CrossMark

CASE STUDY

Sprawl matters: the evolution of fringe land, natural amenities and disposable income in a Mediterranean urban area

Luca Salvati[1,5] · Ioannis Gitas[2] · Tullia Valeria Di Giacomo[3] ·
Efthimia Saradakou[4] · Margherita Carlucci[5]

Abstract We investigate the relationship between land-use changes (1987–2007) and the spatial distribution of the average declared income of resident population in a southern European metropolitan region (Athens, Greece) as a contribution to the analysis of sub-urbanization processes in the Mediterranean region. To demonstrate that urban expansion is accompanied with multiple modifications in the use of the surrounding non-urban land, we developed a computational approach based on spatial indexes of landscape configuration and proximity as a result of changes in the local socio-spatial structure. Diversity in the use of land surrounding built-up parcels in the Athens' metropolitan region increased significantly between 1987 and 2007, reflecting a progressive fragmentation of the exurban landscape. The percentage of forests and (high-quality) natural land surrounding built-up parcels increased from 8.1 to 9.4 % between 1987 and 2007. The reverse pattern was observed for (low-quality) sparsely vegetated areas, declining from 65 to 47 %. Large built-up parcels were surrounded by a higher percentage of natural land than small parcels. The largest increase over time in forest and natural land surrounding built-up parcels was observed in municipalities with high per capita declared income, and the reverse pattern was observed for sparse vegetation. Our results demonstrate that scattered urban expansion determines a polarization in suburban areas with high-quality and low-quality natural amenities. Sprawl increases economic inequality and socio-spatial disparities contributing

✉ Luca Salvati
luca.salvati@entecra.it

1   Council for agricultural research and economics (CREA), Via della Navicella 2–4, 00184 Rome, Italy

2   Laboratory of Forest Management and Remote Sensing, Department of Forestry and Natural Environment, Aristotle University of Thessaloniki, P.O. Box 248, 54124 Thessaloníki, Greece

3   Department of Science and Technology for Agriculture, Forests, Nature and Energy (DAFNE), University of Tuscia, Via San Camillo de Lellis snc, 01100 Viterbo, Italy

4   Hellenic Open University, Odos Parodos Aristoteleiou 18, 26335 Patra, Greece

5   Department of Economic and Social Sciences, University of Rome 'La Sapienza', Piazzale A. Moro 5, 00185 Rome, Italy

to a spatially unbalanced distribution of natural amenities with higher consumption of high-quality land.

1 Introduction

Urbanization determines relevant transformations in the spatial relationship between land uses along the urban gradient (e.g., Antrop 2004; Aguilar 2008; Salvati and Sabbi 2011). In recent decades, urban areas expanded into agricultural and natural land at an accelerated rate creating hybrid and mixed landscapes at progressively larger distances from central cities (Wu 2001; Serra et al. 2008; Bhatta et al. 2010; Shrestha et al. 2012); especially in suburban areas, changes in the use of land reflect the interplay between actors competing for land (Bryant 1995; Irwin and Bockstael 2004; Nechyba and Walsh 2004; Radeloff et al. 2005). The underlying factors contributing to dispersed urban expansion have been demonstrated to affect hierarchy, spatial configuration and composition of agricultural and natural uses of land with impact on environmental quality (Christopoulou et al. 2007; Feranec et al. 2010; Frondoni et al. 2011). Agriculture and forests are intended as elements indirectly preserving land from urbanization and factors of economic marginalization at the same time, providing important ecosystem services while depressing land rent (Economidou 1993; Allen 2003; Cho et al. 2011).

Sprawl, one of the most common patterns of urban expansion worldwide (Bruegmann 2005), shapes the spatial organization of metropolitan regions causing a shift toward scattered, discontinuous and fractal urban structures (Cavailhes et al. 2004). In recent decades, dispersed urbanization has been considered as one of the most powerful drivers of landscape transformations in developed countries (Richardson and Chang-Hee 2004; Bruegmann 2005; Arribas-Bel et al. 2011). For example, dispersed urbanization in Europe consumed every year more than 0.2 % of cropland and 0.1 % of natural and seminatural land in the last two decades (European Environment Agency 2006).

In southern Europe, deregulated urban expansion contributed to the increased demand for housing, transport and natural amenities, shaping a socioeconomic context particularly inclined to sprawl (Catalàn et al. 2004; Chorianopoulos et al. 2010; Terzi and Kaya 2011; Ferrara et al. 2014). The social permeability of fringe land and the poorly organized and sparsely distributed economic functions determine territorial disparities depressing local competitiveness at the same time (Salvati and Gargiulo Morelli 2014). The environmental sensitivity of Mediterranean landscapes—being influenced by dry climate and often poor soils—added to the social fragility of fringe land (Christopoulou et al. 2007), creating unsustainable conditions for a long-term spatially balanced economic development (Salvati et al. 2013). Mixed, fragmented and fragile landscapes are a common trait to several Mediterranean suburban areas (Paul and Tonts 2005; Munafò et al. 2010; Salvati et al. 2014).

Although landscape transformations have been widely assessed in southern European urban regions (Kasanko et al. 2006; Longhi and Musolesi 2007; Turok and Mykhnenko 2007; Schneider and Woodcock 2008), less efforts have been devoted to analyze changes in the spatial relationship between different uses of land as a result of dispersed urbanization (e.g., Bhatta et al. 2010). Salvati and Sabbi (2011) hypothesized that urban

expansion influenced the spatial structure of metropolitan regions altering the long-established relationship between urban, agricultural and natural uses of land.

The present study illustrates an original approach investigating the main changes in the spatial relationship between different uses of land over 20 years (1987–2007) in the metropolitan region of Athens, Greece. Athens' region underwent compact urbanization since the First World War with dispersed growth starting in the late 1960s and culminating in 2004 Athens' Olympics (Economidou 1993; Chorianopoulos et al. 2010; Mallinis et al. 2014). The last two decades were characterized by residential and infrastructure expansion on fringe land around the consolidated city (Salvati et al. 2014). Changes in the use of land surrounding each built-up parcel were assessed by computing the proportion of each class on the total patch perimeter. Diversity in the use of land was evaluated using the Shannon index applied to the composition of landscape bordering each built-up parcel.

