

# Investigating Latent Patterns of Urban Planning in Rome and Barcelona through Soil Quality and Desertification Indices

**Ilaria Zambon <sup>1</sup>, Ilaria Tombolini <sup>2</sup> and Luca Salvati <sup>2,3</sup>**

<sup>1</sup> Department of Agricultural and Forestry Sciences (DAFNE), University of Tuscia,  
Via S. Camillo de Lellis, I-01100 Viterbo (Italy);  
Email: [ilaria.zambon@unitus.it](mailto:ilaria.zambon@unitus.it)

<sup>2</sup> Sapienza University of Rome, Department of Architecture and Project,  
Piazzale A. Moro 5, I-00185 Rome (Italy);  
Email: [ilaria.tombolini@uniroma1.it](mailto:ilaria.tombolini@uniroma1.it), [luca.salvati@uniroma1.it](mailto:luca.salvati@uniroma1.it)

<sup>3</sup> Italian Council for Agricultural Research and Economics (CREA),  
Viale S. Margherita 80, I- 52100 Arezzo (Italy);  
Email: [luca.salvati@crea.gov.it](mailto:luca.salvati@crea.gov.it)

## ABSTRACT

*Recent urbanization led to economic changes exerting a relevant impact on peri-urban soils, and rising environmental concern in ecologically fragile districts. Spatial planning contributes to achieve sustainable land-use patterns and to drive optimal location of settlements and infrastructure. However, spatial planning has been sometimes unable to interpret and manage complex processes of metropolitan development, fueling unregulated and mainly dispersed urban expansion on land with less stringent building constraints. Considering Rome and Barcelona as emblematic cases of dispersed urbanization, this study investigates if the current planning system in the two cities has been conceived in a strategic perspective oriented towards conservation and enhancement of soil quality. The highest values of SDI were detected in consolidated urban areas, indicating processes of land take involving buildable, high-quality soils, and in the environmental network surrounding both cities. Land devoted to natural and semi-natural land-use had a lower soil quality. Results of this study may inform regional planning and policies for preservation of high-quality soils, especially under weak (or partial) regulatory constraints.*

**Keywords:** Fringe land, Mediterranean city, Land degradation, Indicators.

**Mathematics Subject Classification:** 19-xx

**Journal of Economic Literature (JEL) Classification Number:** O18, P25, Q15, Q24, R14

## 1. INTRODUCTION

Urbanization plays a decisive role in land take and soil consumption worldwide (Wasilewski and Krukowski, 2004; Serra et al., 2014). In the recent debate, rural areas are sensitive contexts intensively investigated (Biasi et al., 2015; Chorianopoulos et al., 2010; Cuadrado-Ciuraneta et al., 2017; Oueslati et al., 2015) since rural land has been increasingly converted to residential,

commercial and industrial settlements, producing socially polarized and economically unspecialized places (Antrop, 2004; Strange et al., 2006; Salvati et al., 2013). In fact, recent urbanization processes (e.g. sprawl) involved productive and high-quality rural contexts, seriously threatening natural landscapes (Alberti, 2005; Zambon et al., 2018).

Land degradation and soil quality can be described separately even if they are strongly interrelated (Keesstra et al., 2018). First, land is an essential capital for the environment and the development of almost all economic activities (Giddings et al., 2002). High-quality soils have ensured the historical maintenance of a feasible agriculture (Hubacek and van der Bergh, 2006; Corbelle-Rico et al., 2012). Land supports ecosystem functions, exposing its ability to recover when experiencing biophysical and anthropogenic pressures (Montanarella, 2007). However, if pressure exceeds certain limits, it may no longer be able to perform some key functions, becoming sensitive to degradation (Stellmes et al., 2013). Land degradation is perceived as a noteworthy matter of the 21st century owing to its consequences, e.g. affecting agronomic productivity and the environmental system (Blaikie and Brookfield, 2015; Brevik et al., 2015; Usman et al., 2018; Tarolli et al., 2019). In agreement with scientific and policy-oriented literature, land degradation can be interpreted as the outcome of physical and human interactions, which progressively reduce productive capacity of ecosystem services resulting from land (Oliveira et al., 2018).

Due to processes of land degradation, the value of the biophysical environment is inclined to a set of procedures, which are induced by man and consequently impact soil quality (Montanarella, 2007; Hill et al., 2008; Zambon et al., 2018). Together with a significant conversion of natural and agricultural areas to urban uses, soil capacity decreases at the expense of essential ecosystem services (Wu, 2014) and soil quality, because of a degradation of physical, chemical and biological properties (Schjønning et al., 2004). The concept of "soil quality" is quite complex as demonstrated by the fact that there are numerous definitions of this expression, associated primarily with the concepts of "suitability for use" and "functionality" (Sojka and Upchurch, 1999). The latter notion links soil quality to the ability of a given land to perform functions necessary for its intended use. Karlen et al. (1997) provide a more comprehensive definition of soil quality as the ability of a specific type of soil to perform functions supporting the productivity of plants and animals, maintaining or increasing air and water quality within natural or semi-natural ecosystems. Such meaning emphasizes the value of soil in supporting ecosystem functionality and implies an explicit judgment on which soil conditions are adapted to the principles of sustainability. Its link with sustainability configures soil quality not only as an abstract concept, but also as a management objective to be pursued (Bouma, 2001), integrating joint urbanization dynamics and ecological aspects into landscape governance, and thus linking soil quality with a general notion of land quality (Salvati and Zitti, 2012).

