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Mapping spatial variations of land cover in a coastal landscape using pattern metrics

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Abstract

The aim of this study is to analyze spatial variations of land cover using pattern metrics in the case of a Mediterranean coastal area. Various composition and configuration metrics were used to analyze characteristics of land cover and its spatial heterogeneity. Satellite images (i.e., SPOT) were used to classify land cover. Pattern analyses were conducted in Erdemli district of Mersin, Turkey, from coastline to about 200m ASL. Landscape patterns were quantified and mapped on the basis of number of patches (NP), edge density (ED), largest patch index (LPI), aggregation index (AI), Shannon's and Simpson's diversity and evenness indices (SHDI, SIDI, SHEI, SIEI). A relationship between observed patterns/calculated indices and current land uses were investigated. Results showed that many of the pattern features differed between the coast and upper lands due to varying composition and configuration characteristics of land cover types under investigation.

Keywords: Pattern metrics; landscape change; Mediterranean; Erdemli; spatial diversity

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1. Introduction

Landscape patterns are formed by a mixture of natural and human-managed patches that vary in size, shape, and arrangement in space; the patterns are also correlated with landscape-scale ecological processes (Turner, 1990; Hulshoff, 1995; Han et al., 2005). Spatial pattern of landscapes exhibits different characteristics, depending on the

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scale of observation and analysis (Wu et al., 2002). Landscape pattern analysis studies the composition of landscape components and their spatial arrangements (Cao et al., 2004), and depicts them using certain methods, such as characters, graphs and landscape indices (Liding et al., 2008).

Pattern index is an overall description of the structural characteristic of the landscape type. Different landscape types might possess the same or similar pattern characteristics, so the landscape pattern information only is not enough to fully explain the vulnerability of the eco-environment (Penghua et al., 2007). A plethora of metrics has been developed to quantify landscape patterns on categorical maps. Such metrics fall into two general categories: those that quantify the composition of the map without reference to spatial attributes, and those that quantify the spatial configuration of the map, requiring spatial information for their calculation (Gustafson, 1998; McGarigal and Marks, 1995).

A number of different approaches in representing spatial concepts have resulted in the development of various spatial metrics or metric categories as descriptive statistical measurements of spatial structures and patterns. Commonly applied metrics are patch size, dominance, number of patches and density, edge length and density, nearest neighbor distance, fractal dimension, contagion, etc. (Herold, 2005; McGarigal et al., 2002).

The aim of this study is to analyze spatial heterogeneity of landscape pattern using landscape-pattern metrics in the case of a Mediterranean-type coastal area. Various indices of composition, configuration such as number of patches (NP), edge density (ED), largest patch index (LPI), aggregation index (AI), Shannon’s and Simpson’s diversity and evenness indices (SHDI, SIDI, SHEI, SIEI) were used to analyze characteristics of land cover and its spatial heterogeneity in Erdemli (Turkey).

1.1. Study Area

The study area is Erdemli town (Turkey) and its surroundings, located in the Mediterranean region of Turkey. It extends from coastal plain to the foothills of the Taurus Mountains (Fig. 1). Coastal zone of the area is mainly occupied by coastal plain, while northern fringe represent areas with undulated terrain and steep slopes. The study area and its vicinity have a complex network of streams that flow into the Mediterranean Sea. The climate is typical Mediterranean with mild and rainy winters and hot and humid summers. In general terms, areas with lower altitudes, mainly characterized by a mixture of agricultural patches, pine forests, maquis and shrubs have undergone extensive changes due to agricultural expansion.

The invasive nature of agriculture was also evident in upper lands. Coastline and coastal alluvial plain, on the other hand witnessed rapid urbanization. The town expanded and the coastline was occupied by high multistory buildings serving for domestic tourism (Alphan and Derse, 2013).

2. Methodology

The methodology included three main steps: (1) land cover classification, (2) metric selection and calculations and (3) mapping spatial diversity using pattern metrics.

One of the most important requirements of analyzing landscape patterns is to provide accurate spatial and thematic representations of landscapes. Spatial resolution or scales of this representation also affect analyses (Pascual-Hortal and Saura, 2007). Landscapes in the study area were characterized using CORINE Land Cover (CLC) classification scheme. The CLC is a three-level hierarchical scheme, which comprises three levels of thematic detail. The first level indicates 5 major categories of land cover on a global scale. Second level includes 15 classes, while the third level has 44 classes. A fourth level could also be added for some or all of the items, for studies on national or regional scales.

