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Spatial pattern of urban functional landscapes along an urban–rural gradient: A case study in Xiamen City, China

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ABSTRACT

Since there is an increasing demand for integrating landscape ecology and urban planning theories to study complex urban ecosystems and establish rational and ecological urban planning, we introduced a new concept-urban functional landscapes which can be reclassified based on detailed land use data to fulfill the various urban functions, such as residential, commercial, industrial, and infrastructure purposes. In this paper, urban functional landscapes were defined based on urban land use data produced from Pleiades images, and then landscape metrics and population density were combined to identify the urban functional zones along an urban–rural gradient. The features of urban functional landscape patterns and population density were also analyzed, and their relationship has been explored. The results showed that the pattern of urban functional landscapes and population density in the urban functional zones (Urban center, Urban peripheral area, Landscape barrier, Satellite city and Far-suburb) along the urban–rural gradient in Xiamen doesn't totally conform to the classical theories in spatial and social aspects. Urban functional landscapes is potential of acting as bridges between the landscape ecology and urban planning theories, providing scientific support for rational urban landscape planning and urban land use policy making.

1. Introduction

A landscape is the expression of the interaction between the natural environment and man's activities to make the environment more suitable for his life and needs (Antrop, 1998). Within urban areas, landscapes are highly affected and even dominated by human activities. The outward forms of those city landscapes have significant connections with their economic, social or cultural functions(Wu, 2006, 2010, 2014). The characteristics of urban landscapes have long been a focus in previous studies, which always consider urban landscapes as uniform human-dominant patches sprawling outward and fragmenting natural landscapes(Li et al., 2010; Lin et al., 2013; Ye et al., 2013). The analyses of urban landscape are usually based on land use and land cover. Some researchers regard land use and land cover as landscapes, directly classified from remote sensing images (Plexida et al., 2014; Wu et al., 2015; Yu and Ng, 2007). Some have reclassified land use and land cover as landscapes that reflect the intensity of the given land use and the visual difference of land-use types(Luck and Wu, 2002; Weng, 2007). According to (Wu and David, 2002), urban land structure takes the hierarchy form of land use and land cover → landscape → region, which reflects the hierarchical structure of ecological systems. Cities provide main functions through different land uses (landscapes) within an urban area. Thus, the form of an urban land composition hierarchy could be explained as land use and land cover → urban functional landscape → urban functional zone → built-up land → city (Fig. 1). Land use and land cover is the elementary level. Urban functional landscapes can be reclassified based on detailed land use data and fulfill the various urban functions, such as residential, commercial, industrial and infrastructure purposes. Urban functional zone is a mixture of

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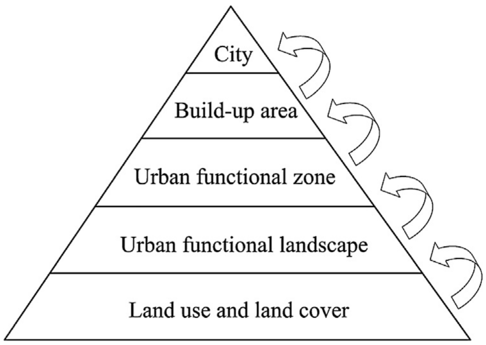

Fig. 1. The pyramid of urban composition.

urban functional landscapes and is characterized by the main urban functions. Different urban functional zones comprise of built-up area of a city. In this hierarchy, we can penetrate into the inside of urban areas to explore urban landscape structures and their relationships with urban land use functions through urban functional landscapes and urban functional zones.

In terms of urbanization, numerous geographers have studied urban morphology throughout history and have introduced some significant theories and plans, such as the concentric zone theory (Burgess, 1925), the sector theory (Hoyt, 1939), the multiple nuclei theory(Harris and Ullman, 1945) and the Greater London Plan(Abercrombie,1944). These classic theories focus on the research of urban structure and urban spatial functional zoning. Compared to the landscape ecology theory, urban morphology and urban planning more heavily emphasize the inherent drivers of human land use demands rather than the interactions between human land use and natural geographical or ecological conditions. The scale and intensity of current urban spatial development have far beyond the explanation capacity of the classical theories, and urbanization has become an important driver of global environmental change(Grimm et al., 2008; Tian et al., 2010). Thus, there is an increasing demand for integrating landscape ecology and urban planning theories to study complex urban ecosystems and establish rational and ecological urban planning. From this point of view, the connections between landscape ecology and urban planning theories would be made through urban functional landscapes, which help the landscape ecologists and urban planners to understand the urban spatial characteristics and its gradient variation.

