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MEASURING URBAN SUSTAINABILITY: AN INTEGRATED METHODOLOGY TO ASSESS THE BENEFITS OF URBAN GREEN AREAS

Tutor

Prof. *Luigi Portoghesi*

PhD student

Dott.ssa *Emanuela Masini*

Abstract

Ongoing urbanization and population growth affect physical, ecological and socio-economic processes within and beyond urban areas. In this context, the physical spatial structure of cities serves as a basis for understanding urban areas in their entirety in order to achieve a sustainable urban growth. This PhD thesis deals with the problem of urban expansion and green space fragmentation. The well-being of urban citizens appears to be closely linked to a balanced growth of urban areas and to the availability of green spaces. Given the current trend of urbanization, the availability of Urban Green Areas (UGAs) is an important indicator of environmental quality. The main objectives are: (I) providing an understanding of socioeconomic drivers shaping urban growth (m^2/inhabitant) in the European urban context; (II) developing a methodology identifying the elements sensitive to urbanization (urban sprawl) to improve the sustainability of urban development; (III) locating lands, that, if converted into connected elements, would enhance the connectivity of the existing Green Infrastructures (GIs); (IV) defining an index of priorities for increasing the GI territory; (V) assessing the distance between urban settlements and the closest Urban green areas (UGAs) access point. For the first time in the literature, a methodology combining the analysis of the distance to UGAs with the assessment of accesses point and UGAs usability has been proposed. The series of steps (III) to (VI) is applied on the municipality of Rome (Italy) as a case study.

Key words: urbanization, ecological connectivity, urban green areas, ecosystem services, accessibility.

Sintesi

Questa tesi affronta il problema dell'espansione urbana e della frammentazione dello spazio verde. Il benessere dei cittadini urbani sembra essere strettamente legato a una crescita equilibrata delle aree urbane e alla disponibilità di spazi verdi. Data la tendenza attuale dell'urbanizzazione, la disponibilità di aree verdi urbane (UGAs) è un importante indicatore della qualità ambientale. Gli obiettivi principali sono: (I) fornire una comprensione dei driver socioeconomici che modellano la crescita urbana (m^2/abitante) nel contesto urbano europeo; (II) sviluppo della metodologia che identifica gli elementi sensibili all'urbanizzazione (espansione urbana incontrollata) per migliorare la sostenibilità dello sviluppo urbano; (III) localizzare le terre, che, se convertite in elementi connessi, migliorerebbero la connettività delle infrastrutture verdi (GI) esistenti; (IV) definire un indice di priorità per aumentare il territorio delle GI; (V) valutare la distanza tra insediamenti urbani e il punto di accesso della UGA più vicino. Per la prima volta in letteratura, è stata proposta una una metodologia combinata della distanza alle UGAs con la valutazione del punto di accesso e della fruibilità delle UGAs. La serie di passaggi (da III) a (VI) è applicata al comune di Roma (Italia) come caso di studio.

Parole chiave: urbanizzazione, connettività ecologica, aree verdi urbane, servizi ecosistemici, accessibilità.

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1. Introduction

In the last century, a continuous increase of population and urban areas was observed worldwide (Pacione, 2009). More than half of the world's population (54%) currently lives in urban areas (United Nations 2014) and this proportion is expected to grow to 66% by 2050. A comparable trend is expected for Europe, with 73% of its population actually residing in urban areas, likely overcoming 80% by 2050 (United Nations 2014). Therefore, urbanization is one of the most relevant factors causing landscape changes, affecting ecosystem health and human well-being for the generations to come (Antrop 2004). The many-sided economy-environment relations observed in dynamic socio-ecological systems contribute to social problems, determining an increased vulnerability of places and people (Pacione 2009). Urbanization-driven land-use changes in wealthiest countries usually determine a progressive reduction of agricultural land and a consequent moderate expansion of natural land including forests (EEA 2006; EEA 2011; Haase et al. 2014; Paulsen 2014; Breuste et al. 2015). Compact and dispersed expansion of urban settlements represent the two most commonly observed paths of urbanization.

Compact urban growth is associated with settlement concentration and a medium-high level of population density, while dispersed urban growth occurs when people tend to move to suburban areas with a consequent decline in the population living in core cities (Zitti et al. 2015).

In last decades several cities in Europe have undergone a very fast transition from the traditional 'compact growth' model to more 'dispersed' ones, characterized by huge expansions of the built-up areas around the core (Schneider and Woodcock, 2008; Salvati et al., 2012, 2016; Duvernoy et al., 2018). The rapid and uncontrolled scattering of urban settlements is defined as "urban sprawl" (EEA, 2006). Urban sprawl increased rapidly (by 1.7% per year between 2006 and 2009, see EEA, 2016) and is expected to continue throughout all European countries.

Many studies show that urban sprawl has long-lasting detrimental effects on environmental, economic and social functions (Ewing et al., 2008; Johnson, 2001; Doygun, 2009; Barbero-Sierra et al., 2013; Wilson and Chakraborty, 2013; Sallustio et al., 2015; EEA, 2016). For topographical and economic reasons, agricultural land represents the most widespread, cheap and suitable land cover type for building in Europe (Kasanko et al. 2006; EEA, 2006; Frondoni et al., 2011). Land taken by urban and other artificial land development was therefore formerly occupied, to a large extent, by agricultural land (Camagni et al. 2002; Quatrini et al. 2015). It was demonstrated that the conversion of productive farmland with fertile soil into urbanized areas, especially with low-density settlements, may lead to inefficient land allocation (Frenkel 2004). The efficiency in the use of land is a representative concept adhering to the sustainable development paradigm. This trends of urban sprawl in many parts of Europe contradict the goals of sustainable development established in the 2030 Agenda for Sustainable Development of the United Nations (2014) and more recently in the Urban Agenda for the European Commission, (2016). Thus, sustainability will become an increasingly more critical issue as sprawl advances (Haber, 2007; Pili et al., 2017).

There is a great interest in devising meaningful measures for urban sprawl. For this purpose, the measures “urban density”, “land use efficiency”, “per capita land use consumption”, etc have been used (e.g., Pendall, 1999; Masek et al., 2000 and Barbosa et al. 2015). Land use efficiency is operatively linked to the ratio of developed land to resident inhabitants and can be assessed using the ratio between built-up area and resident inhabitants (Zitti et al. 2015). Being sprawl defined as dispersed and possibly inefficient urban growth, several indicators that examine the critical impact of urbanization on land resources have been developed (Hasse and Lathrop 2003). Despite new and more complex indexes have been recently introduced (Luck and Wu 2002; Solon 2009), the amount of built-up area per-capita has been demonstrated to be a particularly suited indicator for diachronic studies of urbanization-driven land consumption at both local and regional scales (e.g. Quatrini et al. 2015). A thorough analysis of land-use efficiency should focus on regional (administrative regions, economic districts, etc) and, especially, local scales (e.g. municipalities), since these administrative units have the authority to allocate land to the most efficient uses, screening alternative choices for long-term environmental sustainability and residents' well-being (Giannakourou 2005; Hoymann 2011). In this perspective Nature-Based Solutions (NBS) are crucial elements to support the growing interest in providing sustainable urban design and planning (European Commission 2015). NBS encompass a wide range of interventions to bring more, and more diverse, natural features and processes into cities and landscapes. Specifically, NBS has an important role to play in sustainable urbanization, by supporting the implementation and optimization of green and grey infrastructures (European Commission 2015; Sanesi et al. 2016).

The Green Infrastructure (GI) approach applies key principles of landscape ecology to urban environments, specifically: a multi-scale approach with explicit attention to pattern-process relationships, and an emphasis on connectivity (Ahern, 2007; Jim 2013; Marchetti et al. 2015). The GI-driven method is based on the primary concept that an interconnected network of green features enhances a city's resilience (e.g. climate mitigation, run-off, and flood peak reduction) and brings added benefits (Dige 2011). Green space elements should, ideally, be designed and linked to form a system that includes ecologically important 'hubs' as well as key landscape linkages whilst functioning as an integrated whole (Walmsley 2006). Morphological Spatial Pattern

Analysis (MSPA) allows to classify elements of the GI into its key components; in particular 'hubs' (core areas), and 'links' (bridges) (Soille and Vogt 2009). MSPA provides the tools to classify structural connecting elements of the GI and examine their connectivity at any spatial scale (Vogt et al. 2007; Soille and Vogt 2009). MSPA has been used in different parts of the world for assessing GI at national and regional scale (Ostapowicz et al. 2008; Wickham et al. 2010; Clerici and Vogt 2013). Nevertheless, only a few studies have been developed at urban scale (Barbati et al. 2013; Chang et al. 2014; Ramos-Gonzales 2014; Kang and Kim 2015).

The ecological connectivity provided by urban green areas (UGAs) (such as parks, riparian areas, and other green spaces) is fundamental in maintaining vital ecological processes and ecosystem services as well as making a necessary contribution to the social dimension of sustainable urbanization (Andersson 2006; Madureira et al. 2011; Saura et al. 2011; Pirnat and Hladnik, 2016). In this perspective, UGAs around newly built-up areas can be considered an essential natural capital in the urban context. Creating a balance between urban development and the availability of UGAs is an environmental challenge which impacts on the quality of the lives of the inhabitants and on the economic performance of cities (Kabisch and Haase, 2014).

Accessible and usable UGAs are important indicators of the environmental quality of urban areas. In particular, given the current urbanization trend, the availability of UGAs accessible from new residential settlements is an important issue to be considered in the sustainable governance, management, and design of metropolitan areas. In order to evaluate the accessibility to UGAs, a crucial aspect is the presence of access points (actual accesses) along the perimeter which enable users to enter green spaces. The results of an analysis of accessibility to UGAs may highlight the effects of urban expansion in terms of sustainability, linking spatial distribution of accessible and usable

UGAs with new residential settlements, and underlining the role of UGAs as nature based solution for contrasting urban sprawl (Lafortezza et al., 2013, Fan et al., 2017a). The approach can help urban planners and managers to set action priorities at local scale.

Finally, the goals of this thesis closely linked to one of the targets of United Nations Sustainable Development Goal 11[1]: "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.

[1] Goal 11: "Make cities and human settlements inclusive, safe, resilient and sustainable"; see: http://www.un.org/sustainabledevelopment/cities/ for the full list of targets related to this goal.

2. State-of-the-art

2.1. Urbanization, connectivity and fragmentation

This chapter reviews and discusses the literature on landscape ecology applications in landscape planning with an emphasis on sustainability in urban environments. The section begins with urbanization as an issue and explains how it leads to fragmentation and the loss of connectivity. After giving a brief overview of issues related to fragmentation, it steps on to the relationship between Urbanization and sustainability.

Urbanization can be defined as a dynamic process, where the land is mainly modified with an extension of the urbanised area and/or increased population (Niemelä, 1999; Dawson et al., 2014). Although different social processes are regarded as the main drivers of urbanization (i.e., population growth and employment opportunities), the process of urbanization itself affects social, economic and political life (Macionis et al., 2004; Dawson et al., 2014).

In general, Urbanization is thought to have adverse effects on the nature, biodiversity, the quality of life of people as well as the functioning of local and global ecosystems (Alberti, 2005). Since the built-up areas cover a large proportion of the land surface in urban environments, they are generally thought to be more disturbed and degraded compared to rural areas (Pickett et al., 2001; Alberti, 2005). On the other hand, it has been reported that urbanization may also provide favourable conditions for biodiversity as it creates and supports a variety of species because of the diversity of habitats included in urban environments (Gilbert 1989; Niemelä 1999; Andersson 2006). This is a typical example of the work undertaken by Gaston et al. (2005) who demonstrated that domestic gardens in Sheffield contain a large amount of biodiversity. Moreover, Savard et al. (2000) drew the attention to some other benefits of urban ecosystems to people, species and the other aspects of biodiversity (e.g., population structure and genetic diversity). This is evident in the case of the cultivation of rare plants in urban areas, which may attract species that are dependent on those plants. However, changes in the existing land uses/covers and fragmentation have assumed to be the most important environmental issues associated with the process of urbanization (Saunders et al., 1991; Bennett, 1998; Turner et al., 2001; Bennett, 2003). The term fragmentation reflects both a status and process. As a status, fragmentation can be defined as the degree of isolation of previously connected landscape components (Franklin et al., 2002 and Bennett et al., 2010). As a process, it implies a dynamic process of structural and functional changes in a landscape where a continuous habitat type is split into separated patches with different sizes, shapes and functions (Forman, 1995; Lindenmayeret al., 2006; Selman, 2006).

Bennett (2003) synthesize the major effects of fragmentation under structural changes in the landscapes and adverse effects on wildlife. With regard to its effects on landscape structure, fragmentation causes the loss and/or degradation of valuable habitats with an increasing isolation – or in other words the loss of connectivity (Lindenmayeret al., 2006; Bennett, 1998; Bennett, 2003; Farina, 1998; With, 2002; Hilty et al., 2006). Therefore, the maintenance of connectivity has been regarded as a worldwide concern to mitigate the detrimental effects of fragmentation as well as the conservation of the nature and biodiversity.

2.2. Urbanization and sustainability

Antrop (2006) said that the relationship between urbanization and sustainability largely depends on their dynamic interactions and interdependencies with environmental, societal and economic processes. In urban areas, natural habitats and biodiversity have been subjected to intense human disturbances, and so urban environments and their surroundings have been the focus of conservation efforts (Gill et al., 2007). In conjunction with the increased concerns for nature and biodiversity, several authors (Du Pisani, 2006; Kuhlman and Farrington, 2010 among others) have raised the question of sustainability as a central issue in urban areas. The theme of sustainability in urban areas has become a response to the growing concern for the quality of the natural environment as well as the social and economic life in the early nineteenth century.

With regard to sustainability in landscapes, it is claimed that a generally accepted definition of landscape sustainability is lacking or it is generally defined in different contexts (Wu, 2013; Selman; 2008). While some researchers used the Brundtland Report as the source of definition with an

emphasis on the maintenance of ecological integrity and basic human needs (Forman, 1995 and Turner at al., 2013), some highlighted the importance of natural capital and ecosystem services (Haines-Young, 2000 and Potschin et al., 2006), while others considered the localisation and self-regenerative capacity as the essential property of sustainability in landscapes (Selman, 2007).

Selman (2008) claims that environmental sustainability stems from landscape ecology as a response to the fragmentation of landscapes with an emphasis on the importance of landscape multi-functionality, ecosystem services and/or resilience. As some authors have said (Termorshuizen, 2007; Selman, 2008; Musacchio, 2009; Wu, 2013, among others) first of all, a sustainable landscape should maintain and improve landscape connectivity to facilitate species' life cycles as well as sustaining healthy and viable populations through a biodiverse network of habitats.

The scattered growth of cities often involves moving away from urban sustainability goals. Urban sprawl affects essential environmental, economic and social functions the importance of which is often underestimated (EEA, 2016). In order to control urban sprawl and provide more sustainable cities, as stated by Ozus et al. (2011) and Raymond et. (2017), UGAs are widely known as frameworks for implementing NBSs. Corona et al. (2014a) said that the policy and the urban planning processes should take decisions “evidence-based”.

Against this background, UGAs are Green Infrastructure elements, as pointed out by Lafortezza et al. (2013) and Fan et al. (2017), known as a framework for preserving and increasing environmental values in urbanized contexts supporting a wide range of ecosystem services benefiting the health and well-being of people as well as meeting the different needs of people.

2.3. Accessibility to UGAs in urban context

The analysis of UGAs by agreed sustainable indicators is one of the first steps to support urban sustainable planning (Gupta et al., 2012, 2016; Kabisch et al., 2016; Sanesi et al., 2016). The accessibility of UGAs for residents at European and international level is one of the most debated indicators on making cities more equitable, resilient and sustainable. Consequently, this has been the focus of planning and research over recent decades (Baycan-Levent and Nijkamp, 2009; Kabisch et al., 2016). For example, a number of studies have shown that good accessibility to UGAs results in the better physical and psychological health of city dwellers from a long-term perspective (EEA, 2010; Hartig et al., 2014). However, accessibility is a broad and flexible concept than can be defined according to the particular field of interest. Clarifying its definition is an important prerequisite for further analysis aimed at supporting urban planning options regarding UGAs. According to the definition reported by La Rosa (2014), accessibility means the ability to approach something and denotes an intrinsic spatial feature related to the possibility for city dwellers to reach a particular place. Distance, therefore, is a major aspect in relation to UGA accessibility indicators (Ekkel and de Vries, 2017). The frequency of visits to UGAs declines with increasing distance (Coombes et al., 2010) and proximity is an important determinant of use (Kaczynski et al., 2014). A distance which is not far from the living environment and which is manageable for all population groups is classified in various planning disciplines as ‘within walking distance’ (Grunewald et al., 2017). The definition of threshold values is usually based on literature which considers distance from the residential environment and minimum area sizes (European Commission, 2001; Handley et al., 2003; Barbosa et al., 2007; Grunewald et al., 2017; Poleman, 2016; Richter et al., 2016). Several methods are available to estimate the accessibility to a UGA based on “walking distance” (Higgs et al., 2012; La Rosa, 2014). A recent approach is to measure the nearest neighbor, for example, the distance to the closest UGA using the distance along a road network in a Global Information System (GIS) environment (Comber et al., 2008; Coombes et al., 2010; Gupta et al., 2016; Kabisch et al., 2016). This approach obtains accurate results, although it requires more data and analysis (La Rosa, 2014). In the last decade, network analysis of urban green spaces has been applied at a city scale or at a hierarchical level to investigate relations between accessibility to UGAs and health benefits (Coombes et al., 2010), or in relation to the distribution of ethnic and religious trends (Barbosa et al., 2007; Comber et al., 2008). To date, only a few studies have assessed UGA accessibility in the context of rapid land transformation and urban sprawl (Fan et al., 2017c). In order to evaluate the accessibility to UGAs, a crucial aspect is the presence of access points (actual accesses) along the perimeter which enable users to enter green spaces. In fact, UGAs may be publicly available or not, fenced or not, or restricted to specific social groups (Low, 2013). Furthermore, in order to improve the knowledge on the “usability” of green areas, their amenities (i.e. benches), trails, playgrounds and pathways within them should be taken into account. These facilities promote the more comprehensive enjoyment of UGAs (Sanesi and Chiarello, 2006; Ottoni et al., 2016; O'Brien et al., 2017; Terkenli et al., 2017). Nevertheless, no information is usually available about their actual access and usability. To the best of my knowledge, this is the first time that an analysis of distance to UGAs has been combined with the assessment of access points ("actual accessibility") and "usability", using a new methodological approach based on Urban Atlas (UA), a free European geographical dataset (Urban Atlas 2012).