The European Commission (EC) has proposed several measures to tackle environmental and social issues linked to urbanization and soil sealing. For instance, in the context of the Thematic Strategy for Soil Protection, the EC underlines the need to develop best practices aimed at mitigating the negative effects of sealing on soil functions (EC, 2006). In 2012, the EC published a report on the most effective mechanisms to limit, mitigate or compensate for soil sealing. Furthermore, in 2014, a study

assessing the feasibility of setting up a framework for measuring progress towards a more sustainable use of land was released (EC, 2014). This report stressed that urbanization (Satterthwaite et al., 2010) is primarily responsible for the consumption of fertile soils that are vital for agriculture and food production. Despite the release of this report, where spatial planning is intended to achieve a more sustainable use of land, tackling land degradation is still a challenge for spatial planners, land system scientists, and policymakers (Akhtar-Schuster et al., 2017; Tóth et al., 2018). Spatial planning mechanisms would consider the value and features of different areas and soil functions, balancing them against opposing objectives and private interests, e.g. urban developers. Since the 1990s, strategic spatial planning has been progressively assumed at the urban-regional scale. Throughout the earlier two decades, the shared purposes of strategic spatial planning have been identified by a approach based on a comprehensible spatial growth to edge both medium- and long-term expansion of urban regions (Healey, 2004; Oliveira et al., 2018). This implies the overview of an integrated spatial logic regarding land-use, natural resource valorization, and major infrastructure development, e.g. housing and transportation (Albrechts and Healey, 2003; Demazière and Serrano, 2017).

Strategic spatial planning tools were selected in this contribution as interpretative keys to investigate the progressive development of conservation measures in favor of land. Strategic spatial planning is mainly intended as a 'vision' development, involving various actors and being grounded in the socio-political and institutional complexity typical of urban systems. It is also influenced by power configurations and governance agreements (Oliveira and Hersperger, 2018). Furthermore, strategic spatial planning processes are frequently non-binding, and are consequently less custom-made to officially binding spatial planning and policy tools, therefore offering more returns in a systematic review and simplifications that will help pushing both scientific frontiers and policymaking agendas.

Based on these premises, the aim of the present study is to investigate whether the current planning system of two Mediterranean cities, Rome and Barcelona, has been conceived in a strategic perspective oriented towards conservation and enhancement of the environmental quality of "soil resource", particularly of the unbuilt area, through an original methodology informing land quality, sustainable land management and urban containment. Land planning official data sources for the two cities differ at the local scale; however, based on common planning instruments, a standardization procedure of planned land-use classes was adopted for comparing Rome and Barcelona, being two relevant examples of urban dispersion in a region sensitive to land degradation, such as Mediterranean Europe.

## 2. MATERIAL AND METHODS

### 2.1. Study area

The municipality of Rome and Barcelona were used as study areas in the present paper. These two cities are comparable (e.g. located about the same latitude, similar urban dispersion processes), but also diverge due to different dynamics, e.g. in terms of land management and spatial planning. Rome municipality is separated into 19 urban districts which covers approximately 1285 km<sup>2</sup>. The municipal territory is particularly large, having incorporated areas abandoned for centuries. Population density is not very high (2233 inhabitants/km<sup>2</sup>), due to the presence of green land scattered in the area. Rome is

unique in the Western world for the vastness of the countryside that represents the peripheral crown of the city. The municipality occupies a heterogeneous territory, with mixed impervious and semi-natural land contrasting a compact historical center, where the most important functions are concentrated. With population movements, correspondingly urban morphology has increasingly transformed.

Recent dispersed urbanization in Rome has frequently involved out-of-plan land, with partial regulatory constraints or with mixed/ambiguous destination. Land consumption in Rome was found high during both “compact growth” driven by population increase, and in the most recent time interval characterized by stable population and urban sprawl. Rome’s growth has been made by informal settlements, representing how primary sprawl processes have revealed in a deregulated urban background, comparatively lacking an effective spatial planning agenda (Costa et al., 1991). Notwithstanding urban dispersion, Rome is a city with high levels of (i) urban congestion, (ii) population concentration and (iii) economic polarization. Firstly, resident population decreased only recently in the core municipality, as observed earlier in other Mediterranean cities (Chorianopoulos et al., 2010). Rome’s Master Plan (1993-2008) recognized tourism and culture as two chief sectors endorsing urban development. In 2008, Rome approved after more than 40 years a new strategic Master Plan, including guidelines and procedures to orient the metropolitan development towards a more comprehensible urban design, offering consideration to the matters of decentralization and polycentric urban functions, establishment of suitable services in suburban areas, environmental protection, cultural and historical heritage.

