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REPORT

Effects of thematic resolution on landscape pattern analysis

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Abstract The thematic resolution of mapped data determines the amount of detail of geospatial information, and influences various aspects of landscape classification and the relevance of derived pattern attributes to particular ecological questions. Here we show that changing thematic resolution may significantly affect landscape metrics and in turn their ability to detect landscape changes. The effects of thematic resolution on many landscape metrics tend to show consistent general patterns, but the details of these patterns are likely to be dependent on specific landscape patterns and classification criteria. Thus, the effects of thematic resolution, like those with regard to grain and extent, must be considered in landscape pattern analysis.

Keywords Landscape characterization · Image classification · Thematic resolution · Landscape metrics · Landscape pattern analysis

Introduction

The study of Land Use And Land Cover (LULC) change inevitably involves characterization of landscape pattern using thematic maps classified mostly from remote sensing data. Two related problems must be considered in classifying geospatial data for landscape characterization: the multiplicity of classification schemes and the level of detail of a particular classification. To deal with these problems, efforts for developing a standard system of categories by the remote sensing community have produced some widely accepted LULC classification schemes (e.g. Anderson et al. 1976). The United States GAP Analysis Program lead by the U.S. Geological Survey is another example of a standard system for characterizing biological diversity across heterogeneous landscapes (Scott and Jennings 1998). Also, a standard vegetation classification system has been adopted by the Federal Geographic Data Committee (FGDC 1997). Such standard classification schemes have greatly facilitated the applications of remote sensing data across natural and social disciplines, and enhanced the comparability of thematic maps from different geographic areas and time periods. However, modifications to standard schemes or the adoption of entirely different classification criteria often are necessary to satisfy specific research objectives of particular projects. Whenever this happens, one must determine the appropriate level of thematic detail, i.e., the thematic or categorical resolution of a map.

Thematic maps derived from remote sensing data have routinely been used to compute land-

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scape metrics to quantify the spatial pattern and temporal changes of landscapes. It is imperative to properly understand what these metrics really measure before appropriate interpretation of their results is possible. Thus, the past two decades have evidenced a flurry of studies on the ''behavior'' of landscape metrics, including their statistical relationships (Riitters et al. 1995; Hargis et al. 1998; Neel et al. 2004), responses to changing grain size and extent (Turner et al. 1989; Wickham and Riitters 1995; Wu and Jelinski 1995; Jelinski and Wu 1996; Wu et al. 2000, 2002; Saura 2004; Wu 2006), and, to a much lesser extent, response patterns to changing thematic resolutions of mapped data (e.g. Li and Reynolds 1993; Baldwin et al. 2004; Li and Wu 2004; Buyantuyev and Wu 2006). It is well known now, therefore, that landscape metrics are influenced not only by landscape pattern attributes of interest but also by the ways in which data are manipulated and analyzed (Wu 2006). In fact, effects of changing scale on spatial analysis have been studied for more than 70 years in human geography under the term, modifiable areal unit problem or MAUP (Openshaw 1984; Jelinski and Wu 1996) and ''ecological fallacy'' (Wu 2006).

While the general scaling relations of landscape metrics are fairly well understood (Wu et al. 2002; Saura 2004; Shen et al. 2004; Wu 2004), the problem of thematic resolution has received much less attention. Changing the thematic resolution of categorical maps may often alter the number of classes and their spatial pattern, thus resulting in differences in landscape metrics. Li and Reynolds (1993) showed that the number of patch types in contrived maps, directly related to thematic resolution, had significant effects on contagion. Li and Wu (2004) illustrated how the level of classification detail could affect several landscape indices. Shen et al. (2004) incorporated three levels of categorical detail in simulated landscapes following a factorial design to test scaling relations developed earlier from real landscapes by Wu et al. (2002) and Wu (2004). These authors showed that the number of classes influenced the scaling relations of landscape metrics.

