use and land cover (LULC) types of the watershed are forest, shrub land, grassland, farmland, construction land, water body, and bare land. The watershed is covered by thick loess, a fine silt soil that is weakly resistant to erosion. The Yanhe