Our analysis allows investigating the structural characteristics of urban parcels and the spatial correlation with natural amenities and other predictors of change in the use of land. The relationship between urbanization-driven changes in land-use structure and average per capita declared income was finally investigated at a disaggregated spatial scale (i.e., municipalities) with the objective to assess whether recent urbanization reflected social segregation and increasing territorial disparities (Le Goix 2005). Evidence suggests that dispersed urbanization has determined a polarization in 'gated communities' (residential districts inhabited by high-class society and surrounded by natural amenities) and fragile areas from the socio-environmental point of view (Aguilar 2008). Previous studies have emphasized the role of natural amenities in the consolidation of sprawled patterns of urban expansion (Wu 2006) and provided a framework for analyzing the effect of major territorial features on community characteristics (Lichtenberg and Hardie 2007; Walsh 2007; Wu 2010). Development patterns and the composition of local communities are both influenced by the spatial distribution of natural amenities (Wang and Wu 2011). By introducing amenities into classic economic models, explanations for leapfrog development, class segregation and jurisdictional fragmentation, among others, have been provided (Waltert and Schlapfer 2010). By introducing endogenous agricultural amenities into the classical monocentric model, Coisnon et al. (2014) provided a framework showing how urban development patterns depend on the density of surrounding farms and their ability to produce agricultural and natural amenities (Carruthers and Ulfarsson 2002; Carrion-Flores and Irwin 2004; MacDonald and Rudel 2005). These evidences demonstrate the role of urban sprawl shaping conflicts between the different actors competing for land (Shrestha et al. 2012). Finally, it was shown that, even in the absence of a particular landscape feature or exogenous sources of amenities, urban sprawl is a natural development pattern for a city surrounded by a spatially varying agricultural environment (Castle et al. 2011). In line with these findings, the present study contributes to the spatial analysis of sprawled urban expansion with implications for sustainable management of suburban land in metropolitan regions.

2 Methods

2.1 Study area

The investigated area covers the Athens' metropolitan district extending for 3000 km^2 (Fig. 1) within the administrative region of Attica (European Environment Agency 2010). The study area was administered by 115 municipalities (before the 2011 reform of local
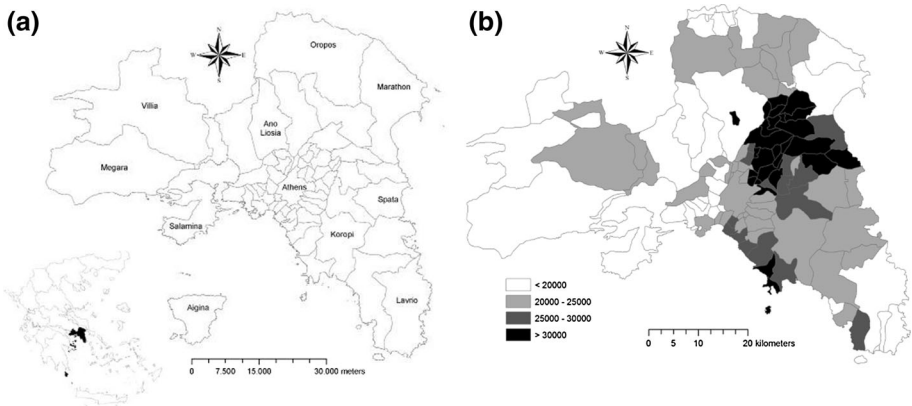
Fig. 1 Maps illustrating (**a**) the boundaries of municipalities and the location of relevant urban centers in the Athens' metropolitan region (*left*) and the position of Attica region in Greece (*insert*) and (**b**) the spatial distribution of average per capita declared income (*euros*) in Attica (*right*)

authorities) of which 58 formed the Athens' urban area (430 km^2). Attica consists of uplands bordering the flat area of Athens. Three plains with isolated hills (up to 300 m at sea level) are located in Attica (from west to east: Thriasio plain, Messoghia plain and Marathon plain) together with some islands among which Salamina is the most populated, with mixed dense and more dispersed settlements constituted mainly by second homes (Salvati et al. 2014).

Athens grew fast during the first postwar decades following the rural exodus; internal migration was progressively replaced by migration from developing countries since the 1980s. Birth rates declined since the 1990s following the same trend observed in other Mediterranean countries (Maloutas 2007). As a consequence of the stratification of demographic (aging) and social (immigration) processes, resident population in Attica was only 1.6 million people in 1951 rising to 3.3 million people in 1981 (with a density of nearly 1050 inhabitants/km^2) and adjusting to 3.8 million inhabitants in 2011 (1250 inhabitants/km^2). Exhibiting similar traits with other European Mediterranean cities in Spain and Italy, Athens' economic structure was based on both manufacturing and urbanization economies that triggered a slow process of industrialization (Leontidou 1990). The occupational structure reflects the weak influence of the city in the international arena and the dominant position within the Greek economic space. The local economy was influenced by the rapid urban expansion with the building sector achieving a prominent position and stimulating industrial growth in related sectors (Delladetsima 2006). The 2004 Olympic Games have played a crucial role in shaping sprawl at the regional scale (Salvati et al. 2013). Finally, forest fires—considered a factor of landscape degradation—were rather common in the study area throughout the investigated time period. The spatial distribution of fire was correlated in part with the expansion of urban settlements, especially of dispersed settlements and informal housing along the sea coast (Economidou 1993).

2.2 Land-use data

Figure 2 illustrates the methodology adopted in this study. The information used here was derived from two comparable maps scaled 1:25,000 and fully described in Salvati et al. (2014). Maps were produced from elaboration on two Landsat TM satellite images
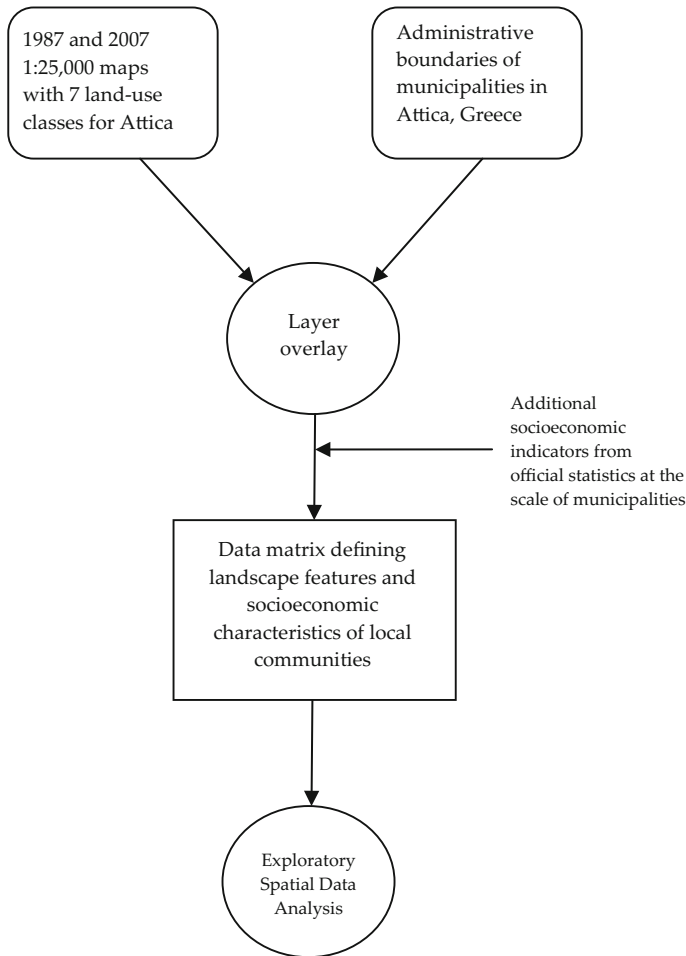
Fig. 2 Flowchart describing the procedure developed in this study

