

# Toward forest “sprawl”: monitoring and planning a changing landscape for urban sustainability

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**Abstract** The present study analyzes the structure and dynamics of the forest landscape in a peri-urban area (Rome, Italy) during the city’s expansion from 1949 to 2008 using landscape metrics and change detection analysis of digital maps of the area (1500 km<sup>2</sup>). While urban settlements increased continuously from 6.5 to 27.5 % of the study area, woodlands changed less clearly, with a moderate increase (from 11.2 to 11.9 % of the total area) and a higher fragmentation as a consequence of Rome’s expansion. The structure of forest landscape changed along the urban-to-rural gradient with patch size increasing with the distance to the inner city in 1949 and substantial landscape homogeneity in 2008. The indicators proposed in this study inform dedicated measures for conserving forest and maintaining landscape diversity. Measures adopted in Rome’s forestation plan to counteract woodland

fragmentation were analyzed and discussed. Based on the complex landscape dynamics found for Rome, an integrated multiscale planning approach targeting forest conservation is considered a key contribution to urban sustainability.

**Keywords** Landscape ecology · Urban form · Forestation plan · Rome · Mediterranean region

## Introduction

Although the area covered by forests has increased for many decades in Europe, the composition, structure and diversity of forest landscapes has changed rapidly in developed regions because of human activities, particularly urban expansion (European Environment Agency 2006). Major increases in forest cover are due to advances in forest management practices and conversion of abandoned farmland in marginal and disadvantaged areas. Forest biomass in the European region is also growing, and the average growth rate has increased from 1990 to 2010. Climate change is expected to depress site suitability, productivity, species composition and biodiversity, especially in southern Europe (Forest Europe, UNECE and FAO 2011). Despite summer fires, severe droughts, overgrazing, soil degradation, desertification and increased anthropogenic pressure, Mediterranean forests still preserve a unique biodiversity of stock and produce key socio-environmental services for the whole region (Salvati et al. 2012; Barbati et al. 2013; Nolè et al. 2013).

The most recent landscape transformation in the northern Mediterranean region reflects the uncontrolled expansion of large- and medium-sized cities caused by demographic, social, economic, cultural and political

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processes leading to exurban development (Kasanko et al. 2006; Longhi and Musolesi 2007; Turok and Mykhnenko 2007; Schneider and Woodcock 2008). While compact and dense settlements intermixed with low-density agricultural areas and pristine natural land have dominated the Mediterranean landscape since the early 1980s, dispersed and discontinuous urban expansion in areas progressively farther from core cities stimulated rapid and intense land-use changes in the most developed regions of southern Europe with fragmentation and simplification of both agricultural and natural lands (Weber and Puissant 2003; Catalàn et al. 2008; Jomaa et al. 2008; Bajocco et al. 2012).

Especially during the demographic boom encompassing the 1950s–1970s, Mediterranean urban and peri-urban forests were massively destroyed by summer fires and converted to urban uses, primarily illegal and spontaneous residential settlements because of poor planning directives. In the most recent decades, however, threats for peri-urban woodlands have only moderately lessened because of infrastructure development causing the fragmentation of less accessible forest stands, the increased building density at urban–wildland interfaces and the growing ecological pressure on forests from urban heat, land degradation, soil salinization and sealing (Marull and Mallarach 2005; Marull et al. 2009; Chorianopoulos et al. 2010; Frondoni et al. 2011).

Planning for compact and self-contained cities and managing peri-urban forests to maximize woodland quality and maintain the pristine characteristics and land-use relationships in complex agro-forest mosaics represent a key strategy to enhance urban sustainability in the Mediterranean region (Sarkar 1998; Wang et al. 2009; Salvati 2013). Although forest land is locally growing in some peri-urban areas due to cropland abandonment and the natural development of pastures and shrubland, southern European cities are promoting forestation plans to increase woodland surface and to improve the aesthetic quality of fragmented urban landscapes (e.g. Paul and Tonts 2005; Christopoulou et al. 2007; Salvati and Sabbi 2011). However, long-term monitoring of forest dynamics and landscape structure (Nolè et al. 2009; Corona 2010) is still needed especially in peri-urban regions.

