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Resilient landscapes in Mediterranean urban areas: Understanding factors influencing forest trends

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A R T I C L E I N F O

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A B S T R A C T

Urban and peri-urban forests are recognized as basic elements for Nature-Based Solutions (NBS), as they preserve and may increase environmental quality in urbanized contexts. For this reason, the amount of forest land per inhabitant is a pivotal efficiency indicator to be considered in the sustainable governance, land management, planning and design of metropolitan areas. The present study illustrates a multivariate analysis of per-capita forest area (PFA) in mainland Attica, the urban region surrounding Athens, Greece. Attica is considered a typical case of Mediterranean urbanization where planning has not regulated urban expansion and successive waves of spontaneous growth have occurred over time. In such a context, an analysis of factors that can affect landscape changes in terms of PFA may inform effective strategies for the sustainable management of socio-ecological local systems in light of the NBS perspective. A total of 26 indicators were collected per decade at the municipal scale in the study area with the aim to identify the factors most closely associated to the amount of PFA. Indicators of urban morphology and functions have been considered together with environmental and topographical variables. In Attica, PFA showed a progressive decrease between 1960 and 2010. In particular, PFA progressively declined (1980, 1990) along fringe areas surrounding Athens and in peri-urban districts experiencing dispersed expansion of residential settlements. Distance from core cities and from the seacoast, typical urban functions (e.g., multiple use of buildings and per capita built-up area) and percentage of agricultural land-use in each municipality are the variables most associated with high PFA. In recent years, some municipalities have shown an expansion of forest cover, mainly due to land abandonment and forest recolonization. Findings from this case study have allowed us to identify priorities for NBS at metropolitan level aimed at promoting more sustainable urbanization. Distinctively, proposed NBS basically focus on (i) the effective protection of crop mosaics with relict woodlots; (ii) the improvement of functionality, quality and accessibility of new forests; and (iii) the establishment of new forests in rural municipalities.

1. Introduction

Urban and peri-urban forests are widely recognized as basic elements for Nature-Based Solutions (NBS) due to their leading role in increasing the environmental quality in urban and peri-urban contexts. Multifunctionality is one of the main characteristics of urban forests (Konijnendijk et al., 2006), which provide ecosystem services including the regulation of infiltration and storm water runoff, mitigation of the microclimate, reduction of the heat island effect and air pollution (De Groot et al., 2010; Dobbs et al., 2014; Mariani et al., 2016). Urban and peri-urban forests also contribute to improve well-being perception by urban dwellers or tourists and restore cognitive resources (e.g., Lafortezza et al., 2009; Salvati et al., 2014; Carrus et al., 2015; Tomao et al., 2016). For these reasons, the amount of forest land per inhabitant is a pivotal efficiency indicator to be considered in the sustainable governance, land management, planning and design of metropolitan areas.

Despite the recognized positive role of forests in metropolitan

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contexts, a reduction in their functionality has been observed in most urban regions (Zipperer et al., 2012; Chas-Amil et al., 2013; Salvati et al., 2016a). In this regard, peri-urban forests are particularly vulnerable to human disturbance because residential and commercial settlements develop close to natural or semi-natural landscapes, creating a wildland–urban interface (WUI). WUIs are usually located in peri-urban areas where urban settlement borders intermingle with natural and semi-natural areas including forests and crop mosaics (Antrop, 2004; Elia et al., 2014). For these reasons, the WUI can be regarded as a conflict zone due to human activities interacting with natural processes that generate both positive and negative feedback (Radeloff et al., 2005; Elia et al., 2015, 2016; Lafortezza et al., 2015). On the one hand, urban expansion is an important factor responsible for irreversible landscape changes in WUIs. It has a number of adverse implications including, for example, depopulation of rural areas (Recanatesi et al., 2016), unsustainable use of land (Salvati et al., 2013) and loss of Ecosystem Services (ES) (Sallustio et al., 2015). Furthermore, both wildfires (Chas-Amil et al., 2013; Biasi et al., 2015) and deforestation can contribute to reducing forest cover in peri-urban areas. On the other hand, urban areas have frequently experienced forest expansion mainly resulting from the spontaneous colonization of abandoned pastures or arable land (e.g., Barbati et al., 2013). In such a context, understanding the factors that may positively or negatively influence changes in Per-capita Forest Area (PFA) is valuable to propose effective NBS for the sustainable management of local socio-ecological systems (*sensu* Folke, 2006).

The socio-ecological status of a region can be assessed through many types of indicators: per-capita forest area is one of those most exploited, since it is positively correlated with the system's health status (e.g., Kapur, 2002; Li and Pan, 2012). Although several indicators describing the impact of urbanization on land resources were proposed (Hasse and Lathrop, 2003; Salvati, 2015; Colantoni et al., 2016), only a few studies have analyzed the complex interactions between ecological processes and socioeconomic changes in peri-urban forest landscapes (e.g., Catalán et al., 2008; Barbati et al., 2013; Colantoni et al., 2015; Ferrara et al., 2017).