These previous studies clearly suggest that the thematic resolution of maps may have various effects on landscape metrics and thus landscape characterization. However, few studies have systematically examined the problem of thematic resolution for its general patterns and consequence for detecting landscape changes. Therefore, as part of the series of investigations of the behavior of landscape metrics conducted by our research group (Wu and Jelinski 1995; Jelinski and Wu 1996; Wu et al. 2000, 2002; Shen et al. 2004; Wu 2004), we have systematically studied the effects of thematic resolution on landscape pattern analysis using a suite of common landscape metrics (Buyantuyev and Wu 2006). The main purpose of this paper is to report on the major findings of this research.

Methods

Our study area is the Central Arizona–Phoenix Long Term Ecological Research (CAP-LTER) site which is located in the Phoenix metropolitan region (Arizona, USA). The analysis was conducted using 15-year time series data of LULC in the region, produced from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) imagery using an expert system approach (Stefanov 2000; Stefanov et al. 2001). LULC maps with 12 classes were first created for five different years between 1985 and 2000, with an overall accuracy of 85% assessed for 1998. These maps were then progressively reclassified into 9-, 6-, 4-, and 2-class maps following the same set of rules (Fig. 1). The resulting 25 LULC maps were used to calculate a series of landscape metrics using the FRAGSTATS software (McGarigal and Marks 1995). We computed 15 landscape level indices, which were selected according to our previous studies, for the purpose of comparison (Wu et al. 2000; Wu et al. 2002; Wu 2004). They included 8 compositional metrics: Patch Density (PD), Edge Density (ED), Diversity (SHDI), Evenness (SHEI), Largest Patch Index (LPI), Mean Patch Size (MPS), Patch Size Standard Deviation (PSSD), and Patch Size Coefficient of Variation (PSCV), and 7 configurational metrics: Landscape Shape Index (LSI), Mean Patch Shape Index (MPSI), Area-Weighted Mean Shape Index (AWMPSI), Perimeter–Area Fractal

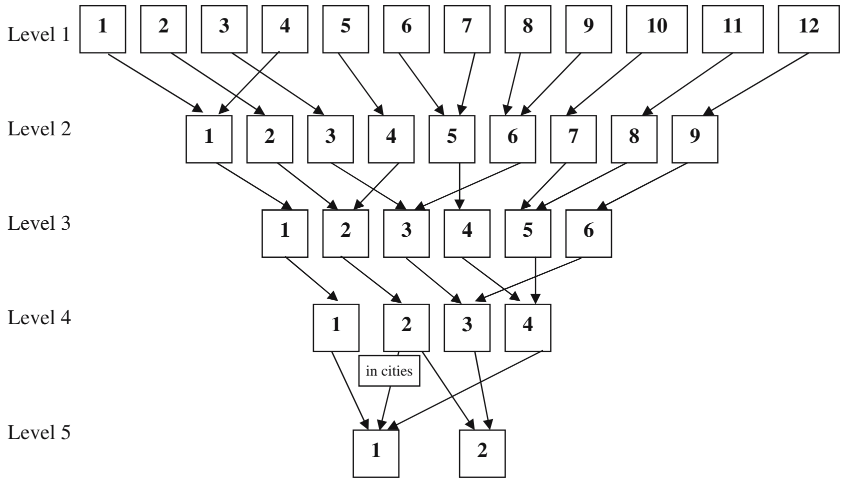

Fig. 1 Illustration of map reclassification rules. Class definitions at Level 1 were adopted from Stefanov *et al.* (2001): Level 1: (1) Cultivated vegetation (active), (2) Cultivated grass, (3) Fluvial and Lacustrine, (4) Compacted soil (prior agricultural use), (5) Vegetation, (6) Disturbed (commercial/industrial), (7) Disturbed (Asphalt/Concrete), (8) Undisturbed (Desert), (9) Compacted soil, (10) Disturbed (Mesic residential), (11) Disturbed (Xeric residential), (12) Water; Level 2: (1) Agriculture, (2) Cultivated grass, (3) Fluvial, (4) Riparian and Dense Urban vegetation, (5) Impervious, (6) Desert vegetation, (7) Mesic residential, (8) Xeric residential, (9) Water; Level 3: (1) Agriculture, (2) Grass and Riparian and Dense Urban vegetation, (3) Desert, (4) Impervious, (5) Residential, (9) Water; Level 4: (1) Agriculture, (2) Grass and Riparian and Dense Urban vegetation, (3) Desert, (4) Urban; Level 5: (1) Anthropogenic, (2) Natural