3. Aims and Structure

The following research objectives and questions are addressed in this study (Table 1):

Table 1: Research objectives and research questions of the study

Research Objectives	***Research Questions***
(I) To provide new knowledge about socioeconomic drivers shaping urban growth (m2/inhabitant) in the European urban context;	*- Is the urban gradient a relevant factor that shaping ecological processes and ecosystem services in European regions?* *- Which are the relevant socioeconomic gradients that may influence land consumption?* *Which is the socio-economic profile of European cities with high efficiency in land use?*
(II) To develop a methodology identifying the elements sensitive to urbanization (urban sprawl) to improve the sustainability of urban development;	*- Where are the most sensitive areas of GI to be preserved from urban encroachment?*
(III) To locate lands, that, if converted into connected elements, would enhance the connectivity of the existing GIs and to define an index of priorities for increasing the GI territory;	*- How can be identified arable lands in the vacant border territories that, if converted into connected elements, would enrich the connectivity?* *- How can be defined an index of priorities for increasing the GI territory by NBSs?*
(IV) To assess the distance between urban settlements and the closest Urban green areas (UGAs) access point.	*- Is it possible to provide a more comprehensive definition of accessibility and usability of UGA?* *- What factors should be taken into account when planning new settlements to favour the use of UGAs?*

In accordance with the research objectives and questions formulated in the previous section, the framework of this study comprises three working steps.

The first working step (§5. Multidimensional analysis of lan-use efficiency) of the study comprises to verify the hypothesis that "land use efficiency" varies along cities depending on a diverse set of socioeconomic and territorial drivers. To address this issue, this study proposes an exploratory data analysis of urban land-use efficiency over 417 metropolitan regions located in five European areas (Atlantic, Northern, Central, Eastern, and Southern regions). The analysis aims at disentangling the role of socioeconomic context on land-use efficiency patterns observed across European metropolitan regions by applying a multi-step statistical strategy incorporating a general linear model and multivariate exploratory techniques applied to a wide set of morphological and functional indicators. This approach allows to identify the factors underpinning local development in different urban types.

In the scope of the second working step (§6. Urban ecosystem conservation and enhancement of the Green Infrastructure), was be proposed a methodology to locate environmentally sensitive areas of a city's GI and to provide a prioritized investment strategy for its growth. A new methodology for analysing the GI at city level is used, making the most out of the combined use of UA resources and MSPA techniques. This approach has been applied to the GI of Rome's municipality in Italy as a case study. In the case of Rome, the dynamics of urban development are similar to that for many cities worldwide. The model of Rome's urban sprawl is similar to other Italian and European cities (Salvati 2013).

In the third working step (§7. Accessibility and usability of the urban green areas), accessibility and usability are analysed of UGAs in the municipality of Rome, a semi-compact city evolving towards a more dispersed and polycentric urban form (Frondoni et al., 2011; Salvati et al., 2012). In particular, the aim at assessing accessibility to UGAs from both old and new residential settlements.

4. Data collection

Land-use datasets and thematic indicators are crucial to explore landscape change drivers (Salvati et al., 2016). For instance, socioeconomic, political and cultural factors influence land-use decisions, especially when focusing on definite peri-urban landscape structures (Pinto-Correia and Kristensen, 2013, Hennig et al., 2015). Social indicators can be related to any given local context influencing metropolitan structures and organization (Moos and Mendez, 2015). Under the hypothesis that the progressive shift to capitalism and market economies has widened population and income disparities in metropolitan regions, demographic and economic indicators (e.g. assessing population concentration and income distribution) have been especially considered when investigating social forces underlying landscape changes (Paulsen, 2014, Hennig et al., 2015, Zitti et al., 2015). In order to empirically assess urban sprawl in Europe, several data sources have been used. Statistical geo-referenced data were combined with raster and vector geospatial data, in a process that uses the database Urban Audit as a starting point, and complements it with spatial information on land-use and land-cover provided by the UA data sets.

4.2. Land use and land cover data

The land use/land cover data are obtained from the European Urban Atlas (UA) project (http://www.eea.europa.eu/data-and-maps/data/urban-atlas). The UA study region encompasses the Large Urban Zones (LUZ) as defined by Urban Audit program. The Urban Atlas project was undertaken by the European Environment Agency (EEA) and all the cities with more than 100.000 and 50.000 inhabitants were mapped for the reference years 2006 and 2012, respectively. It is part of the Global Monitoring for Environment and Security (GMES)/Copernicus land monitoring service program and is distributed free of costs in vector/polygon format over the Internet by the EEA (EEA 2010a). The Urban Atlas nomenclature for all classes is shown in Table 2. Urban Atlas maps are scaled 1:10,000 with 0.25 ha Minimum Mapping Unit (MMU) for Urban classes and 1 ha for Rural classes. UA legend was designed to be comparable with the Corine Land Cover nomenclature system. The nomenclature of the Urban Atlas

“Continuous” and “Discontinuous Urban Fabric” classes (see Table 2) is based on the CORINE land cover classes “Continuous Urban Fabric > 80%” and “Discontinuous Urban Fabric 30-80%”. Nevertheless, some refinements were made. While the class “Discontinuous Urban Fabric >80%” was retained, the class “Discontinuous Urban Fabric 30-80%” was subdivided into two classes. Additionally, two further classes were added to the Urban Atlas classification scheme, namely “Discontinuous Urban Fabric 10-30%” and “Discontinuous Urban Fabric <10%” (Prastacos et al., 2012).

The production of the Urban Atlas datasets has been carried out mainly on the basis of high-resolution (2.5m) satellite images (e.g. Spot 5, Quickbird, Formosat-2, Kompsat-2 and ALOS Data) in combination with topographic, land use and ancillary maps (EEA 2010b: 2; Stathakis and Tsilimigkas, 2013). The degree of sealing of the “Discontinuous” and “Continuous Urban Fabric” classes was derived using a soil sealing layer (EEA, 2010b). This layer provides a quantitative measure of the area covered by buildings, streets and other artificial objects. The production process of the Urban Atlas datasets involved a mix of classification and image-interpretation (Prastacos et al., 2012) following uniform standards which are described in a specific mapping guide (EEA, 2010b). Thus, the Urban Atlas datasets are permitting comparison of land use/land cover between the participating European cities (EEA, 2010a).

Table 2: Urban Atlas nomenclature

Class Code	Nomenclature 2006	Nomenclature 2012	Usage
11100	Continuous Urban Fabric (Sealing Degree > 80%)		Residential
11210	Discontinuous Dense Urban Fabric (Sealing Degree 50 - 80%)		Residential
11220	Discontinuous Medium Density Urban Fabric (Sealing Degree 30 -50%)		Residential
11230	Discontinuous Low Density Urban Fabric (Sealing Degree 10 - 30%)		Residential
11240	Discontinuous Very Low Density Urban Fabric (Sealing Degree < 10%)		Residential
11300	Isolated structures		Non-residential
12100	Industrial, commercial, public, military and private units		Non-residential
12210	Fast transit roads and associated land		
12220	Other roads and associated land		
12230	Railways and associated land		
12300	Port Areas		Non-residential
12400	Airports		
13100	Mineral extraction and dump sites		
13300	Construction Sites		Non-residential
13400	Land without current use		
14100	Green urban Areas		Artificial non-agricultural vegetated areas
14200	Sports and leisure facilities		
20000	Agricultural areas, semi-natural areas and wetlands		Agricultural areas
21000		Arable land (annual crops)	
22000		Permanent crops	
23000		Pastures	
24000		Complex and mixed cultivation	
25000		Orchards	
30000	Forests		Natural and (semi-)natural areas
40000	Water		Natural and (semi-)natural areas

In order to ensure a high quality of the Urban Atlas datasets, the production process further included a three-step validation. This comprised a project intern quality assessment, independent experts as well as a technical review by the European Topic Centre on Land Use and Spatial Information (Prastacos et al., 2012). UA database is a valuable source with which to analyse environmental quality indicators for the largest European cities. This geodatabase is filling a gap in the data about landscape structure and land-use in a large sample of metropolitan regions in Europe.

4.1. Socio-economics data

The Urban Audit database is a project coordinated by EUROSTAT that aims to provide a wide range of indicators (around 300) and variables of several socio-economic, environmental, and other aspects for a sample of the main European cities that represents the population distribution. The project ultimate goal is to contribute towards the improvement of the quality of urban life: it supports the exchange of experience among European cities; it helps to identify best practices; it facilitates benchmarking at the European level and provides information on the dynamics within the cities and with their surroundings.

The spatial dimension of the cities is defined at three different scales: the core city, which encompasses the administrative boundary of the city; the Larger Urban Zone (LUZ), which is an approximation of the functional urban region centred around the core; and the Sub-City District level (SCD), a subdivision of the LUZ (Eurostat, 2004). Since urban sprawl is a phenomenon that particularly affects the fringe of the cities and spreads over the whole urban region, the main unit of analysis in first part of this thesis will be the LUZ. It has been used the boundaries of the LUZs provided by the Urban Audit project in order to delineate the efficiency of land use, while the core city definitions is used to identify the key components of the GI and the accessibility to UGAs.

Urban Audit is clearly not perfect but represents the main effort to compile data as comparable as possible across different countries within Europe and, although it does not include all the cities, to date it is the best available dataset in that direction. 2014, 2011, 2008, 2004 and 2001 are the reference years for the main data collection.

5. Multidimensional analysis of land-use efficiency

5.1. Methodology

5.1.2. Study area

A total of 417 cities from 27 European Countries has been investigated (see Figure 1). The investigated cities have been classified into five main European regions following the indications provided by Hall and Hay (1980): (1) North and Atlantic Europe (79 cities); (2) Western Europe (84 cities); (3) Central Europe (82 cities); (4) Eastern (117 cities) and (5) Southern Europe (55 cities). Cities boundaries are based on the European Urban Areas statistical classification (http://www.urbanaudit.org/) and correspond to the Large Urban Zones (LUZ) of the Urban Audit program, and consist of cities and their commuting zones. The LUZ is an attempt to find a harmonised delineation of metropolitan areas in Europe, intended as an area from which a significant share of the residents commute into the city (Eurostat 2004). European LUZs were considered the elementary spatial unit in the first part of work. This choice is motivated with the fact that earlier studies have successfully explored sprawl patterns and processes at the LUZ level (e.g. Salvati et al., 2016). Such spatial unit usually includes suburbs and a considerable part of neighboring rural areas where sprawl have manifested in the last two-three decades (Oueslati et al., 2015, Pili et al., 2017, Zambon et al., 2017).

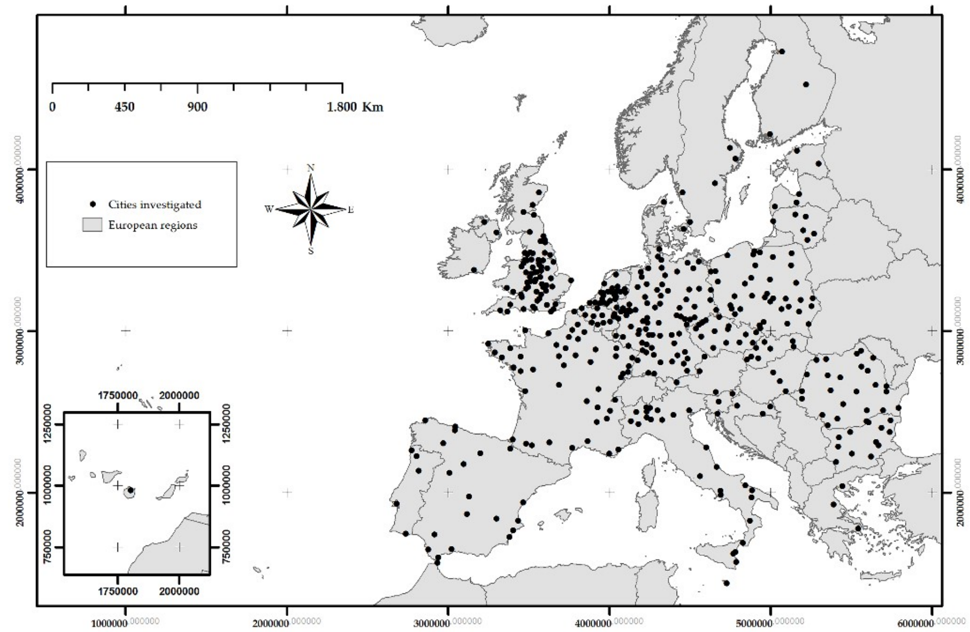

Figure 1: The spatial distribution of the cities investigated

5.1.2. Assessing per-capita built-up area

Land-use efficiency was calculated by the proxy variable per-capita built up area (ratio of built-up areas to resident population) for each LUZ in the sample set of 417 cities for the reference year 2012. Built-up area for each LUZ was devised from the UA classes related to residential areas (considering all UA urban classes with code '1.x' accept the '1.410x' class which includes urban parks and gardens with mainly pervious land). Resident population was derived from the Eurostat Urban Audit database for the year 2011. The spatial domain chosen in the present study allows comparison with external data sources, including statistical datasets derived from official sources. The data collected were checked for internal and external consistency following the approach proposed by Salvati et al. (2013).

5.1.3. Landscape and socioeconomic indicators

A set of 54 indicators describing biophysical and socioeconomic conditions were collected for each European LUZ included in this study. Indicators (listed in Table 3) were classified in two research domains: (i) socio-economic and territorial factors and

(ii) land-use composition and landscape structural attributes. Indicators were derived from statistical data at the LUZ scale for each studied city. Socioeconomic and territorial indicators were obtained respectively from the Urban Audit database and the UA maps. Variables describing landscape structure were calculated using patch analysis toolkit for ArcMap version 10 (ESRI) on the basis of UA maps for the year 2012.