Bearing these considerations in mind, the present study proposes an analysis of PFA as an efficient indicator for sustainable governance and land management between 1960 and 2010 in a southern European region (mainland Attica, Greece). Mainland Attica can be considered a typical case of Mediterranean urbanization, where suburbanization-driven settlement scattering and polycentric development have altered the typical mono-centric spatial organization of metropolitan regions. Moreover, in Attica both wildfires (755 km^2 were burned between 1983 and 2005, http://oikoskopio.gr/pyroskopio/en/) and deforestation have significantly reduced forest cover over time (Salvati and Ranalli, 2015). In our explorative analysis morphological, topographical and environmental indicators have been considered with the aim to identify factors associated with PFA at the local scale focusing on trends in forest cover over time. Findings from this case study allowed the identification of priorities for NBS at metropolitan level for promoting sustainable urbanization in Mediterranean environments.

2. Methodology

2.1. Study area

The metropolitan region of Athens covers approximately 3000 km^2 (Fig. 1). It is administered by 114 municipal authorities, 56 of which are rural municipalities while 58 belong to the Athens-Piraeus urban connurbation. The landform consists mainly of highlands and mountains. Lowlands are concentrated mostly in the central part of the urban area of Athens. The climate regime is Mediterranean and dry: the mean annual temperature is approximately 18 °C, and the average rainfall usually ranges between 400 and 500 mm. The area is densely populated (4400 inhabitants/km^2). From 1951 to 2011, population density has increased by about 2900 inhabitants/km^2 with the gradual establishment of new urban poles outside the boundaries of the consolidated city. After World War II, the two main centers of Athens and Piraeus have developed as principal urban poles due to their socioeconomic functions (services and industry, respectively). Since the early 1990s, the metropolitan area of Athens has experienced a process of urban de-concentration and expansion owing to discontinuous fringe settlements (Chorianopoulos et al., 2010). Two new urban cores were developed: Messoghia (centered in the municipality of Markopoulo), which is considered the largest sprawling area in Attica (Chorianopoulos et al., 2014), and Maroussi, where soil sealing has been driven primarily by the 2004 Olympic games (Couch et al., 2007; Chorianopoulos et al., 2010).

2.2. Assessing per-capita forest area

The analysis covers the time period between 1960 and 2010. PFA has been calculated as the ratio between forest area and resident population for each municipality of the study area every 10 years. Estimates of the resident population for each decade from 1961 to 2011 were obtained from the National Census of Population data provided by the National Statistical Service of Greece (NSSG, 2011, now ELSTAT; http://www.statistics.gr/en/home/). The source of forest cover data is the national census of land-use (from 1960 to 2000) and the Urban Atlas (UA) map referring to 2010 (EEA, 2010). The accuracy of the data collected was evaluated according to Salvati et al. (2013). To assess the reliability of the forest land cover measured for each reference year, additional independent data were used: (i) a soil map provided by the Institute of Geology and Soil Chemistry (Athens) for 1948, (ii) LaCoast (LC) land-use maps of European coastal regions for 1975 (Perdigao and Christensen, 2000), (iii) Corine Land Cover (CLC) maps referring to 1990 and 2000 (EEA, 2006), (iv) the GlobCorine map for 2009 (Salvati, 2014), and (v) statistical data on agricultural land cover at municipal scale for each decade from 1961 to 2009 derived from the Greek National Census of Agriculture.

2.3. Morphological, environmental and topographical indicators

A total of 26 indicators concerning population dynamics, urban morphology, economic activities and topography were selected and derived at the municipal scale from official statistics (Table 1). Values of all basic variables cover the time period analyzed herein. Average elevation, proximity to the seacoast, municipal area and distance to four distinct urban centers (Markopoulo, Messoghia, Maroussi, Athens and Piraeus) were used as topographic and territorial variables (calculated individually) to describe the landscape and urban structure. Topographic variables were measured using ArcGIS software (ESRI Inc., Redwoods, USA). Two indicators of soil quality (EEA, 2009; Ferrara et al., 2014) and climate quality (Bakr et al., 2012) were included in the final stage of the analysis.

2.4. Exploratory data analysis

Data of all the 114 investigated municipalities were used to calculate descriptive statistics for each assessed variable and for each studied time point, including arithmetic and geometric means, median, ratio of median to mean and coefficient of variation. Municipalities were classified into five different categories describing trends of PFA according to the following criteria based on the change of PFA values observed in each decade between 1960 and 2010: "-" = linear and negative; "+" = linear and positive; "=" = no change; "U" = square and U-shaped; "inv-U" = bell-shaped trend; "?" = non-linear, non-square trend. A hierarchical cluster analysis (Ward's method) was also performed using PAST software (Hammer, 2013) to group all variables considered in this study according to their similarity level in terms of multidimensional distance at each year considered. This analysis