Based on these premises, the present study analyzes the structure of forest landscape in a peri-urban area (Rome, Italy) during the city's expansion from 1949 to 2008 using landscape metrics and change-detection analysis of woodland structure and dynamics using digital maps from 1949 and 2008 of the investigated area. The indicators proposed in this study may help determine measures dedicated to forest conservation and the maintenance of landscape diversity (Frondoni et al. 2011). Measures adopted in Rome's recent forestation plan to counteract woodland fragmentation and simplification were also analyzed and

discussed to inform integrated planning approaches targeting forest conservation.

## Methods

### Study area

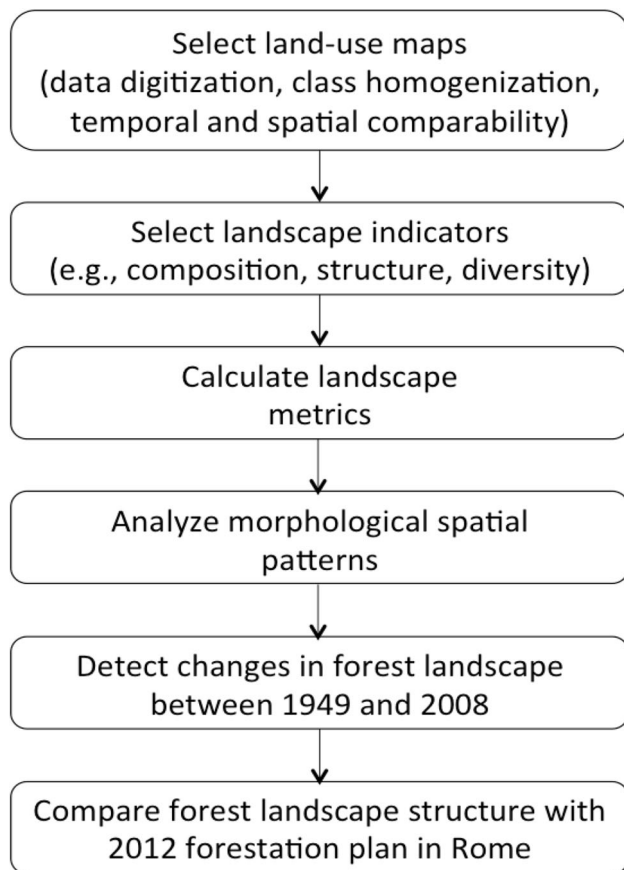
The investigated area covers a part of Nuts-3 Prefecture of Rome including the municipalities of Rome and Fiumicino (1500 km<sup>2</sup>) and comprises nearly 90 % lowlands and 10 % uplands. Although urban fabric occupies an important (and increasing) portion of the region, most of the area still consists of woodland, pastures and cultivated land (Barbati et al. 2013). Lowlands (the so called Agro Romano) extend over the alluvial plain of the Tiber River with relict forest vegetation preserved in some stands along the Tyrrhenian coast and in some protected areas close to the core city. Industrial areas are located in the eastern part of the Agro Romano, while traditional rural areas can still be found in the western part of the municipality (Attorre et al. 2000). Rainfalls concentrated in autumn and spring and mild temperatures in winter determine a Mediterranean climate regime. The average long-term (1961–1990) annual rainfall is 700 mm, and the mean daily temperature is 16 °C.

### Land-use maps and indicators

A flow chart illustrates the main steps of the present study (Fig. 1). To derive reliable land-use data, we elaborated two compatible digital maps: (1) the Italian Istituto Geografico Militare (IGM) topographic map, scaled 1:25,000 and covering the study area for 1949, and (2) an original map (scaled 1:25,000 and referring to 2008) produced from photo-interpretation of digital ortho-photographs released from the Italian National Geoportal (Italian Ministry for Environment, Land and Sea) with a 0.5 m pixel resolution and projected on UTM33 WGS84.

The IGM map was extensively used in previous studies on landscape composition in Italy (e.g., Pelorosso et al. 2009; Geri et al. 2010; Salvati and Sabbi 2011; Salvati 2013). Frondoni et al. (2011) provided detailed technical information on the IGM map. A nomenclature constituted by nine homogeneous classes (arable land, mixed cropland, vineyards, olive groves, forests, pastures, urban parks, wetlands and built-up areas) with a minimum mapping unit of 1 ha was adopted here (Petit and Lambin 2002). The produced land-use figures were checked for reliability and consistency with independent statistics (e.g., agricultural, population and building censuses) and cartographic data (Salvati et al. 2012).