Table 3: List of variables (italics indicate the dependent variable; independent variables were classified by research theme)

Acronym	Name	Measure unit	Data source	Year
pc built-up	*Per-capita built-up area*	*m^2* Inhabitant^{-1}	*Eurostat*	*2011*
	Socioeconomic and territorial indicators			
Pop dens	Population density	Inhabitants/km^2	Eurostat	2011
Mun size	Municipal surface area	km^2	Eurostat	2011
Area	Large urban zone area	km^2	Urban Atlas	2012
Capital	Country capital city	Yes/No (1/0)	Urban Atlas	2012
Airport	Presence of an airport	Yes/No (1/0)	Urban Atlas	2012
Port	Presence of a harbor	Yes/No (1/0)	Urban Atlas	2012
Northern	European Region			
Central	European Region			
Southern	European Region			
Atlantic	European Region			
Western	European Region			
Eastern	European Region			
Inc%(00-07)	Increase of per-capita disposable income	%	Eurostat	2000-2007
Inc%(08-14)	Increase of per-capita disposable income	%	Eurostat	2008-2014
pc income	Per-capita disposable income	Euros	Eurostat	2000
	Landscape structure			
SDI	Shannons Diversity Index		Urban Atlas	2012
SEI	Shannons Eveness Index		Urban Atlas	2012
AWMSI	Area Weighted Mean Shape Index		Urban Atlas	2012
MSI	Mean Shape Index	m/ha	Urban Atlas	2012
MPAR	Mean Perimeter-Area Ratio	m/ha	Urban Atlas	2012
MPFD	Mean Patch Fractal Dimension	m/ha	Urban Atlas	2012
AWMPFD	Area Weighted Mean Patch Fractal Dimension		Urban Atlas	2012
ED	Edge density	m/ha	Urban Atlas	2012
MPE	Mean Patch Edge	m/patch	Urban Atlas	2012
MPS	Mean Patch Size	m/patch	Urban Atlas	2012
MedPS	Median Patch size	m/patch	Urban Atlas	2012
PSCoV	Patch Size Coefficient of Variance		Urban Atlas	2012
	Land-use composition			
1110	Continuous Urban Fabric (Sealed Land > 80%)	% in total land	Urban Atlas	2012
1121	Discontinuous Dense Urban Fabric (SL: 50% - 80%)	% in total land	Urban Atlas	2012
1122	Discontinuous Medium Density Urban Fabric (SL: 30% - 50%)	% in total land	Urban Atlas	2012
1123	Discontinuous Low Density Urban Fabric (SL: 10% - 30%)	% in total land	Urban Atlas	2012
1124	Discontinuous Very Low Density Urban Fabric (SL: < 10%)	% in total land	Urban Atlas	2012
1130	Isolated built-up structures	% in total land	Urban Atlas	2012
1210	Industrial, commercial, public, military and private units	% in total land	Urban Atlas	2012
1221	Fast transit roads and associated land	% in total land	Urban Atlas	2012
1222	Other roads and associated land	% in total land	Urban Atlas	2012
1223	Railways and associated land	% in total land	Urban Atlas	2012
1230	Port areas	% in total land	Urban Atlas	2012
1240	Airports	% in total land	Urban Atlas	2012
1310	Mineral extraction and dump sites	% in total land	Urban Atlas	2012
1330	Construction sites	% in total land	Urban Atlas	2012
1340	Land without current use	% in total land	Urban Atlas	2012
1410	Green urban areas	% in total land	Urban Atlas	2012
1420	Sports and leisure facilities	% in total land	Urban Atlas	2012
2100	Arable land (annual crops)	% in total land	Urban Atlas	2012
2200	Permanent crops	% in total land	Urban Atlas	2012
2300	Pastures	% in total land	Urban Atlas	2012
2400	Complex and mixed cultivation pattern	% in total land	Urban Atlas	2012
3100	Forests	% in total land	Urban Atlas	2012
3200	Herbaceous vegetation association	% in total land	Urban Atlas	2012
3300	Open spaces with little or no vegetations	% in total land	Urban Atlas	2012
4000	Wetlands	% in total land	Urban Atlas	2012
5000	Water bodies	% in total land	Urban Atlas	2012

5.1.4. Statistical analysis

A data mining strategy incorporating Principal Component Analysis (PCA), step-wise multiple regression and non-hierarchical clustering was run on the full sample of cities (n = 417). The multivariate techniques considered here were aimed at (i) analysing the spatial distribution of land use efficiency using descriptive statistics; (ii) exploring land-use efficiency along relevant geographic gradients using principal component analysis; (iii) investigating spatial convergence in land-use efficiency using regression models; (iv) profiling municipalities for urban land-use efficiency using non-hierarchical clustering. The indicators considered in each statistical analysis are listed in Table 1. To explore multiple spatial relationships among response indicators, a PCA was run on a data matrix including values of all response indicators for each of the 417 cities. The PCA aimed at classifying municipalities into a few homogeneous groups according to the latent spatial patterns of per-capita built-up area. This analysis allows also to explore spatial variability of land-use efficiency along relevant geographic and socioeconomic gradients. Components with eigenvalue > 2 and component loadings > |0.45| were considered in the analysis (Salvati et al. 2013).

A multiple regression model was performed to explain spatial variability of per-capita built-up area based on 36 predictors (see section 2.4). A forward step-wise multiple regression analysis was run using per-capita built-up area as the dependent variable to identify response indicators most associated with the level of land-use efficiency. Predictors were included in the model when the p-level associated to the respective Fisher-Snedecor test was lower than 0.01.

A non-hierarchical clustering (using the k-means computation strategy) was run on the variable matrix with the aim to profile municipalities based on their urban land-use efficiency. Following the criterion of parsimony, the analysis was carried out for a set of solutions (cluster numbers). The most efficient cluster partition was identified using pseudo F statistic and the Cubic Clustering Criterion as diagnostic statistics (Duran and Odell 1974; Salvati and Zitti 2009). Based on cluster membership, each k-means group of municipalities was profiled using the average values of contextual indicators considered in the analysis. To allow comparison among different research dimensions, indicators were standardized using (z) scores computing (positive or negative) deviations from the indicator's average. Per-capita built-up area was considered as a supplementary variable and significant differences in the average value of this variable by cluster were evaluated using a Kruskal-Wallis analysis of variance testing at $p < 0.05$.

5.2. Results

5.2.1. Principal Component Analysis

PCA analysis allowed to identify the main gradients associated to land use efficiency in the 417 selected cities. The PCA extracted 6 components explaining together more than 50% of the total variance (Table 4).

The first component (PC1) is correlated to a large number of background indicators and explains 24.3% of the total variance. Indicators linked to territorial characteristics and economic activities including population density, landscape diversity and patch fragmentation, continuous (1110) and discontinuous (1121, 1122) urban fabric, presence of ports and airports are positively correlated to this component. Agricultural and forest land are negatively correlated to PC1. Taken together, these results suggest that component 1 represents a sort of urban-rural gradient common to all European regions, also highlighting that dense cities are well-differenced from less dense ones, since population density received a highly positive loading (0.91). Cities where population density is higher are also smaller in terms of municipal area, with the variable assessing LUZ surface area being negatively correlated to this axis.

Table 4: Principal Component Analysis loadings (see Table 3 for acronyms; only loadings > |0.45| were reported)

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Central					-0.50	
Southern		-0.63				
Atlantic		0.54				
Western			-0.46			
Eastern			0.72			
Pop dens	0.91					
pc built-up	-0.66		-0.48			
Mun size		-0.45				
Area(log)	-0.67					
Inc%(00-07)			0.78			
Inc%(08-14)		0.55				
pc income			-0.75			
SDI	0.86					
SEI	0.89					
AWMSI				-0.62		0.47
MSI		0.74				
MPFD		0.54		-0.45		
AWMPFD	0.59					
ED	0.93					
MPE	-0.66	0.53				
MPS	-0.81					
MedPS		0.55				
1110	0.45					
1121	0.73					
1122	0.69	0.47				
1123	0.48					
1130			-0.45			
1210	0.85					
1221	0.49					
1222	0.93					
1223	0.56			0.49		
1330	0.45					
1340	0.53					
1410	0.73					
1420	0.74	0.51				
2100	-0.45					-0.61
2300					0.53	
3100	-0.47					0.49
3200		-0.49		-0.45		
Explained variance (%)	*24.3*	*9.3*	*7.4*	*5.2*	*4.5*	*4.2*

Component 2 (PC2) explains 9.3% of the total variance and shows a clear geographic gradient, being associated negatively with 'Southern' cities in Europe and positively with 'Atlantic' cities. Cities belonging to Mediterranean Europe are therefore located in the negative part of this axis and are characterised by low total surface area. The cities belonging to Atlantic Europe are grouped in the positive side of this axis and are

characterized by greater values of the shape index (MSI), the fractal index (MPFD), the perimeter index (MPE) and the median land (MedPS). Atlantic cities are also characterized by a very high percentage of discontinuous medium-density urban fabric (1122). Between 2008 and 2014, Atlantic cities also show an increase of per-capita available income compared with the rest of Europe.
The third component (PC3) explains 7.4% of the total variance highlighting a geographical gradient that separates Eastern from Western Europe: a negative loading (-0.46) was attributed to the indicator identifying Western European cities, the reverse being observed for Eastern European cities (0.72). Western European cities are characterized by higher values of per-capita built-up area. Income growth between 2000 and 2007 was higher in the cities of Eastern Europe than in the rest of Europe. Despite economic expansion, Eastern cities had the lowest level of per capita available income in Europe at the beginning of the study period (2000). Concerning landscape structural variables, isolated built up structures (1130) are more frequent in Western cities.
PC4 explains 5.2% of the total variance. This component is positively correlated to fractal indexes of landscape parcels (AWMPFD and MPFD). PC4 suggests how cities characterized by a less fragmented landscape structure are those with more network infrastructures and with a high proportion of herbaceous vegetation. PC5 (4.5% of the total variance) highlights that the cities of central Europe have a low proportion of pastures within their boundaries. The last considered component (PC6) explains 4.2% of the total variance and identifies a cropland-forest gradient; cities characterized by high percentage of cropland are located along the negative side of the axis while those cities with a good proportion of forests are grouped in the positive side of the axis. Finally, cities with larger urban woodlands are characterized by a high fractal index.

5.2.2. *Multiple regression model*

Results for the regression models developed separately for the whole sample ($n = 417$) and for each European region are reported in Table 5. The regressive model for all surveyed European cities has a highly significant ($p < 0.0001$) adjusted R^2 (0.73). Models' results indicate that per-capita built-up area increases in Western cities when metropolitan landscape is characterized by large median patches (MedPS), with highly dispersed urban settlements (1130), cities with an airport and cities situated in Northern Europe. Per-capita built-up area decreases in the cities with predominance of compact residential settlements (1110), industrial settlements (1210) and high landscape heterogeneity (SEI). The model also shows a negative association between per-capita built-up area and per-capita available income or rate of income growth in the period 2000-2007. 'Atlantic' and 'Southern' Europe cities are negatively associated to per-capita built-up area. The models developed for the different European regions are highly significant ($p < 0.0001$), being the adjusted R^2 always higher than 0.7, except for the model representing Southern European cities, with an adjusted R^2 rounding 0.64. The model developed for the 'Atlantic' cities includes only three covariates. Per-capita built-up area in this European region increases with mean patch size (MPS) and the proportion of isolated built-up structures (1130) in total landscape. The wealthiest cities (i.e. with the highest per-capita available income) totalized systematically low values of per-capita built-up area.

Table 5: Step-wise multiple regression analysis results

Variable	Beta	Err.Std.	t(403)	p-level
Total sample: Adj-R²= 0.73; $F_{(13,403)}$=86.3; p<0.0001; D.W.=1.59				
1210	-0.109	0.043	-2.5	0.0127
1110	-0.273	0.034	-7.9	0.0000
Western	0.160	0.032	5.0	0.0000
MedPS	0.278	0.034	8.2	0.0000
1130	0.256	0.030	8.4	0.0000
SEI	-0.266	0.043	-6.2	0.0000
Northern	0.122	0.027	4.4	0.0000
Atlantic	-0.195	0.034	-5.7	0.0000
1310	0.121	0.027	4.5	0.0000
Inc%(00-07)	-0.285	0.048	-5.9	0.0000
Airport	0.122	0.028	4.4	0.0000
pc income	-0.176	0.050	-3.5	0.0005
Southern	-0.113	0.032	-3.5	0.0006
Atlantic Europe: Adj-R²=0.77; $F_{(3,65)}$=75.6; p<0.0001; D.W.=1.99				
MPS	0.683	0.061	11.3	0.0000
1130	0.388	0.061	6.4	0.0000
pc income	-0.146	0.059	-2.5	0.0153
Eastern Europe: Adj-R²=0.72; $F_{(10,106)}$=30.9; p<0.0001; D.W.=1.64				
1110	-0.365	0.065	-5.7	0.0000
Inc%(00-07)	-0.409	0.066	-6.2	0.0000
Area(log)	0.185	0.068	2.7	0.0075
PSCoV	-0.158	0.054	-2.9	0.0046
Mun size	-0.203	0.054	-3.8	0.0003
1221	-0.190	0.056	-3.4	0.0009
4000	0.178	0.053	3.4	0.0010
1420	-0.189	0.059	-3.2	0.0018
1310	0.124	0.051	2.4	0.0169
Airport	0.126	0.058	2.2	0.0306
Central Europe: Adj-R²=0.80; $F_{(9,72)}$=36.2; p<0.0001; D.W.=2.04				
1310	0.289	0.054	5.4	0.0000
1130	0.254	0.060	4.2	0.0001
MPE	0.360	0.082	4.4	0.0000
1221	-0.248	0.073	-3.4	0.0010
pc income	-0.173	0.061	-2.9	0.0056
SDI	-0.265	0.085	-3.1	0.0028
1124	0.172	0.058	2.9	0.0044
1122	-0.176	0.072	-2.4	0.0169
PSCoV	-0.115	0.057	-2.0	0.0478
Western Europe: Adj-R²=0.86; $F_{(11,72)}$=48.6; p<0.0001; D.W.=2.02				
1410	-0.185	0.077	-2.4	0.0187
pc income	-0.114	0.047	-2.4	0.0183
1420	-0.385	0.070	-5.5	0.0000
MPFD	-0,186	0,056	-3,3	0,0015
MPS	0.591	0.112	5.3	0.0000
1340	0.210	0.053	4.0	0.0002
1223	-0.293	0.062	-4.7	0.0000
1230	0,148	0,048	3,0	0,0033
PSCoV	-0.138	0.050	-2.8	0.0069
AWMPFD	0.188	0.083	2.3	0.0268
MPAR	-0.121	0.058	-2.1	0.0409
Southern Europe: Adj-R²=0.64; $F_{(5,49)}$=19.9; p<0.0001; D.W.=1.75				
1110	-0.500	0.091	-5.5	0.0000
MedPS	0.292	0.107	2.7	0.0090
1130	0.273	0.093	2.9	0.0051
1223	-0.204	0.087	-2.3	0.0231
Port	-0.220	0.098	-2.2	0.0291

In ‘Eastern’ European cities per-capita built-up area is positively associated to large cities (with high ‘Area(log)’) and the presence of at least an international airport. However, per-capita built-up area in this region is negatively associated with the proportion of continuous urban fabric (1110), income growth between 2000 and 2007 (inc 00-07%), variability in patch size (PSCoV) and municipal size (Mun size). Based on this model, be can also evidence that the lower the level of per-capita built-up area the greater is the presence of sport and leisure facilities. In ‘Central’ Europe, per-capita built-up area is positively associated with the presence of isolated settlements and fragmentation of landscape patches. In this region, the wealthiest cities show the lowest value of per-capita built-up area, in turn negatively associated with landscape diversity (high values of SDI and PSCoV). Average size (MPS) and fractal dimension of landscape patches (AWMPFD) determine high values of per capita built up areas while fractal index (MPFD), variability in patch size (PSCoV) and patch perimeter-to-area ratio are associated with a decrease in the dependent variable.

Results for the ‘Western’ cities highlight how in this part of Europe per-capita built-up area is negatively associated with per-capita available income, the presence of urban green areas, leisure facilities, and network infrastructures. As observed earlier, the greater is the mean size of patches, the lowest is land-use efficiency. In ‘Southern’ Europe, the dependent variable increases when the landscape is less fragmented (high MedPS) and with isolated built up structures (1130). Conversely, per-capita built-up area decreases in compact cities (1110) with network infrastructures (1223) and port areas.

5.2.3. K-means clustering

Non-hierarchical clustering classified the selected European cities into 4 homogeneous groups (Table 6). Cluster size ranges from 38 cities (cluster 1) to 126 cities (cluster 4). Cluster membership for each city is reported in Figure 2.

Table 6: Results of non-hierarchical k-clustering: standardized scores per variable and group (bold indicates standardized scores with significant deviations from a null model)

Variable	Cl1	Cl2	Cl3	Cl4
# cities	*38*	*81*	*172*	*126*
Pop dens	**1.65**	0.91	-0.20	-0.81
Mun size	-0.95	0.17	-0.20	0.45
Area(log)	**-1.48**	-0.63	0.33	0.40
Capital	-0.06	0.25	-0.11	0.01
Airport	-0.73	-0.22	0.22	0.06
Port	0.06	0.57	0.00	-0.38
Inc%(00-07)	-0.33	-0.19	-0.40	0.77
Inc%(08-14)	0.45	-0.67	0.05	0.23
pc income	0.44	0.26	0.45	-0.92
SDI	**1.52**	0.97	-0.19	-0.82
SEI	**1.68**	0.91	-0.21	-0.81
AWMSI	-0.03	-0.10	-0.26	0.42
MSI	0.49	-0.92	-0.01	0.46
MPAR	0.87	-0.10	0.01	-0.22
MPFD	**1.13**	-0.24	-0.09	-0.07
AWMPFD	**1.03**	0.63	-0.09	-0.59
ED	**1.63**	0.97	-0.12	-0.95
MPE	-0.30	**-1.19**	-0.08	0.97
MPS	-0.95	-0.95	-0.19	**1.15**
MedPS	0.11	**-1.01**	0.03	0.57
PSCoV	-0.71	-0.20	-0.17	0.58
1110	0.28	1.00	-0.34	-0.26
1121	**2.09**	0.33	-0.24	-0.51
1122	**2.26**	0.02	-0.16	-0.48
1123	0.85	0.50	-0.05	-0.51
1124	-0.23	0.53	0.01	-0.29
1130	-0.54	0.60	0.21	-0.51
1210	**2.20**	0.61	-0.30	-0.65
1221	0.47	0.88	-0.09	-0.58
1222	**1.86**	0.87	-0.21	-0.83
1223	**1.56**	0.33	-0.23	-0.38
1230	0.64	0.40	-0.16	-0.23
1240	0.76	0.05	-0.09	-0.14
1310	0.18	0.17	-0.11	-0.02
1330	0.57	0.61	-0.20	-0.30
1340	**1.05**	0.58	-0.24	-0.37
1410	**2.34**	0.24	-0.26	-0.51
1420	**2.34**	0.11	-0.15	-0.58
2100	-0.81	-0.43	0.02	0.50
2200	-0.26	0.54	-0.08	-0.15
2300	-0.25	-0.11	0.30	-0.26
2400	-0.12	0.29	-0.11	-0.01
3100	-0.79	-0.57	0.13	0.44
3200	-0.26	0.65	-0.17	-0.11
3300	-0.08	0.55	-0.12	-0.16
4000	-0.02	0.08	-0.04	0.00
5000	0.14	0.20	-0.14	0.01
*pc built-up**	***-1.12***	*-0.74*	*0.28*	*0.44*

