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Agro-forest landscape and the 'fringe' city: A multivariate assessment of land-use changes in a sprawling region and implications for planning

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HIGHLIGHTS

- Urban expansion and landscape transformations are evaluated in Rome (1949–2008).
- 26 metrics was used to describe landscape composition, structure and dynamics.
- Poorly protected agricultural land experienced fragmentation.
- Class area decreased with patch size except for urban areas and forests.
- Urban containment may contrast cropland and forest fragmentation.

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ABSTRACT

The present study evaluates the impact of urban expansion on landscape transformations in Rome's metropolitan area (1500 km^2) during the last sixty years. Landscape composition, structure and dynamics were assessed for 1949 and 2008 by analyzing the distribution of 26 metrics for nine land-use classes. Changes in landscape structure are analysed by way of a multivariate statistical approach providing a summary measure of rapidity-to-change for each metric and class. Land fragmentation increased during the study period due to urban expansion. Poorly protected or medium-low value added classes (vineyards, arable land, olive groves and pastures) experienced fragmentation processes compared with protected or high-value added classes (e.g. forests, olive groves) showing larger 'core' areas and lower fragmentation. The relationship observed between class area and mean patch size indicates increased fragmentation for all uses of land (both expanding and declining) except for urban areas and forests. Reducing the impact of urban expansion for specific land-use classes is an effective planning strategy to contrast the simplification of Mediterranean landscape in peri-urban areas.

1. Introduction

The composition and structure of rural landscapes changed rapidly in affluent regions because of economic development and socio-demographic changes (Meeus, 1993). Compact and dense urban growth impacts landscape structure and diversity in a relatively well-known manner, by altering landscape composition and increasing patch fragmentation (Alphan, 2003; Weber and Puissant, 2003; Weber et al., 2005; Ioannidis et al., 2009). This process was mainly due to the typical development path observed in compact urban regions (Salvati and Ferrara, 2013) and based on a radio-centric growth around the core city consuming fringe areas already degraded or fragmented by the past expansion (Ferrara et al., 2014).

By changing landscape forms in a more rapid and intense way, low-density urban expansion into agro-forest land at increasing distances from the main urban centres may have unpredictable long-term effects on landscape structure and composition (Catalàn et al., 2008; Terzi and Bolen, 2009; Poelmans and Van Rompaey, 2009; Zhao et al., 2013, among others) that need further investigation especially in environmentally-fragile regions. Preliminary results indicate that urban sprawl invades rural areas further away from the inner city (Bruegmann, 2005) and consumes a larger proportion of high-quality and biodiversity-rich natural habitats (e.g. shrublands, pastures, wetlands) and high value added cropland (Luck and Wu, 2002; Berling-Wolf and Wu, 2004; Song and Knaap, 2004; DiBari, 2007; Aguilera et al., 2011). Compared with compact expansion, urban sprawl caused a decline in landscape and environmental quality at large, with implications for the economic viability of the primary sector due to the uneven fragmentation of productive agricultural land (Couch et al., 2007).

In the Mediterranean basin, regarded as a dynamic region with millenary human–landscape interactions (Alphan, 2003), population concentration and industrial specialization amplified the socioeconomic divide between urban and rural areas and consolidated the

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environmental disparities between coastal and inland regions (Salvati and Zitti, 2007). The most recent landscape transformations in this region are associated to the processes of urban de-concentration observed since the 1980s, crop intensification in flat areas and land abandonment with forest recovery in less accessible upland and mountain areas (Longhi and Musolesi, 2007). These processes shape specific socio-spatial structures and economic functions and drive urban regions towards scattered and dispersed morphologies. Sprawl is a relatively novel phenomenon in southern Europe, whose urban landscapes are recognized as more compact and dense compared with those found in northern and central Europe (Kasanko et al., 2006; Turok and Mykhnenko, 2007; Schneider and Woodcock, 2008).

The conversion of cropland to compact urban fabric was the most visible transformation observed in Mediterranean landscapes determining soil sealing and socioeconomic consequences due to marginalization of rural communities and loss of traditional agricultural practices and landmarks (Munafò et al., 2010). At the same time, urban sprawl may cause more subtle transformations involving the structure of the whole landscape. Landscape fragmentation, simplification, homologation or spatial polarization, alteration of the traditional proximity pattern among uses of land, modification of the intimate spatial relationships among patches and uses of land, together with ecosystem deterioration and loss in biodiversity, are the main transformations observed in peri-urban and rural areas experiencing low-density urban scattering (Seto and Frangkias, 2005; Catalàn et al., 2008; Salvati et al., 2014; Serra et al., 2014; among others). In this context, the negative impact of landscape transformations on the ecosystem stability and resilience is difficult to assess and hard to mitigate with effective policies (Soliman, 2004; Paul and Tonts, 2005; Marull et al., 2009). Unfortunately, it was only partially recognized that planning strategies at both the urban and regional scales should consider landscape as a whole to preserve its structure, composition, diversity and spatial relationships, rather than protecting specific land-use classes (Chorianopoulos et al., 2010).