In urban ecological studies, the ecological consequences of urbanization are generally investigated based on landscape metrics(Buyantuyev et al., 2010; Haas et al., 2015; Wu et al., 2011, 2015; Xu et al., 2007). After the "gradient paradigm" was introduced(McDonnell and Pickett, 1990), Luck and Wu (2002) combined gradient analysis with landscape metrics to identify and characterize the spatial pattern of urbanization in the Phoenix metropolitan region, Arizona, USA(Luck and Wu, 2002). Since then, scholars have analyzed urbanization along an urban-to-rural gradient in many cities of different countries in the following decade, such as Madison in America(Weng, 2007); Guangzhou in China(Yu and Ng, 2007);Leipzig and Halle in Germany(Kroll et al., 2012);Madrid in Spain (DíazPalacios-Sisternes et al., 2014);Bangalore in India(Tv et al., 2012); and Assisi, Bastia, Bettona and Cannara in Italy (Vizzari and Sigura, 2015). Meanwhile, population density also exhibits highly dynamic characteristics similar to urban landscapes (Hammer et al., 2004; Kaya and Curran, 2006). A comprehensive analysis of urban–rural gradients, landscape metrics and spatial population density will provide a new perspective for understanding urban functional landscapes and urban expansion. In this study, landscape metrics and population density were combined to identify the urban functional zones along an urban–rural gradient in Xiamen, China. The pattern features of the urban functional landscapes and population density were explored to address the following questions: (1) what are the general spatial patterns of urban functional landscapes along the urban–rural gradient during urban spatial expansion process (taking Xiamen as case) ? (2) How is the relevance between population density and urban functional landscape pattern? (3) Does the dynamic urban sprawl gradient consistent with the classic urban geographical theories? The answers to these questions will be informative for urban landscape planning and urban land use policy making.

2. Study area

Xiamen City, which comprises Xiamen Island and a larger region on the mainland, is a typical coastal city on the southeast coast of China. As a Special Economic Zone, Xiamen has experienced rapid urbanization since 1980(Zhao et al., 2010). According to previous studies, the city expanded along the main traffic routes over the past three decades(Li et al., 2011). Thus, the urban expansion transect of this study was placed along the main traffic routes of Xiahe Road, Jiahe Road, Xiamen Bridge and Tongji Road to capture the spatial pattern of urban functional landscapes along an urban–rural gradient (Fig. 2). Xiahe Road across the old town is located in the southwest of Xiamen Island and was built in the1920s. Jiahe Road, with a route that includes a railway station, a long-distance bus station and Gaoqi airport, was founded in 1986.Xiamen Bridge, completed in 1991, is one of the main roads connecting Xiamen Island and the mainland. Tongji Road, the main route traffic through the mainland, consists of Tongji South Road, Tongji Middle Road and Tongji North Road, and it was rebuilt in 1995 according to city main road standards. It is a typical urban sprawl gradient.

3. Data and methods

3.1. Urban functional landscape classification

Urban functional landscapes were identified based on the land use data produced from Pleiades images by the Xiamen Municipal Bureau of Land Resources and Real Estate Management in2012. The urban functional landscapes could be classified into 2 levels and 7 categories (Table 1).

3.2. Urban–rural gradient transect

Urban–rural gradient analysis has been approved as a useful tool to analyze the urban spatial expansion and its impact on landscape (Lin and Grimm, 2015; McDonnell and Pickett, 1990). In our study, the urban–rural gradient transect alone the typical urban sprawl direction was 34 km long and 2 km wide. The segmentation process to get 17 quadrats was completed in ArcGIS. Firstly, a buffer with a radius of 1 km was formed along the selected roads; secondly, perpendicular was constructed along the roads every 2 km. A total of 18 perpendicular lines would intersect with the buffer and 19 closed graphics would be formed. At last, 17 graphics in the middle had been selected as quadrats.

3.3. Landscape metrics, various proportions of different urban functional landscapes and population density

The vector data of the urban functional landscapes transect was then converted to a raster format at a pixel size of 1 m^2 using ArcGIS 10.1. To capture the spatial patterns, a suite of landscape metrics were quantified based on the raster format by using FRAGSTATS 4.2 software(McGarigal et al., 2012). The class-level metrics included