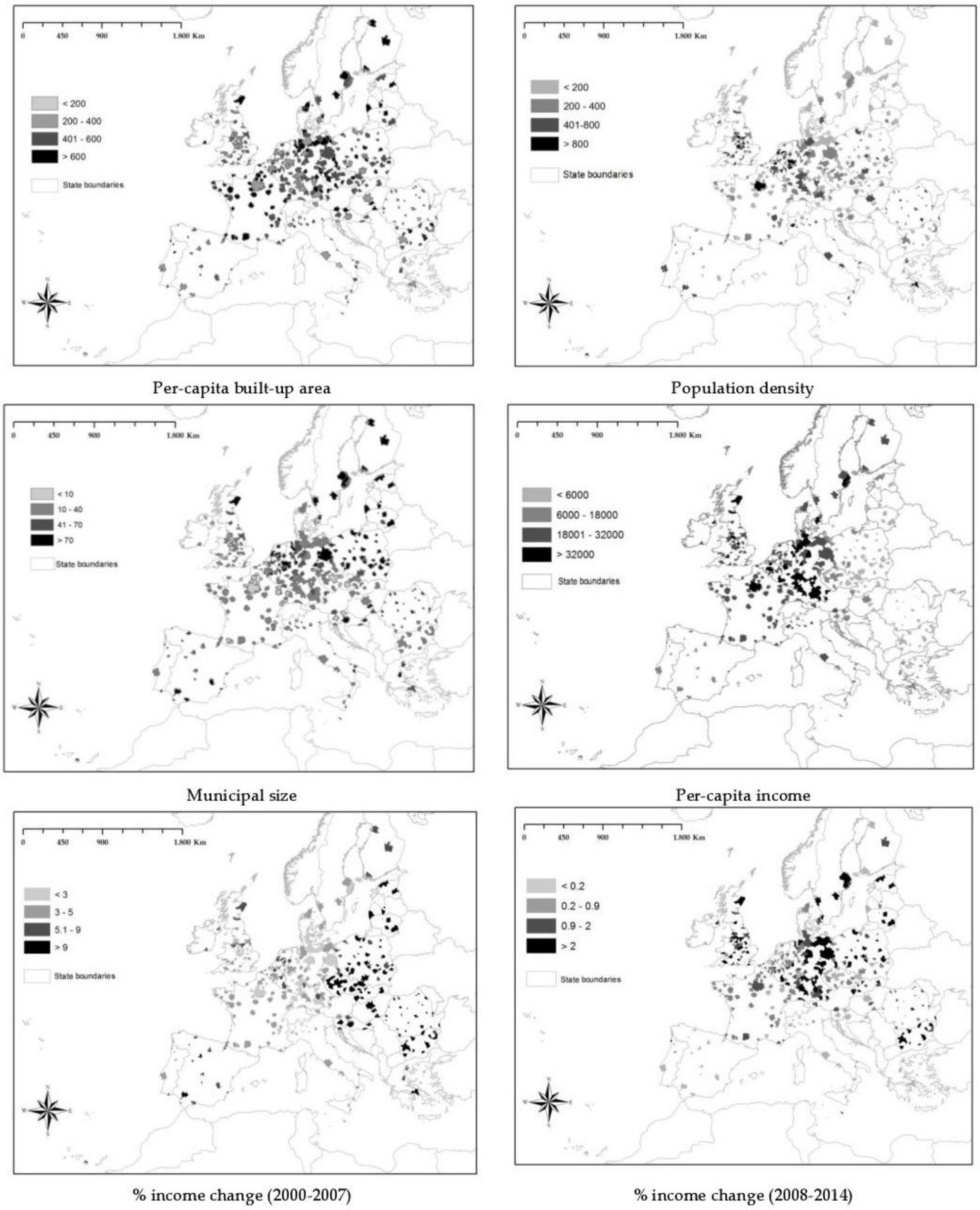

Figure 2: The spatial distribution of selected indicators

K-means clustering identified a gradient of land-use efficiency for the studied cities with highly significant differences in per-capita built-up area among clusters ($H_{k,w} = 53.1$, $n_{obs} = 417$, $n_{groups} = 4$, $p = 0.002$). This gradient was oriented from Cluster 1, representing the most efficient cities in the use of land, to Cluster 4, indicating cities with less efficiency in the use of land. Cluster 1 includes dense cities with average population density 1.65 times higher than the sample mean and a LUZ surface area 1.48

times lower than the sample mean. These European cities have also a heterogeneous landscape: Shannon diversity and evenness index (SDI and SEI) are 1.52 and 1.68 points above average, respectively. Concerning land-use composition, cities belonging to this cluster are characterized by discontinuous low- and medium- density urban fabric, presence of infrastructures (railways and roads), green urban areas, sport and leisure facilities and land without current use. Cluster 1 is dominated by English cities, with 26 out of 38 cities in this cluster located in the United Kingdom. The remaining cities are located in West Germany, Lithuania, Netherlands and, with only one city, Latvia and (Northern) Italy. The 81 cities belonging to Cluster 2 show average and median landscape patch size significantly lower than the reference value of the entire sample. More than half of the cities in Cluster 2 are situated in Mediterranean countries (Italy, Spain, Greece, Portugal and Malta). Cluster 3 includes 172 European cities, with absence of characteristic variables. This cluster may depict average conditions for land-use efficiency in European metropolitan regions. Finally, the 126 cities constituting Cluster 4 have higher mean patch edge (MPE) in respect with the other three clusters, with cities mainly located in Eastern Europe and particularly in East Germany, Romania, Bulgaria and Czech Republic.

6. Urban ecosystems conservation and enhancement of the Green Infrastructure

6.1. Methodology

6.1.1. Study area

The Rome's municipality (Figure 3) has a surface area of about 129,000 ha consisting mainly of uplands and lowlands. This land forms part of 15 neighbourhoods, which form an integrated system of administrative units of Rome Municipality under statute No.11/2013 (https://www.comune.roma.it/PCR/resources/cms/documents/delib_N_11_del_11_03_2013.pdf).

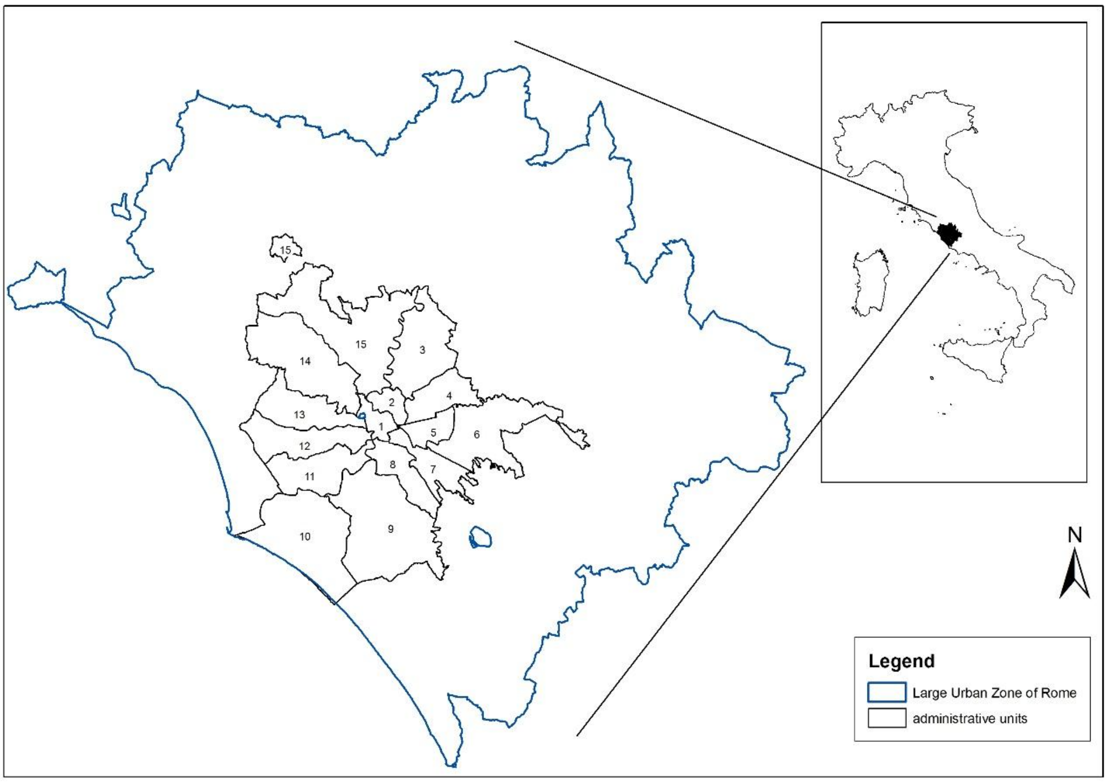

Figure 3: Administrative units of Rome's municipality within LUZ. Coordinate system in WGS84 UTM 33N

Although urban areas occupy a significant portion of the municipal territory, the majority of the surface area is cultivated land, pasture, and forest. According to Salvati et al. (2016), the spatial extent of built-up areas is quadrupled between 1949 and 2008 from 6.5% to 27.5% in the municipality of Rome and its larger urban zone. In the specific case of Rome, the sprawl of built-up areas has been aided by the presence of heterogeneous agricultural areas, characterized by a land mosaic of cultivations, scattered houses, and areas of natural vegetation. Today, however, land-take is controlled in protected territories within of Rome municipality which cover around 32% of Rome municipal area. This territory is some 40,600 ha and includes a diversified and complex heritage of green spaces; agricultural land, parks, historical monumental complex, public gardens and urban green areas.

6.1.2. Selection of land use data

The UA 2012 dataset for Rome was locally validated with the map of the natural and semi-natural environments for the Lazio region (Chirici et al. 2014). This regional map is based on the Corine Land Cover (CLC) nomenclature system as the UA map (Maricchiolo et al. 2005). The Lazio map also overlaps in time with UA map. However, the Map of the natural and semi-natural environments for the Lazio region has higher thematic and spatial accuracy for rural classes than the UA map, with an MMU equal to 5000 m2 and overall thematic accuracy of at least 85%. Because of this disparity we compared the two maps and selected only the rural land mapped on the UA map with the same CLC code as the Lazio map of the natural and semi-natural environments for mapping Rome's green infrastructure (see §*6.1.3*); similarly, areas mapped as arable land by the regional map, but classified differently by the UA map were reclassified as arable land. Overall, the area covered by our analysis is smaller than the original LUZ of Rome as it is limited to city's administrative boundaries (Figure 3).

Finally, we used the UA change 2006-2012 layer. This was derived from the 2006 and 2012 UA data products and maps the land use/cover changes which occurred between these two dates. We identified rural to urban changes to locate areas affected by land take in Rome's municipality during the period. Land use/cover change MMU is 0.1 ha.

6.1.2. Morphological analysis spatial patterns and components

Morphological image processing techniques were introduced almost four decades ago with the purpose of analysing the shape and form of objects (Soille 2003). The methodology relies on the use of the free software toolbox Graphical User Interface for the Description of Image Objects and their Shapes (GUIDOS)

(http://forest.jrc.ec.europa.eu/download/software/guidos), which implements MSPA. MSPA allowed us to segment a raster binary map into seven different and mutually exclusive green infrastructure elements (Soille and Vogt 2009): (i) 'core', (ii) 'islet', (iii) 'bridge', (iv) 'loop', (v) 'branch', (vi) 'edge' and (vii) 'perforation'. The process is based on user-defined rules for outlining connectivity and edge width (Soille and Vogt 2009). Connectivity can be set to either four (cardinal directions only) or eight neighbors (pixel corner and border pixel).
MSPA can be applied to identify hubs and links from a single land cover/land use map by creating structure from the spatial relationships between land cover features (Wickham et al. 2010). Component analysis converts the MSPA elements into connected and isolated core areas. MSPA and component analysis were applied to map and classify GI elements for the municipality of Rome.

6.1.3. Current GI and elements sensitive to urban encroachment

The following UA classes were selected as focal land use/cover elements for GI mapping: "urban green areas" (1.4.1), "pastures" (2.3), "forests" (3.1), "herbaceous vegetation associations" (3.2), "open spaces with little or no vegetation" (3.3), "wetland" (4) and "water" (5). They are recognized as potential components of the GI (Landscape Institute 2009; Karhu 2011). To run MSPA, the resulting GI map using a 10 m pixel size was rasterized. All the other land cover classes were assigned to the background. The default 8-neighbourhood rule and set edge width values equal to 10 m, 20 m, and 40 m, which are integer multiples of the pixel resolution, was applied. MSPA classes were subsequently gathered in components. Component analysis then provided the number of core areas and the overall size of the network of connected core areas and isolated core areas. Results from GUIDOS analysis and other auxiliary variables (GI territory outside protected areas and land take 2006- 2012) have been taken into account to characterize the GI coverage and level of protection across different neighborhoods in the city. In order to locate the most sensitive areas of GI to be preserved from urban encroachment, recent land take patches, as mapped by UA change 2006-2012, were used to locate zones under recent urban expansion at city level. A buffer of 300 m around 2006-2012 land take patches was delineated. The buffer width was defined in accordance with "European Common Indicators, ECI Indicator 4 – Availability of public open areas and services", one of the urban sustainability indicators recognized at European level (Tarzia 2003). Green spaces within this distance are regarded accessible to citizens. On this basis, it was assumed that city development strategies should prioritize conservation strategies of the current GI around sensitive elements located within the 300 m buffer and located outside the borders of protected areas. This basically translates into city development strategies able to control urban sprawl into the vacant territories covered by arable land bordering sensitive elements. Based on the area in hectares of the current GI in the buffer, the administrative units were divided into 3 levels of priority (low, medium, high) according to quantiles.

6.1.4. Scenario of GI expansion and prioritizing intervention action across administrative units

Arable land class (class 2.1), formulated from the validated UA 2012 allowed us to identify potential target areas for the enhancement of the current GI. Arable lands within the 300 m buffer from land take were regarded as more susceptible to future urban encroachment. Accordingly, these border areas were selected and added to the current GI territory to simulate an expanded GI scenario. The resulting map was processed by GUIDOS MSPA and component analysis performed as described in section 6.1.2.

It is unrealistic to believe that urban sprawl can be stopped by the conversion of all vacant arable land into GI elements. However, city development strategies can prioritize investments in the neighborhoods where NBSs for the expansion of current GI are most needed. To this end, administrative units were classified according to an index based on four variables (protected areas, agricultural area in the buffer and outside protected areas, isolated components, land take) so as to establish priorities of action: the higher value of the index, the higher the priority of intervention. According to the budget allocation process (BAP) (Nardo et al. 2005; Tomao et al. 2015), five experts were asked to allocate a budget of one hundred points to the four selected variables (based on their experience and their subjective judgment). The choice of weights reflects the importance assigned to each component of the index. Once the responses of selected experts were collected, the weights applied to each variable were calculated as the average ‘budgets’. The sum of ‘average’ weights is 100. The absolute value of index of each administrative unit is the sum of products between variables and weights. The index is the normalized with the min-max method. Based on the index value the administrative units were divided into 3 levels of priority (low, medium, high) according to quantiles.

6.2. Results

6.2.1. Current GI and land take in Rome Municipality

The territory of Rome's municipal GI, as mapped on the validated UA, covered a surface of nearly 23,000 ha in 2012, corresponding to about 18% of the municipality

(Figure 4). According to the UA 2006-2012 change layer, land use/ land cover change amounts to about 3,000 ha in Rome’s municipality. Over 50% of this is land take, i.e. change from “rural/natural” classes to artificial surface. In particular, mapped land take amounted to 1,767 ha (857 polygons) corresponding to 1.4% of the city area. Land take occurred mainly outside of protected areas (94%).