acquired in 1987 (dated August 13) and 2007 (dated August 20); satellite images were preprocessed for geometric and atmospheric correction (Gitas et al. 2004). We developed an object-based procedure organized in two steps: multi-resolution segmentation and final classification (Blaschke 2010). The first step includes the creation of objects grouping pixels with similar characteristics and properties (i.e., spectral and spatial information, topological relationships, texture features), resulting in two segmentation levels (Benz et al. 2004). The second step is based on fuzzy logic and the determination of the so-called membership functions for each class. During the classification of the first segmentation level, two main classes ('agricultural areas' and 'non-agricultural areas') were separated according to ancillary spatial information (Corine Land Cover 1990 and 2000 and the Land Parcel Identification System). The second segmentation level allowed for the classification of the remaining land-use classes, including built-up areas. Results' accuracy was estimated with field survey collected data and with the use of the LUCAS (Land Use/Cover Area Frame Statistical Survey) dataset. According to Salvati et al. (2014), user accuracy

was estimated to nearly 100 % for forests, 88 % for cropland, 73 % for artificial surfaces, 55 % for sparse vegetation and 40 % for shrublands.

The resulting land-use nomenclature was articulated into six classes: (1) forests (both coniferous and broadleaved), (2) shrublands, primarily dense high shrubs typical of Mediterranean dry landscape, (3) schlerophyllous vegetation, mainly macchia and garrigue vegetation, (4) areas with sparse vegetation, (5) cropland and (6) other uses of land, including burnt areas, bare land and water bodies. According to Economidou (1993), Chorianopoulos et al. (2010) and Salvati et al. (2013), this nomenclature system provides a comprehensive description of the basic uses of land in Athens' region allowing for a diachronic assessment of landscape structure. The coherence of the data derived from the land-use maps described above with independent cartographical sources was verified according to Salvati et al. (2014) using ancillary geo-databases including the 2006 Corine Land Cover map and the 2006 Urban Atlas map.

2.3 Spatial analysis

The statistical analysis was developed using patches as the elementary spatial unit. Non-urban patches bordering each built-up parcel were identified using ArcGIS (ESRI Inc., Redwoods, USA). A procedure based on 'zonal statistics,' 'spatial analyst' and other ArcGIS 'toolbox' commands was developed with the aim of determining the total perimeter of each built-up patch and the share of each surrounding non-urban land class in the total perimeter. For each built-up patch, the percentage in total perimeter was calculated for each non-urban land-use class described in Sect. 2.2. Diversity in the landscape surrounding each built-up parcel was assessed by computation on the proportion of each land-use class in the total patch perimeter (p_i) using the Shannon index (H') calculated as

$$H' = -\sum_{i=1}^{n} p_i \log p_i$$

Based on previous studies (Salvati et al. 2013, 2014), forests, shrubland and sclerophyllous vegetation were considered as homogeneously distributed over the study area and further aggregated into a unique class representing 'natural land.' Natural land has been regarded as a 'landscape amenity' possibly increasing the real estate value at the local scale due to the recognized esthetic, recreational and functional properties (Allen 2003; Carrion-Flores and Irwin 2004; Salvati and Sabbi 2011). Natural areas have been also regarded as a high-quality land class from the environmental point of view because of its recognized contribution to biodiversity conservation and ecosystem services (Radeloff et al. 2005). By contrast, areas with sparse vegetation have been considered a landscape dis-amenity due to the poor esthetic, recreational and functional properties (Economidou 1993; Alphan 2003; Aguilar 2008), and they were classified here as 'low quality' from the environmental point of view due to the association with poor (and often degraded) soils and more arid climate (Paul and Tonts 2005; Serra et al. 2008; Frondoni et al. 2011).

Five ancillary variables were finally calculated at the patch scale with the objective to assess the impact of the local context on the composition of landscape surrounding each urban parcel: (1) distance from the inner city of Athens, (2) elevation (a binary variable distinguishing lowland patches labeled with '0' from hilly and mountain patches labeled with '1', (3) patch size (logarithm), (4) perimeter-to-area ratio and (5) the percentage of sea coast bordering each patch. Distance from Athens was calculated by determining the

centroid of each patch and deriving the linear distance with a central place in the city (Plateia Syntagmatos).

2.4 Statistical analysis

We assessed similarities in the spatial distribution of the land-use classes bordering built-up patches using hierarchical clustering based on Euclidean distances and Ward's agglomeration rule. Differences in the regional landscape composition between 1987 and 2007 were checked using a Mann–Whitney U test computing on the cumulated percentages of class perimeter bordering each built-up parcel in the total patch perimeter for each of the six land-use classes.

Nonparametric, pair-wise Spearman tests were used to investigate the relationship between the share of each land-use class in total patch perimeter and the five territorial variables separately for 1987 and 2007. This analysis was aimed at identifying the possible interactions between the territorial context (e.g., topography, accessibility, urban gradient/human pressure) and landscape structure at the scale of municipalities. Pair-wise correlations were tested at $p < 0.05$ after Bonferroni's correction for multiple comparisons.

A principal component analysis (PCA) was run on the matrix composed of 11 indicators (five land-use classes and six variables resulting from the spatial analysis illustrated in Sect. 2.2), with the objective to identify factors influencing the composition of landscape around each built-up parcel separately for 1987 and 2007. To avoid multi-collinearity, 'natural land' and 'other uses of land' were considered as supplementary variables in the PCA. As the PCA was based on the correlation matrix, components with eigenvalue >1 have been analyzed for loading structure (Coppi and Bolasco 1988). The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy, which tests whether the partial correlations among variables are small, and Bartlett's test of sphericity, which tests whether the correlation matrix is an identity matrix, have been used to assess the quality of PCA outputs. These tests indicate whether the selected model is suited to analyze the original datasets (Salvati et al. 2013).

After standardization of the input variables, stepwise multiple regression models were carried out separately for three basic uses of land (natural land, sparse vegetation and cropland) using the percent share of class perimeter in the total perimeter of each built-up parcel as the dependent variable and six variables (patch size, perimeter-to-area ratio, elevation, distance from Athens, the percentage of sea coast in patch perimeter, Shannon diversity index, H′) as predictors (see Table 1 for details). A forward stepwise linear regression approach was used to identify and rank the most significant predictors associated with the spatial variation of each dependent variable using a F-to-enter p value of 0.01. Results of each regression model were presented using standardized coefficients and tests of significance (a F-statistic testing for the null hypothesis of nonsignificant model and a t-statistic testing for the null hypothesis of nonsignificant regression coefficient). Regression outputs were also used to rank the importance of the different predictors identified by the stepwise procedure.

