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Spatiotemporal variation of landscape patterns and their spatial determinants in Shanghai, China

Yongjiu Feng[a,b,*], Yang Liu[a], Xiaohua Tong[c,**]

[a] College of Marine Sciences, Shanghai Ocean University, Shanghai 201306, China
[b] Key Laboratory of Sustainable Exploitation of Oceanic Fisheries Resources, Shanghai Ocean University, Shanghai 201306, China
[c] College of Surveying and Geo-Informatics, Tongji University, Shanghai 200092, China

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ABSTRACT

Landscape patterns are significantly affected by biophysical factors and human activities, and the identification of their determinants is important in analyzing landscape changes. We assess the spatiotemporal variation of landscape patterns and their spatial determinants in Shanghai, China during the past two decades using exploratory regression and generalized additive model (GAM). Classification of remote sensing images shows that between 1995 and 2015, many agricultural lands were converted to built-up areas, reflecting a dramatic land-use change across Shanghai. The landscape patterns, measured by moving window landscape metrics, are aggregated in Shanghai's center, fragmented in the nearest suburban areas, and more aggregated in the far suburbs. The dominant spatial factors for each landscape metric were identified from eleven candidate factors each year after eliminating their multicollinearity. The sort-order of factors and the accumulation of residual deviance explained in GAM were applied to quantify the effects of factors on landscape patterns. The results from both exploratory regression and GAM indicate that the distances to outer-ring expressway and subway stations inside the outer-ring expressway are most influential to the landscape patterns measured by the moving window metrics. The dominant spatial factors successfully addressed the complicated relationships with the landscape patterns of Shanghai. Our research contributes to methods of examining landscape patterns and their spatial determinants in coastal areas, and improves our understanding of the spatiotemporal variation of landscape patterns in and around Shanghai.

1. Introduction

Landscape patterns usually refer to the spatial structure and configuration of landscape components (Turner, 1990; McGarigal, 2014). Change in landscape patterns is significantly affected by both natural factors and human activities (Gustafson, 1998; Déjeant-Pons, 2006). The issues relating to landscape patterns have drawn attention from international communities concerned with land-use change, urban planning, environmental protection, ecological construction and policymaking (Campbell, 1996; Zhang and Wen, 2008). The spatiotemporal patterns of landscape have been considered a research hotspot in landscape ecology and have been extensively studied during the past three decades (Turner, 1990; Aspinall, 2002; Xie et al., 2006; Serra et al., 2008; Solon, 2009; Bertolo et al., 2012).

In the literature, landscape patterns are commonly measured by a set of indices associated with area, shape, aggregation and diversity to reflect the characteristics and compositions of landscape patches. Among various landscape indices, the landscape metrics included in Fragstats are the most widely used quantifiable measurements (McGarigal et al., 2012). Landscape metrics are often used to detect and quantify the spatiotemporal changes in landscape composition and configuration (Herold et al., 2003; Xie et al., 2006; Fichera et al., 2012), to describe landscape complexity (Herold et al., 2002; Seto and Fragkias, 2005), and to assess landscape destruction and rehabilitation (Herzog et al., 2001; Apan et al., 2002; Huang et al., 2007). The metrics can be calculated based on not only raster-based land-use patterns but also vector datasets that include points, lines and land-use polygons (Moser et al., 2002; Mõisja et al., 2016).

The impact of spatiotemporal scales, and the relationships between landscape patterns and their driving factors are important issues in landscape analysis. Observed landscape patterns are significantly affected by the spatiotemporal scales at which ecological problems are posed (Morris, 1987; Burnett and Blaschke, 2003; Su et al., 2012; Feng and Liu, 2015). The changing scales are of great significance for

* Corresponding author at: Shanghai Ocean University, College of Marine Sciences, Shanghai 201306, China.
** Corresponding author.
E-mail addresses: yjfeng@shou.edu.cn, fengyongjiu@126.com (Y. Feng), xhtong@tongji.edu.cn (X. Tong).