Barcelona, whose central city is partitioned into 10 urban districts, covers an area of 101.4 km<sup>2</sup> and has a population density of 15,984 inhabitants/km<sup>2</sup>. Its topography played a major role in the evolution of the urban form, being dominated by two mountain ranges (the Litoral range, with elevation above 700 m, and the pre-coast range, with elevation above 1700 m) and two flat areas agreeing to Besos rivers and the valleys of Llobregat. The actual form is shaped by the progressive saturation of the inner core that limits future growth of Barcelona municipality and its conurbation (Serra et al., 2014). Soil occupation, loss in agricultural and forest land, decrease in settlement density and the high amount of bare land awaiting further development were all important signals of landscape transformations (Salvati et al., 2013; Barreiro-Lostres et al., 2017). Land-use changes in the area testify an outward expansion of the consolidated area thanks to the high level of car ownership, the relocation of industrial and retailing activities to fringe lands, the development of transport infrastructure and the conversion of second homes into primary residences (Cuadrado-Ciuraneta et al., 2017).

Analyzing the levels of soil sealing (from '0' values, with light red, coinciding with natural and agricultural areas up to high sealing values, with dark red, for densely urban areas), the municipality of Barcelona appears strongly urbanized (Figure 1). The municipality of Rome is much more expanded, then emerge more light colors, e.g. the natural areas that surround the urban heart of the Italian capital.

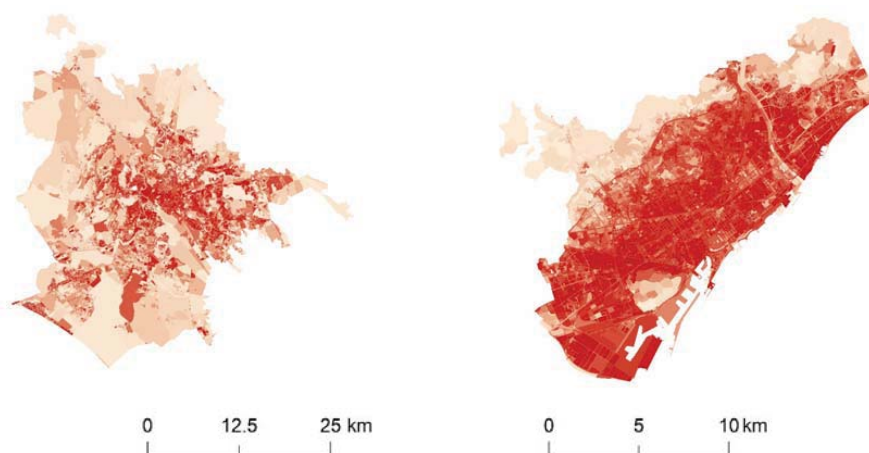


**Figure 1.** Degree of soil sealing in the municipality of Rome (left) and Barcelona (right); darker tonalities indicate a higher intensity of soil sealing.

## 2.2. Data and variables

### 2.2.1. Spatial planning and land zoning

Land-use classes were extrapolated from digital maps illustrating the most recent strategic master plan of the two investigated cities. In the case of Rome, these were extracted from the “Systems and Components” of the general regulatory plan, approved by the City Council with Resolution no. 18 dated 12/2/2008, which governs the physical and functional transformation activities of urban relevance in the municipal territory. The Plan pursues the objectives of territorial redevelopment and enhancement, according to the principles of environmental sustainability and in compliance with the criteria of effectiveness, publicity and simplification of administrative action, within the framework of current legislation (Casini, 2009). In the case of Barcelona, the Urban Map of Catalonia (MUC) as a strategic tool for the implementation of planning policies was used at the municipal scale, which includes all the general planning documents in force on 1st January 2018 in the territory of Catalonia and those in force on 1st July 2017 in the metropolitan area of Barcelona. It is a summary map that allows investigation of the basic attributes of urban planning in the region, contributing to solve the inherent difference in codification, language and representation characterizing Barcelona’s regional plans (Generalitat de Catalunya, 2016).

### 2.2.2. Soil quality

The Environmentally Sensitive Area (ESA) framework was adopted in this study with the aim to provide a comparative and comprehensive assessment of soil quality at the local scale in two regions of Southern Europe (Rome and Barcelona), following the same method applied by Salvati et al. (2014). In order to assess soil resources and degradation processes, the Soil Quality Index (SQI) proposed by the European Environment Agency and based on Kosmas et al. (1999) was adopted in the present study and calculated using the information contained in the European Soil Database produced by the Joint Research Centre (Finke et al., 1998; Panagos et al., 2012). The SQI is a composite index based on four variables: parent material, soil depth, texture and slope angle. A set of

sensitivity scores derived from statistical analysis and fieldwork performed by authors cited in Kosmas et al. (1999) was assigned to each analyzed variable. The SQI was thus estimated as the geometric mean of the different scores attributed to the four selected variables, ranging from 1 (indicating the lowest contribution to land degradation sensitivity and, thus, the highest soil quality) to 2 (indicating the highest contribution to land degradation sensitivity and, thus, the lowest soil quality). The index was made available in raster format and disseminated at a 1 km<sup>2</sup> spatial resolution (Salvati et al., 2008). Despite its acknowledged importance as a tool to assess soil sensitivity to degradation, the SQI presents shortcomings because of the restricted number of considered variables (Ferrara et al., 2014; Salvati et al., 2016). For this reason, the analysis integrated land quality to obtain a more general and 'holistic' assessment of soil quality, referring to basic soil functions such as fertility, given the contribution of physical and chemical attributes and of external environmental factors to overall soil health.