Selected demographic and land-use indicators (resident population, population density, percentage of built-up



**Fig. 1** Flow chart describing the main steps of this study

areas, per-capita built-up area, percentage of forest area, percentage of protected areas) covering the whole investigated region were calculated for 2 years (1949 and 2008). A landscape change detection analysis (1949–2008) was developed by computing the percentage class area (i) transformed from forests to other uses or (ii) converted to forests from other uses.

### Landscape metrics and the distance from the inner city

Metrics assess the spatial relationship between patches and evaluate how these patterns and interactions change over time (Frondoni et al. 2011). Evaluating the complexity of landscape patterns aids in understanding the land-use processes of the investigated area (Salvati and Sabbi 2011). To assess forest landscape composition and structure, we used 11 metrics. Landscape composition refers to features associated with the amount of each patch type within the landscape. Landscape structure refers to the distribution or spatial properties of patches and can be useful to quantify landscape fragmentation (Salvati et al. 2014). The measures included total landscape area (TLA) and 10 class

metrics: mean patch size (MPS), median patch size (MedPS), patch size coefficient of variation (PSCoV), edge density (ED: the edge on a per unit area basis), mean patch edge (MPE: average amount of edge per patch), mean shape index (MSI: the average perimeter-to-area ratio), area weighted mean shape index (AWMSI, weighting patches according to their size), mean patch fractal dimension (MPFD) based on the fractal dimension of each patch, area-weighted mean patch fractal dimension (AWMPFD, weighting patches according to their size), and mean perimeter-area ratio (MPAR, calculated as the sum of each patches perimeter/area ratio divided by number of patches). The total number of patches by class was then provided for each year (NPAT). A detailed list of the most used landscape metrics, including those considered in the present study, is reported in Uuemaa et al. (2009). The distribution of each class metric in 1949 and 2008 was compared separately using a nonparametric Mann–Whitney  $U$  test for significant differences at  $p < 0.05$ .

Two selected landscape metrics (mean patch size and edge density) were compared with the distance from the core city in pairwise correlation analyses using three different coefficients (Pearson parametric product-moment correlation, Spearman nonparametric rank co-graduation and Kendall nonparametric correlation) testing for significance at  $p < 0.01$  for both 1949 and 2008. The proximity of each patch from a central place in Rome (Piazza Barberini, placed in the historical centre of the city) was calculated using the patches’ centroids and linear distances. The analysis was aimed to assess changes in forest structure along the urban-to-rural gradient in Rome.

### Assessing morphological changes in forest structure

Mathematical morphology is a framework analyzing the shape and form of objects (Soille 2003). An algorithm to classify land classes in terms of its morphology is defined by a sequence of logical operations (union, intersection, complementation and translation). One of the most common frameworks in mathematical morphology is morphological spatial pattern analysis (MSPA). The MSPA framework implements image processing routines to identify hubs, corridors and other spatial properties that are relevant to landscape assessment (Vogt et al. 2007). Seven landscape elements identified by MSPA are considered in the present study: (1) core areas, (2) islets, (3) bridges, (4) loops, (5) branches, (6) edges and (7) perforation areas. For each class, pixels classified as the core area are the inner part beyond a certain distance to the boundary; islets are those parts that are too small and isolated to contain a core area. Each core area is surrounded by edges and perforations. A perforated area is the transition zone between a core area and a different land cover class, while the edge

class represents the transition zone between a core and non-core area within the same land-use class. Core areas are also connected to each other by loops, bridges and branches. Loop areas represent corridors that connect to the same core, bridges connect at least two core areas, and branches connect a core area with a non-core area within the same land-use class.

The Guidos software (Joint Research Centre 2014) was used to develop forest land classification based on the MSPA framework. The observed surface area was classified into one of the seven landscape elements described earlier for 1949 and 2008 separately. The forest layer was extracted from the two vector (polygon) maps and converted into raster (grid) maps covering the target area (Barbati et al. 2013). These maps were reclassified into foreground (the coverage of the forest class) and background (all other classes). Technical details on MSPA processing were described by Soille and Vogt (2009).