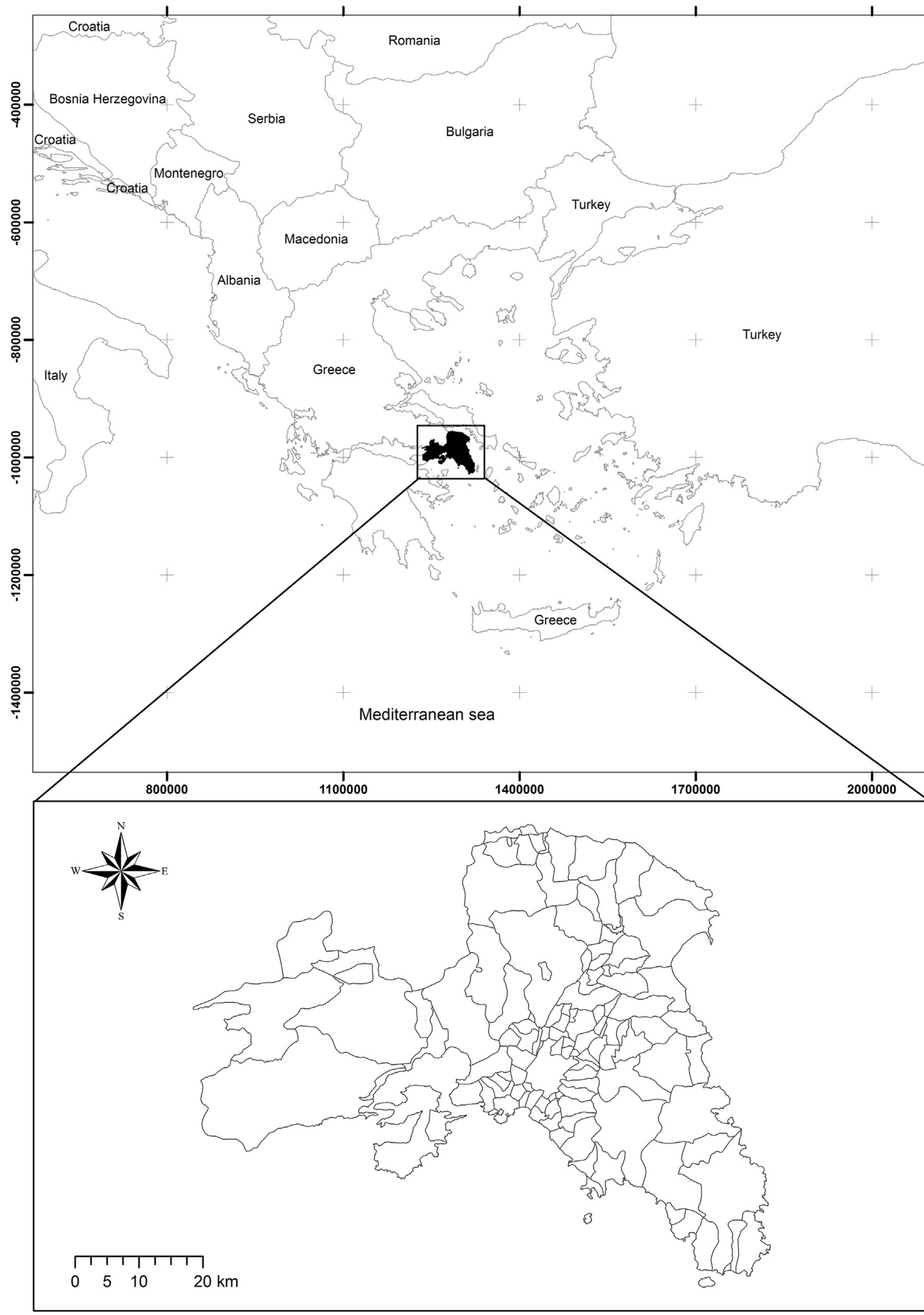

Fig. 1. Maps of Athens' metropolitan region (mainland Attica) showing the administrative municipal boundaries. The coordinate system is Lambert Azimuthal Equal Area (ETRS89-LAEA).

enabled us to understand latent patterns of spatial variability in select indicators over time.

The 26 indicators and PFA were used as independent and dependent variables, respectively, to perform a forward step-wise multiple regression model (n =114) for each of the 6 decades. This analysis allowed us to identify changes in the most relevant factors associated with PFA over time. The relevance of each indicator in spatial patterns of PFA was also evaluated. All variables were standardized prior to

Table 1
List of indicators considered in the study.

Acronym	Variable	Unit of measure	Source	Time interval
Dependent variable				
PFA	Per-capita forest area	m^2	Census of land uses	1960–2010
Population variables				
d	Population density	inhabitants/km^2	Census of population	1951–2011
g	Annual population growth rate	%	Census of population	1961–2011
s	Sparse population	% on total population	Census of population	1961–2011
Landscape variables				
Area	Municipal surface area	km^2	Territorial statistics	1960–2010
a	Agricultural area	% on total municipal area	Census of land-uses	1960–2010
p	Protected land (dummy per municipality)	Dummy (0: non-protected; 1: protected)	Territorial statistics	1960–2010
Urban morphology and function variables				
Urb	Per-capita built-up area	m^2	Census of land-uses	1960–2010
b	Inhabitants per building	Number of inhabitants	Census of buildings	1960–2010
h	Average building height	Number of floors	Census of buildings	1960–2010
c	Self-contained buildings	% on total buildings	Census of buildings	1960–2010
n	One-dwelling buildings	% on total buildings	Census of buildings	1960–2010
u	Diversity in urban land use	N° of building uses on the municipal area	Census of buildings	1960–2010
r	Residential buildings	% on total buildings	Census of buildings	1960–2010
i	Industrial buildings	% on total buildings	Census of buildings	1960–2010
t	Hotel-use buildings	% on total buildings	Census of buildings	1960–2010
e	Service/commerce buildings	% on total buildings	Census of buildings	1960–2010
m	Multiple usage buildings	% on total buildings	Census of buildings	1960–2010
o	Urban masterplan enforced in law	Dummy (0: no; 1: yes)	Territorial statistics	1960–2010
Topographical variables				
Ele	Mean elevation	m	Census of population	Once per time
Sea	Proximity to the seacoast	Dummy (0: internal; 1: coastal)	Territorial statistics	Once per time
dAt	Distance from Athens	km	Territorial statistics	Once per time
dPi	Distance from Piraeus	km	Territorial statistics	Once per time
dMa	Distance from Maroussi	km	Territorial statistics	Once per time
dMak	Distance from Markopoulo M.	km	Territorial statistics	Once per time
Environmental variables				
Cqi	Climate quality index	0–1	Territorial statistics	Once per time
Sqi	Soil quality index	0–1	Territorial statistics	Once per time

