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Sensitivity of correlation structure of class- and landscape-level metrics in three diverse regions

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ABSTRACT

Sensitivity of landscape metrics to selection of spatial scale (i.e., resolution or areal extent), land-use categories, and different landscapes has led to unreliable conclusions for practitioners of landscape analysis and modeling. Unlike previous studies that mostly considered such metrics and assessed the effect of each factor separately, our study focuses on the sensitivity of the correlation structure of different sets of landscape metrics as a whole under different situations via principal component analysis (PCA). We used the congruence coefficient (r_c) to calculate the changes in factor structures under different situations. We used 16 class-level and 15 landscape-level metrics of 900 village-based and 150 town-based samples that were collected from three regions. Five cell sizes, two land-use classes, and two sets of land-use metrics were also considered. We did not control the cell sizes, sample extent, and different landscapes in the sensitivity analysis to study the interactive relationships between different factors. All factors strongly influence the correlation structure of the landscape metrics, with each factor demonstrating a unique influence. Changing cell size significantly affects the correlation structures in the plain region, especially in croplands and built-up lands. Town-based results show a relatively more stable correlation structure than village-based results (except in land-use categories). Different land-use classes show different responses to changing cell size, sample extent, and sets of landscape metrics in different regions. These results show the great interactive influences of these factors, which have often been overlooked in previous studies. The conclusions drawn from fixed factors may be conditional and inapplicable to other situations. The sensitivity of the correlation structure in diverse regions may improve our understanding of landscape metrics as a whole and can provide further insights into the correlation structure of landscape metrics for land-use management and monitoring.

1. Introduction

Accurately quantifying the landscape structure in a region is essential for land-use planning and resource management (Hung et al., 2010; Pecher et al., 2013; Pham et al., 2011). Landscape metrics are useful in quantifying and capturing landscape composition and configuration as well as detecting land-use changes (Sun et al., 2012). Hundreds of landscape metrics that are calculated in FRAGSTATS (McGarigal et al., 2012), Patch Analyst (Rempel et al., 2012), or other software (Zaragozí et al., 2012) have been widely used in characterizing, monitoring, modeling, and assessing landscape pattern and structure (Hung et al., 2010; Kromroy et al., 2007; Ribeiro et al., 2013; Su et al., 2012), and are extensively used to study land-use/land-cover change, landscape and urban planning, the local drivers of biodiversity and biodiversity protection (Mairota et al., 2013; Moser et al., 2002; Paudel and Yuan, 2012; Rayburn and Schulte, 2009).

Many studies have recently investigated the role of landscape metrics (Dale and Kline, 2013; Li and Wu, 2004) in reducing redundancy (Cushman et al., 2008; Griffith et al., 2000; Lausch and Herzog, 2002; Plexida et al., 2014), testing scaling (grain and extent) effects (Buyantuyev and Wu, 2007; Liu et al., 2011; Purtauf et al., 2005; Saura and Castro, 2007; Wheatley and Johnson, 2009), examining the effects of changes in the spatial aggregation or source data resolution (Rutchey and Godin, 2009; Saura and Castro, 2007),

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altering the results according to classification level (Bailey et al., 2007; Peng et al., 2007), and producing contradictory ecological implications (Tischendorf, 2001). With the spatial heterogeneity and nonlinearity of different landscapes, the relationships that are developed from one region may be inapplicable to another (Braimoh, 2006; Corry and Lafortezza, 2007; Plexida et al., 2014; Wu, 2006). Several sensitivity analyses of landscape metrics have enhanced our present understanding of landscape metrics and generated baseline measurements for land-use management (Huang et al., 2006; Riitters et al., 2012; Turner et al., 2012; Zurlini et al., 2006).

Multivariate techniques, such as factor analysis, principal component analysis (PCA), non-metric multidimensional scaling, and cluster analysis, have been used to reduce hundreds of landscape metrics into a meaningful core subset of landscape metrics to effectively characterize landscape patterns (Cushman et al., 2008; Lausch and Herzog, 2002; Plexida et al., 2014). PCA is the most popular technique for choosing the most meaningful metrics (Cushman et al., 2008; Plexida et al., 2014). Given that several factors, such as scale and number of land-use classes, might influence the value of a landscape metric and the PCA results, we used PCA to examine the sensitivity of the correlation structure of the landscape metrics as well as to investigate how this structure responded to the changes in factors. Our sensitivity analysis employed the congruence coefficients (r_c) of the correlation structure of the landscape metrics for two reasons. First, no single metric could adequately capture the pattern of a specific landscape. Second, a small core set of landscape metrics for measuring several components of spatial patterns should be applied when describing landscape patterns. Therefore, a sensitivity analysis of landscape metrics must consider the behaviors of a group of metrics (Griffith et al., 2000; Purtauf et al., 2005; Szabó et al., 2014) and must be simultaneously conducted on multiple factors and factor interactions (Lechner et al., 2013). Analyzing these factors separately may not provide a complete understanding of the landscape metrics because the results for one factor may differ from those for another factor.

