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Research Paper

Analyzing spatial variations in land use/cover distributions: A case study of Nanchang area, China

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ABSTRACT

Quantification of spatial variation is important for analyzing and predicting the environmental and social impacts of land development. This paper presents a density-based framework to analyze spatial variations within land use/cover classes through a case study of the Nanchang area, China. By means of grid sampling, the categorical patches were represented by grid densities, and spatial indicators of class abundance, scale-area curve and neighborhood density were constructed to measure the spatial variables of area, distance and scale. The scale variations within each class were demonstrated by abundance indicators and were divided into three types with different similarity degrees, which were measured by coefficients of congruence. These variations roughly corresponded to the distribution patterns revealed by the scale-area indicators. The scaling behaviors of these patterns exhibited discontinuity and coherence, which were possibly affected by the change rates of some patch characteristics in the classes. The neighborhood density indicators showed that every class was more aggregated at short distances, while multimodal patterns fluctuating in nearly random distributions occurred at considerable distances. The degree of clumping correlated positively with the abundance of each class. The characteristics of distribution sizes, ranges and patch isolation in these classes left some imprints on the variations in aggregation intensity. These findings have implications for data integration, mechanism exploration and methodological framework, which are also needed for management practices.

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1. Introduction

Land use/cover distribution can be viewed as a three-dimensional landscape, where two dimensions represent the geographical space and the third dimension indicates land use/cover attributes. This distribution can also be viewed as a mosaic of many local sites, each characterized by a local density of land use/cover classes. The spatial pattern of land use/cover distribution has been an important theme in geographical and ecological theories and applications (Kupfer, 2012) because it represents the earth's surface as a whole (Hartshorne, 1959) and signals many ecological or biophysical processes (Forman, 1995; Syrbe and Walz, 2012). Typically, land use/cover distribution is visually recorded by spatial data (e.g., remotely sensed data and thematic maps). Moreover, quantitative analysis of spatial patterns can provide a powerful tool to summarize spatial data through simple indicators, which is helpful for extracting essential information about land use/cover distribution. This kind of analysis is a promising way of examining the structure of land use/cover distribution and should be considered in the design of land management and conservation of land diversity (Botequilha Leitão and Ahern, 2002; Renetzeder et al., 2010).

However, describing these patterns remains a challenge, given the complexity of the phenomena involved (Kolasa and Rollo, 1991). Further, some indices of the spatial pattern may vary at different scales (O'Neill et al., 1996) (the term *scale* refers to spatial resolution in this study). According to Abler et al. (1971), the essential indicators of the spatial pattern can be constituted by spatial variables, primarily including area, range, distance, direction, spatial geometries and patterns, spatial connectivity, isolation, diffusion, spatial associations and scale. At present, spatial patterns are

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mainly described using landscape metrics (McGarigal and Marks, 1995; Peng et al., 2010; Uuemaa et al., 2013). They can be used to capture attributes of the entire study area or the classes. In practice, geographical and ecological research usually address categorical data, and analyses restricted to specific land use/cover classes may be the objective of interest (Atkinson and Aplin, 2004). However, quantitative information on how spatial variables vary within these classes is lost (McGarigal and Cushman, 2005). Such spatial variations are not well-studied so far; therefore, concerted empirical studies on the magnitudes and patterns of intra-class spatial variations are urgently needed.

Gradients are useful abstractions for explaining intra-class spatial variations (Austin, 1985; McGarigal and Cushman, 2005). All land use/cover classes are distributed in characteristic and limited geographical ranges. They tend to be more abundant in specific environmental or social conditions. Thus, the compositions of these classes change along the environmental or social gradients. Gradient analyses have been extensively used to investigate vegetation (Whittaker, 1967), urbanization (McDonnell and Pickett, 1990), soil characteristics (Pouyat et al., 1995), bird communities (Blair, 1996), urban landscapes (Luck and Wu, 2002), urban green spaces (Kong and Nakagoshi, 2006), ecosystem services (Kroll et al., 2012) and landscape sequences (Vizzari and Sigura, 2015). However, the spatial variations within land use/cover classes have rarely been compared and analyzed from a gradient perspective. In addition, many gradient analyses have been conducted to measure spatial variations based on distance and direction properties by transect (e.g., Kong and Nakagoshi (2006)) or concentric ring (e.g., Kroll et al. (2012)) approaches. According to the characteristics of the land use/cover pattern, area and scale are also the essential properties that have rarely been assessed. Therefore, considering these literature gaps, our study presents a density-based framework to analyze the intra-class spatial variations by measuring the spatial variables of area, distance, and scale.

