Science of the Total Environment 644 (2018) 556–566

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China

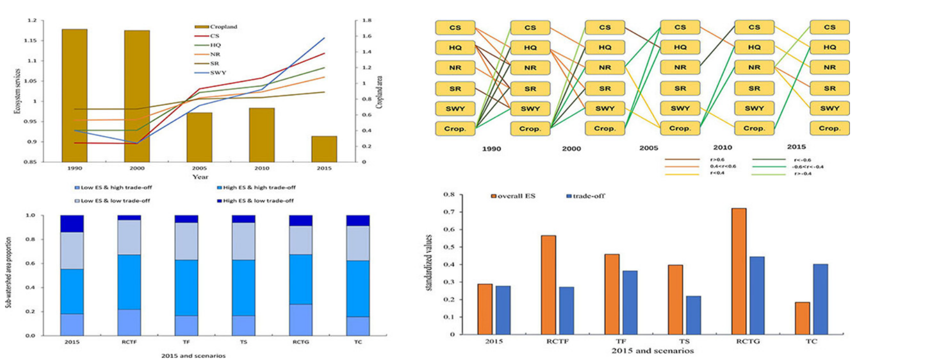
Siqi Yang, Wenwu Zhao *, Yanxu Liu, Shuai Wang, Jing Wang, Ruijie Zhai

State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
Institute of Land Surface System and Sustainable Development, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China

HIGHLIGHTS

- We evaluated five regulating ESs and simulate five scenarios using the InVEST model.
- Seasonal water yield showed a distinct increase after the GFGP was implemented.
- Increased ESs and decreased cropland reduce correlations among them after 2000.
- The Returning Cropland to Grassland scenario is optimal for future land use.

GRAPHIC ABSTRACT



ARTICLE INFO

Article history:
Received 23 April 2018
Received in revised form 27 June 2018
Accepted 27 June 2018
Available online xxxx

Editor: Frederic Coulon

Keywords:
Ecosystem service trade-offs
Land use change
Scenarios
Ecological restoration
InVEST model

ABSTRACT

Land use change can result in variations in ecosystem services (ESs) and their relationships. Studying the temporal dynamics of ESs and their relationships can support scenario analyses that provide the theoretical basis for policy decisions and regional ecosystem management. Previous studies have revealed the trade-offs between two ESs on multiple scales, while the trade-offs between multiple ESs require further analysis. Furthermore, trade-offs are rarely considered in scenario constructions, which weakens the ability of scenarios to inform land use policy. In this study, the InVEST model was applied to assess carbon sequestration, habitat quality, nutrient retention, sediment retention and seasonal water yield at five-year intervals from 1990 to 2015 and to construct five simulated scenarios that represented different ecological restoration and land reclamation policies. The results indicated that the Grain for Green Project (GFGP) increased all ESs, with seasonal water yield increasing by approximately 1.29 times above the initial stage. However, decreasing cropland area reduced the correlations between ESs both in trade-offs and synergies. Among all scenarios studied, the Returning Cropland to Grassland trade-off scenario had the maximum effect, while the natural succession to shrubland scenario had a minimum effect at the pixel level. Except for the land reclamation scenario, the overall ES benefits in the other scenarios exceeded the benefits received in 2015. Given the extent of watershed areas impacted by different overall ES benefit and trade-off situations, the Returning Cropland to Grassland scenario appears to best reduce the impacts of the worst situation compared to 2015, reducing the negative impacts by 22.6%. We suggest that scenarios that combine both overall ESs values and their trade-offs can support more effective and efficient land use decisions.

* Corresponding author at: State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, No. 19, XinJieKouWai St., HaiDian District, Beijing 100875, China.
E-mail address: zhaoww@bnu.edu.cn (W. Zhao).

https://doi.org/10.1016/j.scitotenv.2018.06.348
0048-9697/

1. Introduction

Ecosystem services (ESs) provide a wide range of benefits that improve human well-being (Costanza et al., 1997). Among the four typical ES types, ES studies focus on provisioning services (i.e., crop production) and regulating services (i.e., carbon sequestration, soil retention, nutrient retention) because they play important roles in the production of renewable resources and alleviating the impacts of environmental change (Olver, 2012). Trade-offs and synergies are typical relationships between ESs. Trade-offs occur when the supply of one ES decreases as a result of increased use of another ES (Rodriguez et al., 2006). Trade-offs usually occur between provisioning and regulating services because the two types of ESs support different objectives (Bennett et al., 2009). Trade-off analyses provide a theoretical basis for land use policy making (King et al., 2015), where the goal is to enhance synergies and weaken trade-offs (Tallis et al., 2008; Nelson et al., 2009). In agricultural systems, thoughtful management can substantially reduce or eliminate these trade-offs and maximize synergies (Power, 2010). Lu et al. (2012) have suggested that the Grain to Green Program implemented in the Loess Plateau has facilitated carbon sequestration, soil conservation, and grain production and has improved farmers' economic welfare. This policy can result in the recovery of physical soil properties (Vallauri et al., 2002) and improvements in soil nutrient levels (Zhou et al., 2008), but also exacerbate water scarcity (Wang et al., 2011). Thus, creating win-wins by minimizing unwanted trade-offs between carbon and water ecosystem service is necessary to facilitate socio-ecological systems' sustainable development in the Loess Plateau (Fu et al., 2017). Further, balancing ecological restoration and ES trade-offs should be a top priority in today's land use policies.

