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# Unraveling the 'stable' landscape: a multi-factor analysis of unchanged agricultural and forest land (1987–2007) in a rapidly-expanding urban region

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**Abstract** The present study proposes an original framework to investigate landscape transformations in economically-dynamic regions based on the spatial analysis of unchanged land-use patches over a given time-period. A multi-factor analysis of the stable patches classified at nine land-use classes during 1987–2007 in Attica, Greece, was developed using landscape metrics (number of patches, class area, mean shape index, mean patch size and its coefficient of variation) and territorial variables (elevation, distance from the central city). A Principal Component Analysis (PCA) was carried out to explore the specific relations existing between landscape metrics and territorial variables for each use of land. Areas maintaining the same use of land during 1987–2007 covered 73 % of the total investigated region. Artificial surfaces/bare land and agricultural areas are the most persistent uses of land over time (respectively 95 % and 81 %) while the less persistent uses are shrubland (49 %) and coniferous forests (58 %). On average, stable patches are significantly bigger and more distant from the central city than the patches observed at the beginning of the study period. Deviations to this general pattern have been observed for specific land-use classes. The PCA identified patch area and

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shape as independent descriptors of the stable landscape, being correlated respectively with the distance from the inner city and elevation. Multivariate analysis proved to be a relevant tool for evaluating landscape transformations in rapidly evolving urban regions. Stable agro-forest landscapes are a promising target for environmental conservation policies.

**Keywords** Urban expansion · Landscape metrics · Multivariate analysis · Mediterranean region

## Introduction

Considered as the outcome of millenary uses and transformations of land carried out by human society, the intimate structure of the landscape reflects the stratification of biophysical processes and socioeconomic contexts interacting at various observation scales (Briassoulis 2001; Soliman 2004; Jomaa et al. 2008; Marull et al. 2009). Local decision-making processes dependent on both territorial attributes and land-use policies traditionally shaped the Mediterranean landscape, one of the most complex in the world (Alphan 2003; Antrop 2004; Serra et al. 2008; Salvati et al. 2013).

The Mediterranean landscape, formed by the interpenetration of traditional farming systems with high bio-diversity natural systems (forests, shrubland, pastures), is completed by scattered but morphologically compact human settlements (Cakir et al. 2008; Catalàn et al. 2008; Chorianopoulos et al. 2010). It was widely recognized that landscape patterns in southern Europe are strongly dependent on the action of long-established local communities and basically influenced by the increased anthropogenic pressure in the last decades (Marcucci 2000; Verburg et al. 2004; Marull and Mallarach 2005; Salvati and Ferrara 2014).

The processes of urbanization have involved areas progressively further away from the pre-existing urban centers (Collins et al. 2000; Zipperer et al. 2000; Bruegmann 2005). Urban sprawl - combined with the creation of an increasingly widespread network of infrastructure, the growing pressure from tourism, the spatial reorganization of the industrial areas and the intensification of the agricultural systems - has determined landscape changes not only in peri-urban areas, but also in rural areas with less population density (Christopoulou et al. 2007; DiBari 2007). The analysis of changes in the use of land has focused on specific types of landscape characterized by growing anthropogenic pressure, economic dynamism and continuous urbanization (Jensen et al. 2000; Pauleit and Duhme 2000). The analyses focusing on agro-forest ecosystems have shown such landscapes as slowly-evolving over time (Yang and Lo 2002; Salvati and Sabbi 2011; Sarvestani et al. 2011; Shrestha et al. 2012). The relative stability of rural landscapes limited the potential of traditional change detection analyses aimed at investigating land-use structure/dynamics and at identifying specific spatial determinants (Zhang et al. 2004; Weng 2007; Salvati et al. 2015).