### Analyzing Rome's forestation plan

Rome's forestation plan was prepared in 2010 and 2011 and approved in 2012 by the municipal council. A detailed file describing the forestation measures and the urban sites involved is available (Comune di Roma 2012). Using a digital map provided by Rome's municipality, we calculated the number and size of land patches involved in the forestation program by land tenure (common and private) and distance from the inner city (using two classes: "consolidated city" and "suburbs" according to the available file). Maps illustrating the spatial distribution of the forestation sites against the urban fabric and existing forests in 2008 were finally produced.

## Results

### The evolution of forest cover and urban expansion in Rome (1949–2008)

Rome's expansion was particularly rapid from 1949 to 2008. The resident population increased from 1.6 to 2.7 million inhabitants, producing a marked densification of the urban landscape (from 1103 inhabitants/km<sup>2</sup> in 1949 to 1794 inhabitants/km<sup>2</sup> in 2008). Consequently, impervious surface grew from 6.5 % of the total area in 1949–27.5 % in 2008 (Table 1). Forest area increased moderately, covering 11.2 % of the total area in 1949 and 11.9 % in 2008. According to the population dynamics, per capita forest area declined from 1.02 ha in 1949 to 0.66 ha in 2008. The evolution of forest cover and urban fabric in Rome is mapped in Fig. 2. Rome's expansion progressively consumed cropland and pastures, producing a denser, more

continuous urban fabric around the core city and discontinuous settlements in the Agro Romano lowland. The 2008 map indicates a growing pressure on forests from the proximity to expanding urban settlements. The average (linear) distance between forest and built-up patches decreased from  $0.7 \pm 0.5$  km in 1949 to  $0.2 \pm 0.3$  km in 2008.

### Landscape changes and forest cover dynamics in Rome

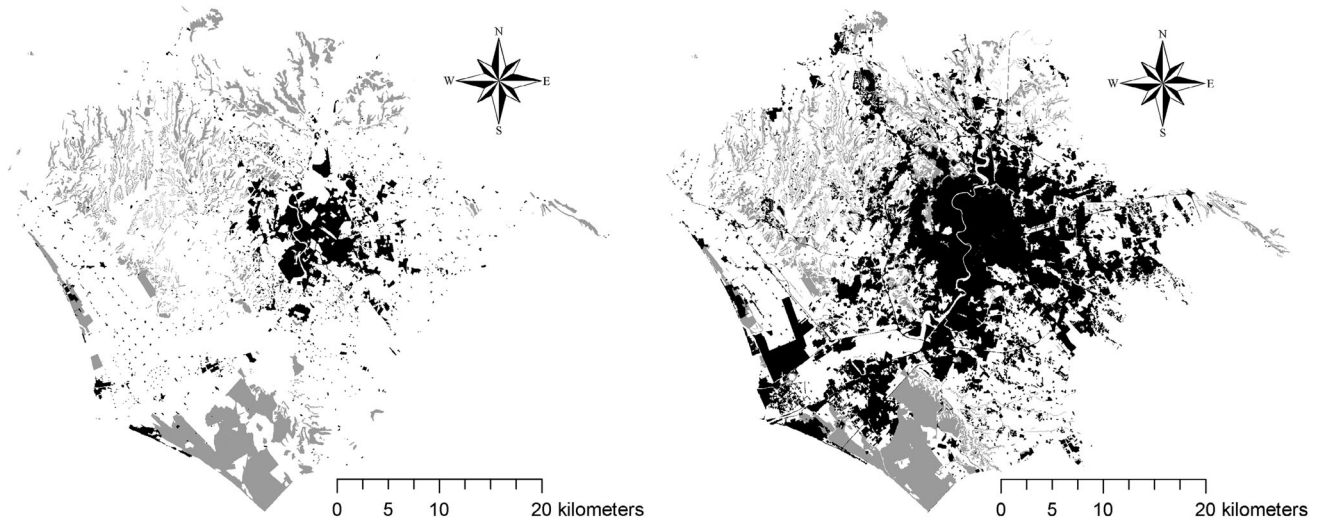
Table 2 reports the results of the change detection analysis (1949–2008) illustrating the intensity of transformations from forest to the eight other landscape classes and conversions from these land-uses to the forest class. Almost two-thirds of the forest area observed in 1949 (63 %) was stable in 2008; the remaining forest cover was converted primarily to arable land (53.6 %), built-up areas (22.5 %) and pastures (19 %). On average, the patch size of land transformed from forest to other uses was the highest for arable land (1.4 ha), decreasing for built-up areas (1.1 ha) and pastures (0.9 ha). In the same time period, conversion to forest involved primarily arable land (76.4 %), pasture (15.4 %) and crop mosaic (5.2 %) patches with a size averaging 1.7–1.8 ha.