regression analysis. Significant predictors were selected on the basis of F-to-remove and F-to-enter thresholds equal to 3 and 1.5, respectively. Adjusted R^2 was calculated for each regression model to assess overall goodness-of-fit. Moreover, the Fisher-Snedecor F test with $p < 0.01$ was performed to verify significance against the null hypothesis of a non-significant model. A Durbin-Watson statistic was performed separately on the residuals from the six least squares regressions. Auto-correlation was considered negligible for Durbin-Watson test values between 1.5 and 2.5.

3. Results

3.1. Descriptive statistics

Table 2 reports descriptive statistics showing a change of PFA in Attica for the investigated time period. Statistics were computed using municipalities as the basic spatial domain. All statistics indicated a progressive decrease in PFA in the decades investigated. The arithmetic mean of PFA at the municipal scale was 10-fold lower in 2000 compared to 1960, stabilizing in the 2000–2010 decade. The median value of PFA decreased by 322 m^2 in the study period (1960–2010), reaching the lowest value (1 m^2 per inhabitant) in 2000. A slight increase was observed between 2000 and 2010. The statistical distribution of PFA progressively deviated from normality, as shown by the increase in skewness and kurtosis over time. Similarly, the coefficient of variation also increased. These results show a progressive polarization between municipalities with high and low per-capita forest area.

Table 2
Descriptive statistics of per-capita forest area (m^2) in mainland Attica by year.

Statistic	1960	1970	1980	1990	2000	2010
Arithmetic mean	4251	4025	2830	923	444	445
Median	330	187	77	18	1	8
Median/mean	0.078	0.046	0.027	0.019	0.001	0.018
Coefficient of variation	2.0	2.1	2.3	2.7	3.7	4.1
Asymmetry	2.8	3.0	3.4	4.1	6.3	7.8
Kurtosis	8.4	9.6	13.8	18.5	43.9	70.2

The spatial distribution of PFA is reported in Fig. 2. In 1960, high values (more than 1500 m^2) of PFA were observed in municipalities situated in the northern part of Attica. These municipalities constituted an example of a 'green belt' around the consolidated built-up area of Athens. The progressive loss of forests resulted in a progressive loss of this belt, especially after 1990. In 2010, rural municipalities with a considerable proportion of forest area in total landscape were situated primarily in the western and northern parts of the region as a consequence of urbanization and sprawl in the eastern part (Messoghia).

All together, this pattern highlights the complex urbanization process observed in Athens that has directly affected forest land in the last 50 years. In fact, a reduction in the number of municipalities characterized by a high percentage of forest area in the total landscape was observed in the study period.

3.2. Profiling Attica municipalities on the basis of forest dynamics

Attica municipalities were classified into homogeneous categories of PFA using specific criteria (Table 3). The PFA of 28 municipalities proved to be constant during the study period (Fig. 3). These municipalities are mainly situated in the consolidated and densely urbanized areas of Athens and Piraeus (6.4 and 8.3 km far from the centroid of these two urban poles, respectively) where there are no forests. A total of 46 municipalities (46.9% of the total investigated land) showed decreasing PFA during the last 50 years (−1243 m^2 per inhabitant on average), while only 7 municipalities (2.9% of the total