Projections of future urbanization trends indicate a continuous expansion through the Mediterranean basin with moderate population growth in southern European countries and concentration in the most accessible rural regions driving important modifications in agro-forest landscapes (Salvati et al. 2013). A more effective regional planning and specific environmental conservation policies are thus required to preserve the traditional patterns (structure, spatial relations and functions) of Mediterranean landscapes (e.g. Collins et al. 2000; Jensen et al. 2000; Zipperer et al. 2000; Zhang et al. 2004). Permanent land-use monitoring and original approaches to complexity in landscape changes are especially needed to assess the non-linear evolution of the rural environments surrounding cities and to estimate forest productivity decline, biodiversity loss and land resource depletion driven by landscape transformations (Fairbanks and Benn 2000; Botequilha Leitato and Ahern 2002; Nikolakopoulos et al. 2005; Weber et al. 2005; Detsis et al. 2010; Nolè et al. 2013). Empirical analysis based on landscape metrics and innovative statistical approaches may contribute to design more sustainable land management strategies (Corona et al. 1997; Cook 2002; Li and Wu 2004; Imre and Rocchini 2009; Jaeger 2000).

The ‘stable landscapes’, i.e. areas that maintain the same use of land for a sufficiently long period of time, have so far been little investigated in the literature of global change. While recent studies assessed the direction and the intensity of changes in Mediterranean landscapes (Bruegmann 2005; Christopoulou et al. 2007; Salvati et al. 2013), few attempts were devoted to explore the structure of land patches with stable use over a given time interval and the latent relationship with selected territorial variables. Such analyses appear as particularly promising in those socioeconomic contexts where the human pressure on landscape is increasing due to growing population, settlements and/or infrastructures.

Based on these premises, the present study investigates the structure and basic characteristics of land patches with stable use during 1987–2007 in the agro-forest landscape of Attica, Greece. This region, one of the most dense in Europe, is a paradigmatic example of a mono-centric structure with a central city and a relevant population gap between the urban areas and the surrounding rural belt (Salvati et al. 2014a, 2015). Despite experiencing dispersed urban expansion, this belt preserves a moderate environmental quality, high biodiversity, traditional agricultural practices and rural culture (Economidou 1993; Moissidis and Duquenne 1997; Salvati et al. 2013).

## Methodology

### Study area

The investigated area covers more than 3000 km$^2$ extending through the Nuts-2 region of Attica encompassing Athens' metropolitan area in Greece (European Environment Agency 2010). The region consists of uplands and mountains (up to 1413 m at the sea level) bordering the urban area of Athens and three coastal plains (Mesogeia, Marathona and Thriasio), together with some islands among which Salamina and Aigina are the most populated (Salvati et al. 2013). Climate is typically Mediterranean with hot and dry summers and mild winters. Land receives an annual precipitation of 400 mm with high evapotranspiration rate (around 1000 mm per year) owing to the warm thermometric regime across the year (19 °C annual average). The synergy of poor soils and vegetation cover well adapted to semi-arid climate contributes to soil erosion and land degradation processes historically observed in the region since millennia (Economidou 1993).

### Land-use maps

A change detection analysis was implemented with the aim to quantify variations in the use of land using multi-temporal remotely sensed data (Yang and Lo 2002; Yang et al. 2003). Two Landsat TM satellite images, the first acquired in 1987 and the second acquired in 2007 were used for mapping the distribution and changes over time of selected land-use classes in the study area. The first step of the methodology was the pre-processing of the satellite images which included their geometric and atmospheric correction followed by an object-based classification step (Salvati et al. 2014a). This step was implemented in two phases, segmentation and classification. To create objects, pixels with similar characteristics and properties (spectral and spatial information, topological relationships, texture features) were grouped together in the multi-resolution segmentation phase. The process resulted into two segmentation levels (Salvati et al. 2015).

The classification, the second phase of the process, was based on fuzzy logic and the determination of the so-called membership functions for each class. During the classification of the first-level uses of land, two main categories ('agricultural areas' [AGR] and 'non-agricultural areas') were separated by taking into account supplementary information derived from the Corine Land Cover map referring to 1990 and 2000. Before the classification at the second level the 'non-agricultural areas' were re-segmented (Salvati et al. 2014a). The classification at the second segmentation level resulted into eight separate land-use categories: coniferous forests (CON), broadleaved forests (BRO), shrubland (SHR), schlerophyllous vegetation (SCL), sparse vegetation (SPA), burnt areas (BUR), artificial surfaces/bare land (URB) and water bodies (WAT).