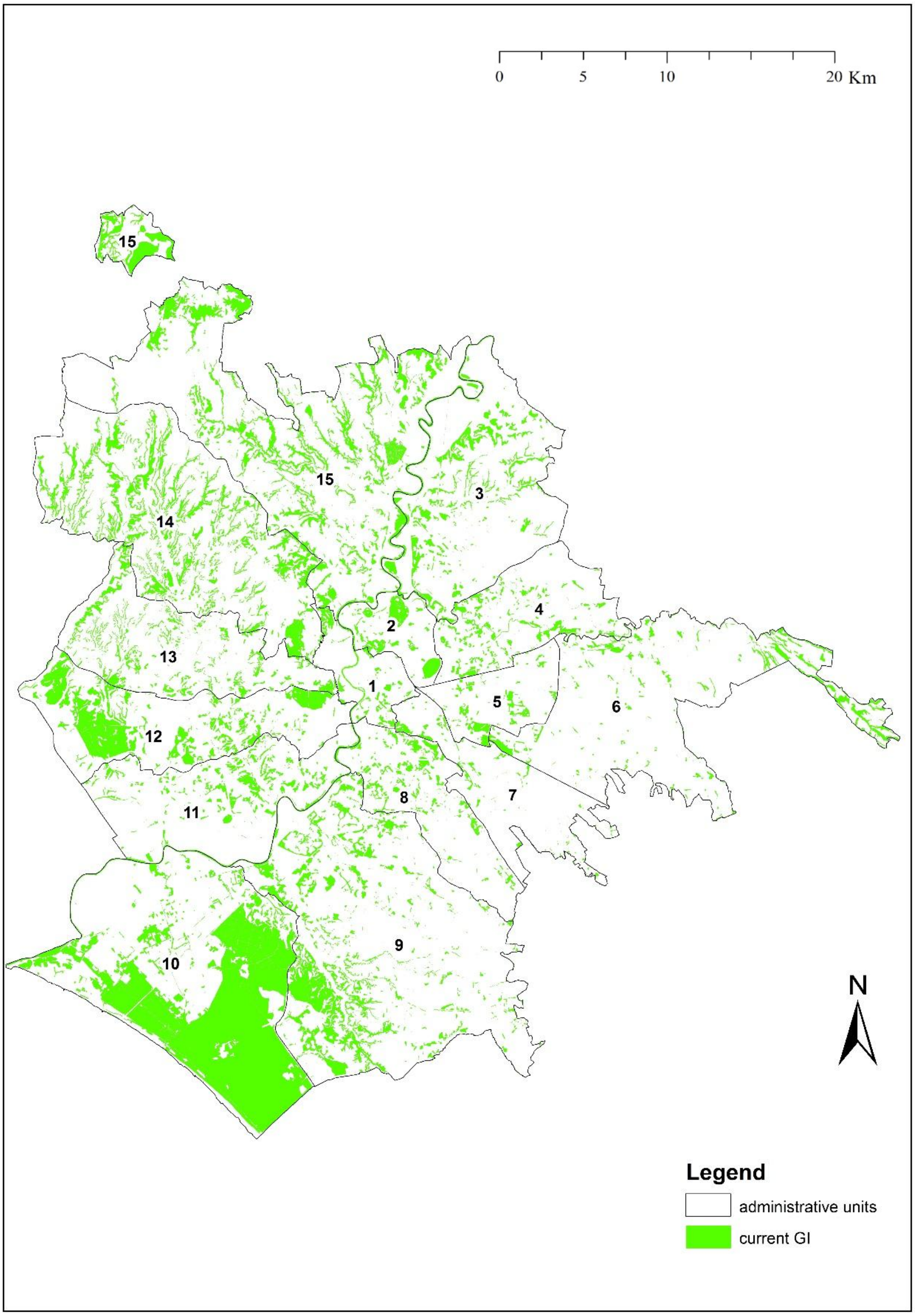

Figure 4: GI in the Rome's municipality according to UA 2012

6.2.2. Current GI connectivity

The MSPA was used to classify green areas within the municipal boundaries as structural classes of GI depending on their size and shape. The structural pattern is affected by the edge width used in the analysis and so three different edge width values (10 m, 20 m, 40 m) were compared to assess the size and the number of GI elements. Table 7 shows the structural component analysis based on the MSPA results. In terms of percentage of pixel compared to foreground, different MSPA analysis highlight that core areas decreased 17 % with 20 m edge and 32% with 40 m edge with respect to core areas with 10 m edge.

Table 7: MSPA class proportion for different edge widths values of GI. Total is the amount of foreground in the map

Class	**Edge width= 10 m**	**Edge width= 20 m**	**Edge width= 40 m**
	%	**%**	**%**
Core	73,76	56,21	41,25
Islet	0,98	3,16	9,09
Perforation	0,49	0,33	0,33
Edge	20,88	28,5	29,16
Loop	0,14	0,45	1,4
Bridge	1,01	4,38	8,12
Branch	2,75	6,98	10,65
Total	100	100	100

The effect of the edge width plays an important role with links. Elements classified as bridges range from 1% for 10 m edge to nearly 8% for 40 m edge, whereas branches increase as much as fourfold compared with those analysed with edge equal to 10 m. Generally, link areas coincide to linear elements of the landscape such as rivers or minor channels including riparian zones and narrow woodlots. The link areas was more affected to edge influence than core areas. According to the results, link areas was classified as core areas when edge width is not too different from their width. Otherwise, as the edge with increases, linear elements take on a role of connectors (bridges) or thicker branches. A 10 m edge was applied for component analysis to take into account the role of linear elements as core areas. In this case the structural pattern of the GI better reflects the potential of the core areas. In terms of surface area, connected components cover about 15,900 ha, nearly to 90% of the total covered by components (Table 8), nevertheless, their number is less than 50% of the total. The average size of the connected core areas is about 16 ha.

Table 8: Core areas and network summary statistics of GI

Component	**Edge width= 10 m**	
	number	**ha**
Connected core areas	996	15.900
Isolated core areas	1.241	1.817
Total	2.237	17.717

On the contrary, the number of isolated core areas corresponds to 55% of the number of components but they cover only 10% of the total component area. The average size of isolated cores is 1.5 ha.

6.2.3. GI elements sensitive to urban encroachment: conservation priority

Over half of the current GI area is included within the boundaries of a protected area (13,300 ha), whereas the 42% (10,700 ha) occupies lands without any legal restriction to land take. Sensitive elements in the GI cover about 1,900 ha, equal to 1.5% of total surface of the municipality and 8% of the current GI. These elements are non-uniformly distributed throughout the 15 administrative units of the municipality, as shown in Figure 5. Most of the vulnerable areas, which are 150 ha to 390 ha in size, are in just five administrative units (6, 9, 11, 12, 14) on the periphery of Rome. Close to the city center, almost completely covered by built-up areas, the number and size of sensitive areas that could still be preserved are substantially smaller.

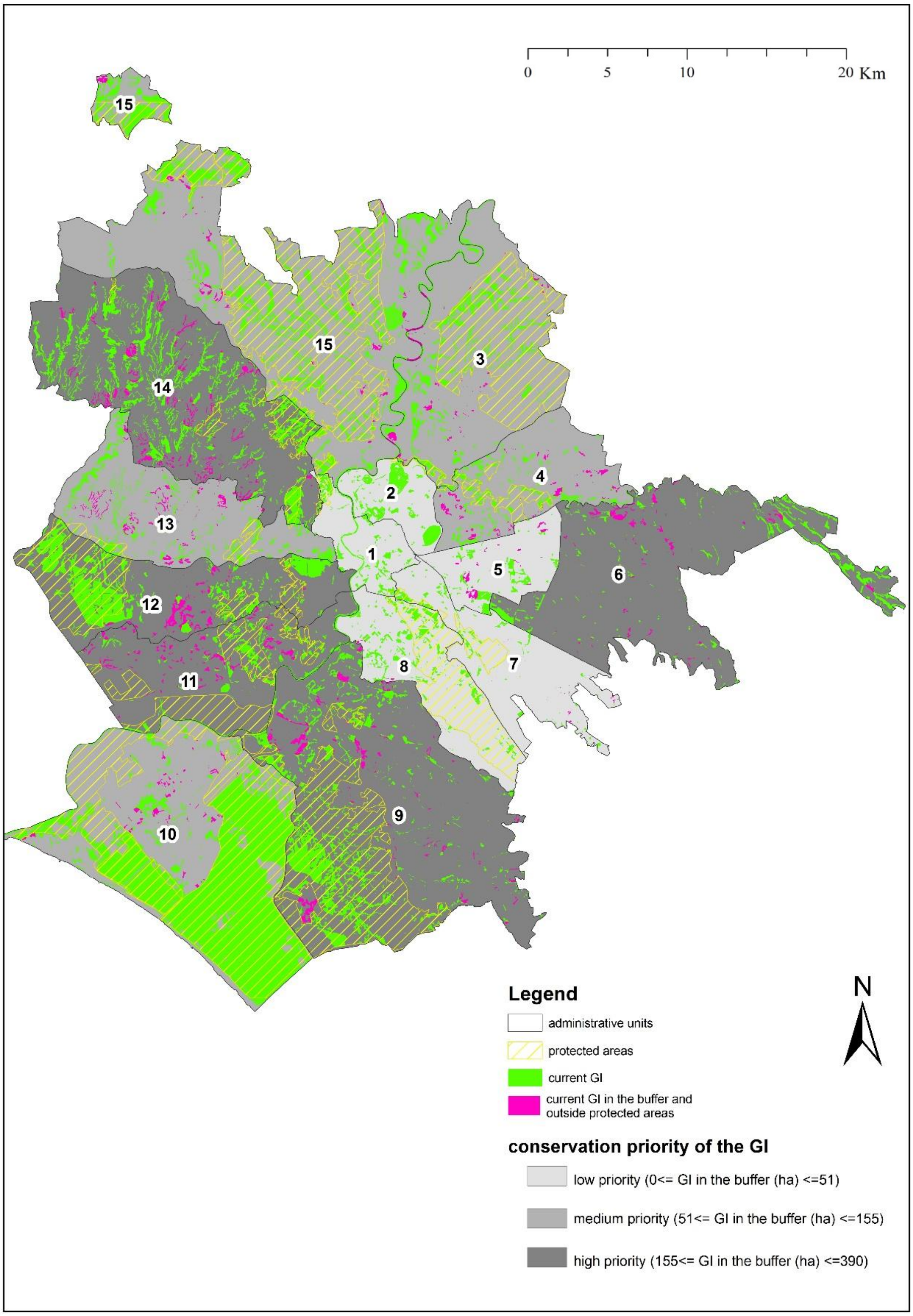

Figure 5: Conservation priority in the current GI

6.2.4. Scenario of GI expansion

Arable lands vulnerable to land take cover a surface of 9,734 ha. If all these agricultural areas were converted into elements of the network, the GI would rise to 32,800 ha. In simulation scenario, core areas territory increase by 2% (about 7,900 ha), while the area covered by bridges and branches remains stable (Table 9).

Table 9: Comparison MSPA classes in current and simulated scenario of GI expansion. Edge width = 10 m

Class	**Current GI**		**Simulated scenario GI**	
	%	**ha**	**%**	**ha**
Core	73,76	17.127	75,94	25.037
Islet	0,98	196	0,56	161
Perforation	0,49	112	0,75	247
Edge	20,88	4.814	19,75	6.466
Loop	0,14	32	0,16	51
Bridge	1,01	267	0,79	262
Branch	2,75	561	2,05	585
Total	100	23.109	100	32.809

According to component analysis, spatial connectivity would also increase (Table 10). Connected components are larger than those in the current GI and their average size ranges up to 23 ha. Overall, the surface of connected core areas increases by about 7,345 ha, compared to the current network.

Table 10: Simulated core areas and network summary statistics for edge width equal to 10 m

Component	**Edge width= 10 m**	
	number	**ha**
Connected core areas	1.017	23.335
Isolated core areas	1.230	2.498
Total	2.247	25.833

6.2.5. Prioritizing intervention for the enhancement of the GI

The BAP approach resulted in the following ‘average’ weights assigned to the four selected variables; 10 (SD=5.0) for protected areas, 41 (SD=5.5) for agricultural areas in the buffer and outside protected areas, 22 (SD=7.6) for isolated components, and 27 (SD=5.7) for land take. Figure 6 shows the variation of the normalized index value across the administrative units of Rome’s Municipality. Administrative units in the core of the city show the lowest index values (less than 0.45), while units 3, 8, 9, 10, 11 fall in the highest index classes (greater than 0.65). For administrative units with the highest indicator values the creation of useful elements to improve the structural connectivity of the network and to limit land take is a priority. Figure 7 shows an example of the selection of vulnerable arable lands around land take.

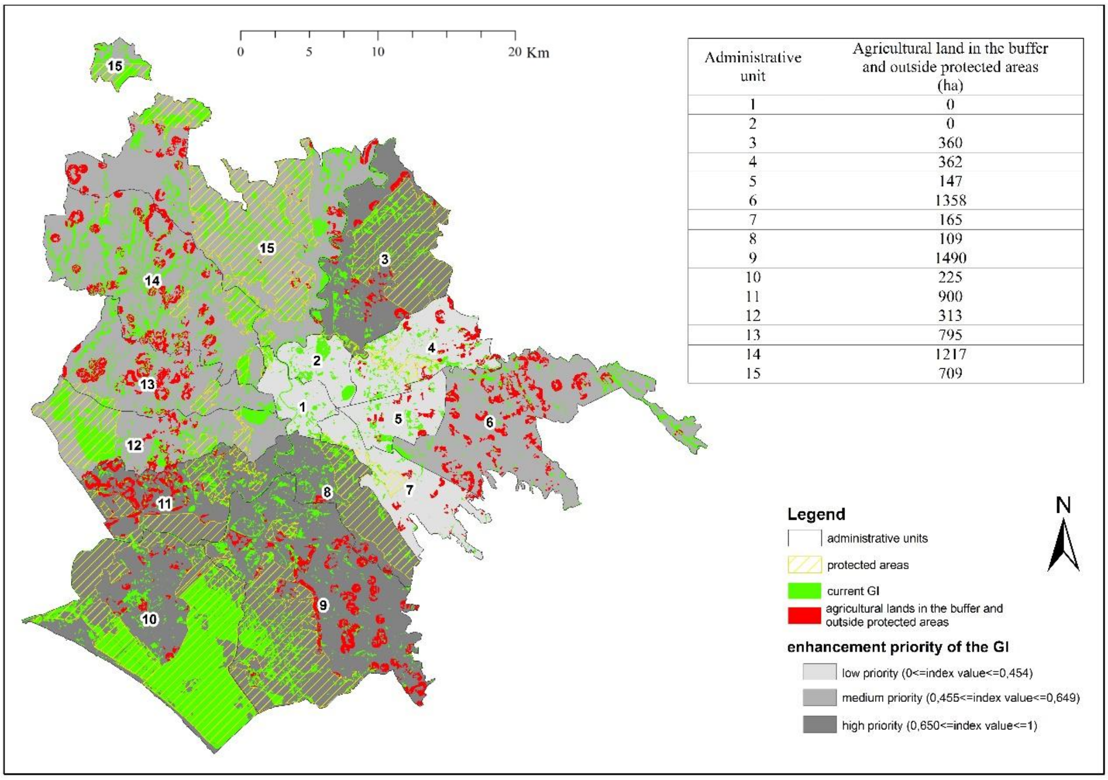

Figure 6: Priority index for GI enhancement

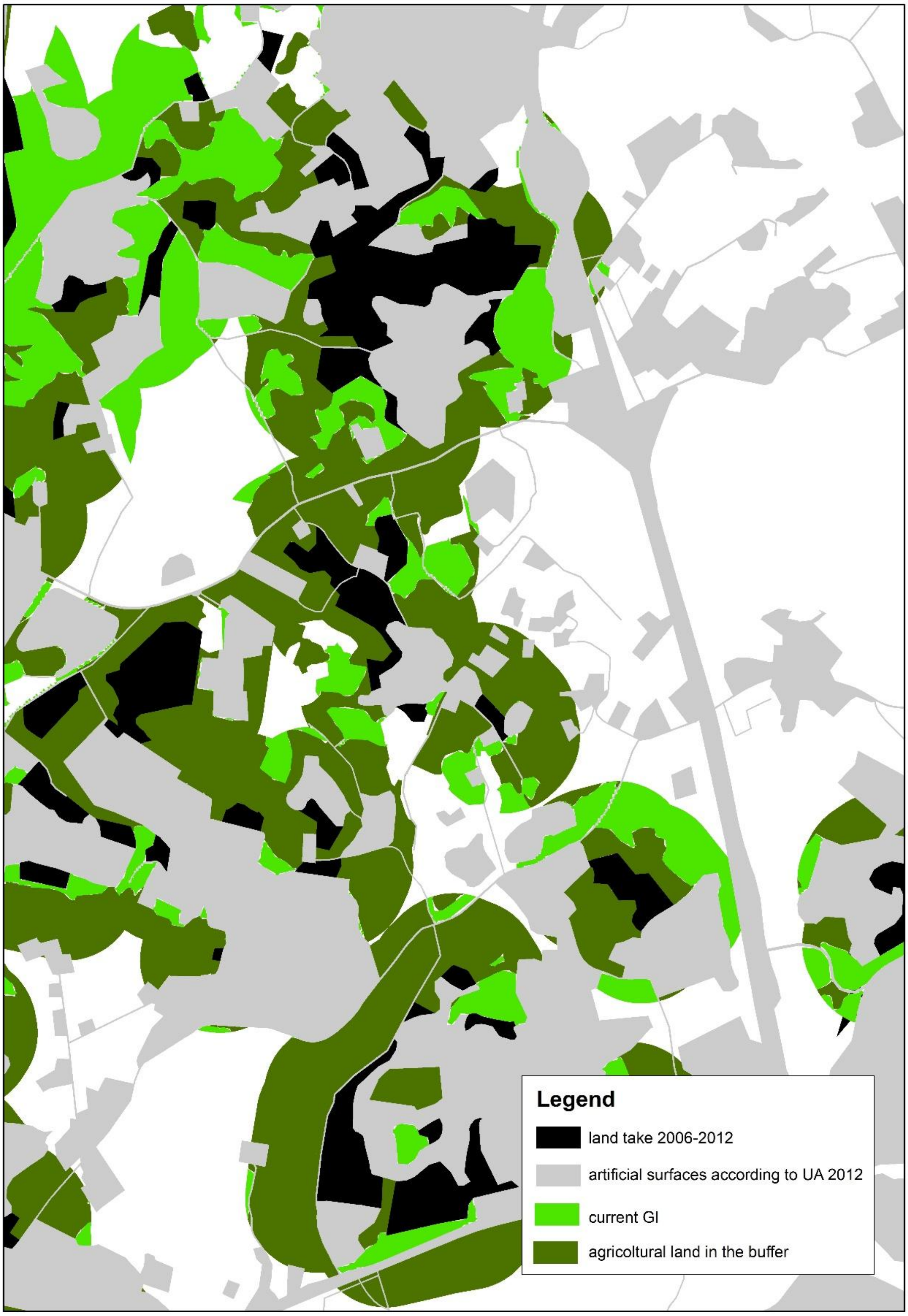

Figure 7: Selection of vulnerable arable lands around land take in an administrative unit with high priority of GI enhancement

7. Accessibility and usability of the urban green areas

7.1. Methodology

7.1.1. Selection of land use data

For the analysis conducted in the third step of this thesis, all artificial surfaces with residential use (code 1.1) were extracted from the UA dataset available for the year 2012. Land cover change from 2006 to 2012 was used to identify land take: all the new residential settlements that in 2006 were encoded as natural surfaces (codes 2 and 3) were selected (see Figure 8). Land take from 2006 to 2012 has been related to the UGAs distribution.

