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Risk management for optimal land use planning integrating ecosystem services values: A case study in Changsha, Middle China

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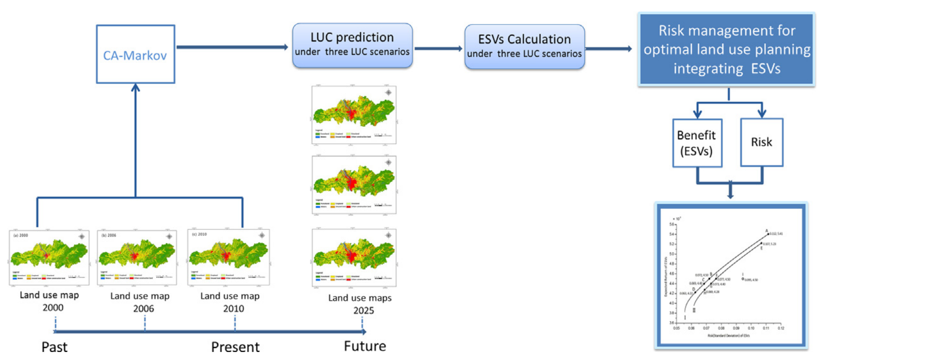
HIGHLIGHTS

- The method integrates ESVs to optimize investment for ecological conservation.
- Risk management reduces risk due to uncertainty of future land use change.
- Tradeoffs between future ecosystem-service benefit and risk are highlighted.

GRAPHICAL ABSTRACT



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ABSTRACT

Land-use change has direct impact on ecosystem services and alters ecosystem services values (ESVs). Ecosystem services analysis is beneficial for land management and decisions. However, the application of ESVs for decision-making in land use decisions is scarce. In this paper, a method, integrating ESVs to balance future ecosystem-service benefit and risk, is developed to optimize investment in land for ecological conservation in land use planning. Using ecological conservation in land use planning in Changsha as an example, ESVs is regarded as the expected ecosystem-service benefit. And uncertainty of land use change is regarded as risk. This method can optimize allocation of investment in land to improve ecological benefit. The result shows that investment should be partial to Liuyang City to get higher benefit. The investment should also be shifted from Liuyang City to other regions to reduce risk. In practice, lower limit and upper limit for weight distribution, which affects optimal outcome and selection of investment allocation, should be set in investment. This method can reveal the optimal spatial allocation of investment to maximize the expected ecosystem-service benefit at a given level of risk or minimize risk at a given level of expected ecosystem-service benefit. Our results of optimal analyses highlight tradeoffs between future ecosystem-service benefit and uncertainty of land use change in land use decisions.

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1. Introduction

Ecosystem services are crucial to human survival and development (Millennium Ecosystem Assessment (MEA), 2005b; Costanza et al., 2014; Kindu et al., 2016; Schägner et al., 2013). Quantification and estimation of ecosystem services can recognize the spatio-temporal changes of ecosystem services and help researchers to study about ecosystem services affected by human activities. It is contributed to raising ecological consciousness, enhancing the management of natural assets and improving decision-making for allocation of resources facing contradiction between supply and demand. In other words, it can intensify conservation of ecosystem (Barral and Oscar, 2012; Costanza et al., 1997; Frélichová et al., 2014; Kindu et al., 2016; Liang et al., 2015; Liang et al., 2014; Liu et al., 2010). In recent years, ecosystem services applications for decision support have been advocated (Bateman et al., 2013; Deacon et al., 2015; Goldstein et al., 2012; Guerry et al., 2015; Luisetti et al., 2014; Schaefer et al., 2015). The United States is trying to integrate ecosystem services into United States federal policies and programs (Schaefer et al., 2015).

Land-use change is one of the most crucial and direct driving factors of changes in ecosystem functions and services (Millennium Ecosystem Assessment (MEA), 2005a; Burkhard et al., 2012; Chhabra et al., 2006; Kindu et al., 2016; Metzger et al., 2006). It alters the ecosystem productivity, modifies the physical parameters of the earth's surface, affects nutritional convey between soil and vegetation by changing biochemical cycles, and influences the element and structure of ecosystems (Huang et al., 2008; Tang et al., 2008; Zang et al., 2011). The dynamic change of land use can bring about changes in the values of ecosystem services (Hu et al., 2008; Kindu et al., 2016; Kreuter et al., 2001; Polasky et al., 2011). Despite the forceful governmental intervention in urban planning and land use planning, future land-use changes cannot be accurately forecasted (Liu et al., 2012). From this point of view, scenario analysis is often integrated into studies about land use change (Labiosa et al., 2013; Liu et al., 2012). In view of the complexity and uncertainty of the future land use change, there is need for simulation and scenario analysis to evaluate future ecosystem service values under different land use change scenario (Landuyt et al., 2016).