A Land use/cover map was produced using digital image classification techniques applied to SPOT (Satellite Probatoire d'Observation de la Terre) image of 2007. Five land cover categories used in image classification were derived from the CLC categories.

Built-up areas in the classification comprised urban fabric (code: 1.1) and industrial, commercial and transport units (code: 1.2) of the CLC. Therefore, continuous urban fabric (1.1.1.), discontinuous urban fabric (1.1.2.), industrial or commercial units (1.2.1), road and rail networks and associated land (1.2.2) and port areas (1.2.3) that were described at the third level were considered in a single “built-up” class. Other classes in the classification (i.e., agriculture, semi-natural areas, bare areas and water) were described using the same approach, combining the corresponding second- and third-level classes of CLC together.

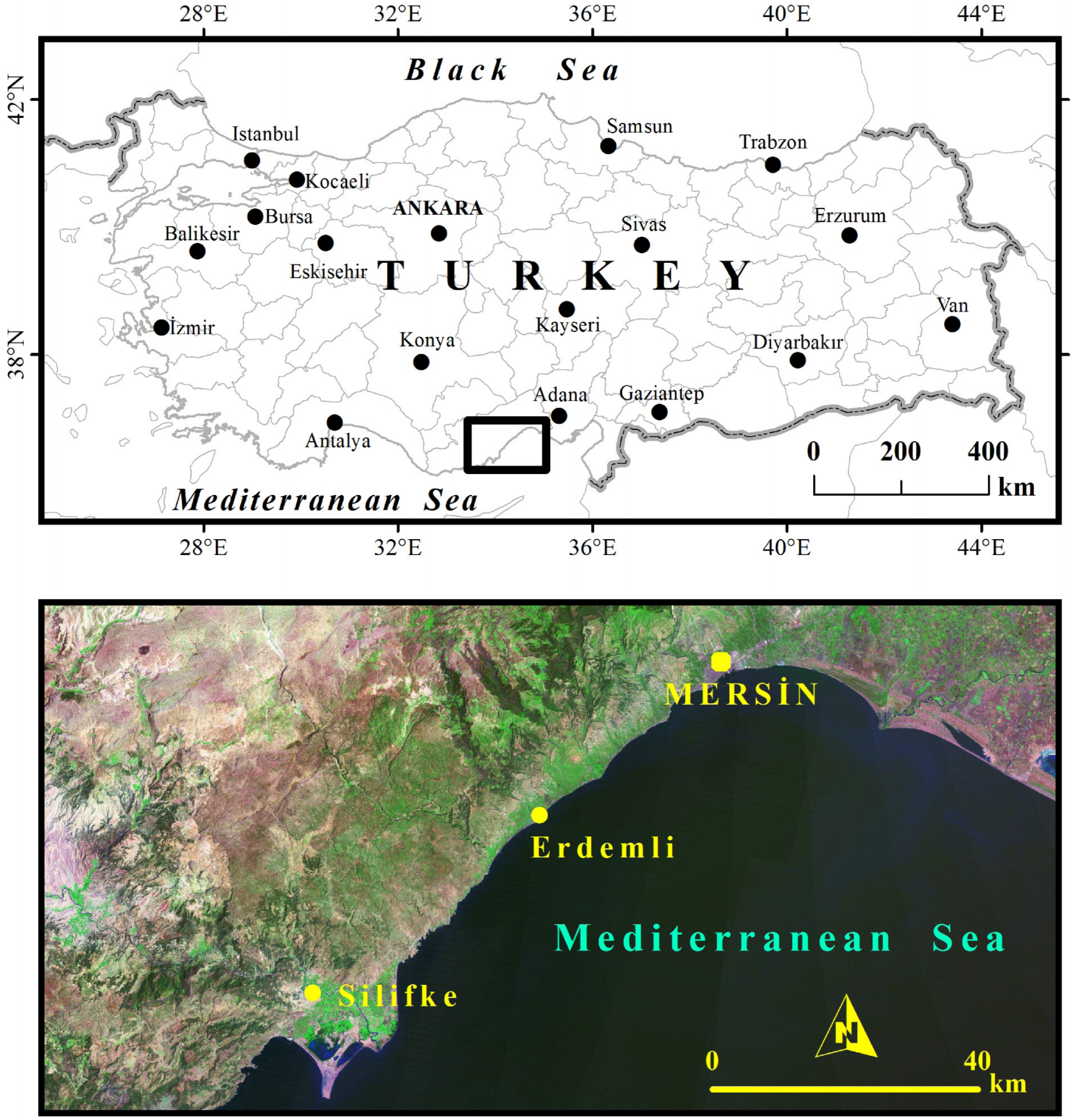

Fig. 1. Study area and its surroundings

Panchromatic SPOT images with 10-meter spatial resolution were geo-referenced in UTM projection. A Quickbird image of 2010 was used for collecting reference points. Very high spatial consistency between the source (i.e. SPOT Panchromatic image of 2007) and the reference (Quickbird image) images was proved by low RMSE (root mean square error) values, which were less than 1 in X and Y directions. Geo-referenced SPOT image acquired in 2007 was classified. After classification the entire study area was divided into 42 grids, each representing 1X1 km landscape. Selected metrics were calculated for these grids. Results were mapped and spatial variability of each of the metric was interpreted.

3. Results and Discussion

3.1. Image classification and land cover mapping

The SPOT image was classified using six land cover classes: built-up and roads, agriculture, forest, semi-natural, bare areas and water. Water was excluded from analyses since this study focused on land areas. Area statistics are given in Table 1. Image classification showed that the area is mainly occupied by agriculture areas. Built-up areas concentrate on the west of Erdemli town. Scattered pattern of built-up areas in close proximity of the town in the east and north is also characteristic. Two isolated forest patches area identifiable in the area. To the northeast of Erdemli town is a Horticulture Research Institute, which is protected under “natural site” status. Another forest patch, which is used as a camping area lies along the west coast of the town. Bare areas include sand dunes on the coastal zone as well as rocky areas and river banks.