### **2.2.3. Land quality and sensitivity to degradation**

An SQI indicator could improve the precision of soil quality assessment. However, land quality is a multi-dimensional component associated to land degradation processes, being intimately related with the socioeconomic context at the local scale and representing the ability of a definite kind of soil to sustain agricultural production and/or natural vegetation (Sposito and Zabel, 2003). In this sense, a score index, used in the Environmentally Sensitive Area (ESA) framework to assess the level of land quality and sensitivity to degradation (SDI), was developed and validated on the field (Lavado Contador et al., 2009). The composite SDI indicator provides a more comprehensive assessment of soil quality than the SQI index, specifically addressing the issue of soil quality. A full description of the methodology is reported in a report of European Environment Agency (2008). The SDI ranges between 1 (the highest land quality and the lowest sensitivity to degradation based on the local environmental context) and 2 (the lowest land quality reflecting the highest sensitivity to degradation). The European Environment Agency (2008) prepared a raster map (1 km<sup>2</sup> grid) of the SDI covering homogeneously the study area and computing 9 biophysical layers: four variables assessing soil quality (parental material, soil depth, texture, slope), climate quality based on the aridity index (the ratio of annual precipitation to annual reference evapotranspiration rate), and four variables assessing vegetation quality (protection from soil erosion, resistance to drought, plant cover, vegetation resistance to fire). Input layers were derived from official data sources referring to the late 1990s and covering homogeneously the Mediterranean European region at a fine spatial resolution (European Environment Agency, 2008). Values of each layer were ranked in the scale 1-2 and the SDI was calculated as the geometric mean of the score of all input layers.

## **2.3. Data analysis**

A land-use nomenclature system that unifies the zoning classification extrapolated from strategic plans of Rome and Barcelona was adopted (Table 1 and Figure 2), consisting of five classes:

- (i) defined contexts regulated by restrictions or with constrained urban development (in red, category 1);

- (ii) the consolidated urban context (in grey, category 2) goes to concentrate in the most compact and dense urban area in the two analyzed cities. Consolidated urban areas, especially linked to historical city and made up of services and infrastructural systems, coinciding with the consolidated settlement system with non-urbanized land destined for economic activities;
- (iii) restructuring areas, which are expected to be restored and redeveloped (yellow, category 3);
- (iv) transforming urban areas, which will undergo residential development (in orange, category 4);
- (v) the environmental system including green spaces, protected natural areas, water and coastal environments (in green, category 5). In this last category, rural areas are included (e.g. 'Agro Romano' is the countryside of the municipality of Rome).

Based on a descriptive analysis of the categories derived from the strategic plans, the different scale among the two cities disclosed that the Roman metropolitan area is much larger since it occupies a larger area destined for the natural and environmental system. Categories of restructuring and transformation fill the gaps among the consolidated urban areas, or merging with other peripheral areas, thus delineating new urban boundaries. Zoning classes are different from land-use categories, as the latter indicates the current land-use, while Strategic Plans indicate with the "zoning" class which proposed land-use will have certain contexts.

| Zoning class                 | Our code | Description of land-use classes in the strategic plans                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              |          | Rome                                                                                                                                                                                         | Barcelona                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Conservation-protection area | 1        | Areas of constrained transformability of the environmental system<br>Areas of constrained transformability of services and infrastructures<br>Structuring projects / protected natural areas | Urban - mixed, conservation<br>Not urbanizable, protection<br>Systems, protection<br>Not urbanizable, Rustic                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Consolidated area            | 2        | Service and infrastructure system<br>Settlement system - Consolidated area<br>Settlement system - Historical city                                                                            | Urban - economic activity, services<br>Not urbanizable - Not urbanizable, Activity authorized<br>Urban - economic activity, industrial<br>Urban - Residential, isolated houses<br>Urban - Residential, grouped houses<br>Urban - Residential, traditional urban<br>Systems, Equipment<br>Systems, Railway<br>Systems, Public donor housing<br>Systems, technical and environmental services<br>Systems, Road, Other road in non-urbanizable soil<br>Systems, Road, Other road in urban soil<br>Urban - Residential, Old Town |
| Restructuring area           | 3        | Settlement system - Cities to be restored<br>Settlement system - Structuring projects - Local central units - Public spaces to be redeveloped                                                | Urban - Mixed, Mixed                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Transformation area          | 4        | Settlement system - urban transformation                                                                                                                                                     | Urbanizable, residential development<br>Urbanizable, Urbanizable not delimited<br>Urban - Residential, open order<br>Systems, Port<br>Systems, Roads, Structural axes                                                                                                                                                                                                                                                                                                                                                        |

|                      |   |                                                |                                                    |
|----------------------|---|------------------------------------------------|----------------------------------------------------|
| Environmental system | 5 | Environmental system - Waters                  | Urban - Mixed, Transformation Systems, Green areas |
|                      |   | Environmental system - Agro Romano             | Systems, Coastal                                   |
|                      |   | Environmental system - Protected natural areas | Systems, Hydrographic                              |

Table 1. The land-use nomenclature system adopted in the present study.

