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Integrating ecosystem services trade-offs with paddy land-to-dry land decisions: A scenario approach in Erhai Lake Basin, southwest China

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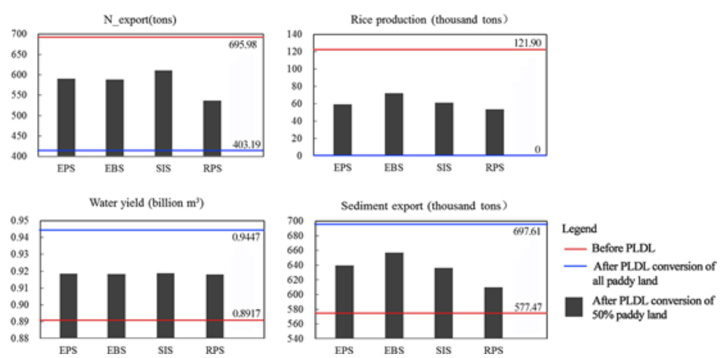
HIGHLIGHTS

- Scenarios approach is applied in land use decision and ecosystem management.
- The optimal land-use pattern is identified using ecosystem services trade-offs.
- The resident participation scenario is chosen to convert paddy land to dry land.
- The object and spatial scale is essential in land use decision-making.

GRAPHICAL ABSTRACT



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ABSTRACT

Ecosystem services are the benefits people obtain from ecosystems, and ecosystem services trade-offs have been widely applied to the development of land-use policy. Although previous studies have focused on trade-offs of ecosystem services, a scenario approach has been seldom used. The scenario approach can reveal the changes of ecosystem services for different land-use patterns in the future, and is of great significance for land-use decisions and ecosystem management. Based on the actual situation of deteriorating water quality and dwindling water supply in the Erhai Lake Basin of southwest China, this study put forward to convert paddy land to dry land (PLDL) in the basin, and simulated its potential impact on ecosystem services. Taking environmental pollution, social impact, economic benefit and residential participation into consideration, four scenarios of PLDL were designed. Then, four ecosystem services (water purification, water yield, soil conservation and rice production) were calculated for each scenario. The optimal scenario of PLDL in the Erhai Lake Basin was identified by trade-offs of the four ecosystem services. The results showed that the total nitrogen export could be reduced by 42.07% and water yield can be increased by 5.61% after converting 100% of paddy lands to dry land, thereby greatly improving the water quality and increasing the water yield of Erhai Lake. However, PLDL involving 100% of paddy lands also increased the sediment export by 17.22%, and eliminated rice production in the region. By comparing the four PLDL scenarios for converting just 50% of paddy lands, the residential participation scenario was identified to be the best choice for PLDL implementation because it achieved the best level of water purification and had the smallest negative effect on other ecosystem services. The optimal scenario for each township

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showed spatial differentiation, and there were conflicts between the optimal scenarios at basin scale and township scale, suggesting that the object and the spatial-temporal scale should be taken into consideration in land-use decisions using ecosystem services trade-offs.

1. Introduction

As the benefits that human well-being directly or indirectly received from natural ecosystem (Costanza et al., 1997), ecosystem services have great impacts on the welfare of human society. The demand of humans for different levels of goods and services is the basic driving force for the formation of ecosystem services (Mach et al., 2015; Ruhl, 2016). To meet the development needs of society, humans often interfere with the structure and function of natural ecosystems by directly influencing the land-use pattern and function (Fu and Forsius, 2015; Wu et al., 2017), which in turn affect the quantity and quality of ecosystem services and lead to trade-offs among ecosystem services (Burkhard et al., 2009; Fu et al., 2013).

During the period of farming civilization, human usually destroyed forest to create farmland, and reclaimed poor quality farmland to improve the yield of agricultural products and increase economic income. In this period, the main focus was set on maximizing the production of single ecosystem goods, often at the expense of regulating services and supporting services (MA, 2005; Dosskey et al., 2012). Late into the modern period of industrial civilization, with an improved environmental protection consciousness, a series of ecological projects have been conducted, such as American Roosevelt Project, former Soviet Stalin Rebuild Nature Plan, Canadian Green Plan, the Green Dam Project of the Five Countries in northern Africa (Li and Zhai, 2002). These ecological projects often carried out in the areas where the maximal improvement of regional eco-environment would achieve, with the decrease of production services such as crop yield (Wang et al., 2017; Zhou et al., 2009). Therefore, the study of land-use or land-cover change with respect to ecosystem services has become a very typical subject among eco-environmental scholars, with a special focus on trade-offs among ecosystem services (Long et al., 2014; Su et al., 2012; Su et al., 2017).