Integrated ES research contributes to the development of efficient and sustainable ecosystems (Apitz et al., 2006). In general, this approach synthesizes quantitative studies and optimizes combinations of multiple ESs under different land use change scenarios to provide scientific support for integrated decision making (Fu et al., 2013). When considering multiple ESs, outcomes should maximize net land use management gains (Crossman and Bryan, 2009). Ecosystem service bundle analyses have been used to manage multiple ESs to achieve resource sustainability; a bundle is usually formed by a set of positively correlated ESs dominated by a few services (Raudsepphearne et al., 2010; Renard et al., 2015). For example, Lin et al. (2018) identified the four distinct ES bundles across the Three Parallel Rivers Region according to the spatial variation in eight ESs, and the four bundles were as follows: developed agriculture, mixed services, forest benefits and major habitat. To better measure trade-off degrees, Lu et al. (2014) proposed a simple root mean square deviation (RMSD) method to illustrate the trade-offs between two or more ESs, and this method has since been applied in several studies (Feng et al., 2017; Wang et al., 2017). However, the detection of multiple ecosystem service trade-offs is still limited, and overall ES mapping techniques rarely consider trade-offs jointly. Nevertheless, an optimal, multi-objective land management strategy must maximize overall ESs while minimizing trade-offs (Bradford and D'Amato, 2012). Thus, spatially evaluating multiple ESs combined with their trade-offs can provide guidance for regional ecosystem management.

Land use change is the primary force driving changes in ESs and their relationships (Crossman et al., 2012; Haase et al., 2012). Rapid land use changes may impact the ES trade-offs both by significance and direction (Fu et al., 2015). The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model has become the most widely used ES model to date and is a spatially explicit modelling tool that estimates ESs based on land use change (Nelson et al., 2009). Polasky et al. (2011) quantified changes in ecosystem services and evaluated the impact of observed land-use change in Minnesota, USA, using InVEST. Arunyawat and Shrestha (2016) analysed the impacts of land use changes on ecosystem services using InVEST, and then mapped and quantified four types of ecosystem services in northern Thailand. Braat et al. (2008) found that, in general, regulating services decrease and provisioning services increase by adding human inputs such as fertilizer in an increased land use intensity scenario. As for ecological restoration region, the reduced land use intensity leading to increase in regulating services and decrease in provisioning services may exacerbate conflicts between food production and ecological conservation. Scenario analysis is the most frequently used tool in regional ES management because it identifies the spatio-temporal dynamics and relationships between ESs and combines the resulting data with future land use change alternatives (Seppelt et al., 2013). Mapping ESs based on multiple land use scenarios can reveal changes in ESs given different future land use patterns to inform land use decisions (O'Farrell and Anderson, 2010; Raudsepphearne et al., 2010; Maes et al., 2012).

The scenarios used are often selected based on existing policies and requirements for future development (Nelson et al., 2009; Goldstein et al., 2012). For example, Shoyama and Yamagata (2014) set three land use scenarios in their study of a Japanese watershed from 2011 to 2060 using the Dyna-CLUE model: maintenance of existing conditions, conservation of biodiversity and climate change (Shoyama and Yamagata, 2014). Thompson et al. (2016) modelled four scenarios in Massachusetts, USA, from 2010 to 2060: forest succession, natural disturbance, land use and climate impacts. In China, Wu et al. (2018) constructed 6859 scenarios for the Yanhe watershed, which were generated by 19 potential land use scenarios that took into account reasonable slope and land use types, as well as three water constraint conditions; the results provided the foundation for new land use policy in the Grain for Green Project (GFGP). Hu et al. (2018) identified scenarios by selecting the first 50% of paddy lands to transform to dry lands given pollution intensity, labour force, rice yield and owners' participation enthusiasm, which had implications for the implementation of the Paddy Land-to-Dry Land project. However, the methods used to establish scenarios in Chinese ecological restoration areas are still not spatially explicit because the selection of input values does not include a land use transformation mechanism and, therefore, does not effectively correlate with land use policy. Accordingly, simulating future ES scenarios using a land use change model with more reasonable transformation rules is a realistic requirement for targeted land use policy decision making.

GFGP was an effective ecological restoration project that helped reestablish vegetation across a large area and significantly improve ESs in the Loess Plateau in recent decades (Feng et al., 2013; Zheng et al., 2016; Li et al., 2017). The ES relationship focused on trade-offs between provisioning and regulating services or two regulating services (Su and Fu, 2013; Zheng et al., 2014; Hou et al., 2017). However, the current understanding of the ES values and their associated trade-offs is still insufficient to support the present land use policy. On the one hand, climate factors also influence the trade-offs between provisioning services and regulating services, obscuring the impacts of land use on ES trade-offs. On the other hand, the long-term ecological restoration of the Loess Plateau will not necessarily maintain the current trend in the future. For example, current net primary production (NPP) in the Loess Plateau is already close to the limit of 400 ± 5 g C m^{-2} yr^{-1}, at which point water shortage will occur (Feng et al., 2016). Therefore, the influence of land use changes on multiple ES trade-offs should take into account past dynamics and future scenarios. Moreover, re-vegetation policies such as those in the GFGP often set targets to transform farmland into forestland or grassland; however, it is not clear which land use transformation can better enhance ES supply while minimizing ES trade-offs.

Given the limitations of existing ES dynamics and scenario studies, we aimed to analyse the influence of land use change on ES trade-offs in the Yanhe watershed in the Loess Plateau. Specifically, we aimed to determine: (1) Whether enhanced ESs influenced by land use change will exacerbate ES trade-offs in the analysed ecological restoration area; and, (2) How a reasonable land use pattern that