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Identifying determinants of urban growth from a multi-scale perspective: A case study of the urban agglomeration around Hangzhou Bay, China

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ABSTRACT

Analyzing the spatial determinants of urban growth is helpful for urban planning and management. In a case study of urban agglomeration around Hangzhou Bay (China), four landscape metrics (total area, total edge, landscape shape index and aggregation index) were used to describe the landscape characteristics of the urban growth at two block scales (4 km and 7 km) during two temporal intervals (1994–2003 and 2003–2009). Spatial autocorrelation regression was employed to identify the geographic determinants of the urban landscape changes. The results indicated that the urban landscapes became more dominant, unstable, irregular and compact, especially in the centers of cities. These changes exhibited notable spatial variations and spatial autocorrelation at the two block scales. The distances to national and provincial roads influenced the urban pattern changes. The impacts of the urban centers on urban expansion gradually declined with the urbanization progress. The slope factor was the most influential determinant of urban growth. Our study emphasized the importance of considering the autocorrelation and scale effects when analyzing the determinants of urban growth. These findings may help land planners create policies and strategies for future urban development.

Introduction

Urbanization has become a global phenomenon. Over the past 30 years, the populations of urban districts have increased, and urban land has rapidly expanded. Urban land has replaced substantial amounts of undeveloped land, such as cropland and forest (Seto & Kaufmann, 2003; Tian et al., 2005). This rapid urbanization has promoted socioeconomic development and has improved the quality of life; however, it has also caused various ecological problems (Antrop, 2000; Botequilha Leitão & Ahern, 2002). Under such circumstances, investigating the urban growth process and its spatial determinants is fundamental for assessing and forecasting the ecological impacts of urbanization.

Many studies have explored the determinants of urban growth. These determinants include proximity variables (Li, Zhou, & Ouyang, 2013; Luo & Wei, 2009; Schnaiberg, Riera, Turner, & Voss, 2002; Yeh & Xia, 2001), topological variables (Dewan & Yamaguchi, 2009; Jenerette et al., 2007; Pijanowski, Tayyebi, Delavar, & Yazdanpanah, 2010; Tian, Qiao, & Zhang, 2012), neighborhood factors (Carrion-Flores & Irwin, 2004; Gustafson, Hammer, Radeloff, & Potts, 2005; Jiang, Deng, & Seto, 2013; Rui & Ban, 2011), socioeconomic factors (Dewan & Yamaguchi, 2009; Seto & Kaufmann, 2003; Sudhira, Ramachandra, & Jagadish, 2004) and policy guidance (Cheng & Masser, 2003; Liu, Zhan, & Deng, 2005; Tian et al., 2005; Xiao et al., 2006). Although these studies advanced our understanding of urban growth determinants, they had several limitations. First, previous cases only focused on the change in area of urban land (Fan, Wang, Qiu, & Wang, 2009; Liu et al., 2005). However, the determinants of landscape characteristics of urban growth, including shape, fragmentation and edge, were rarely analyzed. The analysis of spatial patterns of urbanization with ecological measures and landscape metrics provided an efficient approach for planners to describe urban processes and their consequences (DiBari, 2007; Herold, Couclelis, & Clarke, 2005). Second, spatial autocorrelation, where observations in close proximity exhibit similar attributes (Griffith, 1987), was seldom taken into account (Fielding & Bell, 1997). As mentioned previously, urban expansion is affected by various geographical

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factors. These factors always exhibit spatial autocorrelation and lead to the spatially autocorrelated patterns of urban growth (Gao & Li, 2011). Disregarding the existence of spatial autocorrelation leads to misinterpretation of the results (Overmars, De Koning, & Veldkamp, 2003; Verburg et al., 2002). Third, the temporal scale was ignored in most previous studies (DiBari, 2007; Luo & Wei, 2009; Xiao, Su, Wang, et al., 2013). Specifically, the comparison of the determinants at multiple spatiotemporal scales was not thoroughly investigated.

This study aims to apply geographic information systems (GIS), remote sensing (RS), spatial statistics and landscape metrics to investigate the landscape characteristics of urban growth and their geographic determinants at different spatiotemporal scales. Using the case of urban agglomeration around Hangzhou Bay (UAHB) in eastern coastal China, our objectives are to (1) analyze the landscape characteristics of urban growth patterns, (2) quantify the spatial autocorrelation of urban landscape pattern changes and (3) identify the geographic determinants of urban growth patterns at different spatiotemporal scales.

Study area

The urban agglomeration around Hangzhou Bay is located south of the Yangtze River Delta. This region includes five large megacities and twenty-five counties of the Zhejiang province. The UAHB covers 44,600 km^2 and has a population of approximately 24 million in 2009. It has a subtropical monsoon climate with a mean annual temperature of 17 °C and rainfall of 1450 mm. The northern region consists of plains, whereas the southwestern and southeastern regions are characterized by dense, steep forests (Fig. 1).