### Changes in the forest landscape structure (1949–2008)

On the basis of an analysis of almost 1000 patches, the structure of forests in Rome was assessed through 11 class metrics in both 1949 and 2008 (Table 3). The overall number of forest patches declined moderately from 890 in 1949 to 814 in 2008, with a  $-0.14$  % annual change. Both mean and median patch size increased significantly from 19 to 22 ha and from 2.8 to 3.9 ha, respectively. The coefficient of variation of forest patch size increased markedly from 3.6 to 8.1 %, representing the highest annual growth rate among the investigated metrics. Shape indexes also varied significantly over time: the mean shape index and edge density grew, respectively, by 0.8 and 1.1 % in the study period, and an even larger increase was observed for the average weighted mean shape index (1.6 %). Although the mean perimeter to area ratio showed nonsignificant changes over time, fractal dimension increased moderately. Taken together, results indicate a complex dynamic in Rome's landscape: although increasing in forest cover (from 11.2 to 11.9 % of the entire area), land-use transformations produced a simplification of the forest landscape with a fewer patches and larger patch size. At the same time, changes in shape and fractal dimensions, together with the rise of patch size coefficient of variation, indicated a progressive landscape convolution with

**Table 1** Selected variables to describe and compare the landscape and population in 1497-km<sup>2</sup> area of peri-urban Rome in 1949 and 2008

Variable	1949	2008
Population (thousand people)	1651.3	2684.8
Population density (inhabitants/km <sup>2</sup> )	1103	1794
Built-up area (%)	6.5	27.5
Per capita built-up area (ha)	0.59	1.53
Forest land (%)	11.2	11.9
Per capita forest land (ha)	1.02	0.66
Mean nearest-neighbor distance between forest and built-up patch (km) $\pm$ SD	0.7 $\pm$ 0.5	0.2 $\pm$ 0.3
Protected areas (%)	0.0	27.3

**Fig. 2** The evolution of forest land (grey) and the urban fabric (black) in Rome (left: 1949, right: 2008)**Table 2** Landscape change detection analysis (1949 and 2008) in Rome by land-use class

Class	Transformation from forest		Conversion to forest	
	Class % <sup>a</sup>	Mean patch size (ha)	Class % <sup>a</sup>	Mean patch size (ha)
Built-up area	22.5	1.1	0.1	0.1
Arable land	53.6	1.4	76.4	1.7
Crop mosaic	1.6	0.4	5.2	1.7
Vineyards	0.3	0.2	1.0	0.8
Olive groves	1.4	0.4	0.5	0.6
Pastures	19.0	0.9	15.4	1.8
Urban parks	1.4	0.8	1.0	1.4
Water bodies	0.2	0.0	0.5	0.0

<sup>a</sup> Percentage of the total investigated area occupied by class.

intrinsic fragmentation, thus increasing discontinuity in the woodland matrix, as confirmed by the growing distance from the nearest neighbor forest patch.

Using various statistical coefficients (Pearson, Spearman and Kendall), pairwise correlation analyses between two selected forest class metrics (mean patch size and edge density) and the distance from the inner city of Rome was carried

out by year (Table 4). In 1949, both mean patch size and edge density were significantly correlated with the distance from Rome; all correlation coefficients decreased considerably in 2008, indicating a nonsignificant relationship with the distance from the centre of Rome. These results highlight a drastic change in forest landscape structure along the urban-to-rural gradient in Rome during the investigated period.