Finally, the relationship between changes over time (1987–2007) in the percentage of the three basic uses of land mentioned above and the average per capita declared income was investigated at the scale of municipalities using pair-wise Spearman rank coefficients testing at $p < 0.05$ after Bonferroni's correction for multiple comparisons. The analysis was aimed at identifying the relationship between natural amenities and the socioeconomic structure as reflected in the average per capita declared income. Positive (or negative) changes in the share of natural land, sparse vegetation or cropland perimeter to the total

Table 1 Territorial and landscape attributes of the studied land patches used as ancillary variables in the statistical analysis

Variable	Measurement unit	Note
Patch size	Hectare	A proxy of landscape fragmentation
Perimeter-to-area ratio	m/m^2	A classical index of patch shape
Elevation	m	Calculated using a digital elevation model and averaging values for each patch
Sea coast	%	The perimeter of each patch bordering with the sea shore in the total perimeter
Distance from Athens	km	The linear distance of each patch centroid from a central place in Athens
Shannon diversity	H′	An index assessing the diversity of land-use classes in each patch perimeter

patch perimeter were determined aggregating data for each municipality of the study area. Each patch was assigned to a given municipality by overlap of the 1987 and 2007 land-use maps with a shapefile representing the municipal boundaries. Municipalities with only one land-use class covering homogeneously the whole surface area (e.g., built-up areas) at both years of study were removed from the analysis. Average per capita declared income for 2008 was derived at the municipal scale from Prodromidis (2014) after computation on elementary data (i.e., individual tax declarations) provided by the Greek Ministry of Economics and Finance. Income figures do not include an estimation of informal economy, which is a difficult task for Greece (Salvati and De Rosa 2015). Statistical analyses were performed using Statistica 5.0 package (STAT software Inc., Tulsa, Oklahoma, USA).

3 Results

3.1 Changes in the landscape surrounding built-up parcels (1987–2007)

Built-up areas in Athens grew by 1.8 % per year during the investigated time period with built-up parcels covering 13.8 % of the investigated land in 1987 and 18.8 % in 2007. The predominant land-use classes in Attica were cropland and sparse vegetation in both 1987 and 2007. Cropland was the most stable class covering 33 and 35 % of the study area, respectively, in 1987 and 2007, displaying the lowest rate of conversion (19 %) among non-urban uses of land. Sparsely vegetated areas decreased from 30 to 26 % between 1987 and 2007 with 34 % class area converted to other uses. Natural land showed the largest decrease in class area (from 24 to 22 % during the study period) and the highest percentage of class area transformed to other uses of land (41 %).

The number of built-up parcels increased from 1318 in 1987 to 1729 in 2007 (Table 2) with a moderate increase in the average size (from 31.6 in 1987 to 33 ha in 2007) and a slight increase in the perimeter-to-area ratio. The most accessible land has been developed with urban parcels increasing from 63.7 to 69.9 % of total patches between 1987 and 2007. However, the average distance of built-up patches from Athens increased moderately from 25.9 in 1987 to 26.5 km in 2007.

Statistics on the percent composition of land uses surrounding each built-up parcel are given in Table 2. On average, natural land bordering built-up parcels extends 8.1 and

Table 2 Selected indicators of built-up patches and percent composition of the surrounding uses of land (share in total patch perimeter) in Athens' metropolitan region, 1987 and 2007

Variable	1987	2007	Annual rate of change (%)[a]
Number of patches	1318	1729	1.6
Built-up area (%)	13.8	18.8	1.8
Perimeter-to-area ratio	0.60	0.63	0.3
Mean patch size (ha)	31.6	33.0	0.2
Distance from Athens (km)	25.9	26.5	0.1
Lowland (%)[b]	63.7	69.9	0.5
Sea coast (%)[b]	6.0	6.1	0.1
Forests (%)[b]	2.8	3.4	1.1
Shrubland (%)[b]	4.4	4.3	−0.2
Sclerophyllous vegetation (%)[b]	0.9	1.7	4.3
Natural land (%)[b]	8.1	9.4	1.5
Sparse vegetation (%)[b]	64.6	47.3	−1.3
Cropland (%)[b]	14.1	28.4	5.1
Other uses of land (%)[b]	7.1	8.8	1.2
Shannon diversity index (H′)	0.35	0.41	0.9

[a] Calculated as the absolute difference between the value observed at $t(1)$ and the value at $t(0)$ in turn divided by the value at $t(0)$ and multiplied by 100 and divided by the number of years forming the study period

[b] Share in total patch perimeter

9.4 % of patch perimeter, respectively, for 1987 and 2007. Among 'natural land' classes, shrubland was stable, while forests and sclerophyllous vegetation increased slightly. In 1987, sparse vegetation surrounded more than 64 % of the built-up parcels, declining to 47.3 % in 2007. At the same time, cropland bordering built-up parcels grew from 14.1 to 28.4 %. Other uses of land bordered 7.1 % of built-up parcels in 1987, rising slightly in 2007 (8.8 %). The percent composition of land-use classes around built-up parcels for 1987 was different from what was observed for 2007 (Kruskal–Wallis $H = 14.3$, $p < 0.05$, $n = 6$).

Hierarchical clustering explored similarities in the spatial distribution of land-use classes bordering built-up parcels. Natural land formed a homogeneous group in 1987 and cropland clustered together with urban areas and land bordering the sea (Fig. 2). Areas with sparse vegetation showed a different spatial distribution compared with what was observed for the other classes investigated. This result confirms the typical association between urban areas and sparse vegetation observed on Athens' fringe land until the late 1980s (Salvati et al. 2013). The spatial distribution of land uses surrounding built-up parcels in 2007 was relatively more homogeneous: natural land classes clustered together and sparsely vegetated areas were separated from the main cluster including mixed agricultural-natural uses of land.