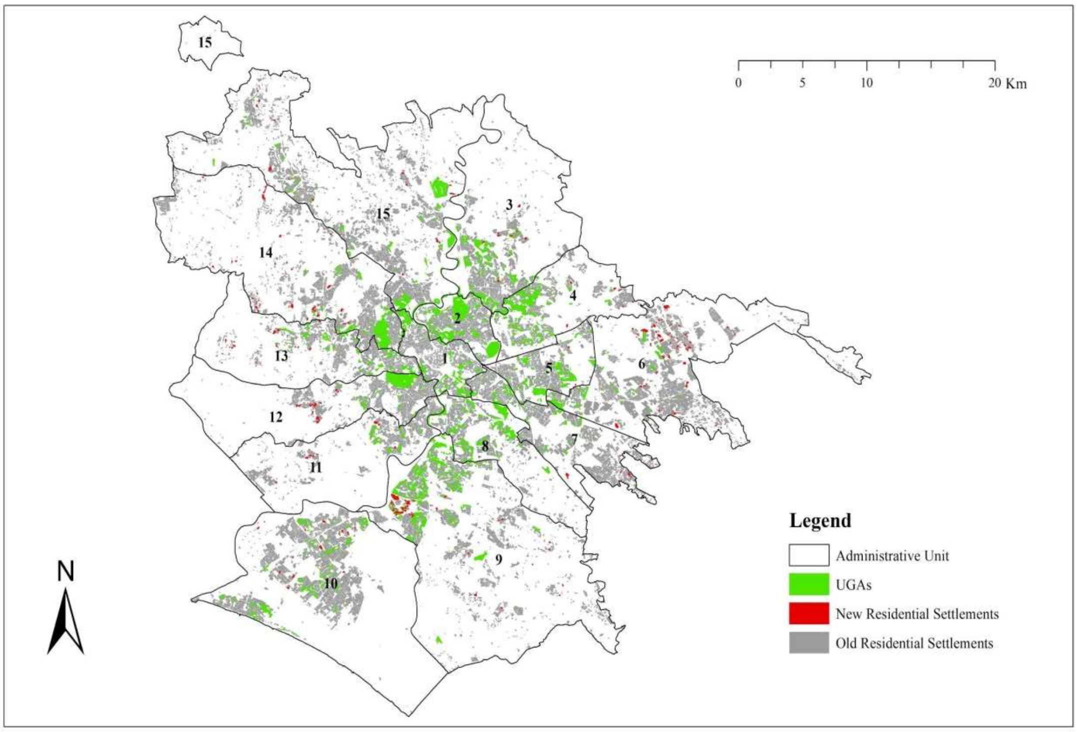

Figure 8: Land use/land cover data obtained from Urban Atlas

The UGAs were selected according to the UA definition (code 1.4.1). The total surface area covered by UGAs in the municipality of Rome is about 3,550 hectares (UGA average area = 3.2 ha, CV = 290%). All UGAs with an area below 0.5 ha were excluded from the analyses. Indeed, several definitions of accessibility identified a minimum threshold of 5,000 m2 for the inclusion of UGAs in the accessibility indicator (see ISPRA, 2010). A summary of the main statistics of the selected UGAs (n=932) for each administrative unit is given in Table 11.

Table 11: The main features of the UGA system within each Rome administrative unit

Administrative unit	UGAs (no.)	Total surface of UGAs (ha)	Mean surface of UGAs (ha)
1	64	227,2	3,5
2	94	193,9	2,1
3	18	63,5	3,5
4	19	217,8	11,5
5	43	126,9	3,0
6	31	262,9	8,5
7	78	305,7	3,9
8	89	397,2	4,5
9	66	226,6	3,4
10	90	307,9	3,4
11	56	192,3	3,4
12	39	119,7	3,1
13	34	80,5	2,4
14	79	289,7	3,7
15	132	433,8	3,3

In the urban core, i.e. the administrative units 1 and 2, no residential settlements were established from 2006 to 2012. Indeed, they have been characterized by a continuous urban fabric since 2006, according to UA classification. For this reason, administrative units 1 and 2 were excluded from the analysis regarding accessibility to UGAs from new settlements. The main statistics of land converted to residential land uses in the study area are reported in Table 12.

Table 12: Statistics of land converted to residential land uses due to the establishment of new residential settlements

Administrative unit	New residential settlements (no.)	New residential settlements (ha)
1	-	-
2	-	-
3	14	14,2
4	9	8,0
5	2	1,7
6	57	63,4
7	15	10,1
8	1	0,6
9	36	62,6
10	17	20,1
11	14	13,2
12	13	17,9
13	17	15,6
14	33	40,3
15	28	22,1

7.1.2. Population data

The population living in the urban settlements under consideration was assessed using Eurostat's 2011 GeoStat population grid (European Commission, 2016). The dataset contains the count of persons at their usual place of residence per km² for the reference year 2011 on the date of the Census. Each cell of the grid covers 1 km2. Only inhabited grid cells are present in the dataset. The population living in each UA residential polygon was obtained by intersecting the UA layer with the population grid in a GIS environment. The population of the 1-km2-cell associated to each UA urban patch was then weighted for the area of the UA polygon. To give a more precise result, the total area of each urban polygon was previously multiplied by the percentage of urban fabric actually present in the polygon (see Table 13). When UA polygons intersected with several cells of the population grid, the population of each portion was summed. In the case of the UA polygon falling outside the grid, the population estimates were obtained by multiplying the area of the polygon by the average population density of the city.

Table 13: Percentage of urban fabric in UA urban patches

UA legend item	**%**
Continuous urban fabric (S.L. : > 80%)	*0,9*
Discontinuous dense urban fabric (S.L. : 50% - 80%)	*0,65*
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	*0,4*
Discontinuous low density urban fabric (S.L. : 10% - 30%)	*0,2*
Discontinuous very low density urban fabric (S.L. : < 10%)	*0,05*
Isolated structures	*0,01*

7.1.3. Road network

The road network was extracted from Open Street Map (OSM). The OSM project was aimed at creating a free and editable world map (Ramm et al., 2011). Volunteers, amateurs and professionals act as sensors and collect geographic data (Flanagin and Metzger, 2008). All collected data are stored according to the OSM data model: linear features are represented by "Ways" and point features by "Nodes". A classification of road typology (e.g. primary roads, secondary roads, motorways, etc.) is also provided. This source layer has been successfully used to perform spatial network analysis by several authors (e.g., Gil, 2015; Cooper, 2017).

7.1.4. Identification of access points to UGAs

As a first phase of the proposed methodology (see Figure 9), the actual accessibility to UGAs was evaluated by identifying the access points to the UGAs using digital orthophotos and GEarthView plugin of QGis. GEarthView displays QGis view and features with attributes (selected layer) into Google Earth and, therefore, enables the associated Google Street view photographs to be visualized (Figure 9).

Figure 9: Example of the access point (right) and no access point (left) at UGAs

UGAs with permanent physical constraints and barriers (fences, walls) limiting user access were excluded from the network analysis. To minimize classification errors, the same visual interpreter carried out the entire classification by checking all potential accesses to each UGA.

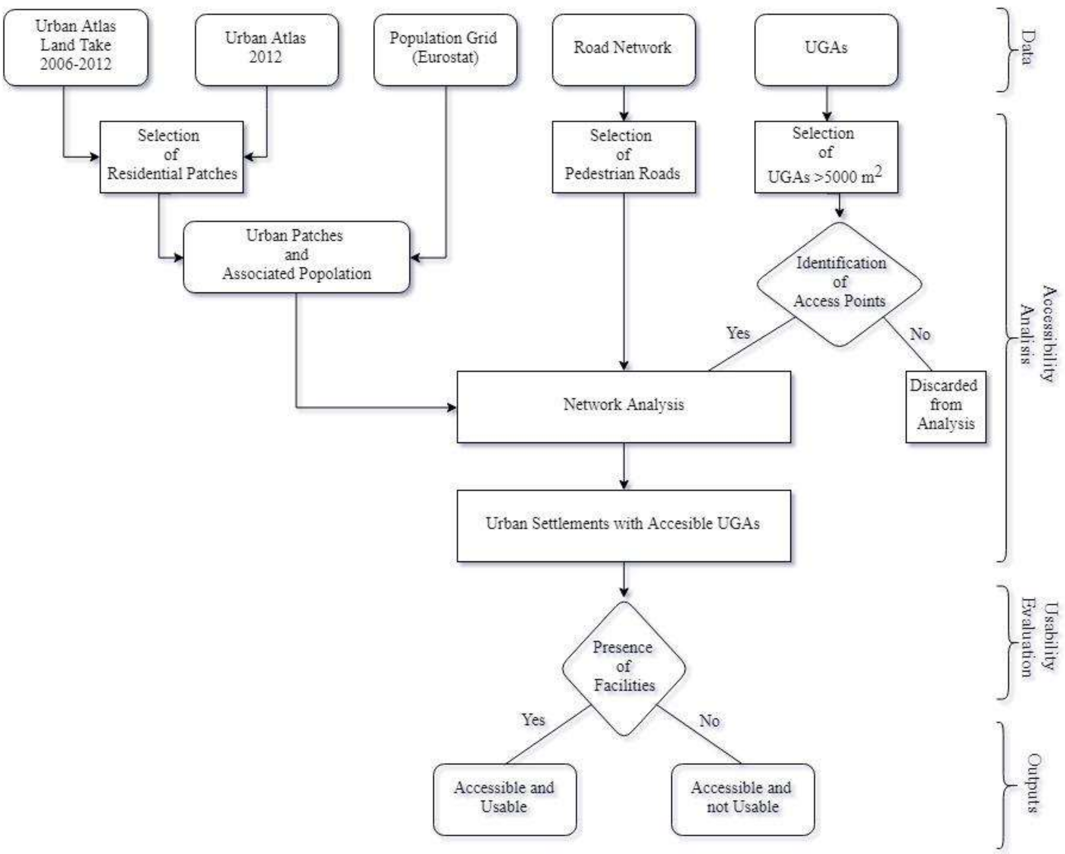

Figure 10: Methodological workflow

7.1.5. UGA accessibility

In order to identify accessible UGAs, the threshold of 15 min' walking distance established by Urban Audit was considered (ISPRA, 2010). Considering the average speed of pedestrians of 4 km/h, 1 km is the distance that can be covered on foot in 15 min (Stanners and Bourdeau, 1995). According to this definition, the residential settlements with accessible UGAs in their surroundings were identified. This analysis was performed on (i) the 2012 residential settlements already present in 2006 and (ii) the new residential settlements established during the 2006–2012 period. Spatial analysis techniques use network data (usually linear, such as routes and paths) to calculate the distance between points or nodes. In the case of study, OSM road layers were network data, whereas access points to UGAs and residential settlements were the nodes. Following the above-mentioned definition of accessibility, all the roads off-limits to pedestrians was excluded. (motorways, motorway links, trunks, trunk links, raceways and railways). Then, network analysis identified the shortest routes between UGAs and residential settlements by using the "New Closest Facility" algorithm. The algorithm calculates the distance between the centroid of urban settlements and access points of the closest UGA (see Figure 10).

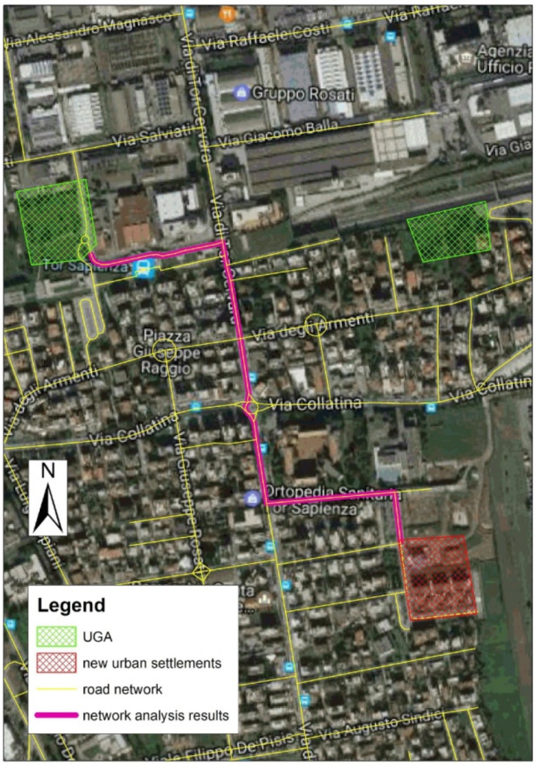

Figure 11: The network analysis identified the shortest routes between UGAs and residential settlements

7.1.6. UGA usability

The presence of facilities able to support people's activities were used as a proxy of usability of UGAs (Van Herzele and Wiedemann, 2003). The considered facilities are those related to the degree of internal usability by visitors, such as footpaths, and those which invite a longer stay, including street lights, benches, toilets, children's play equipment, pools, picnic equipment, sports facilities, cycle tracks and dog walking areas (Van Herzele and Wiedemann, 2003; Sanesi and Chiarello, 2006). The presence/absence of facilities was checked by visual interpretation using the digital orthophotos and GEarthView plugin of QGis within each UGA (see Figure 11). In order to minimize classification errors, the same visual interpreter carried out the entire classification process.

Figure 12: The presence of facilities in two Roma's UGAs

7.2. Results

7.2.1. UGA accessibility

Mapping access points to UGAs evaluated actual accessibility. Overall, 1649 access points was detected. The number of access points per UGA is 2.8, on average (SD=1.9). No access points were found in 354 out of the 932 UGAs selected for the case study. Figure 12 illustrates the percentage of old and new settlements with accessible UGAs in their surroundings within administrative units.

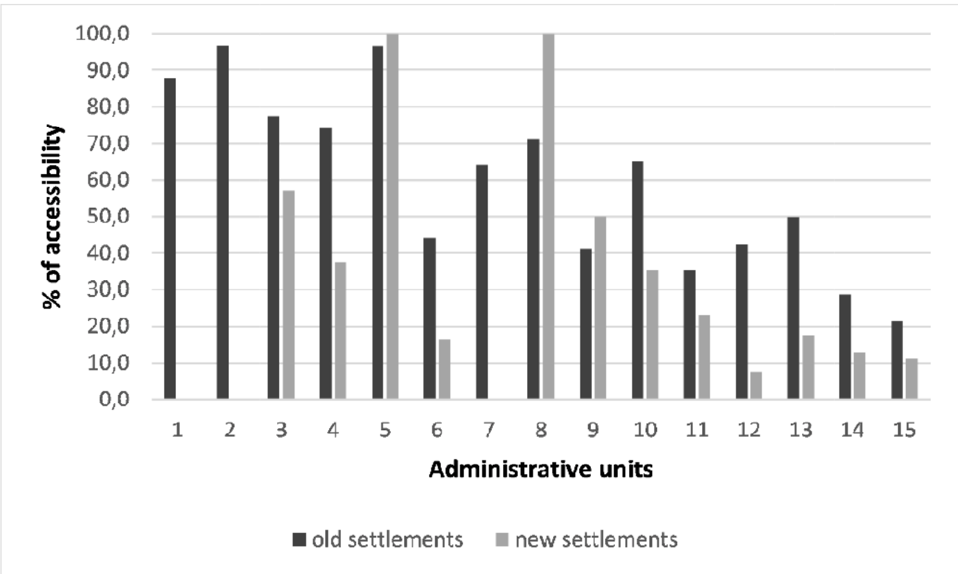

Figure 13: Accessible UGAs from residential settlements in the 15 administrative units of the Rome municipality

In old settlements, 15,359 routes are calculated by the network analysis, in new ones 246 are available. In old settlements, the average length of routes to UGAs is 1837m (SD=2467) and around 57% of the routes (8710) resulted shorter than the accessibility threshold (1 km). In new settlements, the average length of routes to UGAs is 3218m (SD=3051). Only 25% of the routes (61) is shorter than 1 km. At local scale, the administrative units 1 and 5 showed a percentage of old settlements with accessible UGAs greater than 95%. Conversely, the lowest percentages were detected in the administrative units 14 and 15 (28% and 21% respectively). The administrative units 6, 7, 12, 13, 14 and 15 include 63% of the new settlements but, at the same time, the percentage of accessibility to UGAs is lower than 20%. The highest percentages of new residential settlements with accessible UGAs in their surroundings was found in the administrative units 5 and 8 (100%). However, only 3 new residential settlements were established between 2006 and 2012 therein. Around one third of the routes shorter than 1 km (18) are located in the administrative unit 9, where they represent 50% of the total. Comparing the results in new and old settlements, this thesis highlights that new residential areas are characterized by a lower level of accessibility to UGAs. Exceptions are the administrative units 5, 8 where only 2 and 1 routes were calculated, respectively) and 9.