Following the market transition in 1994 and the local policy of "establishing urban agglomeration around Hangzhou Bay", the UAHB has undergone rapid urbanization. The gross domestic product (GDP) in this region has experienced immense growth: it increased from 179 billion RMB in 1994 to 650 billion RMB in 2003 and to 1472 billion RMB in 2009. The population increased from 20.9 million in 1994 to 23.7 million in 2009. Furthermore, the urban population doubled, increasing from 4.5 million in 1994 to 9.1 million in 2009 (Zhejiang Statistical Bureau, 2010). This region also experienced a significant expansion of urban land and dramatic changes to the urban landscape configuration. The UAHB is a typical case to investigate the landscape characteristics of urban growth and their geographic determinants.

Methods and materials

Mapping built-up areas

Built-up land was defined as the land used to build urban and rural houses, public facilities, factories, tourist attractions and military sites. The built-up land data, visually interpreted from Landsat TM/ETM+ images in 1994, 2003 and 2009, were obtained from Xiao, Su, Zhang, et al. (2013). Before interpretation, all images were standardized to the same reference spectral characteristics by atmospheric correction. Then, the images were geometrically rectified to the UTM coordinate system using the quadratic method. For each scene, at least 30 evenly distributed pixels served as ground control points (GCPs), and the root mean squared error (RMS error) of geometric rectification was less than .5 pixels. This precision requirement was met for all images. For details, see Xiao, Su, Zhang, et al. (2013).

Quantifying the urban expansion pattern

Many landscape metrics were developed in recent decades. Riitters et al. (1995) found high collinearity among landscape metrics and emphasized the importance of choosing metrics for monitoring landscape patterns. In this study, four selected metrics (i.e., total area (TA), total edge (TE), landscape shape index (LSI) and aggregation index (AI) (Table 1)) were good representatives in terms of land use patterns and structures. Based on the interpreted land use/land cover data, all landscape metrics in 1994, 2003 and 2009 were calculated by the FRAGSTATS software (McGarigal, Cushman, Neel, & Ene, 2002) at different landscape block scales. Metric analysis was preliminary tested at block sizes of 1–10 km (at 1 km intervals). The block sizes of 4 km and 7 km were selected as the units for the analysis because the values of the metrics exhibited larger variances, thus retaining adequate land use/cover (LULC) information while avoiding the noise (Xiao, Su, Wang, et al., 2013).

The changes in the urban landscape metrics were calculated as:

$$C_i = \frac{M_2 - M_1}{M_1} \times 100\% \qquad (1)$$

where C_i is the change in the urban landscape metrics within temporal interval i, M_1 is the value of the metrics in the previous

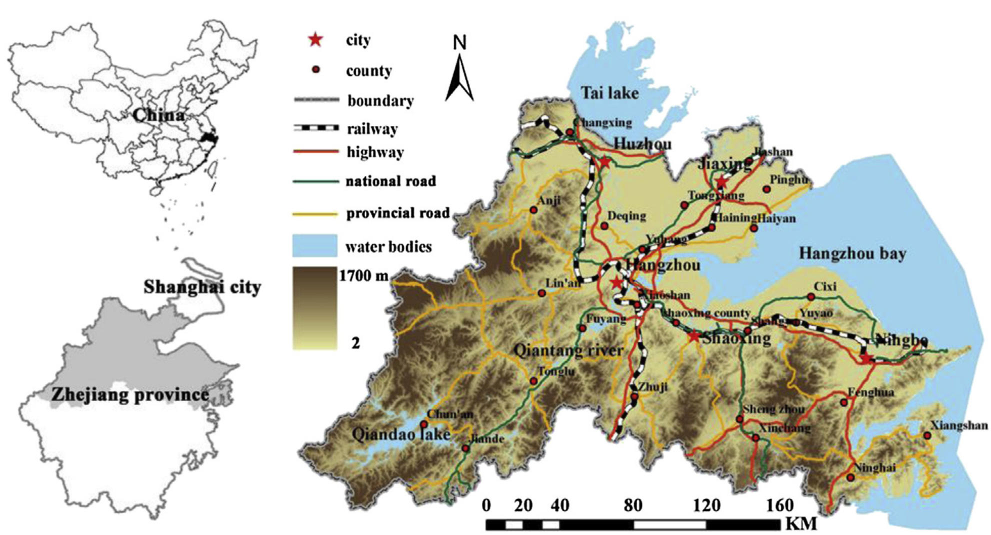

Fig. 1. The location of the urban agglomeration around Hangzhou Bay and the spatial patterns of the main roads, counties and cities.