According to Economidou (1993); Weber et al. (2005); Chorianopoulos et al. (2010) and Salvati et al. (2013), the nine-class nomenclature adopted in the present study allows for a comprehensive description of Attica landscape. The final product of the classification model described above was converted into vector files from which the land-use maps of 1987, 2007 and the change map between 1987 and 2007 were derived (Salvati et al. 2015). The accuracy of the results was estimated with a field survey based on 187 random points covering the whole region.

## Landscape analysis

Land patches with unchanged use over time and forming persistent landscapes over the investigated time period were identified using the abovementioned change map between 1987 and 2007 at 1:25,000 nominal scale. Landscape and class metrics (number of patches, class area, mean shape index, mean patch size and its coefficient of variation) were calculated for both the land patches with unchanged use (1987–2007) and the landscape structure observed in 1987. Mean elevation and average distance from the central city (Platia Syndagmatos in the historical centre of Athens) were also calculated for each stable patch. Calculation was performed using the spatial tool provided by ArcGIS software (Esri Inc., Redwoods, USA).

A non-parametric Mann-Whitney U inference was used separately for each land-use class to test for significant differences in the metrics observed at the beginning of the study (1987) compared with the unchanged patches during 1987–2007. The correlations between the percent class area and the other three landscape metrics (mean patch size, patch size coefficient of variation, mean shape index) and between the percent class area and the two territorial variables (elevation and distance from the central city) were investigated pair-wise using Spearman non-parametric rank tests.

## Exploratory data analysis

A Principal Component Analysis (PCA) was applied to the data matrix containing the two most significant landscape metrics identified in the previous analysis (mean patch size and mean shape index) and the two territorial variables (elevation and distance from Athens) for each stable land patch in Attica. The analysis was aimed at exploring the spatial relationship existing between structural and territorial variables in the stable landscape (Salvati et al.

2014a). The PCA was based on the correlation matrix and the number of significant components was chosen by retaining those with eigenvalue >1. The Keiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were used as PCA diagnostics with the aim to assess if the factor model is appropriate to analyze the original dataset (Salvati et al. 2014b). These statistics test respectively whether the partial correlations among variables are small, and whether the correlation matrix is an identity matrix. Plots of component loadings and scores were used to map variables and land-use classes into different groups: entities placed close each other in the PCA plane indicate spatial association, while entities placed far each other indicate spatial segregation (Salvati et al. 2013).

### Logistic regression

A multiple logistic regression model was developed for each land-use class (except for water bodies, broadleaved forests and burnt areas due to the small sample size) to predict probabilities underlying patch change or stability during the investigated period (1987–2007). The dichotomous dependent variable was reported as 1 (stable patch) or 0 (patch with a change in the use of land over 1987–2007). The model was built up considering five variables as predictors (patch area expressed in logarithm, shape index, distance from the central city, two dummies respectively for flat areas and uplands). All predictors were standardized prior to analysis. Results of the logistic model include the constant and five parameters' estimates and standard errors, together with Wald statistic testing for significant coefficients at $p < 0.001$. Log-likelihood, Pearson Chi-square and the degree of freedom were also reported for each model.

## Results

### *Assessing persistent uses of land (1987–2007) in Attica*

The spatial distribution of the nine uses of land examined in this study was investigated using percent class area for 1987 and changes observed during 1987–2007 (Table 1). Overall 73 % of the total investigated land was classified with the same use in both 1987 and 2007. Built-up areas and bare land showed the highest stability (93 %) followed by agricultural areas (81 %) and schlerophyllous vegetation (71 %) while the less persistent uses are shrubland (49 %), coniferous forests (58 %) and sparsely vegetated areas (66 %). Some of those classes decreased faster in time, as in the case of sparse vegetated areas (−0.21 %) and coniferous forests (−0.18 %) while a modest expansion of schlerophyllous vegetation was observed (0.11 %).