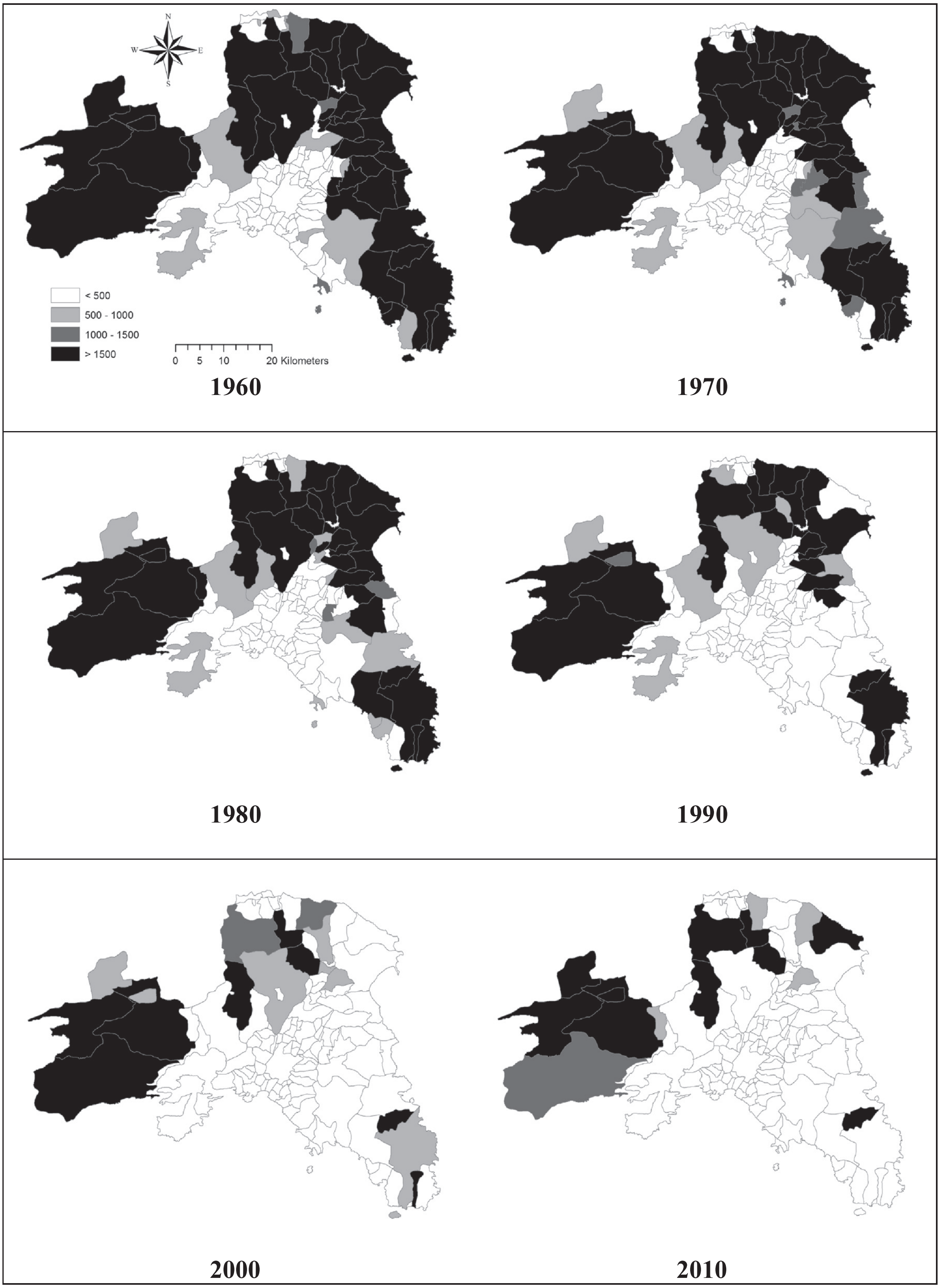

Fig. 2. Per-capita forest area (m^2) by decade and municipality in mainland Attica.

investigated land) showed a slight increase in the last decade (+22 m^2 per inhabitant on average).

Municipalities with decreasing PFA were primarily located in fringe areas and were experiencing considerable forest loss during the study period (from 1.5% to 34% of the total land). In particular, they were concentrated in the eastern part of Attica (only 11 km from the new development center of Markopoulo Messoghias). Municipalities showing an increasing PFA trend were located within coastal strips immediately surrounding Athens and in the northern part of the region. New forest areas have been observed in these municipalities during the last decade.

A total of 26 municipalities (about 31% of the investigated area)

Table 3
Basic characteristics (median values) of municipalities in mainland Attica according to six distinct criteria classifying trends in per-capita forest area (m^2) between 1960 and 2010.

Theme	Year/Variable	=	-	inv. u	+	u	?
Land (%)		4.4	46.9	6.6	2.9	24.5	14.8
No. municipalities		28	46	7	7	19	8
Forest cover (%)	1960	0.0	34.5	22.4	0.0	23.3	7.1
	1970	0.0	28.5	34.2	0.0	26.8	17.3
	1980	0.0	22.8	27.2	0.0	27.3	16.7
	1990	0.0	9.9	1.8	0.0	0.9	15.7
	2000	0.0	7.0	1.4	0.0	0.3	7.5
	2010	0.0	1.5	1.8	1.2	4.4	10.5
	change (1960–2010)	0.0	−23.6	−17.1	1.2	−18.9	1.3
Per-capita forest area (m^2)	1960	0	1360	6870	0	1799	3056
	1970	0	1138	9769	0	821	4890
	1980	0	485	5867	0	771	3716
	1990	0	101	1808	0	18	1792
	2000	0	62	153	0	9	591
	2010	0	17	151	22	74	1356
	change (1960–2010)	0	−1349	−6719	22	−1700	−1700
Elevation	(m)	73	277	263	135	280	398
Coastal municipalities		32	28	14	57	16	38
Soil quality index		0.21	0.34	0.29	0.29	0.38	0.32
Climate quality index		0.42	0.38	0.30	0.40	0.41	0.42
Distance from Athens (km)		6.4	16.3	27.4	18.7	18.1	26.6
Distance from Piraeus (km)		8.3	22.2	35.8	19.0	26.4	31.9
Distance from Maroussi (km)		12.6	11.8	19.5	23.7	19.2	23.1
Distance from Markopoulo (km)		25.1	21.4	29.4	32.8	30.1	43.2
Municipal area (km^2)		4.5	11.7	18.9	12.1	20.6	29.5

Legend: = represents no change in per-capita forest area; - = linear negative trend; inv. u = inverse U-shaped square trend; + = linear positive trend; u = U-shaped square trend; ? = non-linear, non-square trend.

showed a non-linear square trend of PFA (i.e., inv-U shaped and U-shaped trends). Among them, 7 municipalities experienced an increase in the 1960–1970 decade (+2900 m^2 per capita), followed by a decrease in PFA by about 9600 m^2 in the subsequent 40 years. These municipalities were all located in the northern part of Attica, more than 25 km from the centers of Athens and Piraeus. A strong decline in PFA from 1960 to 2000 was observed for the 19 municipalities experiencing