By using the intersection between Eurostat population grid and Urban Atlas residential settlements, how many city dwellers can benefit from accessible UGAs was assessed. (Figure 13). The share of population that can gain access to UGAs within 15 min' walk from old settlements is greater than 80% in administrative units 1, 2, 3, 4, 5, 8. As seen above, the lowest figures are found in the more peripheral administrative units: only 48% and 40% of city dwellers can use accessible UGAs in the administrative units 11 and 15, respectively. When considering only the new settlements, the results show that in some administrative units most inhabitants cannot benefit from accessible UGAs. Indeed, the share of population is lower than 20% in the administrative units 11 and 13, and lower than 5% in the units 6, 7 and 12. 100% of people living in the three new urban areas of the administrative units 5 and 8 can benefit from accessible UGAs.

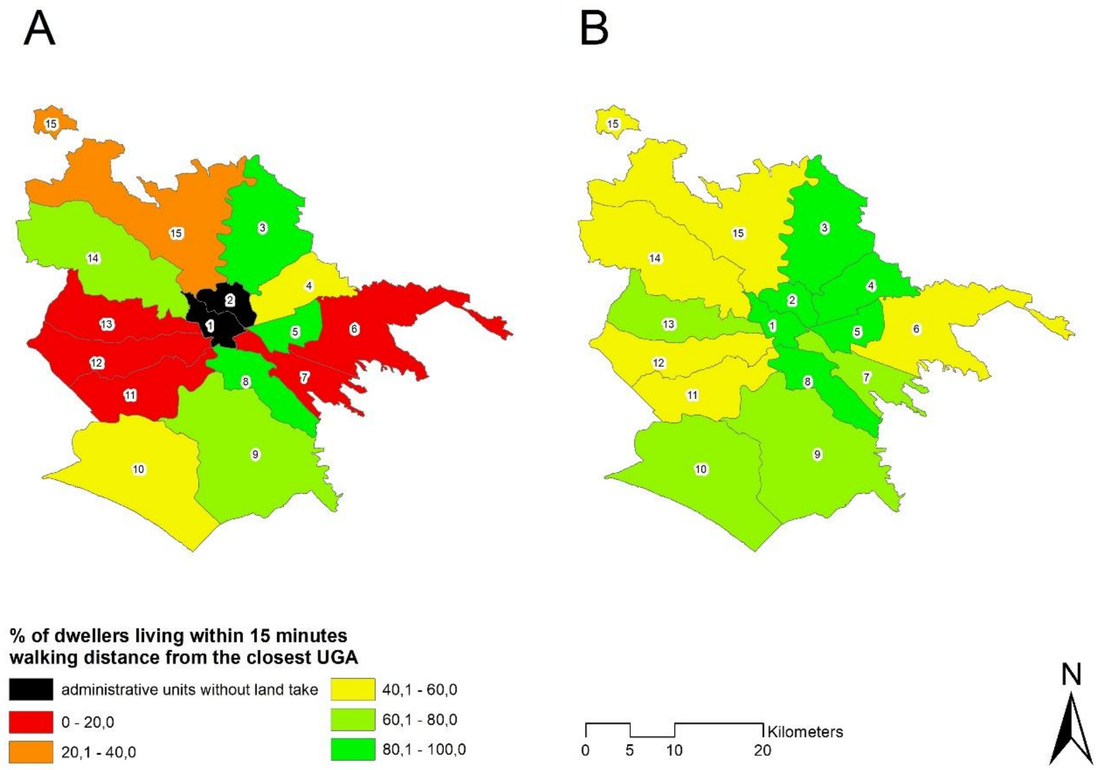

Figure 14: Share of population that can benefit from accessible UGAs from new (A) and old (B) residential settlements in the 15 administrative units of the Rome municipality

7.2.2. Usability of accessible UGAs

The results of the usability analysis for accessible UGAs are reported in Table 13. The total number of accessible UGAs amounts to 500 from old residential settlements and only 39 from new ones. As regards UGAs accessible from the old residential settlements, about 72% have facilities able to support user activities. In the administrative unit 12, all accessible UGAs showed at least one facility (100% usability), while in administrative units 1, 2, 5 and 6 the percentage of UGAs' usability was higher than 80%, which can be therefore considered as the best in terms of usability in the case of study. On the contrary, the lowest levels of usability were found in administrative units 8 and 13, where the percentage of UGAs without facilities was around 40%. Overall, the percentage of usability of UGAs accessible from new residential settlements exceeds 69%. 100% usability was found in the administrative units 5, 12, 14 and 15. The rate of UGAs' usability in the administrative units 8 and 13 was 0%, where only three accessible UGAs appeared from the network analysis.

Table 14: Usability statistics for the accessible UGAs in each administrative unit

	Old residential settlements		**New residential settlements**	
Administrative units	**Accessible UGAs (no.)**	**Usability of UGAs (no.)**	**Accessible UGAs (no.)**	**Usability of UGAs (no.)**
1	34	31		
2	38	32		
3	41	31	7	6
4	57	37	3	2
5	35	30	1	1
6	27	24	7	6
7	21	15	-	-
8	39	26	1	-
9	82	49	7	4
10	64	42	5	3
11	8	6	2	1
12	4	4	1	1
13	15	9	2	-
14	14	10	1	1
15	21	16	2	2
tot	500	362	39	27

8. Discussion

8.1. Multidimensional analysis of land-use efficiency

Policy implementation in different socioeconomic contexts requires practical measures which support adaptive management and effective local governance (Thomas et al. 2012). In this regard, there is a great interest in devising meaningful measures for urban containment, as a response to soil consumption and land degradation in peri-urban areas based on the analysis of land-use efficiency applied to vastly different territorial contexts (Pendall 1999; Masek et al. 2000; Sutton 2003; Barbosa et al. 2015; Salvati et al. 2016). In this line of thinking, per-capita built-up area was extensively used as a proxy of land-use efficiency at metropolitan scale (Zitti et al. 2015), with the final goal to identify typologies of cities characterized by distinct patterns of land consumption. Description of urban spatial structures and factors underlying different values of land-use efficiency under spatially-varying developmental conditions is fundamental to define suitable policies for any given socioeconomic context. In this regard, can be considered that since it is often difficult to distinguish population change in a given jurisdiction as either the cause or effect of urban development, population density cannot be regarded as the most relevant indicator of land-use efficiency. In most cases, an increasing number of activities, including housing, commerce and advanced services would be important indicators of urban sprawl as population growth, possibly reflecting economic opportunities as the major driver of land transformation (Lambin et al. 2001; Ji et al. 2006) Results of the analysis presented in this study have coherently described the urban gradient in European regions as a relevant factor shaping ecological processes and ecosystem services (e.g. Schwoertzig et al. 2016; Baró et al. 2017). This study offers a practical contribution in the characterization of the socioeconomic profile of cities with substantial differences in land use efficiency, by identifying relevant socioeconomic gradients that may influence land consumption and, accordingly urban containment strategies. According to the empirical evidences presented in this paper cities with less efficient land-use (i.e. higher values of per-capita built up areas), are characterized by distinctive features including: (i) large municipal (administrative) size (possibly indicating higher land available for building), (ii) landscape fragmentation (especially affecting cropland and peri-urban forests), (iii) low per-capita available income. Such patterns have been repeatedly observed also in other world regions. For example, recent studies have demonstrated that forest loss and cropland fragmentation in rapidly-evolving areas are largely influenced by socioeconomic changes and human demands (Gong et al. 2013; Lambin and Meyfroidt 2010; Liu et al. 2016; Van Den Hoek et al. 2014).

Geographical gradients in land-use efficiency between Mediterranean and Atlantic or Western and Eastern countries have been also identified. A low level of land-use efficiency is typical of areas with low-density residential settlements especially in Western and Atlantic Europe. In Eastern European cities, dispersed urban expansion was tightly controlled since housing shortage led local authorities to favour high-density social housing developments at the expense of low-density private dwellings (Power 2013). While experiencing an evident increase in per-capita available income between 2000 and 2007 (Kornai 2006), Eastern cities maintained levels of personal income still lower than the rest of Europe (Couch et al. 2008), coupled with intermediate levels of land-use efficiency, possibly due to the legacy of urban containment policies typical of the socialist period (Parysek 2006).

Regression models identified the best descriptors of land-use efficiency in European regions. Per-capita available income was negatively associated with per capita built-up area in Western, Atlantic and Central Europe. This (apparently counterintuitive) result implies that, European cities with higher income may feature a lower level of land consumption compared with more disadvantaged metropolitan regions. Even in regions with substantially low levels of per-capita income, such as Eastern Europe, annual growth of income levels during economic expansion proved to be associated with land-use efficiency. These findings suggest that economic development may promote urban containment, possibly via effective urban planning (Bart 2010). According to models' findings, urban and peri-urban green areas constitute an effective boundary against urban expansion especially around large cities in Western Europe. While landscape diversity demonstrated to have a positive influence on socio-ecological system's resilience (e.g. Abson et al. 2013), in the case of study diversity in the composition of urban (and peri-urban) landscapes was associated with high land-use efficiency, as shown by regression outcomes for the whole of Europe and specifically, for central Europe. Conversely, high mean patch size (reflecting homogeneous landscape structures) were associated with low values of land-use efficiency in European cities. As expected, sprawling cities (i.e. with high percentage of discontinuous low-density urban fabric in total landscape) showed lower levels of land-use efficiency than compact or semi-dense cities. Based on these results, it seems clear that strategies that redirect urban expansion towards self-contained development featuring compact urban morphologies, should be based on the promotion of semi-dense, continuous settlements (Hofstad 2012). These policies could be more effective in wealthy and spatially-accessible socioeconomic contexts characterized by a mixed urban landscape and a diversified natural landscape surrounding central cities.

Clusters analysis allowed identifying a gradient of land-use efficiency for the 417 cities, from Cluster 1, representing the most efficient cities in the use of land, to Cluster 4, indicating with less efficiency. The 38 cities classified within Cluster 1, are located in the Atlantic region, particularly in the United Kingdom. Cities in Cluster 4, concentrate mainly in Eastern Europe, showed an opposite overall profile, that can be explained by past urban development strategies. Indeed, European cities had very diverse histories of urban development, especially since World War II, with the iron curtain separating capitalist and communist urban development and the economic transition after the early 1990s. In this regard, the sharp divide between Eastern and Western Germany (cities belonging to Cluster 4, and to Clusters 2 or 3, respectively) is particularly interesting. After the fall of the Iron Curtain, the cities became independent self-ruling entities, and had to adapt quickly to the new democratic and market economy structures (Tölle 2010; Kubeš 2013). However, the processes that followed the collapse of the communist command economy and the entering of those cities into the system of a globalising economy led in most cases to a severe recession going far beyond strictly economic questions, possibly resulting in peculiar spatial structures affecting land-use efficiency (Tosics 2005; Parysek 2006; Stanilov 2007).

8.2. Urban ecosystems conservation and enhancement of the Green Infrastructure

Land use/land cover change mapping is essential in the evaluation of the extent, dimensions, consequences, and causes of landscape transformations, and is a vital aid to the prediction of future trends and to support sustainable urban planning (Houet et al. 2010; Koschke et al. 2012; Haase et al. 2014). The territory of built-up areas, as delineated by UA 2012, amounts to 47,400 ha within Rome's Municipality boundaries, about 37% of the Municipality "city-board". On the other hand, the GI territory extends over the 18% of the city-board space. The use of variable edge width size in the analysis of the structural connections within current the GI, highlights that core areas increase from 41% with 40 m edge width to 73% using 10 m edge width. Therefore, linear elements play a strategic role in the backbone of the current GI, as hinted in other studies (Barbati et al. 2013; Salvati et al. 2016). Component analysis also reveals a large number of small isolated core areas. These areas often correspond to small isolated green elements within the center of the city next to the continuous urban fabric. These results reflect the simplification and fragmentation of the urban landscape brought about by urban expansion in Rome (Salvati et al. 2016). The creation of a system of protected areas in the 1980's has contributed to the preservation of green areas in Rome's Municipality (Gasparella et al. 2017). At the administrative unit level the largest protected area corresponds to the most extended tracts of the existing GI. However, study findings also show that about the 42% of the territory of current GI is located outside protected areas. This may constitute a threat for the preservation of local tracts of Rome's GI, considering that the actual rate of land take amounts to 1.4% of the municipality's area in only 6 years. If land take were to remain at current levels built-up areas would reach 45% of the municipality by 2050. Therefore, adopting an ecological approach to future urban planning will become increasingly more crucial in maintaining the long term sustainability of the existing GI and preserving its environmental and social benefits. In fact, the ecological value of a green network is better than those of the sum of the green spaces individually. A network of hubs and links can provide connectivity of natural elements (Wu and Hobbs 2002), help counteract uncontrolled urban development better than individual green spaces, and enhance biodiversity by preserving the links between different ecosystems (Bierwagen 2007; Uy and Nakagoshi 2008). From this perspective, the proposed methodology supports the development of a smart spatial planning strategy by controlling land take by promoting local actions for the conservation and expansion of the current GI territory. Its major contribution lies in the use of a straightforward approach to map the GI and surrounding agricultural land vulnerable to land take at the scale of the city that is directly translatable into information that supports local strategies for the control of urban encroachment in the city-board space. From findings in this study highlight the following observations and recommendations for city development strategies:

i) Recognizing that built-up areas currently occupy more territory on the city-board than the current GI; the selection of GI elements both within the buffer as well as outside the protected areas allows us to rank administrative units by conservation priority. The largest areas of sensitive elements in the GI are located in those administrative units where land take is also favored by the fewer protected areas. Conservation strategies here should focus on legal/spatial planning measures to conserve arable land in the border territories between sensitive elements and existing built-up areas as much as possible;

ii) Identifying areas where MSPA, applied to potential scenarios that involve conversion of selected arable areas into GI elements, confirms beneficial effects both in terms of structure and of connectivity. These strategically-placed “white” stones would enhance the structural connectivity measured both in terms of number and in area. In ecological terms, a greater value is recognized to arise from the larger areas (Simberloff 1997; Zipperer 2005);

iii) Recognizing that although final decisions about the future urban landscape pattern much depends on land use regulations and on the goals and objectives of landowners, a scoring approach to prioritize actions is useful in identifying neighborhoods of the municipality where investments in NBSs to convert agricultural land into elements of GI are most compelling. The creation of new GI elements close to the newly urbanized areas also improves the accessibility for citizens to green spaces right where urban development is more intensive (Tarzia 2003).

8.3. Accessibility and usability of urban green areas

Urban sprawl affects essential environmental, economic and social functions the importance of which is often underestimated (EEA, 2016). Scattered growth of cities often involves moving away from urban sustainability goals.
In order to control urban sprawl and provide more sustainable cities, UGAs are widely known as frameworks for implementing NBSs (Ozus et al., 2011; Raymond et., 2017).

On the other hand, policy and planning processes should take decisions that are "evidence-based" (Corona, 2014). For this purpose, indicators based on the total area of UGAs (e.g. m2 of UGAs/number of inhabitants) are often used to assess urban sustainability and to support planning actions. However, such indicators might show only a biased UGA availability for city dwellers. In this perspective, indicators such as accessibility and usability of the UGAs may offer additional information to support the decision-making processes, especially to improve new residential settlement planning and make green areas more attractive (Neuvonen et al., 2007; Žlender and Ward Thompson., 2017; Fan et al. 2017c). In recent years, forward-looking cities have already considered accessibility in planning UGA networks (Barbosa et al., 2007; Fan et al., 2017b; 2017c; Grunewald et al., 2017). For example, Grunewald et al. (2017) proposed the indicator "Accessibility of green spaces" for the assessment of recreation-related ecosystem services in Germany: the German environmental authorities have accepted this indicator to address the goals of increasing the amount of UGAs and other green infrastructure elements near residential settlements. Although several methodological approaches were applied and compared in various contexts to evaluate the accessibility of UGAs (Barbosa et al., 2007; Oh and Jeong, 2007; Gupta et al., 2016), there is a knowledge gap regarding their actual accessibility and usability. This study suggested a more comprehensive definition of accessibility and usability. It was referred to actual accessibility and usability in order to give a more comprehensive description of UGA availability. In this regard, facilities are considered as fundamental elements supporting people's activities and experiences in green spaces (Van Herzele and Wiedemann, 2003; Schipperijn et al., 2010). A large number of UGAs, points of access and facilities for pedestrians increase the visits to green areas (Grahn and Stigsdotter, 2003; Neuvonen et al., 2007; Sugiyama et al., 2010; Koohsari et al., 2013). Therefore, they are positively related to the well-being of city dwellers and to the provision of both psychological and physical benefits deriving from contact with nature (Carrus et al., 2015). However, the distance to travel is considered the main limitation in using UGAs, particularly in urban peripheral areas where rapid land transformation takes place (Fan et al., 2017b), so that this factor should be considered in planning new settlements. In order to consider all these elements, a straightforward, practically feasible and replicable approach was developed that assesses and integrates actual accessibility and usability by using free datasets available at European scale (Urban Atlas, Open street map).