3.2 The relationship between use of land and territorial variables

A nonparametric correlation analysis illustrated the main changes in the spatial relationship between selected territorial variables and the share of each land-use class surrounding

Table 3 Spearman rank correlations between land-use classes and territorial variables

Variable	Sea coast	Distance from Athens	Patch size	Perimeter-to-area ratio	Elevation
1987					
Forests			0.16	−0.16	0.15
Shrubland		0.18	0.16	−0.15	
Sclerophyllous			0.12	−0.11	0.11
Natural land		0.20	0.14	−0.13	0.08
Sparse vegetation	−0.44	−0.16	0.42	−0.44	0.14
Cropland		0.20	−0.20	0.22	−0.26
Other land uses	−0.24	−0.25			0.34
Shannon H′	0.27	0.14		0.08	
2007					
Forests			0.19	−0.19	0.12
Shrubland		0.08	0.25	−0.24	0.09
Sclerophyllous	−0.07		0.20	−0.20	0.21
Natural land		0.09	0.23	−0.22	0.18
Sparse vegetation	−0.28	−0.17	0.32	−0.32	0.20
Cropland	−0.09	0.15	−0.09	0.10	−0.35
Other land uses	−0.18	−0.18			0.32
Shannon H′	0.41	0.16			−0.10

Significant coefficients at $p < 0.05$ after Bonferroni's correction for multiple comparisons are reported

built-up parcels (Table 3). In 1987, the proportion of forest and sclerophyllous vegetation bordering built-up parcels increased with patch size and elevation and decreased with the perimeter-to-area ratio. Shrubland showed a similar spatial pattern, growing with the distance from the inner city of Athens but no longer displaying a significant correlation with elevation. Overall, natural areas were more abundant around built-up parcels at a larger distance from the central city. On average, urban parcels surrounded by natural land were larger and with a significantly lower perimeter-to-area ratio. The proportion of sparse vegetation in the total perimeter of built-up parcels was correlated with all the examined variables, although a decrease in the intensity of correlation was observed in some cases for 2007 with respect to 1987. The percentage of cropland bordering urban parcels increased, for both 1987 and 2007, with the distance from the inner city and the perimeter-to-area ratio. Diversity of landscapes surrounding urban parcels in Athens increased with the proximity to the sea coast and with the distance from Athens, highlighting the importance of disturbance factors shaping the spatial distribution of land use in peri-urban areas. Being positively correlated with the perimeter-to-area ratio in 1987, Shannon diversity decreased with elevation in 2007. These evidences indicate that a subtle process of landscape homogenization—driven by urban expansion and the abandonment of remote, rural land—altered the structure of hilly, peri-urban landscapes in recent decades.

3.3 A multivariate analysis

A principal component analysis (PCA) was carried out to identify the most relevant factors characterizing the landscape surrounding urban parcels in Athens. The PCA extracted four

Table 4 Variables' loading to the four principal components by year

Variable	1987				2007			
	PC 1	PC 2	PC 3	PC 4	PC 1	PC 2	PC 3	PC 4
Forests	−0.12	−0.47	0.37	−0.22	0.03	0.38	0.38	0.20
Shrubland	−0.26	−0.47	−0.08	−0.10	0.03	**0.51**	0.27	0.01
Sclerophyllous	−0.15	−0.35	0.39	**0.53**	0.10	0.32	0.26	0.38
Sparse vegetation	**0.91**	0.18	0.02	0.13	**0.72**	−0.11	**−0.57**	−0.06
Cropland	**−0.60**	0.05	−0.35	−0.44	−0.50	**−0.54**	**0.61**	−0.12
Shannon H′	−0.48	**−0.62**	−0.16	−0.01	**−0.57**	0.34	−0.48	−0.19
Sea coast	**−0.56**	0.30	−0.05	0.49	−0.11	**0.76**	0.04	−0.22
Distance	−0.31	−0.20	−0.20	**0.50**	−0.34	0.27	0.02	−0.39
Log (area)	**0.62**	−0.43	−0.39	0.12	**0.67**	0.02	0.29	−0.43
Perimeter-to-area ratio	−0.44	0.36	**0.60**	−0.08	−0.47	0.01	−0.25	**0.65**
Elevation	0.33	−0.39	**0.55**	−0.14	**0.59**	0.17	0.16	0.45
Other land uses[a]	0.08	−0.06	0.27	−0.15	0.18	0.12	−0.03	0.24
Natural land[a]	−0.30	**−0.72**	0.28	−0.01	0.08	**0.68**	0.50	0.28
Variance (%)	23.8	14.4	11.8	9.8	20.6	14.6	12.7	11.3

Bold indicates loadings >|0.5|

[a] Supplementary variables (see Sect. 2.4)

components with cumulated variance higher than 61 % for both 1987 and 2007 (Table 4). The Kaiser–Meyer–Olkin measure of sampling adequacy and Bartlett's test of sphericity (both $p < 0.001$) suggest that the multivariate model is suited to analyze our data. Component 1 for 1987 (24 % of the total variance) illustrated a patch size gradient separating sparsely vegetated areas (associated to large urban parcels) from cropland (bordering small urban parcels). Component 1 for 2007 (21 % of the total variance) represented the same patch size gradient associated positively with sparse vegetation and elevation and negatively with landscape diversity.

Component 2 for 1987 (14 % of the total variance) identified a natural land gradient positively associated with landscape diversity. Component 2 for 2007 (15 %) illustrated the same gradient which was associated positively with shrubland and proximity to the sea and negatively with cropland. Component 3 (12 % for 1987) represented the elevation gradient in turn associated with the ratio of patch perimeter to area. Component 3 (13 % for 2007) discriminated urban parcels bordered by sparse vegetation from parcels surrounded by cropland. Finally, component 4 (10 % for 1987) discriminated urban parcels surrounded by sclerophyllous vegetation from the remaining built-up parcels. Component 4 (11 % for 2007) discriminated urban patches based on high (or low) perimeter-to-area ratio.

3.4 Natural amenities and territorial variables

A stepwise regression analysis was carried out with the objective to identify the most relevant variables associated with three land-use classes (natural, cropland and sparse vegetation) surrounding built-up parcels in the two study years (Table 5). Spatial variability in the percentage of natural land surrounding urban parcels was explained by landscape diversity, distance from Athens, proximity to the sea coast, perimeter-to-area

Table 5 Results of stepwise multiple regression analysis with the percent share in the total patch perimeter by land-use class and year as dependent variable

Variable	1987		
	Beta	SE	$t(1312)$
Natural land: Adj-R^2 = 0.18, $F_{(5,1312)}$ = 60.5, $p < 0.0001$			
Shannon H′	0.37	0.03	14.4
Sea coast	−0.14	0.03	−5.3
Distance (Athens)	0.14	0.03	5.7
Perimeter-to-area ratio	0.11	0.03	4.3
Elevation	0.10	0.03	4.0
Sparse vegetation: Adj-R^2 = 0.52, $F_{(3,1314)}$ = 469.8, $p < 0.0001$			
Shannon H′	−0.46	0.02	−23.6
Patch size (log)	0.36	0.02	17.8
Sea coast	−0.29	0.02	−14.0
Cropland: Adj-R^2 = 0.21, $F_{(5,1312)}$ = 70.3, $p < 0.0001$			
Patch size (log)	−0.30	0.03	−11.6
Elevation	−0.28	0.03	−10.9
Shannon H′	0.24	0.03	9.4
Sea coast	−0.21	0.03	−7.7
Distance (Athens)	0.10	0.03	3.8
Variable	2007		
	Beta	SE	$t(1722)$
Natural land: Adj-R^2 = 0.17, $F_{(5,1722)}$ = 73.4, $p < 0.0001$			
Shannon H′	0.34	0.02	15.0
Elevation	0.21	0.02	9.1
Sea coast	−0.16	0.02	−6.4
Distance (Athens)	0.09	0.02	4.1
Perimeter-to-area ratio	0.07	0.02	3.3
Sparse vegetation: Adj-R^2 = 0.15, $F_{(4,1723)}$ = 77.2, $p < 0.0001$			
Patch size (log)	0.25	0.02	10.4
Sea coast	−0.14	0.03	−5.5
Shannon H′	−0.13	0.02	−5.6
Elevation	0.08	0.02	3.6
Cropland: Adj-R^2 = 0.23, $F_{(5,1722)}$ = 102.7, $p < 0.0001$			
Elevation	−0.38	0.02	−16.8
Sea coast	−0.31	0.02	−12.9
Shannon H′	−0.18	0.02	−8.3
Patch size (log)	−0.11	0.02	−4.8
Distance (Athens)	0.09	0.02	4.2

