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Regional ecosystem health response to rural land use change: A case study in Lijiang City, China

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ABSTRACT

Quantitative analysis of the response of ecosystem health to rural land use change is required to comprehend the human-nature coupling mechanism and to explore the process of global environmental change, which can interpret the ecological effects of regional land use and land cover change comprehensively. However, the existing regional ecosystem health assessment largely ignored either the internal connection of ecosystem health to land use patterns or the internal representation of ecosystem services to ecosystem health. Using Lijiang City of China as a study area, the average normalized difference vegetation index (NDVI), landscape metrics, and ecosystem elasticity coefficient based on different land use types were used as quantitative indicators. Then the coefficient of spatial neighboring effect was introduced to characterize the adjacency effect on ecosystem services, and to generate the index of integrated ecosystem health. The results showed the change of land use was close to 30% at county level from 1986 to 2006, and forest land was the primary land use type. With respect to the declining physical health of ecosystems in all the four counties, the integrated health experienced a slight increase in Lijiang County. The vast majority of towns' ecosystem physical health and integrated health declined, while more than 70% of towns did not change distinctly. Ecosystem physical health had distinct influence on the integrated ecosystem health, and ecosystem vitality was the main factor affecting the condition of physical health. Emphasized in the interconnection of pattern and process, this study provided an ecosystem health approach to assessing the integrated ecological effects of regional land use change.

1. Introduction

The upsurge of industrialization and urbanization with expanded breadth and intensity of human activity has changed the global ecosystem at unprecedented speed and scale, leading to ecosystem degradation and significant threats to the survival and development of human society. Facing the impacts of ecosystem degradation on human sustainable development, increasing attentions have been paid to how to monitor, evaluate, and regulate the state and sources of risk, and the safety or sustainability degree of ecosystem health (Calow, 1992; Cairns et al., 1993; Dernbach and Mintz, 2011; Peng et al., 2007; Rapport, 1989; Suter, 1993; Wicklum and Davies, 1995). Ecosystem health refers to the ability to meet the reasonable requirements of human society and the ability to self-maintain and update the ecosystem (Lackey, 2001; Rapport, 1998). Maintaining healthy ecosystems is fundamental to guarantee the achievement of sustainable socio-economic development, as natural ecosystems provide material basis and ecological services for human survival (Rapport and Maffi, 2011). As the concept of health portrays essential features of a sustainable future (Patten and Costanza, 1997), when the health of natural ecosystem deteriorates severely from rapid socio-economic development, ecosystem health is considered as the purpose and basis of environmental management (Costanza, 1992, 2012). At the core position of integrated ecosystem assessment, ecosystem health is regarded as one of the most important issues for ecosystem management in macro ecological studies (Belaoussoff and Kevan, 2003; Burger and Gochfeld, 2001; Pinto et al., 2013; Tiwari et al., 1998; Watson et al., 2005). Therefore, because ecosystem health represents integrated regional ecological quality from the two aspects of ecosystem structure and function, this concept is an important foundation for integrated ecosystem assessment and management at macro scale.

Land use change has not only brought tremendous changes for the structure of surface landscapes, but also affected materials

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circulation and energy flow of landscapes, resulting in significant change in regional climate, soil, biodiversity, hydrology and water resources, and profoundly impacting on regional ecological processes (Lavigne and Gunnell, 2006; Nainggolan et al., 2013; Niedertscheider et al., 2012; Torres et al., 2014). Land use and land cover change (LUCC) affects the ability of ecosystems to provide the services and biodiversity on which humans ultimately depend (Wan et al., 2015). A comparative LUCC study that compares different change processes could help to highlight the essential features of regional land use change and to provide an effective assessment of the ecological effects of regional land use change (Napton et al., 2010; Turner, 2010). Currently, quantitative assessment has become mainstream in single factor analysis of LUCC's ecological effects (Imhoff et al., 1997; Weng, 2001; Weng and Lo, 2001; Yokohari et al., 2001). However, to reveal the integrated ecological effects of LUCC besides the single ecological processes, comprehensive indicators are still in need (Shi et al., 2009), in spite of the difficulty to accurately measure the contribution of land use patterns to the variety of regional eco-environmental quality (Zhang et al., 2015).

Ecosystem services can directly link regional land use with ecological quality; and the proportional relationship between different land use types and economic value of ecosystem services calculated by Costanza et al. (1997), has been widely applied to quantify global, national, or regional ecological quality corresponding to a certain land use structure. Thus, the quantification of ecosystem services can help to make an integrated assessment of ecological effects with the change of quantitative structure of regional land use types (Li et al., 2007). The introduction of regional ecosystem health indicators based on ecosystem services and land use patterns to characterize eco-environmental quality will establish a direct bridge between LUCC and regional ecological state. However, although applying ecosystem health indicators to comprehensively measure the influence of LUCC on regional ecological quality is a meaningful exploration, the detailed process is still obscure.