The percentage of unchanged (1987–2007) class area increased with percent gain area and decreased with percent loss area. The most stable classes are spatially concentrated (URB, AGR) compared with the less stable classes (e.g. SHR, SPA, CON) resulting more dispersed and poorly connected (Fig. 1). A positive relation ($r_s = 0.73$, $p < 0.05$, $n = 7$) between the percent class area in 1987 landscape and the percent class area in the stable (1987–2007) land patches was observed (Fig. 2).

### The structure of stable land-uses in Attica

By comparing selected class metrics (percent class area, mean patch size, patch size coefficient of variation, mean shape index) for land patches with stable use between 1987 and 2007 and

**Table 1** Land-use changes in Attica during the investigated time interval (1987–2007)

| Class | 1987 | 2007 | Annual change (%) | Stable class area (%)* |
|---|---|---|---|---|
| Artificial surfaces and bare land | 13.2 | 18.1 | 0.24 | 94.6 |
| Agricultural areas | 33.3 | 34.6 | 0.06 | 81.1 |
| Natural areas | 53.3 | 45.9 | −0.37 | 59.2 |
| *Coniferous forests* | *11.1* | *7.4* | *−0.18* | *58.8* |
| *Broadleaved forests* | *0.0* | *0.2* | *0.01* | - |
| *Shrubland* | *8.6* | *6.8* | *−0.09* | *48.9* |
| *Sclerophyllous vegetation* | *3.8* | *5.9* | *0.11* | *71.5* |
| *Sparsely vegetated land* | *29.7* | *25.5* | *−0.21* | *66.3* |
| Burnt areas | 0.1 | 1.3 | 0.06 | - |
| Waterbodies | 0.1 | 0.1 | 0.00 | 70.2 |
| *Total investigated area* | *3128.7* | | - | *72.6* |

*Broadleaved forests and burnt areas were not evaluated due to the restricted percent class area found in Attica

the metrics referring to the 1987 landscape (Table 2), stable patches were systematically bigger (22 ha) than the average patch size measured at the beginning of the time interval (10.5 ha). Significant differences have been observed for artificial surfaces/bare land, agricultural areas, coniferous forests, shrubland, sclerophyllous vegetation and sparsely vegetated areas. The coefficient of variation of patch size for the stable landscape (15.4 %) is significantly lower than the same metric recorded for the 1987 landscape (19.2 %).

A significant difference was observed at the class level for agricultural areas, coniferous forests and shrubland indicating higher dimensional homogeneity for the unchanged patches. The reverse pattern (higher CV observed for unchanged patches) was observed for schlerophyllous vegetation. The mean shape index was found systematically lower in the stable landscape (0.4) compared with the 1987 landscape structure (0.7). Significant differences in the same direction were found for agricultural areas, coniferous forests, shrubland and schlerophyllous vegetation. The average distance of unchanged patches from the inner city (29.7 km) was slightly lower than that observed for the 1987 landscape patches (28.8 km).

Significant differences were found for agricultural areas (stable patches found closer to the inner city) and schlerophyllous vegetation (stable patches found, on average, at higher distance from the inner city than the 1987 land patches). The average elevation was similar for stable patches and the total patches in the landscape. Only shrubland and sparse vegetation stable patches are less common in flat areas than the respective class patches observed in the 1987 landscape. Among the selected metrics, patch size CV and the mean shape index increased significantly with percent class area respectively in the 1987 landscape and in the stable landscape (1987–2007).

## ‘*Stable landscape*’, *elevation and distance from the central city*

The relationship between two selected class metrics (patch size and shape index) and two topographic variables (distance from the central city and elevation) was studied using non-parametric Spearman correlation analysis (Table 3). While stable coniferous forest and schlerophyllous vegetation patch size and shape did not correlate with either distance or

Elevation

Agricultural areas

Coniferous forests

Shrubland

Schlerophyllous vegetation

Sparsely vegetated land

**Fig. 1** Elevation map of Attica (upper left) and the distribution of stable patches during 1987–2007 by land-use class

elevation, sparse vegetation and artificial surfaces/bare land stable patches significantly decreased with the distance from Athens. By contrast, the spatial pattern observed for stable agricultural patches modified with the distance from Athens. Shrubland patch size and shape increased significantly with elevation. The shape index for sparse vegetation and artificial surfaces/bare land stable patches increased with the distance from Athens while decreasing for