Dimension (PAFD), Mean Patch Fractal Dimension (MPFD), Area-Weighted Mean Fractal Dimension (AWMFD), and Contagion (CONTAG).

Results

Our study showed that thematic resolution had significant effects on most of the 15 landscape metrics (Fig. 2). Specifically, the values of 12 out of the 15 landscape metrics changed considerably with increasing thematic resolution represented by the number of classes. Three general response patterns emerged: increase, decrease, and little change. Most of the changes appear either linear or similar to a power-law. With increasing thematic resolutions, PD, ED, SHDI, LSI, and CONTAG showed a monotonically increasing trend, while MPS, SHEI, PSSD, AWMPSI, LPI, and AWMFD showed a consistently declining trend (Fig. 2). Three metrics (PAFD, MPSI, and MPFD) showed little change with thematic resolution. The only metric that did not show a clear directional change pattern was PSCV (Fig. 2).

Are the general patterns of thematic resolution effects robust when landscape data of different times used? Or, how do they vary in response to different stages of landscape transformation (urbanization in this case)? Answers to these questions can be found by examining the distances between lines and the relative positions of individual lines in Fig. 2. Evidently, the general response patterns of most landscape metrics to changing thematic resolution seemed similar among different years, with a few exceptions (e.g. PAFD and AWMPSI).

Can these observed effects of thematic resolution significantly influence the ability of landscape metrics in detecting temporal changes of landscapes? Is there an ‘‘optimal’’ thematic resolution for detecting landscape changes? We found that, for most metrics (except for MPFD and MPSI), the thematic resolution effects could lead to significantly different landscape change patterns as depicted by these metrics (see examples in Fig. 3). The differences include both quantitative discrepancies (e.g. metric values) and qualitative divergence (e.g. direction of changes).

