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

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ABSTRACT

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