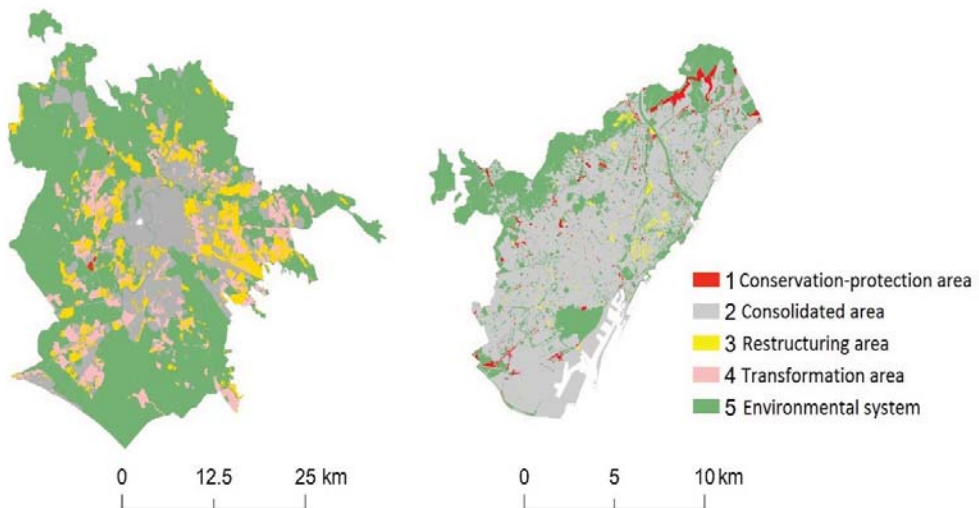


Figure 2. Maps of Rome and Barcelona following the elaborated categories from the strategic plans.

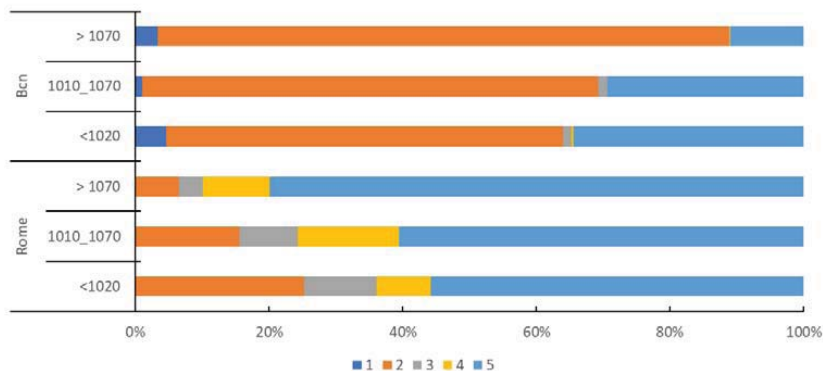
The raster files were re-classified using ArcGIS 10.5.1 (ESRI Inc., Redwoods, USA), defining homogeneous classes for the two key indicators (SQI and SDI), comparing appropriately the two study contexts. Since the aim of this study is to investigate whether spatial planning mechanisms consider the characteristics of different land areas and soil functions, the raster maps of SQI and SDI were then overlaid to the planned land-use maps of Rome and Barcelona using a GIS program. SQI values were defined into three classes with decreasing soil quality (high quality, intermediate quality and low quality of soil). SDI was organized in four classes. As already described, SDI ranges among 1 (the highest land quality and the lowest sensitivity to degradation based on the local environmental context) and 2 (the lowest land quality reflecting the highest sensitivity to degradation). In the two investigated regions, SDI assumes - on average - a value between 1.1 and 1.3, exposing a rather high land quality. In this regard, four classes of SDI were structured: values less than 1.1 indicate contexts with a comprehensive high quality of land; more intense values, as in the two central intervals between 1.1 and 1.2 and among 1.2 and 1.3 specify intermediate quality; highest values of SDI ( $> 1.3$ ) designate worst land quality. For each soil class both of SDI and SQI, relative values, expressed in percentages, define the ratio of the surface area occupied by each zoning category on the total area of all the zoning classes. Average SDI and SQI scores were calculated for each class of planned land-use, making it possible to derive information on the biophysical conditions and land quality characterizing the codified zoning classes.

### 3. RESULTS

For the value of SQI, Rome and Barcelona recorded different values. The values of SQI by type of zoning were expressed in terms of surface area occupied (hectares) and in percentage terms, calculating a ratio among hectares detected in a specific class of SQI compared to the total surface area designated for the considered zoning area (Table 2). Allowing an accurate comparison between Rome and Barcelona, these categories were further reclassified. First, the total extension of natural areas, including the zoning category '5' in our classification, in Rome is huge if compared to that of Barcelona (about 72,740 vs 3,900 hectares). Nonetheless, this data depends also on the fact that the municipality of Rome is much larger than Barcelona (about 123,550 vs 13,300 hectares), since Barcelona is one-tenth of Rome's region. Observing each zoning categories, the area devoted to conservation and protection (category '1') extends across a higher surface area concerning the high degree of soil quality in Barcelona (168.85 hectares), while this zoning area occupies about 90 hectares of high-quality soils in Rome. In both absolute and percentage terms, the highest values of SQI exposed that the highest soil quality can be found in the environmental context (category '5') in Rome (56%), while the consolidated area (category '2') covers the largest areas of high soil quality in Barcelona (59%), followed by the environmental contexts (34%). However, 80% of contexts with low soil quality was found into the environmental system in Rome. For Barcelona, contexts with lesser soil quality were found in the consolidated contexts (86%).