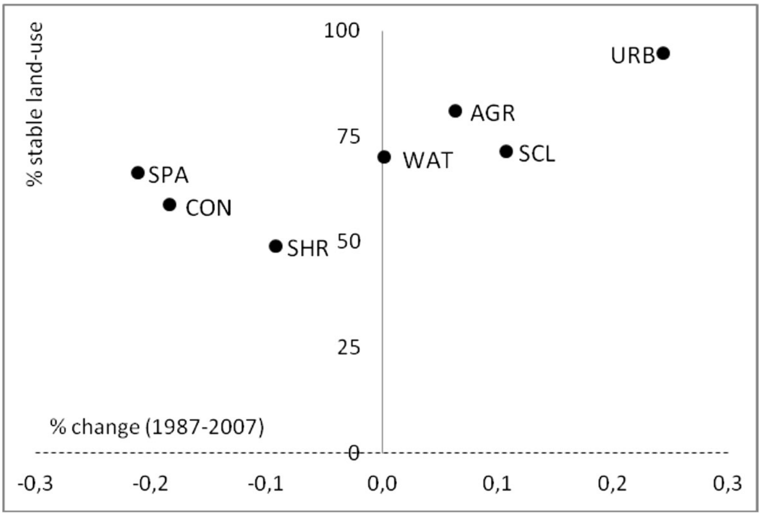

**Fig. 2** The relationship between the percent class area with stable use of land and percent class change (gain or loss) over time (1987–2007)

agricultural patches. Shrubland and sparse vegetation stable patches were found significantly bigger at higher elevation while their shape index decreased with elevation. The reverse pattern was observed for anthropogenic uses of land such as agriculture and artificial surfaces/bare land.

## Exploratory data analysis

The two components extracted by the PCA showed a cumulated variance higher than 51 % (Fig. 3, left). The Keiser–Meyer–Olkin measure of sampling adequacy and Bartlett's test of sphericity ($p < 0.001$) indicates that the factor model was appropriate to analyse the original data matrix. Component 1 (explaining 26 % of the total variance) represents the elevation gradient which influences negatively the shape index. Component loadings suggest that heterogeneous and irregular shapes are found more likely at lower elevation. Component 2 (explaining 25 % of the total variance) represents the urban-to-rural gradient which influences negatively the size of landscape patches. Patches are ordered according to the component score plot (Fig. 3, right). Artificial surfaces/bare land patches are relatively more homogeneous compared with the natural patches (oriented primarily through the elevation-shape axis) and the agricultural patches, oriented preferentially along the area-distance axis.

## Logistic regression

A logistic model assessing the importance of the four selected metrics (mean size and shape) and territorial variables (elevation and distance from the inner city) associated to the 'stable' or 'changed' status for each land patch was developed for the six most common land-use classes in Attica (Table 4). Compared to changed patches, coniferous forest and shrubland stable patches were characterized by significantly higher mean patch size and mean shape index and a lower occurrence in the upland zone. Sclerophyllous vegetation stable patches featured

**Table 2** Landscape structure in 1987 and selected metrics measuring patches of land with stable use (1987–2007) by class

