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Spatiotemporal change in land use patterns of coupled human–environment system with an integrated monitoring approach: A case study of Lianyungang, China

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ABSTRACT

There is an urgent need to quantitatively monitor the spatiotemporal pattern–process interactions of coupled human–environment systems in rapidly urbanizing areas. In this study, we mainly referred to structural(not functional) aspects of land-use pattern, and especially, we targeted at landscape composition and landscape fragmentation. We applied an integrated monitoring approach, to a case study of a new and fast-growing city in the east coast of China. This approach included gradient, spatial overlay and square blocks sampling analysis. The results showed that (1) over the past seven years, the urbanization intensified with its percentage of construction land from 8.19% in 2004 through 17.15% in 2008 to 25.79% in at the cost of more fragmentized agricultural land system and loss of wetland ecosystems; (2) Lianyungang is experiencing rapid urban expansions over the 2004–2008 and 2008–2011 periods in a dispersed and leapfrogged but not compact form; (3) the hypothesis of urban expansion following a process of diffusion and coalescence proposed by Dietzel et al. (2005) were confirmed again by this study; (4) the relationship between patch density of construction land and the degree of urbanization was characterized as an inverted Ushape pattern. Moreover, this study revealed the threshold of the changes of landscape fragmentation while the degree of urbanization is increasing until about 20–40% for Lianyungang city, which should be carefully applied to other places; (5) mean patch size follows an exponential growth or a quadratic growth in the process of urbanization in this study, which is new finding that has not been revealed by other relative case studies reviewed and stand the tests.

1. Introduction

Land-use/cover changes due to urbanization (Miles and Kapos, 2008) directly alter landscape patterns, which subsequently affect ecosystem structure and function (Scheffer et al., 2001), main biogeochemical cycles (Foley et al., 2005), and hence the delivery of ecosystem goods and services that human system depends on (Millennium Ecosystem Assessment, 2005). The dynamics and consequences of land-use/cover changes have been examined under LUCC, as well as under Global Environmental Change and Human Security (GECHS), Land-Ocean Interactions in the Coastal Zone (LOICZ), Institutional Dimensions of Global Environmental Change (IDGEC), Industrial Transformation (IT) and Urbanization, and the cross-cutting projects of the ESSP – the Global Carbon Project (GCP), Global Environmental Change and Food Systems (GECAFS), the Global Water System Project (GWSP), and Global Land Project (GLP) (Foley et al., 2005; IGBP Secretariat, 2005; Turner et al., 2007). Among the major scientific issues raised by the aforementioned projects regarding the dynamics and consequences of land-use/cover changes, applying sophisticated diagnostic approaches to quantitatively explore landscape pattern changes in response to urbanization is a primary focus of current landscape ecology (Lambin et al., 1999; Turner et al., 2007; Wu et al., 2011). Over the last few decades, analysis of spatio-temporal patterns associated with the process of urbanization has been undertaken by a variety of researchers (Buyantuyev et al., 2010; Camagni et al., 2002; Deng et al., 2009; Liu et al., 2005; Long et al., 2009; Wang et al., 2010). As many researchers have pointed out, exploring landscape pattern changes in response to urbanization was the first essential step toward understanding the relationship between landscape pattern and urban ecological process (Chen et al., 2009; Luck

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and Wu, 2002; Schröder and Seppelt, 2006; Turner, 1989; Zipperer et al., 2000).

Landscape pattern can be reduced to the analysis of composition (the amount, how much of something is there), and configuration (how it is spatially arranged) (Herold et al., 2003; Luck and Wu, 2002; McGarigal et al., 2002; O'Neill et al., 1988; Riitters et al., 1995; Weng, 2007; Yu and Ng, 2007). In the scope of configuration, landscape fragmentation has become the hotspot of landscape ecology at present (Di Giulio et al., 2009; Girvetz et al., 2008; Jaeger et al., 2008). Landscape fragmentation due to introducing linear transportation infrastructures and the spread of uncontrolled urban sprawl is known to be a major disturbance regime that threatens human and environmental well-being by increasing noise and pollution from traffic, reducing the habitat area and degrading habitat quality of wildlife populations, facilitating the spread of invasive species, and impairing the scenic and recreational qualities of the landscape (Jaeger et al., 2008). There is an increasing need and interest in monitoring and identification of the landscape fragmentation and in investigation of its dynamics in response to urbanization (Irwin and Bockstael, 2007). In this study, we mainly referred to structural (not functional) aspects of land-use pattern, and especially, we targeted at landscape composition and landscape fragmentation.