A total of eight metrics were applied for each of the 42 landscape grids. These include NP, ED, LPI, AI as well as Shannon’s and Simpson’s diversity and evenness indices (SHDI, SIDI, SHEI, SIEI). Maps of NP, ED, LPI, AI and SHDI, SIDI, SHEI, SIEI are given in Figure 2 and 3, respectively. As stated by McGarigal and Marks (1995), NP is a valuable measure since it is easily interpretable and it creates a basis for calculating many other metrics. It simply equals the number of patches in the landscape. Fig. 2 shows spatial change of NP throughout the study area. As shown in Fig. 2, NP is highest for the town of Erdemli. It is also high in the central north, resulting from a mixed pattern of agriculture, bare and semi-natural areas.

Table 1: Area coverage of five land cover types under investigation

Land Cover Type	Area (ha)
Built-up and roads	4.55
Agriculture	28.12
Forest	1.52
Semi-natural	2.44
Bare	2.10

3.2. Metric calculations and mapping

Edge metrics usually are best considered as representing landscape configuration. At the class and landscape levels, total edge (TE) is an absolute measure of total edge length of a particular patch type (class level) or of all patch types (landscape level).

In applications that involve comparing landscapes of varying size, this index may not be useful. Edge density (ED) standardizes edge to a per unit area basis that facilitates comparisons among landscapes of varying size (McGarigal and Marks, 1995). The study area is analyzed using 1X1 km grids. However, alignment of coastline and the northern boundary of the study area results with the landscapes of varying sizes (i.e. less than 1 sq km) along the coast and the northern fringe of the study area. Therefore edge density (ED) was calculated. ED equals the sum of the lengths of all edge segments in the landscape divided by the total landscape area (McGarigal and Marks, 1995). The ED values of 42 grids were combined to show spatial variations in ED in the study area (Fig. 3). Fig. 3 suggested that the town of Erdemli and the north of the study area have higher ED values compared to the east and the west parts of the coastal zone. In fact, the ED was determined both by occurrence of varying land cover types and/or complexity of road network in a particular landscape (i.e. grids). High ED values in the central north was due to a combination of complex road network and heterogeneity of land cover.

LPI equals the percentage of the landscape comprised by the largest patch. Total landscape area (A) includes any internal background present. It is expressed as follows (Mc Garigal and Marks, 1995) (1):

$$\mathrm{LPI} = \frac{\overset{n}{\underset{j=1}{\max}}(a_{ij})}{A}(100) \qquad (1)$$

Where, “Pi” is the proportion of the landscape occupied by class “i” and “m” is the number of classes present in the landscape.