The study of ecosystem services change and their trade-offs before and after land-use changes can objectively reveal the overall effect of an implemented land-use policy. However, previous studies on this topic have mainly focused on the temporal dimension of a specific period in the past, lacking direct decision-making guidelines for the future. In contrast, scenario analysis approach provides an effective tool for decision-makers to optimize a future land-use plan for achieving proposed objectives through ecosystem services trade-offs. In this context, scenario analysis is based on simulation of future land use patterns (Maes et al., 2012; Tammi et al., 2016; Zheng et al., 2016).

A scenario refers to the possible future of focused topics. Considering the uncertainties of the future and the demand for realistic decisions, scenario analysis has been gradually applied to land-use planning and decision-making (Bai et al., 2013; Gascoigne et al., 2011; Peterson et al., 2003). For example, Nelson et al. (2009) used scenario analysis to predict changes in ecosystem services in the Willamette Watershed in the United States, pointing out that landowners cared more about market returns than about ecosystem services and preferred land-use patterns with low ecosystem services supply and weak biodiversity conservation. Goldstein et al. (2012) designed seven land-use scenarios based on the development needs of the Kamehameha School in Hawaii, and assessed the economic value of ecosystem services change in different scenarios. However, previous studies mainly focused on the trade-offs between economic growth and environmental protection; the scenarios rarely considered the details of specific elements, such as residential participation and other influencing factors in the process of implementing an ecological project.

China's paddy land-to-dry land (PLDL) program was started in 2006 when Beijing City signed a rice-to-dryland conversion agreement with Chengde City and Zhangjiakou City, two main cities of Hebei Province located in the upstream region of Miyun Reservoir Watershed. In the agreement, approximately 6900 ha of paddy lands were converted to dry land to plant corn and other low water-demanding crops. This change was made to improve the water quality and water yield of Miyun Reservoir, which is an important source of drinking water for Beijing City. In return, the government of Beijing City provided a corresponding payment of ecosystem services to Chengde City and Zhangjiakou City. Implementation of the PLDL program between Beijing City and Hebei Province is a typical case in which humans adjust ecosystem services by artificially changing land-use types (Yuan et al., 2017).

Water resource constraints have continued to increase in the process of urbanization in China (Bao and He, 2015). PLDL conversion has gradually demonstrated its great significance in protecting water stressed areas and important water bodies in northern China. At present, studies on PLDL programs are rare. Most of related studies have focused on specific ecological effects (Zheng et al., 2013), the payment of ecosystem services between upstream and downstream regions (Zheng et al., 2013), and the impact on household livelihoods (Yuan et al., 2017). However, these studies considered only the past and current impacts of PLDL programs, lacking the comparison of multi-scenario effects in the future and failing to explore the most suitable pattern for PLDL conversion. Thus, existing studies are not very useful in directly supporting decision-making of PLDL implementation.

Located in southwest China, Erhai Lake is the second largest plateau freshwater lake in Yunnan Province. However, the water quality of Erhai Lake has frequently failed the secondary water quality standard, indicating preliminary eutrophication in recent years (Ji et al., 2017). Agricultural planting in the Erhai Basin has been shown to be the main reason for the water consumption and water pollution of Erhai Lake (Guo et al., 2001). The local government faces severe pressure to protect the water resource and water environment of Erhai Lake; PLDL conversion provides a possible solution.

In this study, the Erhai Lake Basin was selected as the study area, and the village was used as the basic unit for analyzing PLDL conversion options. In China, a village may comprise a large area and include both urban and rural land uses. Then several PLDL conversion scenarios were defined, and the optimal PLDL scenario was identified according to ecosystem services trade-offs. Specifically, the objectives of this study were to: (1) define PLDL conversion scenarios from the aspects of environmental pollution, social effect, economic benefit and residential participation; (2) evaluate changes of local typical ecosystem services in each scenario, such as water purification, water yield, soil conservation and rice production in Erhai Lake Basin; and (3) determine the optimal PLDL program based on ecosystem services trade-offs in different scenarios.

2. Materials and methods

2.1. Study area and data sources

Erhai River Basin in Yunnan Province, China lies in the intersection of watersheds of the Lantsang River, Jinsha River, and Yuanjiang River, with a total area of 2565 km^2 (Fig. 1). This basin crosses Dali City (a county-level city) and Eryuan County, and contains 18 towns and 205 administrative villages. The elevation of Erhai Lake Basin is 1478–4081 m, and