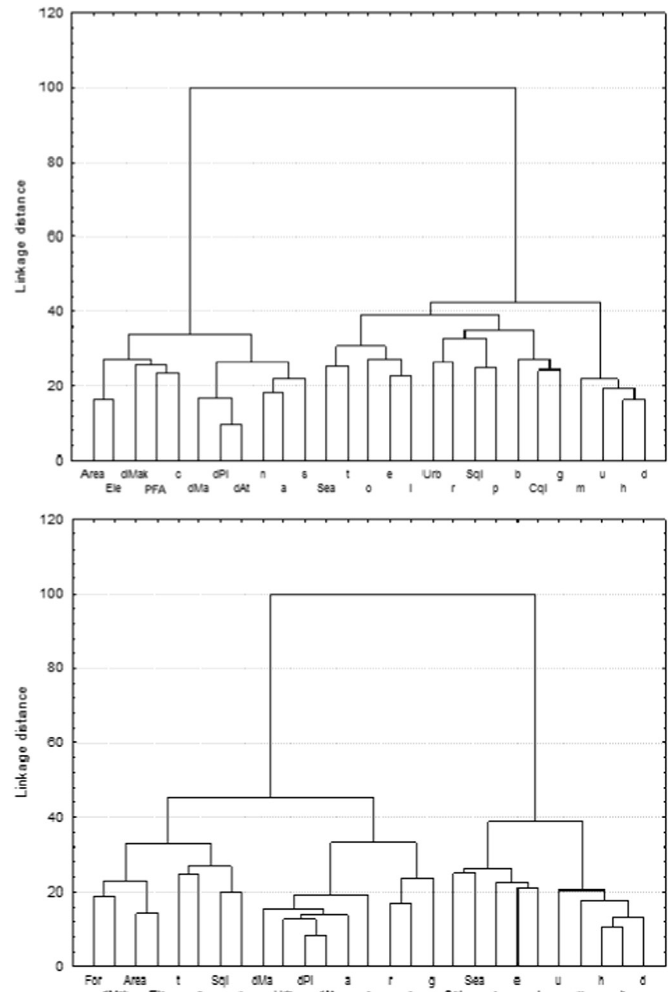

Fig. 4. Hierarchical clustering of variables influencing per-capita forest area in mainland Attica (above: 1960, below: 2010).

a U-shaped PFA trend. However, a reverse trend (+65 m^2 per capita) was observed in the last decade. Land in these municipalities was characterized by an optimal soil quality. Mixed and heterogeneous

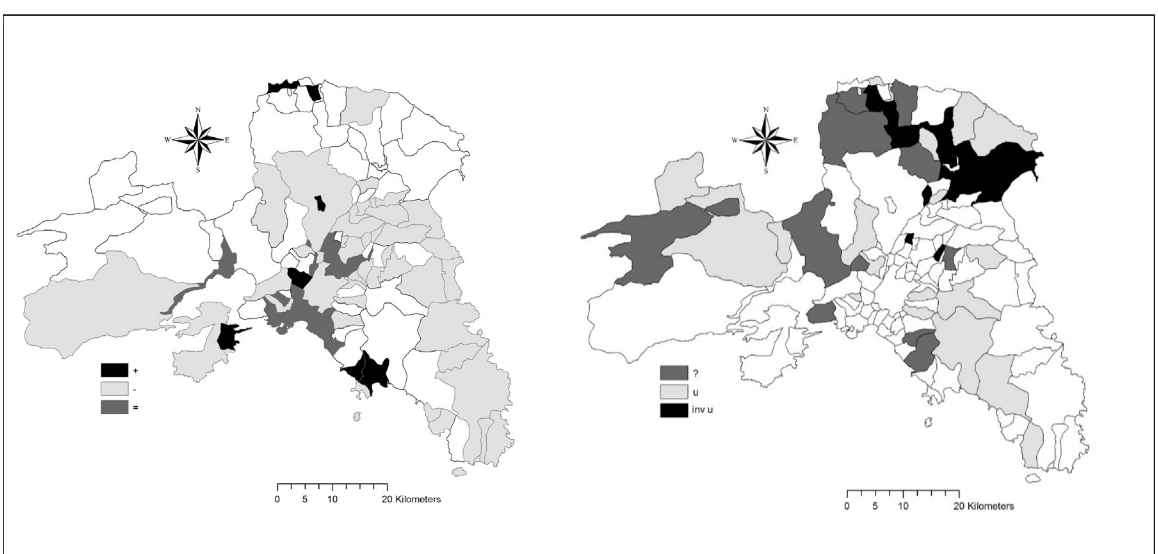

Fig. 3. Classification of municipalities in mainland Attica based on long-term trends in per-capita forest area. Figure on the left shows linear trend classes: "-" = linear and negative; "+" = linear and positive; "=" = no change. Figure on the right shows non-linear trend classes: "U" = square and U-shaped; "inv-U" = bell-shaped trend; "?" = non-linear, non-square trend.

Table 4
Results of the forward stepwise discriminant analysis with per-capita forest area as the dependent variable.