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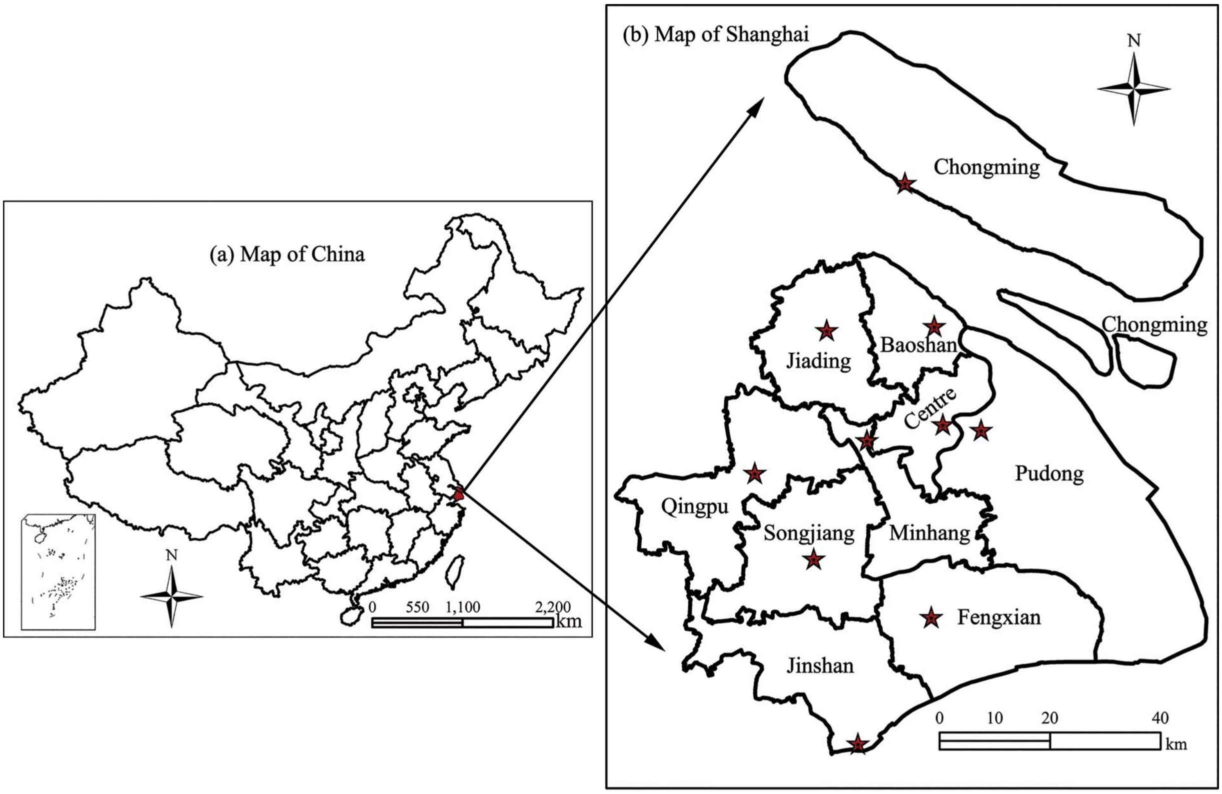

Fig. 1. Location of Shanghai Municipality.

analyzing the ecological diversity and spatial patterns of geographical entities because different scales reflect different landscape characteristics (Turner et al., 1989). Through a systematic examination of multi-scale analysis, ecologists are now well aware of how landscape metrics change with scales (Wu, 2004). The fractal dimension can detect the scale sensitivity of landscape metrics at both landscape and class levels, and therefore it can quantify the effects of spatial scales (Feng and Liu, 2015). Landscape analysis is also affected by biophysical and human-induced factors that may lead to variation in landscape patterns (McCarthy et al., 2010; Peng et al., 2017).

Examination of landscape patterns and their relationships with driving factors are significantly facilitated by remote sensing, geographical information systems (GIS), land-use models and statistical methods (Ji et al., 2006; Deng et al., 2009; Steiniger and Hay, 2009; Lal et al., 2017). Using sophisticated GIS and free Fragstats software, landscape patterns and their spatially explicit driving factors can be derived and visualized from remote sensing imagery (Bürgi et al., 2005; Liu et al., 2005; Deng et al., 2009). Examination of these relationships has benefited considerably from the earlier studies of land-use dynamics (Tian et al., 2005). Logistic regression was frequently used to evaluate the descriptive effects of various factors on the conversion of agricultural land into other land-use types (Van Doorn and Bakker, 2007; Baus et al., 2014). Canonical correlation analysis was employed to capture the relationships between landscape patterns and social metabolism flow (Cui and Wang, 2015). Geographically weighted regression was utilized to detect non-stationary relationships between urban landscape fragmentation and its related factors (Gao and Li, 2011). More recently, multivariate logistic regression has been used to quantify the effects of driving factors on landscape patterns and identify the determinants such as the minimum distance to construction land and the growth rate of built-up areas (Peng et al., 2017). Earlier studies have made progress in exploring the relationships between landscape patterns and their factors (Riitters et al., 1995; Lee et al., 2009; Su et al., 2012; Asgarian et al., 2015), but the driving factors can be highly correlated and thus too many factors can lead to multicollinearity and variable redundancy. We believe that more efforts should be made to identify the dominant factors and thus capture these relationships accurately.

Exploratory regression is a readily applicable method to mitigate multicollinearity among factors. By assessing all potential combinations of factors under specified criteria, exploratory regression can identify statistically significant factors that reflect justifiable relationships with landscape patterns (Kauhl et al., 2015). In this paper, we use exploratory regression to identify those dominant factors and then use a generalized additive model (GAM) to explain the effects of these factors on landscape patterns.

China's land-use and landscape patterns have dramatically changed over the past two decades. Among the many giant coastal cities of China, Shanghai experienced the most rapid change and had attracted great interest from researchers (Cui and Wang, 2015; Feng and Tong, 2017). Our study aims to (1) examine the spatiotemporal variation of landscape patterns in Shanghai between 1995 and 2015, (2) identify the dominant driving factors using exploratory regression and explore the relationships between the landscape patterns and these driving factors, and (3) analyze the variation of landscape patterns in response to each dominant factor. Our research contributes to the methods of analyzing landscape patterns and their factors, and improves our understanding of the variation of landscape patterns in Shanghai and other Chinese coastal cities.

2. Study area and dataset

2.1. Study area

Shanghai is the chief metropolis and the commercial and financial center of China. It is bounded by longitude 120°52′ − 122°12′E and latitude 30°40′–31°53′N in the Yangtze River Delta (Fig. 1a), with a total area of 6340 km^2 and population of 24 million as of 2015. Shanghai contains 16 administrative districts, of which Huangpu, Jing'an, Xuhui, Hongkou, Changning, Yangpu and Putuo constitute the city's center