Comprehensive empirical studies using real landscape data are indispensable because actual phenomena or laws are realized through these studies. Large and diverse land-use spatial databases provide new platforms for analyzing the sensitivity of landscape metrics. We took advantage of the land-use spatial databases of Hubei, Hunan, and Guizhou provinces in China. Data sources of land-use and remote sensing images are usually linked in terms of land use and land cover (Brown and Duh, 2004). Land use refers to the human purpose of land, which is closely associated with human behavior, social, and economic factors. By contrast, land-cover refers to the ecological state and physical appearance of the land surface. Land-use and land-cover data have three major semantic differences, namely, category definitions, geometric expressions, and spatial rules for assigning attributes, which affect their interoperation (Brown and Duh, 2004; Dale and Kline, 2013). Land-use monitoring is usually tied to administrative entities, which are the basic units of land-use policy and preservation practices in China, to provide suggestions and comments that can be easily developed and implemented in land-use management (Cheng et al., 2006). By contrast, land-cover monitoring always uses a block sampling unit (Hassett et al., 2011). Given that land-use issues were usually analyzed in administrative units, we used administrative units (e.g., village or town) as the sampling unit in our sensitivity analysis.

This study aimed to analyze the sensitivity of the correlation structure of a group of common landscape metrics at the class and landscape levels under different situations. Correlation structure was evaluated using PCA, whereas the r_c and the average (±SD) of the coefficients were used to reveal the sensitivity of the correlation structure. We calculated the landscape metrics of hundreds of land-use samples from several village and town units in three geographically isolated regions to test the effects of different cell sizes, sample extent, regions, land-use categorization, and landscape metrics on the correlation structure. The effect of the interactions among different factors was also considered.

2. Methods

2.1. Study areas

The samples were collected from three different, disjunctive geographical regions in Hubei, Hunan, and Guizhou (Fig. 1). These three sub-landscapes significantly differ in terms of their altitudes and spatial characteristics. The first region (plain) covers approximately 57,272.87 km^2 (16 cities or counties, 263 towns, and 5779 villages) of Hubei and is located in the Jianghan Plain, which is the "national base of fish and rice" in China and the major farming area of the province. The altitude of the region ranges from 20 m to 40 m. This region is dominated by cultivated land and its land is increasingly utilized for human activities. The second region (hilly) covers approximately 52,210.79 km^2 (39 cities or counties, 715 towns, and 15,986 villages) of Hunan and is located in the Jiangnan hilly region, which is known for its staggered low mountains. Hills and basins are distributed throughout the region, with an altitude that ranges from 72 m to 2098 m, and forest land is the main land-use type. The third region (mountainous) covers approximately 57,272.99 km^2 (25 cities or counties, 536 towns, and 8606 villages) of the western part of Guizhou and is located in the Yunnan–Guizhou Plateau with an altitude ranging from 189 m to 3987 m. Forest land is also the main land-use type in this mountainous region.

The sample landscapes were selected based on village- and town-based spatial units. The samples were collected from the three sub-landscapes via simple random selection. A total of 300 village-based and 50 township-based samples were selected in each sub-landscape, eventually amounting to 900 village-based and 150 township-based samples. The average areas of the selected villages in the plain, hilly, and mountainous regions were 6.17, 5.98, and 11.07 km^2, respectively, while the average areas of the selected towns in these regions were 131.17, 97.71, and 124.27 km^2. Table 1 shows the main features of the samples.

2.2. Calculation of landscape metrics

Several studies suggest that the structure of the components will differ at the class and landscape levels because class-level metrics describe the characteristics of each single class type, while landscape-level metrics examine the spatial structure in multi-class patch mosaics (Cushman et al., 2008). Therefore, we computed the landscape metrics at both levels. More than 100 different landscape metrics have been recently developed and used to characterize landscape patterns. Previous studies have also employed a restricted set of better-defined and measurable metrics to characterize landscape or ecological patterns that can generate a large amount of information (Cushman et al., 2008; Lausch and Herzog, 2002; Mairota et al., 2013; Pham et al., 2011). A total of 16 class- and 15 landscape-level metrics were selected (Table 2) based on the criteria of comparability with previous landscape studies (e.g., low redundancy, ability to reflect the characteristics in the landscape analyses, and well-documented effectiveness) (Kromroy et al., 2007; Pasher et al., 2013; Pecher et al., 2013). The correlation coefficient between two of our selected variables was not higher than or equal to $|r| \geq 0.9$. Given the relatively low factor loadings of PROX_AM and ECON_SD, we used CORE_MN and DIVISION instead to test the sensitivity of different sets of variables at the landscape level. We also replaced ECON_SD and IJI with CORE_MN