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Spatial identification and dynamic analysis of land use functions reveals distinct zones of multiple functions in eastern China

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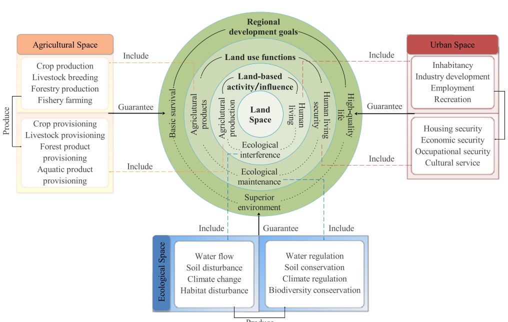
HIGHLIGHTS

- We identified and quantified 12 land use functions (LUFs) from the perspective of spatial planning
- We analyzed the change of LUFs between 2000 and 2015 at the county level
- We analyzed the correlations among 12 LUFs in 2000 and 2015
- We revealed four distinct zones of multiple functions at the county level

GRAPHICAL ABSTRACT



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ABSTRACT

Land use function (LUF) is a valuable concept that allows for more integrated assessments of land system change. Identifying the changes and relationships of multiple LUFs is pertinent to land use planning and management. Selection and quantification of LUF indicators are critical for LUFs assessment. However, past studies have mostly assessed LUFs using socioeconomic data, which are not suitable for spatial variable quantification. In this study, we proposed a new LUFs classification system based on spatial planning goals, and we applied the system to assess 12 LUFs across 63 counties in Jiangsu Province of eastern China based on multi-source data using geospatial modeling tools combined with statistical analysis of socioeconomic data. We also analyzed the change in LUFs between 2000 and 2015, as well as the interactions among multiple functions. Finally, we identified distinct function zones based on the LUFs assessment in 2000 and 2015 using *k*-means clustering. The result showed that 12 LUFs displayed significant changes and interactions between 2000 and 2015, which can be explained by differing topography and social-ecological characteristics among counties. Additionally, we found four distinct LUF zones that are spatially agglomerated in similar landscapes and characterize specific LUF relationships in each cluster. In the future, local LUFs and their changes over time should be taken into consideration for land use planning and management, which provide a reference for policy-makers to make decisions that better match local development realities.

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1. Introduction

Land use and land cover change has been identified as one of the primary determinants of global change, having major impacts on ecosystems, global biogeochemistry, climate change, and human vulnerability (Foley et al., 2005; Pijanowski and Robinson, 2011). Recently, the emergence of the interdisciplinary field of land change science (GLP, 2005; Turner et al., 2007; Verburg et al., 2009) has focused on the interactions within land use systems. Interacting land use systems can provide a wide variety of goods and services to human society, which are collectively referred to as land use functions (LUFs; MEA, 2005; Wiggering et al., 2006; Verburg et al., 2009). Land cover change can be determined by remotely sensed data or survey summary data (Pijanowski et al., 2014; W. Song et al., 2015); however, the changes of LUFs cannot be determined from observable land cover alone—social-ecological data are also needed to assess LUFs and their possible changes (Long, 2015; Song and Deng, 2017).

The concept of LUFs originated from agricultural research (Helming et al., 2008) and mainly refers to agricultural production functions (Verburg et al., 2009; Andersen et al., 2013). The Millennium Ecosystem Assessment (MEA) has stimulated extensive studies of ecosystem services (MEA, 2005; Bennett, 2017; Costanza et al., 2017; Jiang et al., 2018; Hu et al., 2018). However, in urban and cropland systems, ecosystem services are limited to those provided by a small proportion of natural capital (Gómez-Baggethun and Barton, 2013; Yang et al., 2015). To address the issue on artificial ecosystems, LUFs were proposed to present connotations related to economic, societal, and environmental fields which are broader than ecosystem services (Paracchini et al., 2011; Liu et al., 2016).

LUFs are the outputs provided by land use systems that refer to any type of ecosystem and contribute to human well-being directly or indirectly (Wiggering et al., 2006; Verburg et al., 2009; Yang et al., 2015). In different type of land use systems, LUFs refer to different goods and services. For example, in agricultural system, agricultural products (e.g., crop, livestock, forest and aquatic product) are the main outputs; living securities (e.g., residence, economic output, employment, recreation) are the key elements supported by urban system; regulation services, such as water regulation, soil retention, climate regulation, and biodiversity conservation are mainly provided by natural ecosystem. Assessing LUFs is critical to understanding the complexity of interactions among multiple land use systems to achieve sustainable regional development.