Ecosystem services analysis is favorable for recognition of the costs and benefits in land management and decisions (Johnson et al., 2012). There are a mass of studies on ESVs and its response to land use change (Costanza et al., 1997; Costanza et al., 2014; Hu et al., 2008; Kindu et al., 2016; Kreuter et al., 2001; Metzger et al., 2006; Polasky et al., 2011; Xie et al., 2015; Xie et al., 2008; Zang et al., 2011). However, the study on the application of ecosystem services in decision-making was insufficient (Goldstein et al., 2012; Guerry et al., 2015; Schaefer et al., 2015). Efforts have been advocated for integrating ecosystem services into land use decisions, but there are few methods and demonstrations in practice (Goldstein et al., 2012; Guerry et al., 2015; Polasky et al., 2015; Schaefer et al., 2015). The transdisciplinary research is urgently needed to provide evidence-based methods and policies for decision-making (Paudyal et al., 2016). These methods can help to promote interaction between researchers and policymakers. It is one of the research focuses in resource and environment filed that how to strengthen the land use management, so that resources and environmental capacity, land use benefit and land development costs would be spatial balanced to promote sustainable development in rapid urban expansion process (Fu et al., 2010).

Due to the rapid urbanization, a large number of natural land (such as forest, grassland, and wetland) was converted into developed land (such as urban and cropland) and thus pressures on environment and ecosystem are increasing (Zang et al., 2011). Meanwhile, land-use decisions frequently neglect the value of ecosystem services (Bateman et al., 2013). Decision-makers need to control land use change and become more concerned about ecological benefit of land use. There is more uncertainty in land use planning and management with the development of market economy (Ci-Fang and Shao, 2005; Qun and Wan-mao, 2012). Huge uncertainty exists in future land use change (Wang and Wang, 2011), which affects future ecosystem-service benefit and leads to investment risk. Risk management in investment provides more management options for decision-makers than simply maximizing the expected benefit (Knoke, 2008; Liu et al., 2015).

Integrating natural capital and ecosystem services into decision-making is vital to maintain sustainable development (Guerry et al., 2015). Land, as an important natural capital, is an important foundation to realize sustainable development of human society. In this study, we attempt to integrate ESVs into land use decisions by an optimal model. This model is evolves from Modern Portfolio Theory (MPT). MPT means that diversified investment normally results in portfolios with greater expected benefit and lower variance compared with single-asset investments (Markowitz, 1952), which can deal with uncertainty by extending portfolio diversification to decrease exposure to risk in decisions (Matthies et al., 2015). MPT has often been applied to analyze and reduce risk of decision-making in natural resources and the environment. These applications include biodiversity conservation, land allocation, water management and the like (Hua et al., 2015; Knoke et al., 2015; Yuan et al., 2015). In our optimal model, ESVs is regarded as expected return, and the uncertainty of land use change is regarded as risk. This method can be used to reduce risk of land use decision-making by balancing ecosystem-service benefit and risk.

In this paper, a method integrating ESVs was developed to optimize investment in land for ecological conservation in land use planning, using Changsha as an example. Firstly, we forecasted land use change resulting from three different scenarios and policies in 2025. Secondly, ESVs under the three land use scenarios have been evaluated. Thirdly, the developed optimal model integrating ESVs was applied to optimal future spatial distribution of investment in land. The aims of this paper are: (1) to examine the dynamic patterns of land use changes in Changsha from 2000 to 2025 and the impacts of the past and future land use changes on the ESVs; (2) to optimize allocation of investment based on the ecosystem service evaluation from the view of risk management; and (3) to integrate ESVs into land use decision for ecological conservation.

2. Materials and methods

2.1. Study area and data sources

2.1.1. Study area

Changsha, the provincial capital, is located in the northeast of Hunan Province, China (111°54′–114°15′E, 27°51′–28°40′N). It covers an area over 11,819 km^2. As the core district of Chang-Zhu-Tan urban agglomeration and a test area of national resource-saving and environment-friendly society, Changsha needs to pay more attention to ecological benefit of land use. In this study, Changsha was divided into four regions according to the administrative divisions, including Changsha town, Ningxiang County, Liuyang City and Changsha County (Fig. 1).

2.1.2. Data sources

Data used in this study includes land use data, land use planning data, socio-economic data and ecosystem services value coefficients for Changsha. A time series of land use maps were needed to predict land use. Landsat Thematic (TM) images (30 × 30 m) of 2000, 2006 and 2010 were chosen as sources of land use maps. Remote sensing imageries in 2000 and 2006 were obtained from the Institute of Remote Sensing and Digital Earth Chinese Academy of Sciences (http://ids.ceode.ac.cn/ftpdownload/ftpDownload.aspx). Remote sensing imagery in 2010 was obtained from United States Geological Survey (http://glovis.usgs.gov/). Land use types were classified into six categories, including cropland, forestland, grassland, waters, urban construction land and unused land (Song et al., 2015; Wang et al., 2014). Land use planning data were acquired from Changsha land use planning (2006–2020) and Changsha environmental protection plan (2014–2033).

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