**Table 3** Landscape metrics for forest classes in Rome by year

Metric	1949	2008	Change (%)	<i>U</i> test <sup>a</sup>
Number of patches	890	814	-0.14	–
Mean patch size (ha)	18.9	21.9	0.26	*
Median patch size (ha)	2.8	3.9	0.64	**
Patch size coefficient of variation (%)	3.6	8.1	2.12	**
Edge density (m/ha)	14.7	24.0	1.06	**
Mean patch edge (m)	2480	4404	1.31	**
Mean shape index	2.1	3.0	0.78	**
Average weighted mean shape index	3.0	5.7	1.58	*
Mean perimeter to area ratio	758	688	-0.16	n.s.
Mean patch fractal dimension	1.37	1.42	0.06	*
Average weighted mean patch fractal dimension	1.32	1.40	0.10	*
Average nearest neighbor distance among forest patches (km)	0.3	0.4	0.26	*

<sup>a</sup> Mann–Whitney nonparametric *U* test for differences in each landscape metric separately between 1949 and 2008

\* significant difference at  $0.001 < p < 0.05$ , \*\* significant at  $p < 0.001$  after Bonferroni correction for multiple comparisons)

\*\* significant at  $p < 0.001$  after Bonferroni correction for multiple comparisons)

n.s. Nonsignificant difference

**Table 4** Correlation coefficients between selected forest class metrics and the distance from the inner city of Rome by year

Variable	<i>n</i>	Pearson		Spearman		Kendall	
		1949	2008	1949	2008	1949	2008
Mean patch size	890	0.20*	0.07	0.22*	0.04	0.15*	0.02
Edge density	814	0.27*	0.12	0.17*	0.05	0.11*	0.03

\* Significant correlations at  $p < 0.01$

### Core and islets: the evolving forest landscape in Rome

On the basis of the Guidos class metrics, the forest landscape in Rome was classified into 2092 patches in 1949 and 2906 in 2008 (Table 5), indicating a progressive fragmentation of woodlands. The surface of patches classified as core forests decreased from 36.6 % in 1949 to 29.2 % in 2008 with a corresponding decline in patch number (from 146 to 108). Conversely, patches classified as islets increased in size and number (respectively, from 22.8 to 36.8 % of the total forest surface and from 981 patches to 1821). While edge patches decreased from 18.3 to 9.6 % of forest surface with a stable patch number, loop and bridge patches increased moderately, indicating a more complex landscape in 2008. Although increasing in the number of patches, branch areas declined from 13.3 to 9.5 %.

### Insights from Rome's forestation plan: analyzing the spatial dimension

Rome's forestation plan (Comune di Roma 2012) includes 231 sites ( $0.15 \text{ sites/km}^2$ ) covering 1848 ha, representing

1.2 % of the investigated area (Table 6). The average size of the forested sites is  $8.0 \pm 12.0$  ha with a median size of 3.7 ha. Although the mean patch size of the forested sites is below the value of the metric observed for the whole forest class in 2008 (21.9 ha, see Table 3), the median value is comparable (3.9 ha). Forestation sites are concentrated in the suburbs (75.9 % of intervention areas), but the average size of forestation sites differs only moderately between suburbs and the consolidated city (8.5 vs. 6.8 ha). According to the forestation plan, the private land is nearly 23 % of total intervention land showing, on average, larger patches than common land (10.0 vs. 7.5 ha). Figure 3 shows the spatial distribution of forestation sites overlaid with the urban fabric and existing forest patches in 2008. Although quite homogeneously distributed over the study area, forestation sites were generally established at the boundaries of built-up large patches with less connection with the existing forest patches. The nearest-neighbour distance between forestation sites and urban patches and between forestation sites and existing forest patches averaged 0.1 and 0.4 km.

### Discussion

Habitat fragmentation, landscape simplification and homogenization, spatial polarization in high- and low-quality uses of land, land degradation, loss in biodiversity and, ultimately, ecosystem deterioration are the main modifications observed in urban regions experiencing scattered settlement expansion (Bruegmann 2005). Understanding