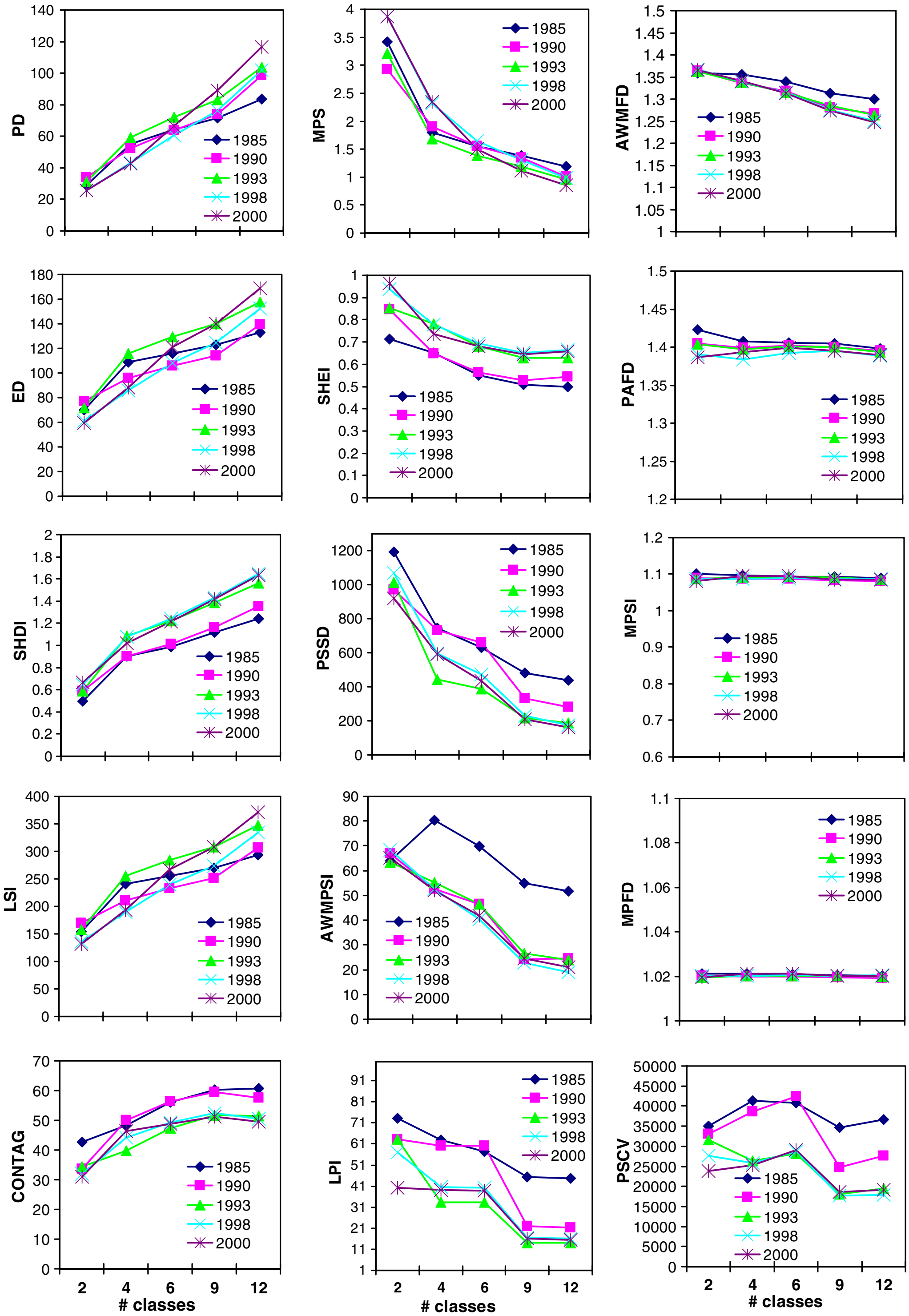

Fig. 2 The effects of thematic resolution of categorical maps on landscape metrics with multiple-year land use and land cover data for the Phoenix, USA metropolitan region (representing different stages of urbanization between 1985 and 2000). Landscape metrics are described in the text