Table 2. SQI results (hectares and percentages) in Rome and Barcelona by zoning class (see Table 1).

| Zoning class | Rome            |                      |             | Barcelona    |                      |             |
|--------------|-----------------|----------------------|-------------|--------------|----------------------|-------------|
|              | High quality    | Intermediate quality | Low quality | High quality | Intermediate quality | Low quality |
|              | <i>Hectares</i> |                      |             |              |                      |             |
| 1            | 89.50           | 0.31                 | 1.42        | 168.85       | 90.01                | 40.91       |
| 2            | 24312.00        | 2087.64              | 870.57      | 2164.45      | 5803.17              | 1062.54     |
| 3            | 10501.43        | 1172.73              | 466.96      | 44.98        | 111.78               | 1.79        |
| 4            | 7842.86         | 2044.26              | 1346.80     | 10.73        | 0.00                 | 1.04        |
| 5            | 53927.04        | 8143.26              | 10668.58    | 1257.10      | 2505.40              | 136.36      |

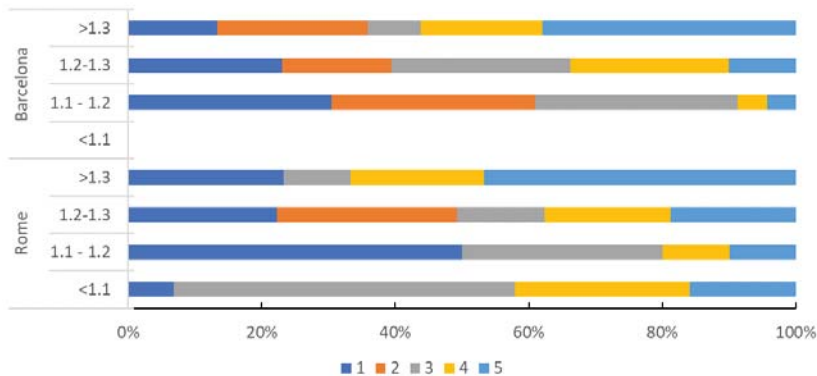


For the SDI, Rome and Barcelona are compared with equal intervals (Table 3). In Rome, the largest surface area concerns the consolidated zones (category '2'), particularly in a class < 1.1, but also with

more intense values as in the interval between 1.2. and 1.3. In addition to this category, its environmental system has a huge surface area, especially for the medium-high category (1.2-1.3). In percentage terms, the class interval among 1.2 and 1.3 is occupied more frequently by the consolidated system. While, the areas to be restructured and/or requalified affected more the lower categories of SDI. In Barcelona, however, the same process occurred. The highest values of SDI (> 1.2) were detected in the consolidated area and in the environmental network surrounding both cities. In percentage terms, all the categories concern above all the medium-high range of SDI, even if the environmental category records a strong percentage of surface areas falling within the highest SDI category (71%).

*Table 3.* SDI results (higher values indicate worst land quality) in hectares and percentages in Rome and Barcelona.

| Zoning class | Rome    |           |          |         | Barcelona |           |         |        |
|--------------|---------|-----------|----------|---------|-----------|-----------|---------|--------|
|              | <1.1    | 1.1 - 1.2 | 1.2-1.3  | >1.3    | <1.1      | 1.1 - 1.2 | 1.2-1.3 | >1.3   |
| 1            | 0       | 0         | 90.92    | 0.31    | 0         | 37.02     | 118.48  | 113.25 |
| 2            | 11697.8 | 688.08    | 12934.77 | 897.31  | 0         | 920.11    | 4818.24 | 974.31 |
| 3            | 2573.65 | 150.9     | 7723.87  | 617.73  | 0         | 1.7       | 60.21   | 32.59  |
| 4            | 1460.99 | 143.52    | 7174.01  | 1408.46 | 0         | 0.18      | 2.86    | 7.49   |
| 5            | 3663.92 | 3015.91   | 54160.52 | 4272.52 | 0         | 431.91    | 1961.68 | 791.8  |



Average and standard deviation were applied within each zoning class to compare the two case studies (Table 4). In statistics, the average is a single numerical value that briefly describes a set of data, since it is calculated by adding all available values and dividing the result by the total number of data. The standard deviation is an indicator of the dispersion of a distribution of values. If the standard deviation is large, the values of the distribution are dispersed; conversely, if the standard deviation is small, the values are concentrated close to the mean. The average is very high for rural contexts in Rome, as the plot for each type of SDI and SQI is very large. On the other hand, the parcels in Barcelona are on average small with a higher average in the agricultural context (although not as in Rome). The standard deviation assumes higher values in Rome, especially in rural areas, while in Barcelona the character of the consolidated cities emerges more, assuming high values for the consolidated city.