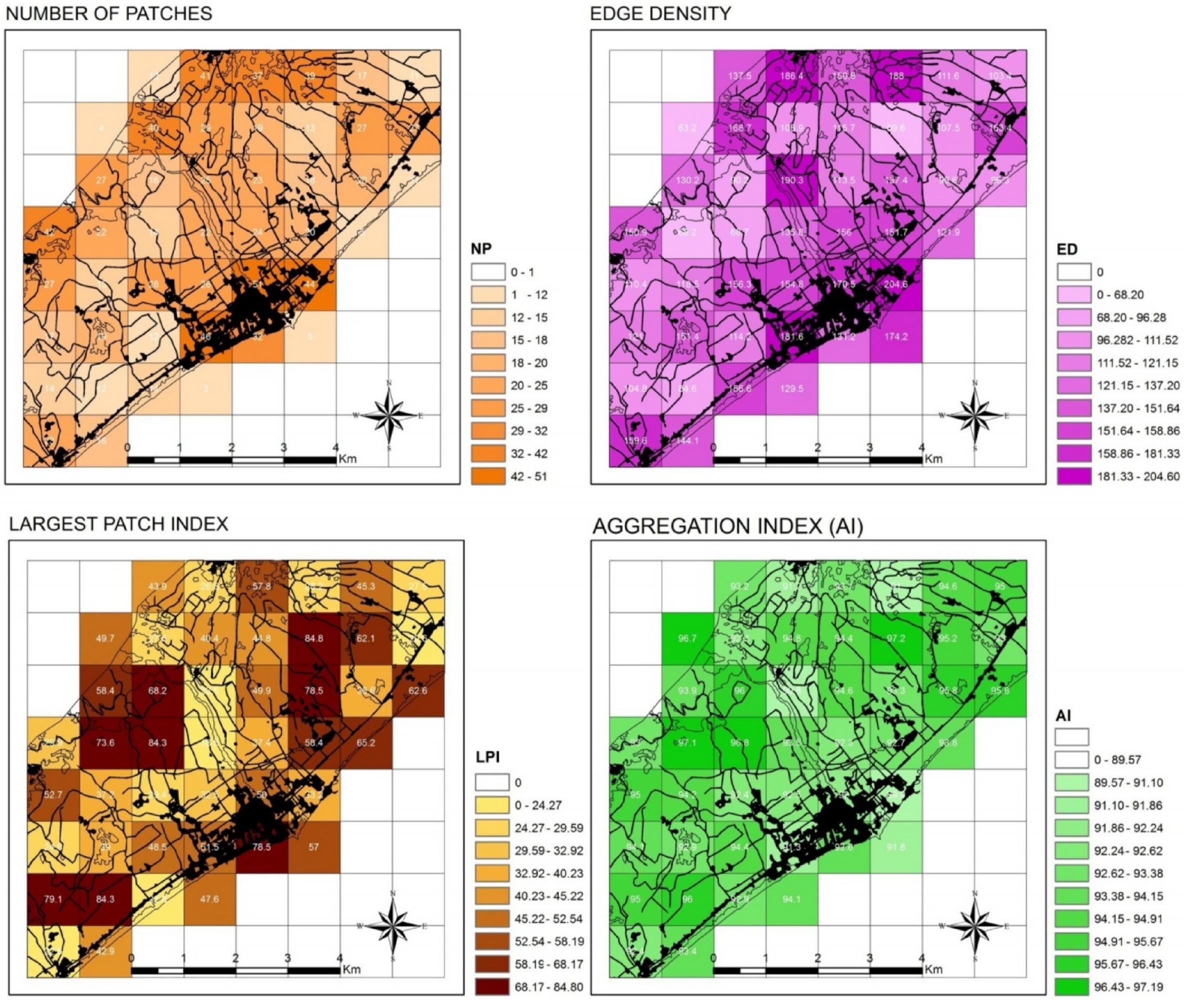

Fig. 2. NP, ED, LPI and AI values calculated for 1x1 Km grids covering the town of Erdemli (Turkey) and its surroundings

LPI approaches 0 when the largest patch in the landscape is increasingly small. LPI equals 100 when the entire landscape consists of a single patch; that is, when the largest patch comprises 100 % of the landscape (Mc Garigal and Marks, 1995). Fig. 3 suggested that higher LPI values exist both on the coastline and inland. For example, at location “a” (town center) high LPI value is due to a large urban patch of consolidated building islands that almost cover the entire grid (excluding background), while at location “b” high LPI value is a result of the agriculture. It is worth to mention that composition of agriculture patches varied throughout the area, resulting from the type of agricultural activities taking place within each of the agriculture patches that support varying compositions of orchards, vineyards, olive groves and open fields.