t indicates a Student's t-statistic with the related degrees of freedom reported in brackets; all Student's t-statistics are significant at $p < 0.001$

ratio and elevation (adjusted R^2 = 0.18 for 1987 and 0.17 for 2007). Territorial variables explained the spatial variation in the percentage of sparse vegetation surrounding urban parcels better in 1987 (adjusted R^2 = 0.52) than in 2007 (adjusted R^2 = 0.15). Landscape diversity, patch size and proximity to the sea coast were the most significant predictors of the percentage of sparse vegetation in the total patch perimeter for 1987. Patch size, proximity to the sea coast, landscape diversity and elevation were identified as the most

relevant predictors for 2007. The spatial variability in the percentage of cropland surrounding built-up parcels was correlated with patch size, elevation, landscape diversity, proximity to the sea coast and distance from Athens (adjusted $R^2 = 0.21$ and 0.23, respectively, for 1987 and 2007). Predictors of this model changed moderately for 2007: elevation and proximity to the sea coast became the most relevant variables shaping the proportion of sparse vegetation around urban parcels.

Based on the analysis described in Sect. 2.4, changes over time in the composition of the landscape surrounding each built-up parcel were calculated at the municipal scale in the Athens' metropolitan region and then correlated with the average per capita declared income observed in each municipality of the study area (Fig. 3). The proportion of natural land surrounding built-up parcels increased significantly in municipalities with higher per capita declared income ($r_s = 0.70$, $p < 0.01$), and the reverse pattern was found for sparse vegetation ($r_s = -0.53$, $p < 0.05$). A nonsignificant relationship was found for cropland ($r_s = 0.09$, $p > 0.05$) (Fig. 4).

4 Discussion

The present study introduces an original analysis investigating changes in the use of fringe land in a compact region undergoing dispersed urban growth in recent decades. The proposed methodology assesses the evolution of land use in the immediate surroundings of
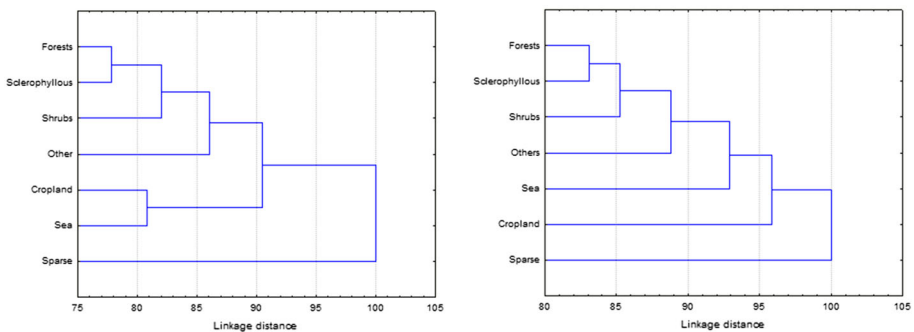
Fig. 3 Hierarchical clustering of the spatial distribution of the land-use classes surrounding built-up parcels in the Athens' metropolitan region (*left* 1987; *right* 2007)
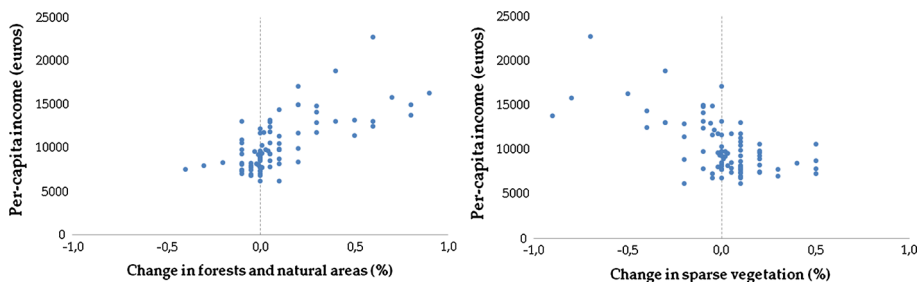
Fig. 4 Relationship between changes over time (1987–2007) in selected land-use classes and average per capita declared income at the municipal scale in Athens' metropolitan region

built-up areas as a contribution to the analysis of urbanization-driven land consumption and urban sprawl. The approach proposed in this article provides a simplified and flexible methodology to identify landscape and territorial factors associated with urban expansion and changes in the use of fringe land. Our study has also examined the importance of natural amenities as a determinant of sprawl. The use of two elementary spatial units (i.e., land patches and municipalities) supports a comprehensive analysis of landscape structure allowing for the effective integration of territorial and socioeconomic variables. Evidence derived at these spatial levels is relevant from both the positive and normative points of view, informing planning decisions and contributing to ecological studies and social disciplines at the same time.

Athens' growth was characterized by the expansion of scattered residential settlements, ribbon sprawl and leapfrog development of services and industrial activities (Grekousis et al. 2013). This development pattern was observed in other southern European cities hosting mega-events and attracting population from depressed rural areas (Richardson and Chang-Hee 2004; Couch et al. 2007; Longhi and Musolesi 2007; Turok and Mykhnenko 2007). Urban expansion in the study area determined the consumption of high-quality natural land (mainly forests and shrubland) and a progressive fragmentation of cropland (Mallinis et al. 2014). This confirms a previous definition of suburban areas as 'laboratories of land-use changes' (Salvati et al. 2014) suggested by the increasing anthropogenic pressure on relict natural ecosystems. Based on these premises, the increasingly mixed use of land—a specific characteristic of fringe areas under intense speculative pressures (Frenkel 2004)—has been interpreted as a factor influencing the structure of landscapes around urban settlements. For example, fallow land arose significantly from 1971 to 2000 in the study area (from 300 to 360 km^2) confirming the progressive increase in land 'waiting for urbanization' (Salvati et al. 2013). Real estate speculation was an important driver of urban change and exurban development in Athens (Chorianopoulos et al. 2010).