Table 4. SDI results (higher values indicate worst land quality) in hectares and percentages in Rome and Barcelona.

| SQR     |       |           |       |       |  | Barcelona |           |       |       |  |
|---------|-------|-----------|-------|-------|--|-----------|-----------|-------|-------|--|
| Rome    |       |           |       |       |  |           |           |       |       |  |
| Average | <1020 | 1020-1070 | >1070 | Total |  | <1020     | 1020-1070 | >1070 | Total |  |
| 1       | 6.9   | 0.1       | 0.4   | 4.6   |  | 0.5       | 0.2       | 0.3   | 0.3   |  |
| 2       | 1.4   | 1.1       | 1.2   | 1.3   |  | 0.6       | 0.6       | 3.7   | 0.7   |  |
| 3       | 1.6   | 1.6       | 1.7   | 1.6   |  | 0.2       | 0.3       | 0.3   | 0.3   |  |
| 4       | 0.8   | 0.9       | 1.3   | 0.9   |  | 0.9       | -         | 1.0   | 0.9   |  |
| 5       | 54.3  | 34.8      | 103.6 | 54.7  |  | 1.3       | 1.1       | 0.8   | 1.1   |  |
| Total   | 2.7   | 2.6       | 6.2   | 2.9   |  | 0.7       | 0.7       | 2.1   | 0.7   |  |

| SDI    |       |           |       |       |  | Barcelona |           |       |       |  |
|--------|-------|-----------|-------|-------|--|-----------|-----------|-------|-------|--|
| Rome   |       |           |       |       |  |           |           |       |       |  |
| Dst    | <1020 | 1020-1070 | >1070 | Total |  | <1020     | 1020-1070 | >1070 | Total |  |
| 1      | 10.5  | 0.1       | 0.5   | 9.0   |  | 2.8       | 0.4       | 0.6   | 1.7   |  |
| 2      | 8.3   | 5.1       | 3.0   | 7.9   |  | 3.0       | 5.5       | 13.6  | 5.3   |  |
| 3      | 4.4   | 4.2       | 4.8   | 4.4   |  | 0.4       | 0.6       | 0.2   | 0.5   |  |
| 4      | 2.2   | 2.5       | 4.8   | 2.5   |  | 1.1       | -         | -     | 1.1   |  |
| 5      | 251.7 | 205.5     | 391.0 | 258.2 |  | 8.8       | 6.4       | 2.5   | 7.0   |  |
| -Total | 43.4  | 44.2      | 87.9  | 46.8  |  | 4.6       | 5.5       | 9.7   | 5.4   |  |

| SDI     |      |           |         |      |       |      |           |         |      |       |
|---------|------|-----------|---------|------|-------|------|-----------|---------|------|-------|
| Average | <1.1 | 1.1 - 1.2 | 1.2-1.3 | >1.3 | Total | <1.1 | 1.1 - 1.2 | 1.2-1.3 | >1.3 | Total |
| 1       | -    | -         | 5.3     | 0.2  | 4.8   | 0.0  | 0.3       | 0.2     | 0.8  | 0.3   |
| 2       | 1.1  | 2.0       | 1.4     | 1.2  | 1.3   | 0.0  | 1.1       | 0.6     | 0.6  | 0.6   |
| 3       | 1.1  | 1.5       | 1.7     | 2.0  | 1.5   | 0.0  | 0.3       | 0.3     | 0.2  | 0.3   |
| 4       | 0.8  | 1.0       | 0.8     | 0.8  | 0.8   | 0.0  | 0.2       | 0.6     | 0.8  | 0.7   |
| 5       | 12.3 | 41.9      | 64.9    | 27.4 | 47.9  | 0.0  | 1.1       | 1.0     | 1.6  | 1.1   |
| Total   | 1.3  | 6.0       | 3.5     | 2.4  | 2.7   | 0.0  | 1.0       | 0.6     | 0.8  | 0.7   |

| SDI   |      |           |         |      |       | Barcelona |           |         |      |       |
|-------|------|-----------|---------|------|-------|-----------|-----------|---------|------|-------|
| Rome  |      |           |         |      |       |           |           |         |      |       |
| Dst   | <1.1 | 1.1 - 1.2 | 1.2-1.3 | >1.3 | Total | <1.1      | 1.1 - 1.2 | 1.2-1.3 | >1.3 | Total |
| 1     | -    | -         | 9.6     | 0.1  | 9.2   | 0.0       | 0.4       | 0.7     | 3.7  | 1.6   |
| 2     | 7.5  | 7.7       | 7.9     | 3.4  | 7.5   | 0.0       | 3.3       | 4.9     | 2.3  | 4.5   |
| 3     | 3.5  | 3.5       | 4.6     | 4.8  | 4.3   | 0.0       | 0.5       | 0.7     | 0.4  | 0.6   |
| 4     | 2.3  | 2.0       | 2.2     | 2.4  | 2.2   | 0.0       | 0.0       | 0.7     | 0.9  | 0.8   |
| 5     | 66.1 | 185.6     | 278.5   | 99.3 | 228.0 | 0.0       | 6.6       | 7.3     | 5.2  | 6.9   |
| Total | 11.5 | 62.2      | 54.2    | 23.6 | 42.3  | 0.0       | 4.3       | 5.3     | 3.2  | 4.9   |

#### 4. DISCUSSION AND CONCLUSIONS

A more effective integration of economic, societal and environmental dimensions in spatial planning ensures the achievement of truly sustainable development paths at both regional and local scale (Zambon et al., 2018). Urban expansion into fertile and productive soils would require continuous attention through e.g. interventions in support of the stability of ecosystem balance and sustainable land-use (Biasi et al., 2015, 2017; Colantoni et al., 2016b; Demazière et al., 2017). It is necessary to effectively challenge the loss of fertile soils through the development of calibrated medium and long-term intervention strategies (Zitti et al., 2015). In this regard, data integration that can be achieved

using composite indexes, e.g. SQI and SDI, supports strategic planning aimed at achieving intelligent soil management.