Variable	1960	1970	1980	1990	2000	2010
u	4.82**	5.05**	6.83**	3.95*		3.74*
dPi	5.27**	4.88**	4.63**			
dMak	4.52**	4.68**	4.78**	3.48*	3.42*	4.21**
Urb	4.70**					
a	3.06*	3.09*	4.29**	10.63**	10.72**	7.17**
Sea			3.50*	4.36**	4.28**	4.44**
m					4.05**	
F-to-remove	5.86	6.24	6.09	7.09	6.89	6.89
df	*25.391*	*20.352*	*35.391*	*20.352*	*20.352*	*20.352*
p-level	**	**	**	**	**	**

Legend: * indicates significant coefficient at $p < 0.05$; ** indicates significant coefficient at $p < 0.01$; F-to-remove illustrated in the table; F = Fisher-Snedecor test; df = degrees of freedom. Acronyms: u = diversity in urban land use; dPi = distance from Piraeus; dMak = distance from Markopoulo M.; Urb = per-capita built-up area; a = agricultural area; Sea = proximity to the seacoast; m = multiple usage buildings.

forest classes were mostly concentrated in hilly areas (400 m a.s.l. on average) far away from both Athens and Markopoulo, displaying the largest average municipal area in Attica.

More than 10% of the study area (corresponding to 8 municipalities) showed a less regular trend, as PFA decreased in the 1970–2000 time period, while it increased between 1960 and 1970 as well as in the last decade. These municipalities are the largest in term of municipal area and are situated in both hilly and flat areas.

3.3. Factors influencing per-capita forest area

Homogeneous groups of drivers impacting PFA were identified by cluster analysis. The results of hierarchical clustering suggest that two main groups of variables can be observed for both 1960 and 2010 (Fig. 4). Landscape and topographical variables were included in the same cluster for 1960, separate from the one including urban morphology and function variables. This separation was no longer observed in the 2010 cluster since the two clusters contained all types of variables.

A forward stepwise discriminant analysis (Table 4) was used to identify variables impacting PFA levels at each study period. All predictors affected PFA positively over the study period. Distance from Markopoulo Messoghias and density of agricultural land were relevant descriptors of PFA at all time points. Per capita built-up area and multiple-use buildings were significant only for one year (1960 and 2000, respectively). Distance from Piraeus was significant until 1980. This is probably due to the development of the new urban centers in fringe areas. Diversity in urban land-use was significant until 1990, possibly showing a progressive polarization in areas with high and low density of forest land. Conversely, distance from the seacoast became significant after 1980 due to the change in PFA values in hilly municipalities. In 1960, distance from Piraeus was the most relevant predictor positively impacting PFA, while agricultural land was the most relevant variable in 2010. These findings were explained by the recent expansion of forest surfaces in the rural municipalities of Attica.

4. Discussion

By profiling forest cover trends at the local scale this study analyzed a complex issue in urban ecology with implications for landscape studies, forest policy and planning perspectives in light of the NBS framework. By exploiting multivariate statistical procedures, indicators were selected and proposed as a set of descriptors analysing PFA.

Our results showed a continual decrease of PFA over time in the Attica region, except for the last decade. The decline in PFA was observed mainly in fringe municipalities, where a greater loss of forest cover, possibly driven by multiple factors (e.g. clear-cutting, wildfires, urbanization), was observed. Consequently, this process led to the loss of the connected natural areas surrounding Athens. This network constituted a sort of non-planned 'green belt', which was clearly identifiable in 1960.

Urban sprawl driven by tourism development, second-home expansion and decentralization of business activities negatively affected natural landscapes (Frenkel, 2004; Salvati et al., 2016b). An example is the ensemble of municipalities that gravitates around the expanded centers of Messoghia. After an initial period (1960, 1970) when urban areas with mixed economic functions and high settlement compactness were clearly distinguishable from rural areas with high PFA, values of this indicator decreased (1980, 1990) along fringe areas surrounding Athens and in 'sprawl' districts (such as Messoghia). The important changes observed at both the regional and local levels pointed out an increasing polarization in areas with low and high efficiency in land-use along the urban-rural gradient. This polarization was also observed in the North-West of Greece (Zomeni et al., 2008).

Some municipalities in Attica experienced an increase in PFA with a linear or non-linear time pattern (i.e., linear positive and U-shaped trends). These municipalities are located both in heavily urbanized areas and in strictly rural contexts. This phenomenon can be easily explained by an increase of forest cover. However, few afforestation and reforestation interventions have been established in Attica in recent decades: at the end of the 1990s, only 2.4 ha of woodland were planted (Arabatzis, 2005). This finding may be explained in light of the so-called 'forest transition theory' (FTT). FTT refers to forest recovery resulting from a long period of decline: in developed countries, farmers are engaging in more economically attractive opportunities, abandoning agricultural lands that have undergone forest recolonization (e.g., Mather, 2004; Cimini et al., 2013; Zitti et al., 2015). FTT may thus be suitable to describe trends in forest decline/expansion in the Attica region and other southern European cities characterized by peri-urban landscapes with fragmented agro-forest systems (Ferrara et al., 2015). Indeed, the evolution towards new forests is occurring in rural areas because of the abandonment of cultivated fields caused by the economic crisis. In some urbanized areas, this phenomenon can also occur within brownfields (Salvati et al., 2014).