Density, referring to the amount of land use/cover class per unit area in this study, is a suitable indicator for quantifying gradient information of intra-class variations. Generally, configuration and composition are the two fundamental aspects that define spatial characteristics in categorical landscape maps (Li and Reynolds, 1994). These two aspects can influence scaling behaviors of categorical spatial data (Hall et al., 2015). Composition measures non-spatial components of spatial patterns, such as the number of landscape classes and their proportions; in contrast, configuration measures spatial components, such as the spatial arrangement, shape and neighborhood of landscape patches (Li and Reynolds, 1994). In many aspects of composition and configuration, class abundance and pattern aggregation are the main factors that influence spatial behaviors (Saura, 2002; Hall et al., 2015). The local abundance of a land use/cover class can represent its distribution and corresponds to local environmental or social conditions (Brown et al., 1995). Class abundance can be denoted by the local densities of a class (Brown, 1984). On the other hand, aggregation measures the degree of departures from randomness in spatial distributions. These deviations may result from the influences of regional differences or social forces, which limit the distributions (Clark, 1955; Hengeveld and Heack, 1981; Hengeveld and Heack, 1982). Moreover, the density may indicate the extent to which a class tends to occur in spatial clusters and shows a close association with aggregation (Réjou-Méchain et al., 2011). Therefore, the density-based framework presented here is constructed from the perspective of abundance and aggregation. In recent years, there have been many contributions that have looked at proportional ranges of land cover classes (e.g., sub-pixel remotely sensed data) and transformed them into discrete formats for computing landscape metrics (Arnot et al., 2004; Walsh et al., 2008; Rashed, 2008; Van de Voorde et al., 2011; Frazier and Wang, 2011, 2013).

In this paper, we addressed the following questions: (1) How do class abundances change with scales? (2) How do distribution patterns change with scales? (3) How do aggregation intensities change with distances? Further, we have tried to show that analysis of intra-class spatial variations through the density-based framework can effectively capture additional gradient information within a landscape and deepen our theoretical understanding of intra-class variations. It is essential for monitoring and assessing spatial patterns and would be a major prerequisite for land use/cover analysis, planning and management.

2. Materials and methods

2.1. Study area

The city of Nanchang is close to Poyang Lake, the largest freshwater lake in China. The study area is a rectangular zone that includes the core and peripheral area of the city, comprising approximately 900 km^2 (Fig. 1). The area covers the main geomorphologic types in the Nanchang area, including mountains in Meiling, Piedmont in Changbei, and plains of the Gan River. This area is representative of the land use/cover changes in the Nanchang area over the last 20 years. Since the 1980s, developed land rapidly expanded while cultivated land shrunk substantially, following an accelerating stage of urbanization (Zhang and Xu, 2015).

2.2. Data source

We extracted land use/cover thematic data from Landsat 5 Thematic Mapper (TM) images. Six separate land use/cover classes were identified: Cultivated Land, Forests, Urban and Industrial Land, Rural Settlements, Rivers and Bottomlands, and Ponds and Reservoirs. A universally accepted land use/cover classification scheme does not exist given the nature of multiple scales (Foresman et al., 1997; Ju et al., 2005). To guarantee classification accuracies, we adopted the above classification system based on land use/cover recognizability in the TM images. Fig. 2 shows the spatial distributions of each class represented by the geographical maps. According to subjective impressions gained from visual map analysis, the six classes represent a broad range of spatial distributions. Cultivated Land is the dominant class in terms of area, while Rural Settlements is dispersed and is distributed in small patches. Forests and Urban and Industrial Land are moderately common, but dense, classes. Rivers and Bottomlands are clumped and form the second largest class, ranking behind Cultivated Land; in comparison, Ponds and Reservoirs are scattered.

2.3. Study methods

2.3.1. Selection of spatial variables

Based on the characteristics of land use/cover pattern and spatial organization concept proposed by Abler et al. (1971), we selected area, distance and scale as the essential spatial variables to illustrate intra-class variations. Area is the chief determinant of a spatial pattern (Gustafson and Parker, 1992; Moody and Woodcock, 1995; Kupfer, 2012) and can serve as a common currency for various measures (Kunin, 1998). It took the form of grid density, class abundance and area of occupancy in this study. Recently, more attention has been given to the possibility of using distance as a variable in land use/cover analyses (Hagoort et al., 2008). Among the many distance relationships, the most easily determined and most adaptable to mathematical treatment is the distance to the neighborhood (Clark and Evans, 1955). It was considered as another important indicator of spatial variations. In addition, it has been widely recognized that spatial patterns are scale dependent (Levin, 1992; Wu, 2004). Obtaining an understanding of scale effects can provide the

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