Preserving soil quality and mitigating land degradation is a pivotal scope of local planning and environmental management in Mediterranean cities (Ceccarelli et al. 2014; Ferrara et al., 2014; Salvati et al. 2013d; Salvati and Zitti 2012). The present study explains an original methodology informing land quality, sustainable land management and urban containment approaches in two Mediterranean cities (Zambon et al., 2018; Ceccarelli et al. 2014; Salvati and Zitti 2012). Results of our study indicate that the intrinsic fragility of Mediterranean landscapes - thanks to soil degradation, climatic drought and aridity, forest fires and anthropogenic pressure (Salvati et al., 2008; Colantoni et al., 2015a; Keesstra et al., 2016; Prosdocimi et al., 2016) - requires a serious reflection on the irreversible transformation of agricultural soils and the loss of land providing local food and ecosystem services (Colantoni et al., 2015b; Delfanti et al., 2016; Kosmas et al., 2013).

The current structure of both cities includes open spaces that, although highly fragmented, would be suitable for non-intensive agricultural production included in a network of agro-forest relict land (Monarca, 2011; Barbati et al., 2013; Biasi et al., 2015). In these regards, peri-urban areas in both cities are characterized by a production potential that is currently underestimated, as it is threatened by the low value of the agricultural sector and land dynamics driven by real estate speculation (Salvati et al., 2012). Giving a new socio-environmental role to green spaces in metropolitan regions is a key opportunity to halt the irreversible transformation of fringe land and the consumption of fertile soils.

For the value of SQI, Rome and Barcelona recorded different values. In Rome, natural areas occupied a large extension if compared to Barcelona, which it is one-tenth of Rome municipality. Although, conservation and protection areas extend along a higher surface area concerning the high degree of soil quality in Barcelona, while this zoning area in Rome occupies about 90 hectares of high-quality soils. Following SQI results, the highest soil quality in Rome can be found in the environmental context (56%); while, the highest soil quality extends to the consolidated city in Barcelona (59%), followed by the environmental areas (34%). Furthermore, for low soil quality, 80% was observed into the Roman environmental system and 86% was detected in the consolidated contexts of Barcelona. Based on SDI results, the largest surface area in Rome concerns the consolidated zones, mainly in the class  $SDI < 1.1$ , but also with more intense values as in the interval 1.2-1.3. In addition, the Roman environmental system has a huge surface area, especially for the medium-high category (1.2-1.3). In percentage terms, the class interval among 1.2 and 1.3 was occupied more recurrently by the consolidated city. Whereas, restructured and/or requalified areas affected more the lower categories of SDI. Similar results occurred in Barcelona, where the highest values of SDI ( $> 1.2$ ) were perceived in the consolidated area and in the environmental network surrounding both cities. In percentage terms, all the categories concern primarily the medium-high range of SDI, although the environmental category archives the 71% of surface areas falling within the highest SDI category.

Results of this study also suggest how the analysis of urban patterns and processes can benefit from comparative studies in cities, characterized by a different degree of planning regulation, foundation

age, urban structure and socioeconomic constraints (Colantoni et al., 2016a). Spatio-temporal trends in land take indicators can provide a base to assess formal (and informal) urban expansion (Oueslati et al., 2015). Their informative role in design of policies for urban containment and sustainable growth is relevant (Colantoni et al., 2016b; Salvati et al., 2016; Zitti et al., 2015). The application of the two indicators considered (SQI and SDI) is key for territorial planning, offering a correct urban (and peri-urban) management. Soil quality and the sensitivity to desertification are issues of current importance which must be included in scenarios analysis and regional strategies (Dumanski and Pieri 2000; Salvati and Zitti 2012; Salvati et al., 2013; Ceccarelli et al., 2014; Ferrara et al., 2014). Since land consumption and degradation processes stand as the most thoughtful dangers to urban sustainability, particularly in high quality soil sealing (Siebielec et al., 2011; Artmann, 2014; Robinson et al., 2017), the knowledge of spatially-varying, multifaceted relationships among urban expansion, metropolitan structure and land-use is particularly demanding. In this way, prevention and mitigation actions must be increasingly targeted at the areas to be protected (Smith et al., 2016), both for their soil quality value and for their greater vulnerability (Colantoni et al., 2015b). Moreover, the comparison between these two Mediterranean cities seem comparable since they expose similar needs but still linked to place specific factors (Zambon et al., 2017). A comprehensive understanding of some central issues of land susceptibility in combined metropolitan frameworks involves enduring monitoring, informed policies and practical responses (Steer, 1998; Dumanski and Pieri, 2000; Veron et al., 2006; Salvati et al., 2012). Environmental characteristics sensitive to complex trajectories of urban growth are assuming a key role when unravelling interactions e.g. among ecological factors and political actions (Ibanez et al., 2008). Development of urban scenarios is finally useful in containing significant impact of metropolitan expansion in complex socio-environmental systems.

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