Aggregation in the study area was also investigated. AI, which is expressed as percentage was calculated for each of the grids. It equals 0 when the patch types are maximally disaggregated. AI increases as the landscape is increasingly aggregated and equals 100 when the landscape consists of a single patch. At landscape level, the AI index is computed simply as an area weighted mean class aggregation index, where each class is weighted by its proportional area in the landscape (Mc Garigal and Marks, 1995). The AI values in the study area ranged between 89.5 and 96.4 (Fig. 3). As suggested by Fig. 3, AI values were relatively higher in inland agriculture fields.

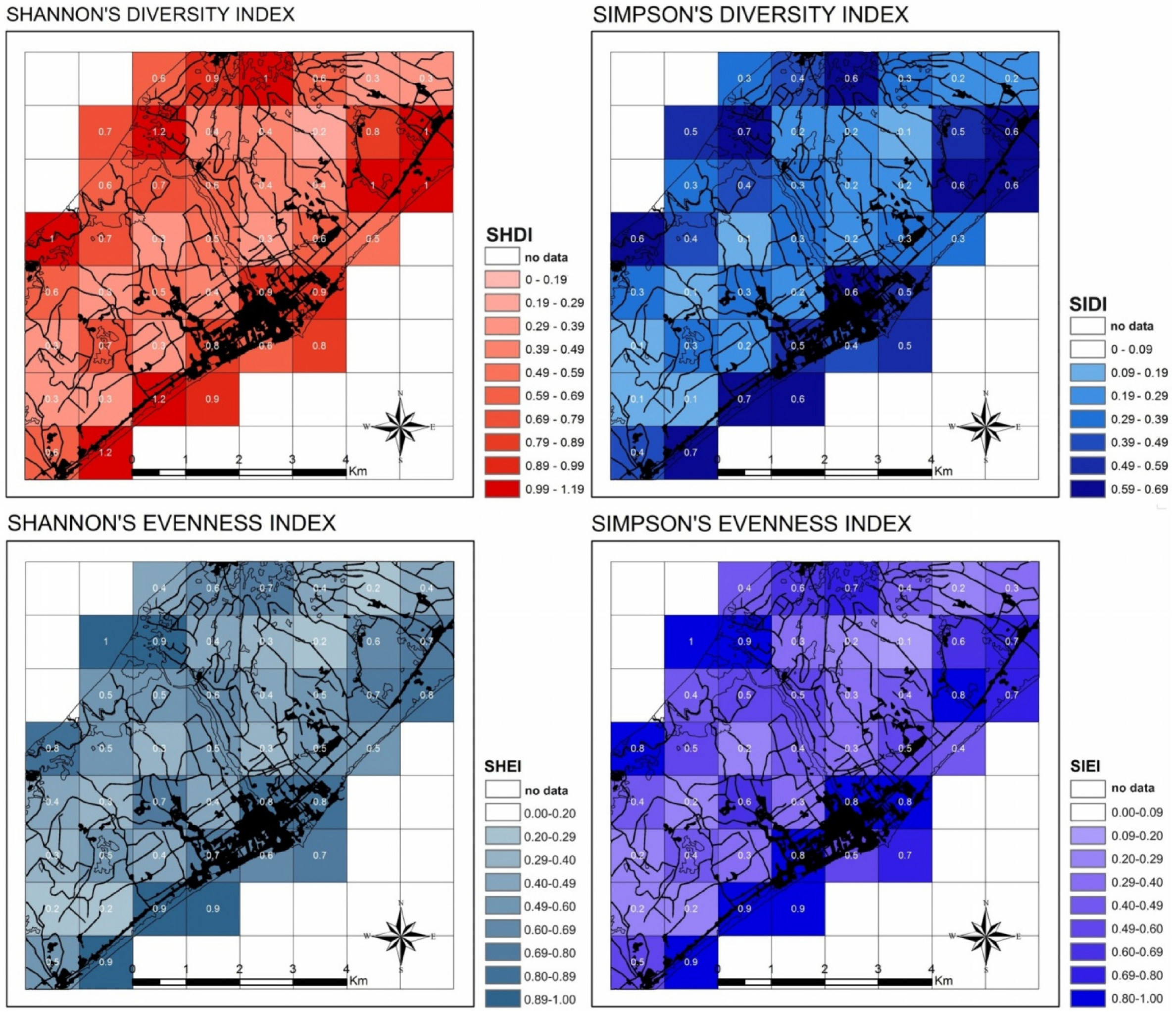

Fig. 3. Spatial variations of diversity and evenness indices in the study area

Diversity indices were also analyzed. Many diversity indices exist; most of them are used in ecological applications. Richness and evenness are two components of diversity, referring to the number of patch types present and distribution of area among different types, respectively. Mc Garigal and Marks (1995), note that some indices (e.g., Shannon's diversity index, SHDI) are more sensitive to richness than evenness. Thus, rare patch types have a disproportionately large influence on the magnitude of the index. Compared to SHDI, Simpson's index (SIDI) is less sensitive to the presence of rare types. Specifically, the value of Simpson's index represents the probability that any 2 pixels selected at random would be different patch types.

Evenness is the relative abundance of different patch types, typically emphasizing either relative dominance or its compliment, equitability. It is usually reported as a function of the maximum diversity possible for a given richness. SHDI, SIDI, SHEI and SIEI are computed as follows (Mc Garigal and Marks, 1995) (2,3,4,5):

$$\mathrm{SHDI} = -\sum_{i=1}^{m} (P_i * \ln P_i) \qquad \mathrm{SIDI} = 1 - \sum_{i=1}^{m} P_i^2 \qquad (2, 3)$$

$$\mathrm{SHEI} = \frac{-\sum_{i=1}^{m} (P_i * \ln P_i)}{\ln m} \qquad \mathrm{SIEI} = \frac{1 - \sum_{i=1}^{m} P_i^2}{1 - \left(\frac{1}{m}\right)} \qquad (4, 5)$$

Where, “Pi” is the proportion of the landscape occupied by class “i” and “m” is the number of classes present in the landscape.

SHDI and SIDI equal zero when the landscape contains only one patch (i.e., no diversity). The value increases as the number of different patch types (i.e., patch richness, PR) increases and/or the proportional distribution of area among patch types becomes more equitable (Mc Garigal and Marks, 1995). Shannon’s and Simpson’s diversity and evenness indices were computed and mapped to represent spatial variations in diversity and evenness in the study area. Maps are given in Fig. 3.