**Table 5** Forest class GUIDOS metrics in Rome by year

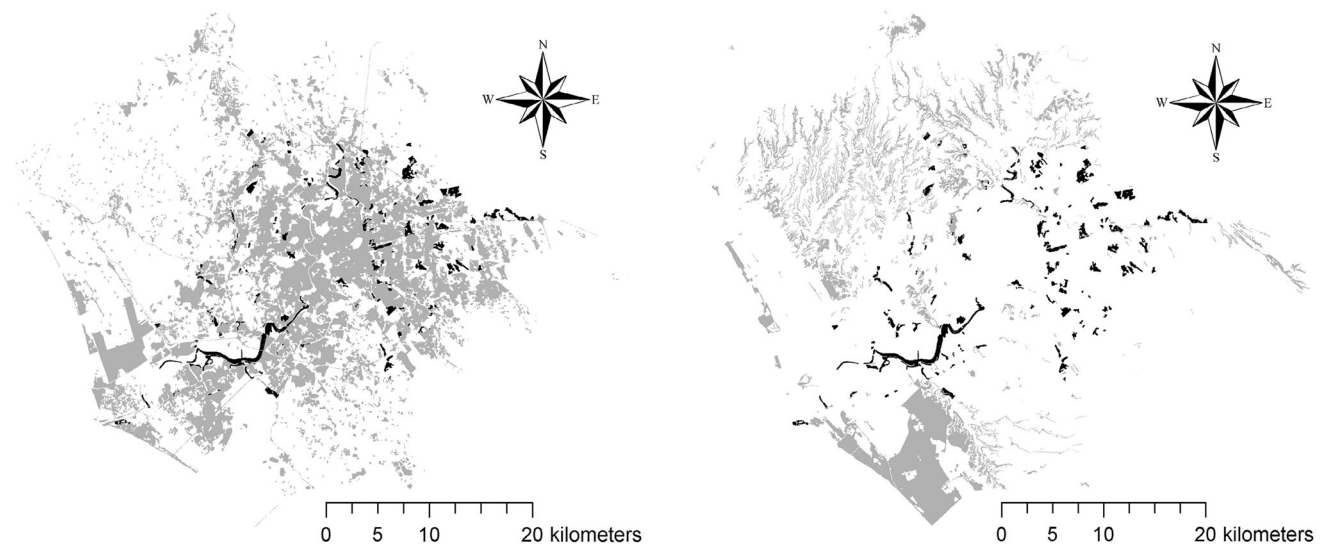
Type	1949			2008			Change % (1949–2008)		
	Class (%) <sup>a</sup>	Landscape (%) <sup>b</sup>	<i>n</i>	Class (%) <sup>a</sup>	Landscape (%) <sup>b</sup>	<i>n</i>	Class (%) <sup>a</sup>	Landscape (%) <sup>b</sup>	<i>n</i>
Core	36.6	2.12	146	29.2	1.73	108	−0.34	−0.31	−0.44
Islet	22.8	1.32	981	36.8	2.18	1821	1.04	1.10	1.45
Perforation	0.6	0.04	6	0.4	0.02	4	−0.64	−0.85	−0.56
Edge	18.3	1.06	203	9.6	0.57	199	−0.81	−0.78	−0.03
Loop	1.8	0.11	20	5.1	0.3	37	3.01	2.93	1.44
Bridge	6.5	0.37	66	9.4	0.56	38	0.78	0.87	−0.72
Branch	13.3	0.77	670	9.5	0.56	699	−0.48	−0.46	0.07

<sup>a</sup> Percentage of the total investigated area occupied by class.

<sup>b</sup> Percentage of total investigated area

**Table 6** Statistics from Rome’s Forestation Plan adopted by the municipal council in 2012.

Variable	Number	Surface area (ha)	Mean size (ha)
Sites involved	231	1848.0	8.0 ± 12.0
Land tenure			
Public	187	1408.9	7.5
Private	43	427	10.0
Private (% of total)	18.6	22.9	–
Distance from the centre of Rome			
Consolidated city	66	445.8	6.8
Suburbs	165	1402.2	8.5
Suburbs (% of total)	71.4	75.9	–

**Fig. 3** Maps of sites targeted by Rome’s forestation plan (illustrated in *black* in both maps; *grey* indicates built-up areas and existing forests in 2008, respectively, represented in left and right map).

patterns of natural forest expansion in these regions is therefore crucial for integrated spatial planning across the urban-to-rural gradient since forest expansion is recognized

as the natural process that may better counteract the consumption of the natural resources and ecosystems services of rural lands (European Environment Agency 2006).