| Class | Class area (%) | Mean Patch Size (ha) | Patch size CV (%) | Mean Shape Index | Distance from the inner city (km) | Elevation† | n |
|---|---|---|---|---|---|---|---|
| *Landscape structure (1987)* | | | | | | | |
| Artificial surfaces and bare land | 13.2 | 22.6 | 21.7 | 0.5 | 24.5 | 79.1 | 1826 |
| Agricultural areas | 33.3 | 19.9 | 18.1 | 1.3 | 30.8 | 68.3 | 5249 |
| Coniferous forests | 11.1 | 9.1 | 6.2 | 0.8 | 31.7 | 14.5 | 3834 |
| Broadleaved forests | 0.0 | 0.0 | 0.0 | 0.3 | 45.7 | 1.00 | 4 |
| Shrubland | 8.6 | 3.9 | 4.8 | 0.4 | 30.6 | 26.2 | 6910 |
| Sclerophyllous vegetation | 3.8 | 4.6 | 2.7 | 0.7 | 29.2 | 16.5 | 2572 |
| Sparsely vegetated land | 29.7 | 9.9 | 8.7 | 0.6 | 28.9 | 43.0 | 9392 |
| Burnt areas | 0.1 | 19.8 | 1.9 | 0.1 | 18.1 | 5.8 | 18 |
| Waterbodies | 0.1 | 4.1 | 4.5 | 1.2 | 26.7 | 54.3 | 86 |
| *Total investigated area* | *100.0* | *10.5* | *19.2* | *0.7* | *29.7* | *50.5* | *29,891* |
| Correlation with % class area‡ | - | 0.44 | 0.68* | 0.45 | −0.02 | −0.51 | - |
| *Stable land-use patch (1987–2007) metrics* | | | | | | | |
| Artificial surfaces and bare land | 94.6 | 41.8 | 16.3 | 0.4 | 23.2 | 73.5 | 933 |
| Agricultural areas | 81.1 | 92.5 | 9.2 | 0.5 | 27.8 | 69.7 | 914 |
| Coniferous forests | 58.8 | 26.9 | 3.9 | 0.5 | 31.6 | 17.2 | 760 |
| Broadleaved forests | 0.0 | - | - | - | - | - | 0 |
| Shrubland | 48.9 | 7.3 | 2.3 | 0.2 | 30.6 | 19.6 | 1160 |
| Sclerophyllous vegetation | 71.5 | 5.8 | 4.9 | 0.4 | 30.8 | 15.6 | 2288 |
| Sparsely vegetated land | 66.3 | 14.4 | 8.4 | 0.5 | 28.2 | 37.4 | 4270 |
| Burnt areas | 0.0 | - | - | - | - | - | 0 |
| Waterbodies | 70.2 | 35.2 | 1.5 | 0.2 | 30.4 | 59.5 | 7 |
| *Total investigated area* | *72.6* | *22.0* | *15.4* | *0.4* | *28.8* | *50.5* | *10,332* |
| Correlation with % class area‡ | - | 0.55 | 0.49 | 0.70* | −0.39 | 0.04 | - |
| *Ratio of 'stable' landscape (1987–2007) to 'stock' landscape (1987)* | | | | | | | |
| Artificial surfaces and bare land | 7.2 | 1.9* | 0.8 | 0.7 | 0.9 | 0.9 | 0.5 |
| Agricultural areas | 2.4 | 4.7* | 0.5* | 0.4* | 0.9* | 1.0 | 0.2 |
| Coniferous forests | 5.3 | 3.0* | 0.6* | 0.6* | 1.0 | 1.2 | 0.2 |
| Broadleaved forests | - | - | - | - | - | - | - |
| Shrubland | 5.7 | 1.9* | 0.5* | 0.5* | 1.0 | 0.7* | 0.2 |
| Sclerophyllous vegetation | 18.8 | 1.2* | 1.8* | 0.6* | 1.1* | 0.9 | 0.9 |
| Sparsely vegetated land | 2.2 | 1.5* | 1.0 | 0.9 | 1.0 | 0.9* | 0.5 |
| Burnt areas | - | - | - | - | - | - | - |
| Waterbodies | 702 | 8.6 | 0.3 | 0.2 | 1.1 | 1.1 | 0.1 |
| *Total investigated area* | *0.7* | *2.1* | *0.8* | *0.6* | *1.0* | *1.0* | *0.3* |

†Measured as percent land area < 100 m elevation on the total land area

*The difference in each metric between the 1987 landscape structure and the stable landscape was tested using Mann-Whitney statistics at $p < 0.05$

‡Spearman rank correlation coefficient with *indicating significance at $p < 0.05$