Quality (e.g., in terms of forest type, *sensu* Barbati et al., 2014) of newly created forest surfaces should be monitored and investigated with the aim to understand their contribution to green infrastructure and to ecosystem service provisioning under the NBS framework including sustainable exploitation natural renewable resources (Corona et al., 2002). On the one hand, an increase in forest cover has a positive effect because it enhances provision of ecosystem services (Barbati et al., 2013). On the other hand, uncontrolled and unplanned landscape changes may represent a serious threat extending WUI boundaries. The biomass of newly formed forests, for example, is the most susceptible to fire risk (Koutsias et al., 2010; Moreira et al., 2011; Bajocco et al., 2015). Therefore, an important issue is to monitor the evolution of these forests (e.g., Corona, 2016) as well as to steer silvicultural practices to reduce fuel (e.g., Corona et al., 2015). In such a perspective, forest planning (through agriculture recovery or forest management plans) in urban and peri-urban areas is increasingly required (Colantoni et al., 2015; Salvati et al., 2016c). Improving functionality, quality and accessibility of new forests should become management priorities. The perception of well-being, for instance, is not the same in all forest areas, but depends on stand structure (e.g., Lafortezza et al., 2009; Carrus et al., 2015; Tomao et al., 2016). Indeed, stand structure and dynamics should be carefully considered when managing forest areas for multifunctional purposes (Marchetti et al., 2015).

NBS-related policies, such as effective protection of agricultural land, especially crop mosaics with relict woodlots, are also needed to reduce uncontrolled forest expansion. The application of sustainable agricultural measures is recommended, including, for example, greening measures defined by the new Common Agricultural Policy (Swinnen, 2015). Establishment of ecological network elements such as tree lines, bushes or wetlands, may support the provision of multiple ecosystem services better than the increase of forest cover (Capotorti et al., 2015), thus promoting synergies among ecosystem services as suggested by the NBS approach (Lafortezza and Chen, 2016).

Within municipalities where PFA remained stable or decreased (i.e., with linear negative or inv-U–shaped PFA trends), the recovery of mature vegetation is a basic priority. In such urbanized contexts, degraded neighborhoods or public green spaces are suitable areas for forest plantation (Capotorti et al., 2015). The ecological value and consequent provision of ecosystem services may thus be increased in urban areas. Furthermore, forest plantation can be carried out in protected areas to reduce contrasts with agricultural practices (Colantoni et al., 2015). Ineffective forest protection and urban containment policies are currently in force in the Attica region. Athens' expansion has not been regulated by integrated planning for the growing metropolitan area (Chorianopoulos et al., 2010). Indeed, successive waves of spontaneous growth have occurred (Salvati et al., 2013). Changing trends in land cover for the Attica region and their implications in PFA can be an example for other Mediterranean cities experiencing similar sprawled development (Catalán et al., 2008; Quatrini et al., 2015).

Concerning the factors most associated with changes in PFA, the results derived from cluster analysis allow evaluating how an enhanced complexity occurred in forest dynamics of the Attica region. The separation found in 1960 between territorial, environmental, topographical variables and aspects related to urban morphology functions was not observed in 2010, suggesting that these aspects should be considered altogether in the landscape and NBS planning. This more complex situation can be explained by the progressive urbanization of fringe municipalities around Athens.

The stepwise regression analysis highlighted that distance from new developing urban centers, such as Markopoulo Messoghias, as well as the share of agricultural areas in the total landscape seem to significantly influence PFA at all the investigated time points. This can be easily explained by (i) the low percentage of forest cover from 1960 to 2010 in this area; (ii) the low population density in the 1960–1970 decade; and (iii) urban development mainly within agricultural areas. Distance from the seacoast was also a relevant factor contributing to determine this trend in per-capita forest area. Although in the first time period high values of PFA were observed even close to the seacoast, nowadays the highest values of this indicator only persist in areas located far from urbanized coastal landscapes. Forests in coastal areas, in fact, are widely recognized as key elements of green infrastructure able to reduce environmental impacts such as land take (Gasparella et al., 2016). Our results allowed us to identify the areas where NBS planning is primarily needed: in coastal areas, near new urban centers and in the agricultural land surrounding urban boundaries.

5. Conclusions

The present study assesses the factors influencing forest trends in Attica, Greece, proposing a replicable methodology using quantitative indicators and multivariate statistical approaches. An exploratory analysis was carried out in a southern European urban region where consecutive phases of compact and dispersed urban expansion occurred, causing a progressive loss of forests and agricultural land.

Our research clarified the relationship between PFA and local socio-ecological contexts, identifying the variables most associated with forest cover trends. Distinctively, distance from city centers, distance from the seacoast, typical urban functions (multiple use of buildings and per-capita built-up area) and percentage of agricultural land in each municipality are the variables most associated to high per-capita forest area. Furthermore, PFA has proved to be a useful indicator for identifying priorities for NBS at regional and municipal scales.

The metropolitan area of Athens proves to be sensitive to deforestation because of different drivers, including land take and urbanization of fringe areas. This suggests the importance of multi-scale sustainable land management policies to contain and reduce the sprawl of built-up areas in peri-urban contexts. At the same time, a more effective protection of forests and agricultural land is required, especially for rural and remote districts. Our results can therefore support effective NBS planning, identifying priority areas for the improvement of green infrastructure by (i) the effective protection of crop mosaics with relict woodlots; (ii) the enhancement of functionality, quality and accessibility of new forests; and (iii) the establishment of new forests in rural municipalities.

Further studies are increasingly required to understand the impacts of other drivers not directly considered in this study, such as wildfires or illegal deforestation. Moreover, considerable efforts are still needed to design tools capable of assessing and guiding towards sustainable use of land; in particular, the identification of WUI areas becomes one of the main bases for effective land-use planning.

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