Landscape fragmentation can be characterized by development of quantitative indices such as patch density, mean patch size, and effective mesh size (Girvetz et al., 2008; Jaeger et al., 2008; Li, 2000; Luck and Wu, 2002; Weng, 2007). When addressing the issue regarding the relationship between landscape fragmentation and urbanization, the quantitative indices should be combined with spatial analysis techniques. Of these analysis techniques, gradient analysis is the most typical, as it parallels the intensity of urbanization and can capture the spatio-temporal complexity of landscape pattern (McDonnell and Pickett, 1990). Several recent studies have demonstrated the effectiveness of the combined method of gradient analysis and metric analysis for quantitatively identifying and characterizing the complex spatial pattern of urbanization (Bridges et al., 2007; Luck and Wu, 2002; Seto and Fragkias, 2005; Weng, 2007; Yeh and Huang, 2009; Yu and Ng, 2007). Sampling square blocks is another efficient analysis technique that has been widely used to detect and represent inter-temporal characteristics of land use change (Liu et al., 2005; Wang et al., 2010; Yeh and Huang, 2009).

By combination of quantitative indices and spatial analysis technique, some general trends of the spatial change of landscape fragmentation in response to urbanization are revealed by the case studies reviewed (Herold et al., 2003; Luck and Wu, 2002; Weng, 2007). The works of Herold et al. (2003) and Weng (2007) have revealed that the relationship between patch density and urbanization level can be characterized as inverted 'V' shape. Other works showed that the most fragmented landscapes are located at the urban fringes rather than at the very urban center (Irwin and Bockstael, 2007).

Despite the aforementioned achievements, the spatial-temporally varying relationships between landscape fragmentation and urbanization have not been fully understood. Although Herold et al. (2003) and Weng (2007) have revealed the degree of fragmentation, which was quantified by the index of patch density, is positively related to the degree of urbanization in the early stage of urbanization and then negatively related to the degree of urbanization after reaching at a threshold of urbanization level, statistical sample sizes (e.g., only seven sample points along the urban–rural transact in the study of Weng (2007)) for analyzing this relationship were both too small. Besides, other dimensions of landscape fragmentation such as mean patch size associated with urbanization were not fully analyzed in the works of Herold et al. (2003) and Weng (2007).

Therefore, in this study, several previously developed and widely used monitoring approaches (including gradient analysis, spatial overlay analysis, and square blocks sampling analysis) packaged as integrated monitoring approach were combined with two commonly used landscape fragmentation indices (including patch density, and mean patch size) to address the following questions: (1) How do landscape fragmentation change along the urban-to-rural gradient and through time? (2) Whether the clearer trend of the spatial change of landscape fragmentation in response to urbanization can be characterized by adding more sample points with the aid of overlay of square sampling blocks? (3) By comparison with the works of Herold et al. (2003) and Weng (2007), whether the relationship between patch density and urbanization level revealed as inverted 'V' shape is a common phenomenon that can be applied to other places was validated in this study. What are the relationships between other dimensions of landscape fragmentation (namely mean patch size and cohesion) and urbanization level? (4) What are other general trends of landscape fragmentation changes in response to distance to nearest urban (or county) center? Lianyungang, a rapidly urbanizing city in the east coast of China, was selected for the case study.

2. Study area

Lianyungang, with a total area of 7446 km^2, is the northernmost coastal city of Jiangsu Province, eastern China (Fig. 1). It is comprised of four counties (Donghai, Ganyu, Guanyun, and Guannan) and three urban districts (Haizhou, Xinpu, and Lianyun). (In China, province equals to state of America; City belongs to province and county/district belongs to city whereas in most of cases county belongs to state and city belongs to county in U.S.) The old urban center is located at Haizhou District while there are other three newly developed urban centers located in Lianyun District, Ganyu County, and Guanyun County. Lianyungang is one of the first 14 Chinese coastal cities opened to the outside world in 1984 and is widely known as the Eastern Terminal of the New Eurasia Land Bridge (ETNELB). Since the beginning of the 21st century, Lianyungang has experienced a tremendous land transformation from agricultures as well as salt fields to urban area. The total built-up area has increased by 173.75% from 51.8 km^2 in 2001 to 90 km^2 in 2007 with an annual growth rate of 9.64%. This growth is much faster than that occurred during the period 1997 through 2001 (0.87%). Consequently, the city has been ranked high among sprawl-threatened coastal areas over the last ten years in China (Li et al., 2010). Rapid urbanization has resulted in a large-scale modification of the natural and semi-natural ecosystems. Furthermore, the city is still growing. A new round of urban master planning of Lianyungang, which was vetted and approved in 2008 by Jiangsu Provincial Government, designates another 13,498 ha of land as suitable for development. Of this area, approximately 27.56% is earmarked for industrial development and 17.18% is intended for new housing. Therefore, Lianyungang city was the typical case for exploring the spatial-temporally varying relationships between landscape fragmentation and urbanization.

3. Data and methods

3.1. Data sources and processing

In order to trace the temporal trend of landscape fragmentation in response to urbanization, three sets of Landsat TM images were obtained in December 2004, February 2008, and March 2011 from the Remote-Sensing Satellite Ground Stationat the Chinese Academy of Sciences and used for this study. Each TM image was corrected and georeferenced to the WGS 84 datum and UTM