**Table 3** The relationship between selected class metrics and territorial variables (distance from Athens and elevation) by class for 1987–2007 stable landscape in Attica

| Class* | n | Distance from Athens† | | Elevation‡ | |
|---|---|---|---|---|---|
| | | Patch size | Patch shape | Patch size | Patch shape |
| Coniferous forests | 760 | 0.031 | −0.044 | 2.08 | 1.69 |
| Shrubland | 2288 | −0.009 | 0.008 | 488.2* | 513.5* |
| Sparsely vegetated land | 4270 | −0.033* | 0.035* | 271.5* | 310.4* |
| Agricultural areas | 914 | 0.091* | −0.102* | 6.91* | 6.98* |
| Artificial surfaces and bare land | 933 | −0.105* | 0.099* | 24.1* | 23.67* |
| Schlerophyllous vegetation | 1160 | −0.028 | 0.031 | 4.73 | 4.13 |

†Spearman non-parametric rank correlation coefficients testing for significance at $p < 0.05$

‡Kruskal-Wallis non-parametric analysis of variance with 3 elevation classes (flat, hilly and mountain) testing for significance at $p < 0.05$ (Agricultural areas were compared along the elevation gradient using Mann-Whitney non-parametric test since this class was not present in the mountain zone)

*Broadleaved forests, burnt areas and water bodies were not considered due to the restricted number of patches surveyed

higher patch size and distance from Athens. Sparse vegetation stable patches showed lower distance from Athens and higher shape index compared with the land patches experiencing a change in their use. Agricultural stable patches are characterized by higher mean patch size and higher occurrence in flat areas and lower distance from Athens compared with transformed patches. Finally, artificial surfaces/bare land stable patches featured higher mean patch size and lower distance from Athens compared with transformed patches.

## Discussion

The present study proposes an original land-use change analysis based on the concept of 'stable landscape'. An evolutionary assessment of land-use dynamics was proposed focusing on change patterns only as the base for environmental monitoring and modeling at the regional

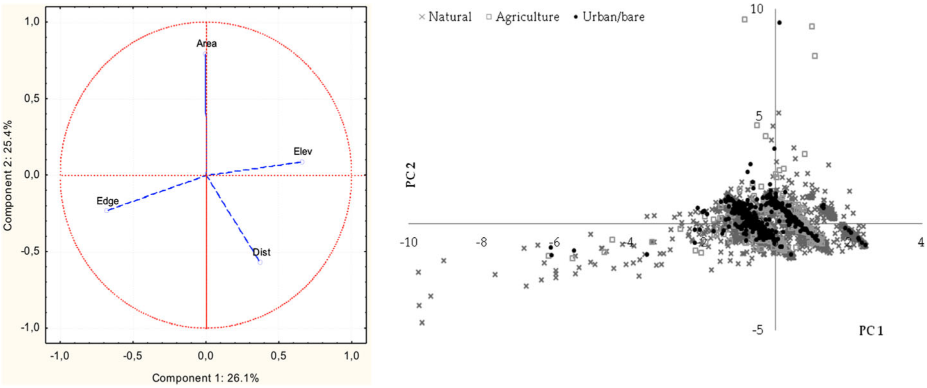

**Fig. 3** Principal Component Analysis investigating the stable landscape structure (1987–2007) at the patch scale (left: loadings' plot; right: scores' plot; 'area' means patch size; 'edge' means patch shape'; natural land-uses include the following classes: CON, SHR, SCL, SPA)

**Table 4** Logistic regression for stable vs changed land-use patches (estimate ± standard error; * indicates significant Wald test for logistic coefficients at $p < 0.001$)