Based on these premises, the present study investigates composition and structural changes of a peri-urban landscape experiencing long-term urban expansion (Rome, Italy). Rome's metropolitan area is a well-established example of the semi-compact and dense Mediterranean cities undergoing sprawl. The aims of this paper are (i) to assess landscape transformations driven by rapid urbanization, (ii) to quantify changes in the structure of the rural landscape and, finally, (iii) to verify if changes in landscape composition are associated to changes in landscape structure. Results inform planning strategies aimed at promoting urban containment and sustainable land management of southern European urban regions.

2. Methods

2.1. Study area

The investigated area covers a part of Rome's province including the local municipalities of Rome and Fiumicino for a total surface area of 1500 km^2 consisting of nearly 90% flat areas and 10% hilly areas (Salvati, 2014). Lowlands (the so called 'Agro Romano', a cultivated area with traditional rural landmarks, biodiversity and cultural heritage) surrounded the inner city of Rome developing over the alluvial plain of the Tiber river. Traditionally, the 'Agro Romano' rural landscape was formed by a balanced and visually agreeable mosaic of tree crops, garden crops and pastures intermixed with arable land parcels and sparse woodland (Attorre et al., 2000). Despite increasing human pressure that threatened the original forest vegetation, relict high forests are preserved along the coastal rim. Industrial areas were mainly located in the eastern part of the city while traditional cropland intermixed with pasture and shrub land still occurs in the western part of the study area. Rome's climate is typically Mediterranean, with rainfalls concentrated in autumn and spring and relatively mild temperatures in winter. The average long-term (1961–1990) annual rainfall and mean daily temperature in Rome were 700 mm and 16 °C respectively. However, precipitation rate decreased and growing average temperatures have been recorded in the last decades (Salvati et al., 2012).

According to previous studies (Munafò et al., 2010; Salvati and Zitti, 2007; Salvati and Sabbi, 2011), Rome's growth was mainly compact and dense between the early 1950s and the 1980s while it expanded through medium- and low-density settlements during the most recent decades. During the 'dense growth' phase, population grew in urban areas at a higher rate than the suburban area. Consequently, the population density gap between the two areas increased moderately with the ratio of suburban to urban population passing from 27% in 1951 to 35% in 1981. During the latter period, population declined in the urban area while increasing rapidly in suburban areas from 256 inhabitants km^{-2} in 1981 to 342 inhabitants km^{-2} in 2011 with the ratio of suburban to urban population reaching 47% in 2011.

2.2. Land-use data

Land-use data were obtained from the elaboration of two compatible digital maps: (i) the Italian Istituto Geografico Militare (IGM) topographic map scaled 1:25,000 and covering the study area for 1949 and (ii) an original map (scaled 1:25,000 and referring to 2008) derived from photo-interpretation of digital ortho-images released from the Italian National Geoportal (Italian Ministry for Environment, Land and Sea) with a 0.5 m pixel and projected in UTM33 WGS84 system. The IGM map was extensively used in previous studies on landscape composition in central Italy (Geri et al., 2009; Salvati and Sabbi, 2011; Salvati, 2014). Frondoni et al. (2011) provide further information on the IGM map such as a useful cartography for assessing land-use changes and landscape structure on a local scale. A nomenclature including nine homogeneous classes (arable land, crop mosaic, vineyards, olive groves, woodland, pastures, wetlands/water bodies, urban parks and urban areas) with a minimum mapping unit of one hectare has been selected (Salvati, 2014). The produced land-use figures have been checked for consistency with independent statistical (e.g. agricultural and building censuses) and cartographic data (Salvati et al., 2012).

2.3. Landscape spatial analysis

Landscape indicators assess the spatial relationship among patches within a landscape mosaic and evaluate how these patterns and interactions change over time (Frondoni et al., 2011). To provide an in-depth diachronic analysis of landscape transformations in Rome, a total of 26 metrics were considered. Two types of metrics were adopted: (i) 12 traditional metrics assessing landscape composition and structure and (ii) 14 metrics derived from a mathematical morphology framework. Mathematical morphology is a framework for analyzing the shape and form of objects (Soille, 2003). An algorithm to classify uses of land in specific morphological categories is defined by a sequence of logical operations such as union, intersection, complementation and translation (Vogt et al., 2007). Only recently, thanks to the diffusion of geographic information systems and user-friendly softwares, these techniques have been used in landscape ecology and environmental geography applications (Soille and Vogt, 2009).

2.3.1. Landscape metrics

A preliminary, exploratory analysis of land-use changes in the study area was developed using a landscape change matrix (1949–2008) computing the percent unchanged area for each use of land as a proxy of class stability. The 12 traditional landscape metrics include: (i) Class Area (CA), (ii) Mean Patch Size (MPS), (iii) Median Patch Size (MedPS), (iv) Patch Size Coefficient of Variation (PSCoV), (v) Edge Density (ED: the edge to a per unit area basis), (vi) Mean Patch Edge (MPE: the average amount of edge per patch), (vii) Mean Shape Index (MSI: the average perimeter-to-area ratio); (viii) Area Weighted Mean Shape Index (AWMSI) weighting patches according to their size,