The fact that SHDI values were higher on the coast and on the foothills of the mountains is due to increasing numbers of patch types in these zones. SHDI values ranged between 0.19 and 1.19, while SIDI values were between 0.098 and 0.69. Diversity patterns derived from SHDI and SIDI calculations that were depicted in Fig. 3 were quite similar. Both SHDI and SIDI suggested high diversity values along the coastal zone and also towards the northern fringe of the study area, which is a transition zone between the coast and Taurus Mountains. As shown in Figure 3, evenness patterns were also similar to those of SHDI and SIDI.

4. Conclusions and prospects

Landscape patterns are functions of both natural processes and human interference in biophysical environment. In the Mediterranean coast human activities alter landscapes at unprecedented rates. Status of landscapes resulting from these alterations can be quantified using pattern analyses and the results may be incorporated into GIS to produce more interpretable outputs and help perform further spatial analyses. This study quantified and mapped spatial change of landscape in a coastal area using pattern metrics. Several metrics were calculated for 48 grids and the results were combined. According to analyses, patchiness was higher in the areas closer to the coastline. Areas in close proximity to the coast represented a pattern, which is composed of built-up areas, forest, semi-natural and bare areas. Landscape changed spatially from a mixed pattern of built-up, semi-natural and agriculture to a predominantly agricultural pattern as distance from the coastline increased. Agricultural areas are also diverse in this area including several agricultural classes such as orchards, greenhouses, vineyards, olive groves. Despite the fact that spatial change of the composition and/or configuration of various classes of agriculture may have serious implications on characterizing these landscapes, we did not take the variability of agriculture class into account owing to the fact that main focus of this study is assessing the study area in terms of broader land cover classes such as agriculture, built-up, forest and semi-natural areas. The higher rates of aggregation (i.e., AI) observed in the areas distant from the coastline were due to extensive and highly aggregated nature of the agriculture.

This study qualified and quantified status of landscape pattern in Erdemli, Turkey. Change analyses for these patterns are also important for understanding trends and make future predictions. This can be achieved by adding a time scale to these analyses in order to analyze temporal change. Main difficulty of performing change detection in this area is the requirement of historical datasets of high spatial resolution, which at least date back to several decades ago. This may be may be overcome by using historical SPOT imagery that has been archived since 1980s.

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