It is quite well documented (Soliman 2004; Couch et al. 2007; Terzi and Bolen 2009; Chorianoopoulos et al. 2010) that, during the decades following World War II, the compact and dense/semi-dense urban growth from the expansion of informal settlements and unregulated residential districts impacted Mediterranean landscapes mainly through clear-cutting and forest fires that destroyed peri-urban forests. In the most recent decades, although population growth slowed in many urban regions, the expansion of discontinuous medium- and low-density settlements and infrastructure development impacted peri-urban forests, altering the pristine landscape structure, composition and diversity, as clearly illustrated in the present study and in previous research (e.g., Polyzos et al. 2008). Urban sprawl thus leads to ecosystem fragmentation, decline in cultivated land and higher pressure on natural and semi-natural habitats (Salvati and Sabbi 2011; Salvati and Ferrara 2013). Assessing the severity of the structural alterations of agroforest systems resulting from increased human pressure is crucial to developing programs to aid environmentally fragile regions undergoing climate changes and extensive soil and land degradation as in southern Europe (Salvati 2013; Colantoni et al. 2015).

The present study contributes to this deserving issue by analysing long-term forest structure and dynamics in a representative case study of southern European peri-urban regions. Using landscape metrics, we identified changes in the structure of forest landscape along an urban-to-rural gradient during the last 60 years. The originality of the study lies in its integration of traditional landscape metrics and a more refined morphological spatial approach to describe long-term changes in forest landscape structure.

The main results of the study can be summarized as follows: (1) urbanization caused a rearrangement in the structure of forest landscape along the urban-to-rural gradient, as testified by the correlation analysis; (2) although forest cover increased over the investigated time span, forest landscape in Rome became more fragmented and heterogeneous; and (3) fractal and shape indexes significantly increased, possibly from an indirect impact of infrastructure development and low-density settlement expansion in neighboring agricultural areas.

These results were confirmed by the thorough decline of the core forest class, which represents nonfragmented, pristine natural habitats, and by the corresponding increase in forest patch areas, isolated fragments that are poorly connected with the core stands (Barbati et al. 2013). Although corridor elements like loops and bridges, which were found to increase in the study area, are important landscape elements as potential pathways for supporting animal movement and plant dissemination, they are vulnerable to fragmentation and conversion to isolated patch elements. Forested land classified as these morphological

classes are regarded as “broken connections” (Vogt et al. 2007). Taken together, these results indicate landscape simplification and forest fragmentation as the main consequences of urban expansion in Rome. Protected areas and green belts to preserve forests and semi-natural areas around major urban centres are considered as effective conservation measures for sustainable management of ecologically fragile Mediterranean environments (Attorre et al. 2000).

In this context, the negative impact of landscape transformations on ecosystem stability and resilience has been poorly monitored, and specific mitigation measures are needed (Marull and Mallarach 2005; Christopoulou et al. 2007; Polyzos et al. 2008; Marull et al. 2009). Landscape complexity and the level of coordination and multiscale complexity adopted by urban sustainability plans are the primary influences on the effectiveness of measures to contain urban sprawl and reduce land fragmentation. The intrinsic complexity of the spatial relationships observed among land-uses, typical of the Mediterranean landscape, usually reduces the efficacy of environmental (or integrated socio-ecological) plans targeting natural habitats.

Rome’s forestation plan offers a set of practical interventions to increase forest cover and improve woodland quality on a local scale (Comune di Roma 2012). Although the characteristics of the forestation sites seem to be rather homogeneous with the observed landscape and their distribution over the municipal area is quite balanced, the spatial connection with natural areas is relatively weak. In other words, the plan is correctly implementing a network of urban woodlots (possibly in connection with urban parks and gardens), but specific measures should be aimed at reducing the fragmentation of core forest areas and the fractal dimension of existing wood patches (Barbati et al. 2013). To contribute to urban sustainability, an efficient planning approach should promote an increase in forest cover and patch connection while reducing patch fragmentation.

## Conclusions

By integrating a monitoring framework based on multi-temporal landscape metrics with the in-depth analysis of an environmental plan to promote landscape quality on a local scale, the new approach used in this study should be a useful tool to develop a local strategy to conserve natural habitats. The indicators proposed may inform decisions on measures dedicated to conserving forests and maintaining landscape diversity. Based on the results derived from landscape analysis, measures adopted in Rome’s forestation plan tend to mitigate woodland simplification but should also improve the spatial connection with the



existing forest patches and network of protected areas established at the municipal scale. Based on the complex dynamics observed in Rome’s landscape, together with present rapid socioeconomic and territorial changes at the regional scale, an integrated, multiscale plan to target forest conservation is particularly needed as a key contribution to urban sustainability. Policies targeting urban containment should therefore be integrated more tightly with measures to conserve priority natural habitats.

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