The emergence of a mixed (urban–rural) landscape around newly expanding suburban areas in Athens confirms evidence provided by European Environment Agency (2006) for southern European cities. Factors influencing the composition of landscape surrounding urban parcels are also mixed and incorporate the effect of distance from the inner city, elevation, patch size and shape. The socio-environmental impact of urban expansion determined increased disparities in the distribution of natural amenities around settlements discriminating poor from rich communities (Cho et al. 2011).

During compact growth, a higher proportion of natural land surrounding urban settlements was associated with larger built-up parcels, while cropland increased at lower elevation and sparse vegetation dominated the landscape around fringe settlements closer to the inner city. The role of factors such as the distance from the inner city in shaping the structure of suburban landscapes declined moderately and the reverse pattern was observed for the size of built-up parcels. This evidence may confirm the progressive decline of the monocentric spatial organization typically observed in Athens up to the late 1980s (Salvati et al. 2014).

Despite the (supposed) homogeneity in urban dynamics and land-use transformations observed in southern European cities (Salvati and Gargiulo Morelli 2014), the results of the present study indicate that trends in the spatial relationship between the different land-use classes in Athens are rather similar to what was observed in other European urban regions (Paul and Tonts 2005; Chorianopoulos et al. 2010; Salvati 2015), suggesting that socioeconomic contexts, processes and spatial determinants of urban change across countries are more similar than what was expected from a preliminary analysis (Dahlman 2006; Kasanko et al. 2006; Longhi and Musolesi 2007; Catalàn et al. 2004; Serra et al.

2008). At the same time, our results corroborate evidence from the European Environment Agency (2006) identifying population density and growth, compact settlements and infrastructure development as the most relevant variables influencing the spatial distribution of natural land (Allen 2003; Antrop 2004; Christopoulou et al. 2007; Schneider and Woodcock 2008).

5 Conclusions

The newly emerging forms of dispersed urbanization require original approaches to the analysis of land-use relationships pointing out the relevance of a permanent assessment of landscape transformations supporting policies for urban sustainability (Laidley 2015). Spatial analysis provides a base for planning strategies containing the expansion of urban settlements into high-quality landscapes. Our study demonstrates that how urban sprawl in Athens—and possibly in other Mediterranean cities—impacts jointly environmental quality and social structures, contributing to the polarized distribution of natural amenities around residential settlements. Comparative investigation is required to ascertain the socio-environmental implications of high- and low-density urban expansion patterns in socially divided and ecologically fragile European regions, with the final objective to identify a land-saving and socially sustainable model of urban growth.

References

Aguilar, A. G. (2008). Peri-urbanization, illegal settlements and environmental impact in Mexico City. *Cities, 25*, 133–145.

Allen, A. (2003). Environmental planning and management of the peri-urban interface: Perspectives on an emerging field. *Environment and Urbanization, 15*(1), 135–147.

Alphan, H. (2003). Land use change and urbanisation of Adana, Turkey. *Land Degradation and Development, 14*, 575–586.

Antrop, M. (2004). Landscape change and the urbanization process in Europe. *Landscape and Urban Planning, 67*, 9–26.

Arribas-Bel, D., Nijkamp, P., & Scholten, H. (2011). Multidimensional urban sprawl in Europe: A self-organizing map approach. *Computers, Environment and Urban Systems, 35*(4), 263–275.

Benz, U. C., Hofmann, P., Willhauck, G., Lingenfelder, I., & Heynen, M. (2004). Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. *ISPRS Journal of Photogrammetry, 58*, 239–258.

Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Quantifying the degree-of-freedom, degree-of-sprawl, and degree-of-goodness of urban growth from remote sensing data. *Applied Geography, 30*(1), 96–111.

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry, 65*, 2–16.

Bruegmann, R. (2005). *Sprawl: A compact history* (p. 301). Chicago: University of Chicago Press.

Bryant, C. R. (1995). The role of local actors in transforming the urban fringe. *Journal of Rural Studies, 11*(3), 255–267.

Carrion-Flores, C., & Irwin, E. G. (2004). Determinants of residential land-use conversion and sprawl at the rural-urban fringe. *American Journal of Agricultural Economics, 86*(4), 889–904.

Carruthers, J. I., & Ulfarsson, G. F. (2002). Fragmentation and sprawl: Evidence from interregional analysis. *Growth and Change, 33*(3), 312–340.

Castle, E., Wu, J., & Weber, B. (2011). Rural-urban economic spatial relations: A different perspective. *Applied Economic Perspectives and Policy, 33*, 1–26.

Catalàn, B., Sauri, D., & Serra, P. (2004). Urban sprawl in the Mediterranean? Patterns of growth and change in the Barcelona Metropolitan Region 1993–2000. *Landscape and Urban Planning, 85*, 174–184.

Cavailhès, J., Frankhauser, P., Peeters, D., & Thomas, I. (2004). Where Alonso meets Sierpinski: An urban economic model of a fractal metropolitan area. *Environment and Planning A, 36*(8), 1471–1498.

Cho, S. H., Kim, S. G., & Roberts, R. K. (2011). Values of environmental landscape amenities during the 2000–2006 real estate boom and subsequent 2008 recession. *Journal of Environmental Planning and Management, 54*(1), 71–91.

Chorianopoulos, I., Pagonis, T., Koukoulas, S., & Drymoniti, S. (2010). Planning, competitiveness and sprawl in the Mediterranean city: The case of Athens. *Cities, 27*, 249–259.

Christopoulou, O., Polyzos, S., & Minetos, D. (2007). Peri-urban and urban forests in Greece: Obstacle or advantage to urban development? *Journal of Environmental Management, 18*, 382–395.

Coisnon, T., Oueslati, W., & Salanié, J. (2014). Urban sprawl occurrence under spatially varying agricultural amenities. *Regional Science and Urban Economics, 44*, 38–49.

Coppi, R., & Bolasco, S. (1988). *Multiway data analysis*. Amsterdam: Elsevier.

Couch, C., Petschel-held, G., & Leontidou, L. (2007). *Urban sprawl in Europe: Landscapes, land-use change and policy* (p. 252). Hoboken: Blackwell.

Dahlman, C. (2006). Detour to Europe: Enlargement, Southeast Europe, and the EU's external dynamic. *Eurasian Geography and Economics, 47*(6), 683–697.

Delladetsima, P. M. (2006). The emerging property development pattern in Greece and its impact on spatial development. *European Urban and Regional Studies, 13*, 245–278.

Economidou, E. (1993). The Attic landscape throughout the centuries and its human degradation. *Landscape and Urban Planning, 24*, 33–37.

European Environment Agency (2006). Urban sprawl in Europe—The ignored challenge. Copenhagen: EEA Report no. 10.

European Environment Agency (2010). Mapping guide for a European urban atlas. Copenhagen.

Feranec, J., Jaffrain, G., Soukup, T., & Hazeu, G. (2010). Determining changes and flows in European landscapes 1990–2000 using CORINE land cover data. *Applied Geography, 30*, 19–35.