| Variable | Coniferous forests | Shrubland | Schlerophyllous vegetation | Sparsely vegetated land | Agricultural areas | Artificial surfaces and bare land |
|---|---|---|---|---|---|---|
| Intercept | −1.460(0.050)* | −0.703(0.026)* | −0.333(0.049)* | −0.199(0.021)* | −2.167(0.037)* | −0.197(0.058) |
| Mean patch size | 0.728(0.053)* | 0.300(0.037)* | 0.661(0.061)* | 0.071(0.027) | 0.252(0.046)* | 0.236(0.064)* |
| Distance | 0.021(0.044) | 0.038(0.027) | 0.253(0.043)* | −0.116(0.020)* | −0.314(0.038)* | −0.274(0.052)* |
| Mean shape index | 0.299(0.045)* | 0.171(0.041)* | 0.219(0.069) | 0.098(0.028)* | 0.028(0.044) | 0.145(0.071) |
| Flat areas | −0.081(0.071) | −0.205(0.060) | −0.037(0.071) | 0.136(0.051) | 6.208(0.038)* | 0.605(0.187) |
| Uplands | −0.318(0.066)* | −0.263(0.060)* | 0.019(0.063) | 0.058(0.051) | 0.500(0.180) | 0.408(0.188) |
| Loglikelihood | −1789 | −4341 | −1679 | −6440 | −2356 | −1234 |
| Pearson $\text{Chi}^2$ | 4018 | 6911 | 2575 | 9392 | 5268 | 1826 |
| Degr. freedom | 3828 | 6904 | 2566 | 9386 | 5244 | 1820 |

scale (e.g. Marcucci 2000; Pauleit and Duhme 2000; Marull et al. 2009). Unfortunately, these studies lack a specific focus on the structure and basic characteristics of persistent landscapes. Our paper is aimed at filling this gap by analyzing selected landscape metrics over twenty years for the patches with unchanged use in a Mediterranean region and correlating their spatial distribution with proxy variables for the urban-rural gradient (elevation, distance from the central city). Using a basic landscape analysis coupled with exploratory multivariate statistics, findings of this study may contribute to design a sustainable land management strategy for agro-forest systems on the fringe of large cities in southern Europe.

Our results indicate that the anthropogenic land-use classes (e.g. agriculture) are more stable than the natural classes, corroborating previous findings by Salvati et al. (2014a). Among natural land-uses, sparse vegetation shows a higher stability than shrubland and forests. Based on these findings, specific protection measures for high-quality natural areas mainly formed by sparse forests and shrubland are recommended in the study area (Economidou 1993; Christopoulou et al. 2007; Chorianopoulos et al. 2010). Moreover, the stable landscape (1987–2007) in Attica shows a peculiar structure if compared with the landscape structure at the beginning of the study period (1987).

The largest patches are those with the lowest probability to be converted to other uses. At the same time, the patches more distant from the central city and placed at higher elevation are those with the lowest probability to undergo changes in their use. The mean shape index of unchanged patches decreased with elevation indicating less land fragmentation in mountainous areas compared with flat and hilly areas. Interestingly, our analysis demonstrates that patch size and shape, the two structural dimensions considered in this study, are not correlated. This may reflect the distinct impact of elevation on patch shape and of the distance from the central city on patch size. Such findings suggest that the majority of changes in the use of land depends on the increased human pressure driven by urbanization and continuous transformations in the spatial organization of the region (Cook 2002; Luck and Wu 2002; Zhang et al. 2004; Shrestha et al. 2012).

As our study clearly shows, a multivariate approach applied to metrics evaluating the structure of the 'stable' landscape, allows exploring the relationship between landscape composition and structure along the urban gradient (Salvati et al. 2014b). This approach proved to be a meaningful contribution to landscape studies since it provides a summary picture of land fragmentation over the last twenty years. Results are in agreement with local-scale analyses indicating a landscape rearrangement driven by urban scattering, forest fires, pasture land abandonment and shrubland expansion, agricultural intensification or extensivation (Nikolakopoulos et al. 2005; Weber et al. 2005; Chorianopoulos et al. 2010; Ferrara et al. 2014; Salvati et al. 2014a).

Data mining is a promising tool for evaluating landscape modifications in rapidly evolving urban regions (Salvati et al. 2013). Multivariate analysis is specifically important when evaluating fast and slow transformations over time by linking structural and compositional features of landscapes (Salvati et al. 2015). Research should concentrate on innovative techniques for the integrated, multi-dimensional assessment of landscape modifications in regions experiencing anthropogenic pressures (e.g. Salvati et al. 2014b). The identification of fast and slow structural variables in land-use change analysis may inform more effective policies promoting sustainable urban forms and protecting high-quality, relict agro-forest landscapes at the fringe.

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