Previous studies of LUFs primarily have two foci. One focus is ecosystem services and landscape multi-functionality of a specific region (Raudsepp-Hearne et al., 2010; Leh et al., 2013; Queiroz et al., 2015; Peng et al., 2016; Mouchet et al., 2017; Baró et al., 2017). The second focus is on the function of a specific land use type, such as forests, cultivated land, urban land, or rural land (Barbier et al., 2010; Andersen et al., 2013; Lovell and Taylor, 2013; W. Song et al., 2015; X. Song et al., 2015; Jiang et al., 2016). The former are more systematic in the framework and approaches; they identified ecosystem service bundles or landscape multi-functionality and revealed the relationships among multiple services/functions. Nevertheless, these studies mainly referred to natural ecosystems and are difficult to employ in artificial ecosystem (e.g., urban and cropland system).

Some studies have focused on the dynamics of LUFs related to both socioeconomic and environmental fields at the regional scale (Zhou et al., 2017; Sun et al., 2017) and provided some feasible ways to analyze LUFs. However, the assessment and measurement of these functions are still challenging as most ecological functions are difficult to quantify using socioeconomic data (Turner and Daily, 2008; Norris, 2012). Additionally, multiple LUFs interact with each other in unpredictable ways, which results in trade-offs and synergies among LUFs (Bennett et al., 2009). Trade-offs reflect inverse relationships among LUFs, whereas synergies reflect direct relationships among LUFs (Bennett et al., 2009; Lin et al., 2018). Analyzing the interactions of multiple LUFs is helpful in evaluating the impact of land use policies on LUFs, especially for regions with a shortage of natural resources; however, most studies do not identify trade-offs and synergies among LUFs (Bennett et al., 2009; Raudsepp-Hearne et al., 2010; Peng et al., 2016).

The Jiangsu Province in eastern China is located within the largest economic zone in the nation, the Yangtze River Delta. By the end of 2015, the urbanization rate in the region was 66.5%, 10.4 percentage points higher than the national average. Agricultural and ecological space are heavily occupied and are threatened by the rapid expansion of urban space. During the period 2000 to 2015, per capita arable land dropped from 0.071 ha to 0.057 ha; ecological land (e.g. rivers, lakes, reeds, and beaches) has been reduced by approximately 0.18 million ha. These declines are the result of interactions among LUFs and will likely restrict regional sustainable development.

In this study, the social-ecological complexity of land use systems with a large proportion of urban and agricultural land was taken into consideration. We proposed a new LUFs classification system for assessing LUFs in Jiangsu Province, specifically, but which can be applied to any geographical area. We also used geospatial modeling tools, i.e., Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST, Tallis et al., 2011) and Revised Universal Soil Loss Equation (RUSLE; Wischmeier and Smith, 1978), to quantify the ecological functions based on fine-scale data (e.g., land use spatial data, remote sensing data) to address the limitations of socioeconomic-data-based ecological indicators. These tools have been used to identify ecosystem services in many studies and have been shown to be more effective and reliable methods to assess the provisioning of ecological goods and services at a fine scale (Leh et al., 2013; Hamel et al., 2015; Jiang et al., 2018; Hu et al., 2018). In addition, we further analyzed the trade-offs of LUFs and revealed spatial variation of LUFs to provide a wider perspective for LUFs studies. The objectives of the study were to:

(1) Identify and quantify LUFs from the perspective of spatial planning.
(2) Measure the status of LUFs and analyze the change of LUFs between 2000 and 2015 at the county level.
(3) Analyze changes in spatial autocorrelation of LUFs and correlations among individual function.
(4) Identify distinct LUF zones based on the status and dynamics of LUFs at the county level.

2. Materials and methodology

2.1. Study area

Jiangsu Province is situated in the coastal center of eastern China, bordering the Yellow Sea and covering 107,200 km^2 (Fig. 1), and is an important strategic fulcrum of the Yangtze River Economic Belt. The area had a total population of 67.67 million people in 2015 and includes 63 county-level administration districts. Plains and surface water account for approximately 70% and 17% of the total area, respectively. The area is in the transitional zone between temperate and subtropical climates with mild temperatures, moderate rainfall, and distinct seasons. Superior environmental conditions provide an attractive foundation for rapid economic and social development in the area.

Nevertheless, the area also suffers from severe resource shortage, with the per capita arable land (0.057 ha) equaling approximately half of the average amount in China and approaching the minimum amount of per capita arable land (0.053 ha) stipulated by Food and Agriculture Organization of the United Nations (Wang, 2001). The total population and economic output per square kilometer are five and eight times the average value of China, respectively. Land development intensity in the region was 4.7% greater than the national average during the study