Unlike the rapid urbanization with substantial transformation to construction land in the east of China, the southwest of the nation is mountainous with abundant biological resources, experiencing slow but noticeable land use change (Peng et al., 2008). Lijiang City in the southwest of China has been identified as a globally significant region for its rich biodiversity (Xu and Wilkes, 2004), which is an ideal study area to perform a regional ecosystem health assessment. Thus, besides the theoretical object of completing a quantitative assessment of the LUCC's ecological effects in the view of ecosystem health, two detailed research objects were: firstly, to clarify the process of regional land use change in Lijiang City; and secondly, to integrate landscape composition and configuration metrics, as well as the neighborhood effects of ecosystem services in the paradigm of ecosystem health assessment.

2. Study area and data source

2.1. Study area

Lijiang City is located in the middle-upper stream of the Jinsha River in the northwest of Yunnan Province, covering an area of 21,219 km^2. The longitude of Lijiang City ranges from 99°23′ to 101°31′E, with the latitude from 25°59′ to 27°51′N. Located in the joint position of Qinghai–Tibet Plateau and the Yunnan–Guizhou Plateau, and crossing the two geomorphic units of Hengduan Mountains Canyon and Western Yunnan Plateau, Lijiang City has substantially more mountains than plains, with over 2000 m above sea level accounts for 92.3% of the total area (Fig. 1). Lijiang City has the multi-year average precipitation of about 1000 mm, and the annual mean temperature of 12.6–19.9 °C. Although the heat is insufficient, tourism resources, biodiversity and water resources highlight the huge potential for regional development. In the view of land use structure, forest land, grassland, and dryland account for a considerable proportion of the land use, while the lowest proportion is construction land (Peng et al., 2008).

There are four counties and one district in Lijiang City now, i.e. Gucheng District, Yulong County, Yongsheng County, Huaping County, and Ninglang County. However, before 2002, Gucheng District and Yulong County were combined as one Lijiang County. As a result, the four counties of Lijiang, Yongsheng, Huaping, and Ninglang were selected for comparative study. Generally speaking, the socioeconomic development was obviously not in equilibrium in the four counties of Lijiang City. The most densely populated was Yongsheng County, with the least for Ninglang County. The gross domestic product of Lijiang County accounted for the highest proportion of the whole city (35–50%), while the economic aggregate of Ninglang County was minimal (10–16%). Lijiang County was also the heart of the city's tourism development, while tourism accounts for a very small proportion of the city's total tourism revenue in Yongsheng County and Huaping County. Overall, the levels of socioeconomic development of the four counties were, Lijiang County, Huaping County, Yongsheng County, and Ninglang County in descending order. The similar natural environmental basis and different stages of socioeconomic development which triggers land use change had make the study area one of the ideal targets for a comparative LUCC study.

2.2. Data source and processing

The study used the Landsat TM remote sensing image data. The detailed stripe number/date were as follows: 131041/1986-11-02, 131042/1986-11-02, 132041/1986-11-25, 131041/2006-01-25, 131042/2006-01-25, and 132041/2006-02-01. Related fieldwork data in 2000, 2001, 2002, and 2005 were adopted as auxiliary for interpretation. After image geometry correction, this study used supervised classification and visual correction methods to obtain land use maps in different periods with the support of the remote sensing image processing software ERDAS 8.4 and geographic information system ARC/INFO 8.3. There were 8 kinds of land use classified, i.e. paddy field, dryland, forest land, grassland, bare land, water body, glacier and snow, and construction land. The overall classification accuracy in 1986 and 2006 was 83.2% and 85.9%, respectively; and the Kappa coefficient was 0.77 and 0.83, respectively. Then FRAGSTATS 3.3 was used to calculate the landscape metrics and the transformation matrix of landscape components during the study period. Thereafter, the study analyzed the characteristics of land use change. Meanwhile, according to the band ratio derived from band 3 and band 4, comparable normalized difference vegetation index (NDVI) values of each pixel during the study period were also obtained.

3. Methods

3.1. Land use change measurement

In this study, the transformation matrix method was used to quantify transition probabilities of different land use types, and then, a comparative analysis was undertaken. That is, for any two of the land use maps A_{i*j} and B_{i*j}, using the formula (1) of map algebra method, we can obtain land use change map C_{i*j} from periods A to B, which reflects the change in the land use types and their spatial distribution.

$$C_{i*j} = A_{i*j} \times 10 + B_{i*j} (\text{applicable for land use types} \le 10) \quad (1)$$

Landscape ecology, which emphasizes on the interaction between spatial patterns and ecological process, provides effi-