Ferrara, A., Salvati, L., Sabbi, A., & Colantoni, A. (2014). Urbanization, soil quality and rural areas: Towards a spatial mismatch? *Science of the Total Environment, 478*, 116–122.

Frenkel, A. (2004). The potential effect of national growth-management policy on urban sprawl and the depletion of open spaces and farmland. *Land Use Policy, 21*(4), 357–369.

Frondoni, R., Mollo, B., & Capotorti, G. (2011). A landscape analysis of land cover change in the Municipality of Rome (Italy): Spatio-temporal characteristics and ecological implications of land cover transitions from 1954 to 2001. *Landscape and Urban Planning, 100*, 117–128.

Gitas, I. Z., Mitri, G. H., & Ventura, G. (2004). Object-based classification for burned area mapping of Creus Cape, Spain, using NOAA-AVHRR imagery. *Remote Sensing of Environment, 92*(3), 409–413.

Grekousis, G., Manetos, P., & Photis, Y. N. (2013). Modeling urban evolution using neural networks, fuzzy logic and GIS: The case of the Athens metropolitan area. *Cities, 30*, 193–203.

Irwin, E. G., & Bockstael, N. E. (2004). Land use externalities, open space preservation, and urban sprawl. *Regional Science and Urban Economics, 34*(6), 705–725.

Kasanko, M., Barredo, J. I., Lavalle, C., McCormick, N., Demicheli, L., Sagris, V., et al. (2006). Are European cities becoming dispersed? A comparative analysis of Fifteen European urban areas. *Landscape and Urban Planning, 77*, 111–130.

Laidley, T. (2015). Measuring sprawl. A new index, recent trends, and future research. *Urban Affairs Review,*. doi:10.1177/1078087414568812.

Le Goix, R. (2005). Gated communities: Sprawl and social segregation in Southern California. *Housing Studies, 20*(2), 323–343.

Leontidou, L. (1990). *The Mediterranean city in transition*. Cambridge: Cambridge University Press.

Lichtenberg, E., & Hardie, I. (2007). Open space, forest conservation, and urban sprawl in Maryland suburban subdivisions. *American Journal of Agricultural Economics, 89*(5), 1198–1204.

Longhi, C., & Musolesi, A. (2007). European cities in the process of economic integration: Towards structural convergence. *Annals of Regional Science, 41*, 333–351.

MacDonald, K., & Rudel, T. K. (2005). Sprawl and forest cover: What is the relationship? *Applied Geography, 25*(1), 67–79.

Mallinis, G., Koutsias, N., & Arianoutsou, M. (2014). Monitoring land use/land cover transformations from 1945 to 2007 in two peri-urban mountainous areas of Athens metropolitan area, Greece. *Science of the Total Environment, 490*, 262–278.

Maloutas, T. (2007). Socio-economic classification models and contextual difference: The "European socio-economic classes" (ESeC) from a South European angle. *South European Society and Politics, 12*, 443–460.

Munafò, M., Norero, C., Sabbi, A., & Salvati, L. (2010). Urban soil consumption in the growing city: A survey in Rome. *Scottish Geographical Journal, 126*(3), 153–161.

Nechyba, T. J., & Walsh, R. P. (2004). Urban sprawl. *Journal of Economic Perspectives, 18*(4), 177–200.

Paul, V., & Tonts, M. (2005). Containing urban sprawl: Trends in land use and spatial planning in the metropolitan region of Barcelona. *Journal of Environmental Planning and Management, 48*, 7–35.

Prodromidis, P. (2014). *The evolution of personal incomes across Greece: 2001–2008.* Athens: Stamoulis.

Radeloff, V. C., Hammer, R. B., & Stewart, S. I. (2005). Rural and suburban sprawl in the US Midwest from 1940 to 2000 and its relation to forest fragmentation. *Conservation Biology, 19*(3), 793–805.

Richardson, H. W., & Chang-Hee, C. B. (2004). *Urban sprawl in Western Europe and the United States.* Aldershot: Ashgate.

Salvati, L. (2015). Agro-forest landscape and the 'Fringe' city: A multivariate assessment of land-use changes in a Sprawling region and implications for planning. *Science of the Total Environment, 490*, 715–723.

Salvati, L., & De Rosa, S. (2015). Economic structure and the spatial distribution of declared income in a Mediterranean city: Persisting disparities in a 'locked' social context? *Current Politics and Economics of Europe, 25*(1), 3–11.

Salvati, L., & Gargiulo, Morelli V. (2014). Unveiling urban sprawl in the Mediterranean region: Towards a latent urban transformation? *International Journal of Urban and Regional Research, 38*(6), 1935–1953.

Salvati, L., & Sabbi, A. (2011). Exploring long-term land cover changes in an urban region of southern Europe. *International Journal of Sustainable Development and World Ecology, 18*(4), 273–282.

Salvati, L., Sateriano, A., & Bajocco, S. (2013). To grow or to sprawl? Evolving land cover relationships in a compact Mediterranean city region. *Cities, 30*, 113–121.

Salvati, L., Ranalli, F., & Gitas, I. (2014). Landscape fragmentation and the agro-forest ecosystem along the urban gradient: An exploratory study. *International Journal of Sustainable Development and World Ecology, 21*(2), 160–167.

Schneider, A., & Woodcock, C. E. (2008). Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. *Urban Studies, 45*, 659–692.

Serra, P., Pons, X., & Saurí, D. (2008). Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography, 28*(3), 189–209.

Shrestha, M. K., York, A. M., Boone, C. G., & Zhang, S. (2012). Land fragmentation due to rapid urbanization in the Phoenix Metropolitan Area: Analyzing the spatiotemporal patterns and drivers. *Applied Geography, 32*, 522–531.

Terzi, F., & Kaya, H. S. (2011). Dynamic spatial analysis of urban sprawl through fractal geometry: The case of Istanbul. *Environment and Planning B: Planning and Design, 38*(1), 175–190.

Turok, I., & Mykhnenko, V. (2007). The trajectories of European cities, 1960–2005. *Cities, 24*, 165–182.

Walsh, R. (2007). Endogenous open space amenities in a locational equilibrium. *Journal of urban Economics, 61*(2), 319–344.

Waltert, F., & Schläpfer, F. (2010). Landscape amenities and local development: A review of migration, regional economic and hedonic pricing studies. *Ecological Economics, 70*(2), 141–152.

Wang, C., & Wu, J. (2011). Locational amenities, increasing returns, and urban development. *Journal of Economic Geography, 11*(4), 687–707.

Wu, J. (2001). Environmental amenities and the spatial pattern of urban sprawl. *American Journal of Agricultural Economics, 83*, 691–697.

Wu, J. (2006). Environmental amenities, urban sprawl, and community characteristics. *Journal of Environmental Economics and Management, 52*(2), 527–547.

Wu, J. (2010). Economic fundamentals and urban-suburban disparities. *Journal of Regional Science, 50*, 570–591.