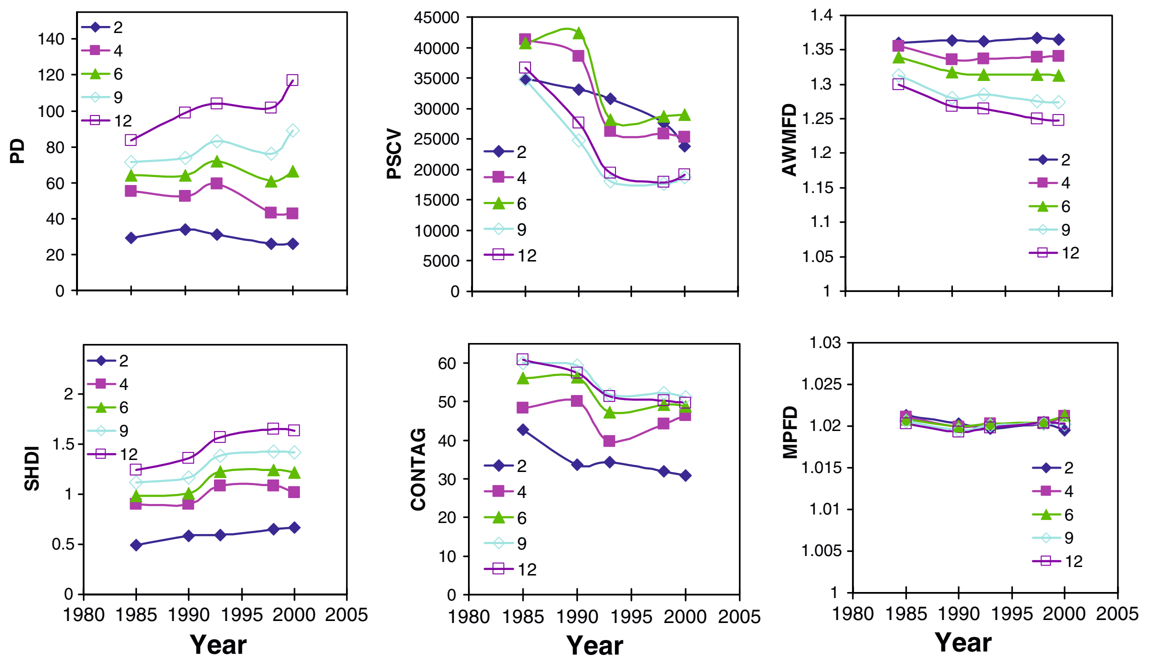

Fig. 3 Selected examples showing how landscape metrics computed at different thematic resolutions change with time, and how the effects of thematic resolution may affect the results of detecting changes in land use and land cover pattern using landscape metrics

Discussion and conclusions

As we noted earlier in this paper, several previous studies have indicated that changing the thematic resolution or the number of classes of a categorical map may affect different measures of landscape attributes and mapping accuracy. But in-depth studies are lacking to answer questions of how and why. Our previous studies on the scaling behavior of landscape metrics led us to a hypothesis that the general response patterns of landscape metrics to changing thematic resolution could be inferred from scaling relations with regard to grain size. Our hypothesis was based on the observation that systematically increasing grain size results in a progressive reduction in the number of classes, while increasing thematic resolution leads to a consistent increase in the number of classes. Thus, the general response patterns of landscape metrics to increasing grain size should resemble those to decreasing thematic resolution. A direct comparison between these results on thematic resolution and those on scaling relations in Wu et al. (2000, 2002) and Wu (2004) corroborates our hypothesis. Beyond the correspondence of the general direction and trend of change, however, the details of the response patterns to thematic resolution may differ significantly from those to changing grain size. A main reason for this is the difference in spatial aggregation between increasing grain size and decreasing thematic resolution: the former always aggregates neighboring grid cells (following the majority rule in many cases), whereas the latter combines cells of similar patch types that may be far apart.

Several important conclusions can be drawn from the results of our systematic investigation. First, different thematic resolutions can lead to considerable differences in the values of most compositional and configurational landscape metrics. Second, the effects of thematic resolution tend to exhibit a few general patterns: monotonic increase, monotonic decrease, no change, or erratic. Inferred from our previous studies of changing grain size, the general patterns for most of the landscape metrics examined here should be robust to different types of landscapes, but some metrics may show completely different trends with different landscapes (e.g. CONTAG and PSCV). Third, the effects of thematic resolution can significantly affect the ability and consistency of landscape metrics in characterizing spatial and temporal patterns of landscapes. We realize that these results are from only one urban landscape although five different time periods were considered in the analysis. More research is needed to confirm and refine these findings.

The effects of thematic resolution on landscape pattern analysis may be considered as a form of the modifiable areal unit problem which focuses on the effects of scale and zoning (see Openshaw 1984; Jelinski and Wu 1996; and Wu 2006 for reviews). Our study demonstrates that landscape maps produced with the same classification scheme but different levels of detail are likely to result in significant differences in landscape characterization of the same geographic area for the same time period. For a given research project, there may not be the single optimal thematic resolution or level of detail, but there must be some thematic resolutions that are better balanced between the amount of detail and the degree of uncertainty. Because landscape metrics computed at an improper thematic resolution may lead to the so-called ''ecological fallacy'' for correlation and regression analysis (Wu 2006), it is critically important to identify an appropriate level of detail surely relevant for ecological processes of interest.

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