In Rome, only 57% of residential settlements have accessible UGAs in their surroundings, but the percentage is much lower (25%) if it considers those established between 2006 and 2012. This evidence also holds good at administrative unit scale. Overall, two-thirds of the administrative units have more than 50% of the new settlements with UGAs farther than 1 km, although lower percentages (<20%) were recorded in many units (i.e. 6, 7, 12, 13, 14, 15), especially where most settlements were established between 2006-2012. Similarly, the share of population that cannot benefit from accessible UGAs is lower in the new settlements, notably in the more peripheral administrative units. The administrative units (i.e. 5 and 8) showing the best results in terms of UGA proximity to new settlements (100% of accessibility) are characterized by the lowest level of land take. The low accessibility and usability from new settlements point out that Rome is still far from sustainability with regard to urban development and planning. Furthermore, it is worth to say that UGAs can be considered effective tools to limit land take.

9. Conclusions and Future Perspectives

The dataset used takes the Urban Atlas project as a starting point and complements it with other statistical information sources. This combination gives us the best possible data currently available. As an exploratory analysis of efficiency in the use of land in metropolitan Europe assessed by per-capita built up areas, first step of this thesis may be regarded as an exercise to infer interesting questions and suggest new hypotheses and developments. For example, in future studies, land-use efficiency may be measured by the share of sealed land, instead of the urban land use, per inhabitant. However, this study provides robust evidences that across Europe less efficient land use in urban environments is associated to large municipal size, landscape fragmentation and low per-capita available income.

Since several authors agree that environmental planning and policy must be evidence-based (Corona 2016), the methodological framework proposed in the step 2 and 3 of the thesis supports the integration of new elements in the GI of Rome, facilitates the adoption of NBSs, and proceeds toward the EU target of no net land uptake by 2050 (United Nations 2014). From this perspective, the study findings should be considered in the selection or creation of future urban development planning tools, such as the Masterplan of the ecological network of Rome’s Municipality.

In fact, the results obtained by this study may help to increase and improve quantity and quality GI elements such as the UGAs, driving, e.g., planning priorities. Combining accessibility and usability with territorial information systems (i.e. network analysis within Global Information System, GIS), especially referring to new residential settlements, can be an effective tool both to preserve and monitor UGA networks and/or to identify urban areas as new UGAs (Van Hezerle, 2001; Van Hezerle and Wiedemann, 2003; Ruangrit and Sokhi, 2004; Fan et al., 2017b). In this regard, new UGAs may be realized on the so-called “land without current use” (code 1.3.4 of the UA dataset) or by due to land abandonment and forest recolonization (Barbati et al., 2013; Cimini et al., 2013; Ferrari et al., 2017; Tomao et al., 2017a). Of course the methodology here proposed can be further improved. For example, in the case of accessibility assessment other means of transportation to reach urban green spaces (public transportation, biking or driving), several forms of access or specific population subsets (e.g. children) may be considered for further applications of the assessment approach here proposed at European scale. Additionally, by means of free and constantly updated European datasets, UGA changes over time could be relevant topics to investigate.

The monitoring of urban growth, land-use efficiency, GI elements connectivity and availability proved to be a suitable information tool for national and regional planning to set effective priorities and targets. Land-use efficiency, e.g., increased in contexts with high diversity in urban landscapes. Less efficient land use in urban environments is associated with large municipal size and landscape fragmentation. Consequently, it is very important to conserve and enhance the functional connection for biodiversity and people in an increasingly fragmented urban environment

10. References

Abson DJ, Fraser EDG, Benton TG, 2013. Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. Agric and food securm 21,:2. doi:10.1186/2048-7010-2-2

Ahern J, 2007. Green infrastructure for cities: the spatial dimension. In: Cities of the Future: Towards Integrated Sustainable Water and Landscape Management. IWA Publishing.

Alberti M, 2005. The effects of urban patterns on ecosystem function. International Regional Science Review. 28.2: 168–192.

Andersson E, 2006. Urban landscapes and sustainable cities. Ecol Soc 111,. http://wwwecologyandsocietyorg/vol11/iss1/art34/. Accessed 1 March 2017

Antrop M, 2004. Landscape change and the urbanization process in Europe. Landsc urban plan 671,:9–26. doi:10.1016/S0169-204603,00026-4

Antrop M, 2006. Sustainable landscapes: contradiction, fiction or utopia? Landscape and Urban Planning. ; 75.3: 187–197.

Barbati A, Corona P, Salvati L, Gasparella L, 2013. Natural forest expansion into suburban countryside: Gained ground for a green infrastructure? Urban For Urban Greening 121,:36-43

Barbero-Sierra C, Marques MJ, Ruíz-Pérez M, 2013. The case of urban sprawl in Spain as an active and irreversible driving force for desertification. J. Arid Environ. 90, 95–102.

Barbosa J, Araújo C, Mateus R, Bragança L, 2015. Study of the concept of community buildings and its importance for Land Use Efficiency. Paper presented at the EURO-7, Portugal.

Barbosa O, Tratalos JA, Armsworth PR, Davies RG, Fuller RA, Johnson P, Gaston KJ, 2007. Who benefits from access to green space? A case study from Sheffield, UK. Landsc. Urban Plan. 83, 187–195.

Baycan-Levent T, Nijkamp P, 2009. Planning and management of urban greenspaces in Europe: comparative analysis. J. Urban Plan. Dev. 135, 1–12.

Bennett AF, 1998. Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation. International Union for Conservation of Nature and Natural Resources: Gland, Switzerland and Cambridge, UK. 262p.

Bennett AF, Saunders DA, 2010. Habitat Fragmentation and Landscape Change. 2010: 88–106. In: Sodhi NS, Ehrlich PR Eds., Conservation Biology for All. Oxford: Oxford University Press. 352p.

Bennett AF, 2003. Linkages in the Landscape: The Role of Corridors and Connectivity in Wildlife Conservation. International Union for Conservation of Nature and Natural Resources. 2nd ed.: Gland, Switzerland and Cambridge, UK. 254p.

Bennett AF, Saunders DA, 2010. Habitat Fragmentation and Landscape Change. 88–106. In: Sodhi, N.S., Ehrlich, P.R. Eds., Conservation Biology for All. Oxford: Oxford University Press. 352p.

Bierwagen BG, 2007. Connectivity in urbanizing landscapes: The importance of habitat configuration urban area size and dispersal. Urban Ecosystems 101,:29-42

Breuste J, Artmann M, Li J, Xie M, 2015. Special issue on green infrastructure for urban sustainability. J Urban Plan D-Asce 1413,: A2015001

Camagni R, Gibelli MC, 2002. I costi collettivi della città dispersa. Alinea, Firenze. (in Italian)

Carrus G, Scopelliti M, Lafortezza R, Colangelo G, Ferrini F, Salbitano F, Agrimi M, Portoghesi L, Sanesi G, 2015. Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. Landsc. Urban Plan. 134, 221–228.

Chang Q, Liu X, Wu J, He P, 2014. MSPA-based urban green infrastructure planning and management approach for urban sustainability: Case study of Longgang in China. J Urban Plan D-Asce 1413,: A5014006

Chirici G, Fattori C, Cutolo N, Tufano M, Corona P, Barbati A, Blasi C, Copiz R, Rossi L, Biscontini D, Ribera A, Morgante L, Marchetti M, 2014. La realizzazione della carta delle formazioni naturali e semi-naturali e della carta forestale su basi tipologiche della regione Lazio. Forest@ - J Selvic For Ecol 111,:65

Cimini D, Tomao A, Mattioli W, Barbati A, Corona P, 2013. Assessing impact of forest cover change dynamics on high nature value farmland in Mediterranean mountain landscape. Ann. Silvic. Res. 37 1,, 29–37.

Clerici N, Vogt P, 2013. Ranking European regions as providers of structural riparian corridors for conservation and management purposes. Int J Appl Earth Obs Geoinf 21:477-483

Comber A, Brunsdon C, Green E, 2008. Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. Landsc. Urban Plan. 86, 103–114.

Coombes E, Jones AP, Hillsdon M, 2010. The relationship of physical activity and overweight to objectively measured green space accessibility and use. Soc. Sci. Med. 70, 816–822.

Cooper CH, 2017. Using spatial network analysis to model pedal cycle flows, risk and mode choice. J. Transp. Geogr. 58, 157-165.

Corona P, 2014. Forestry research to support the transition towards a bio-based economy. Ann Silvic Res 382,: 37-38. doi:10.12899/ASR-1015

Corona P, 2016. Consolidating new paradigms in large-scale monitoring and assessment of forest ecosystems. Environ Res 144: 8-14

Couch C, Leontidou L, Petschel-Held G, 2008. Urban Sprawl in Europe: Landscapes, Land-use Change & Policy. Oxford: Blackwell. pp. 1-273. doi:10.1002/9780470692066.

Dawson RJ, Wyckmans A, Heidrich O, Köhler J, Dobson S, Feliu E, 2014. Understanding Cities: Advances in Integrated Assessment of Urban Sustainability. Newcastle, UK:Centre for Earth Systems Engineering Research CESER,. 232p.

Dige G, 2011. Green infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems RPRT,. Technical Report 18. European Environment Agency Copenhagen Denmark. http://www.eea.europa.eu/publications/green-infrastructure-and-territorial-cohesion. Accessed 1 March 2017

Doygun H, 2009. Effects of urban sprawl on agricultural land: a case study of Kahramanmaraş, Turkey. Environ. Monit. Assess. 158, 471-478.

Du Pisani JA, 2006. Sustainable development – historical roots of the concept. Environmental Sciences. 3.2: 83–96.

Duran BS, Odell PL, 1974. Cluster analysis. New-York: Springer-Verlag.

Duvernoy I, Zambon I, Sateriano A, Salvati L, 2018. Pictures from the Other Side of the Fringe: Urban Growth and Peri-urban Agriculture in a Post-industrial City Toulouse, France,. J. Rural Stud. 57, 25-35.

EEA, 2006. Urban Sprawl in Europe. The ignored challenge. EEA report No.10,. Copenhagen: European Environment Agency. Retrieved from https://www.eea.europa.eu/publications/eea_report_2006_10

EEA, 2011. Landscape fragmentation in Europe. Joint EEA-FOEN report. EEA Report No. 2,. Publications Office of the European Union, Luxembourg. Retrieved from: https://www.eea.europa.eu/highlights/increasing-fragmentation-of-landscape-threatens.

EEA, 2010a. Urban Atlas. Retrieved from http://www.eea.europa.eu/data-and-maps/data/urban-atlas retrieved on 6/6/2017,

EEA, 2010b. Mapping Guide for a European Urban Atlas. Retrieved from http://www.eea.europa.eu/data-and-maps/data/urban-atlas/mapping-guide Last changed on 8/26/2010, retrieved on 6/15/2017,

Ekkel ED, de Vries S, 2017. Nearby green space and human health: Evaluating accessibility metrics. Landsc. Urban Plan. 157, 214–220. doi:10.1016/j.landurbplan.2016.06.008.

European Commission, 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities. Final report the Horizon 2020. https://ec.europa.eu/research/environment/index.cfm?pg=nbs. Accessed 5 September 2016

European Commission, 2016. GEOSTAT 1km2 population grid. Retrieved from: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat accessed May 2017,.

Ewing RH, 2008. Characteristics, Causes, and Effects of Sprawl: A Literature Review. In: Marzluff J.M. et al. eds, Urban Ecology. Springer, Boston, MA. https://doi.org/10.1007/978-0-387-73412-5_34

Fan P, Xu L, Yue W, Chen J, 2017a. Accessibility of public urban green space in an urban periphery: The case of Shanghai. Landsc. Urban Plan. 165, 177–192.

Fan P, Ouyang Z, Basnou C, Pino J, Park H, Chen J, 2017b. Nature-based solutions for urban landscapes under post-industrialization and globalization: Barcelona versus Shanghai. Environ. Res. 156, 272–283. doi:http://dx.doi.org/10.1016/j.envres.2017.03.043

Fan P, Xu L, Yue W, Chen J, 2017c. Accessibility of public urban green space in an urban periphery: The case of Shanghai. Landsc. Urban Plan. 165, 177–192.

Farina A,1998. Principles and Methods in Landscape Ecology. Chapman & Hall: London. 235p.

Ferrari B, Corona P, Mancini LD, Salvati R, Barbati A, 2017. Taking the pulse of forest plantations success in peri-urban environments through continuous inventory. New For. 48, 527–545.

Flanagin AJ, Metzger MJ, 2008. The credibility of volunteered geographic information. GeoJournal 72, 137–148.

Forman RTT, 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge: Cambridge University Press.. 656p.

Franklin AB, Noon BR, George TL, 2002. What is habitat fragmentation? Studies in Avian Biology.; 25: 20–29.

Frenkel A, 2004. The potential effect of national growth-management policy on urban sprawl and the depletion of open spaces and farmland. Land use policy 214,:357–369. doi:10.1016/j.landusepol.2003.12.001

Frondoni R, Mollo B, Capotorti G, 2011. A landscape analysis of land cover change in the Municipality of Rome Italy,: Spatio-temporal characteristics and ecological implications of land cover transitions from 1954 to 2001. Landsc. Urban Plan. 100, 117–128.

Gasparella L, Tomao A, Agrimi M, Corona P, Portoghesi L, Barbati A, 2017. Italian stone pine forests under Rome’s siege: learning from the past to protect their future. Landsc. Res., 42, 211-222.

Gaston KJ, Warren PH, Thompson K, Smith RM, 2005. Urban domestic gardens IV,: the extent of the resource and its associated features. Biodiversity and Conservation. 14: 3327–3349.

Giannakourou G, 2005. Transforming spatial planning policy in Mediterranean countries: Europeanization and domestic change. Eur Plan Stud 132,:319–331. doi: 10.1080/0365431042000321857

Gil J, 2015. Building a multimodal urban network model using OpenStreetMap data for the analysis of sustainable accessibility, in: OpenStreetMap in GIScience. Springer, pp. 229–251.

Gilbert OL, 1989. The Ecology of Urban Habitats. London: Chapham & Hall. 369p.

Gill S, Handley J, Ennos R, Pauleit S, 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environment; 33: 115–133.

Gong C, Yu S, Joesting H, Chen J, 2013. Determining socioeconomic drivers of urban forest fragmentation with historical remote sensing images. Land Urb Plan 117:57-65. doi:10.1016/j.landurbplan.2013.04.009

Grahn P, Stigsdotter UA, 2003. Landscape planning and stress. Urban For. Urban Green. 2, 1–18.

Grunewald K, Richter B, Meinel G, Herold H, Syrbe RU, 2017. Proposal of indicators regarding the provision and accessibility of green spaces for assessing the ecosystem service "recreation in the city" in Germany. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 13, 26–39.

Gupta K, Kumar P, Pathan SK, Sharma KP, 2012. Urban Neighborhood Green Index–A measure of green spaces in urban areas. Landsc. Urban Plan. 105, 325–335.

Gupta K, Roy A, Luthra K, Maithani S, Mahavir, 2016. GIS based analysis for assessing the accessibility at hierarchical levels of urban green spaces. Urban For. Urban Green. 18, 198–211.

Haase D, Larondelle N, Andersson E, Artmann M, Borgström S, Breuste J, Gomez-Baggethun E, Gren A, Hamstead Z, Hansen R, Kabisch N, Kremer P, Langemeyer J, Rall EL, McPhearson T, Pauleit S, Qureshi S, Schwarz N, Voigt A, Wurster D, Elmqvist T, 2014. A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. Ambio 434,:413-433. doi:10.1007/s13280-014-0504-0

Haber W, 2007. Energy, food, and land-the ecological traps of humankind. Environ. Sci. Pollut. Res. 14, 359–365.

Haines-Young R, 2000. Sustainable development and sustainable landscapes: defining a new paradigm for landscape ecology. Fennia. 178.1: 7–14.

Hall P, Hay D, 1980. Growth Centres in the European Urban System. Univ of California Press.

Handley J, Pauleit S, Slinn P, Lindley S, MB, Barber L, Jones C, 2003. Providing accessible natural greenspace in towns and cities: a practical guide to assessing the resource and implementing local standards for provision. Rep. to Nat. Engl. 1–36.

Hartig T, Mitchell R, de Vries S, Frumkin H, 2014. Nature and Health. Annu. Rev. Public Health 35, 207–228.

Hasse JE, Lathrop RG, 2003. Land resource impact indicators of urban sprawl. Appl Geogr 232-3,:159-175. doi:10.1016/j.apgeog.2003.08.002

Higgs G, Fry R, Langford M, 2012. Investigating the implications of using alternative GIS-based techniques to measure accessibility to green space. Environ. Plan. B Plan. Des. 39, 326–343.

Hilty JA, Lidicker WZ, Merelender AM, 2006. Corridor Ecology: The Science and Practice of Connectivity for Biodiversity Conservation. Washington DC: Island Press. 344p.

Hofstad H, 2012. Compact city development: High ideals and emerging practices. European Journal of Spatial Development 11,:1-23.

Hoymann J, 2011. Accelerating urban sprawl in depopulating regions: a scenario analysis for the Elbe River Basin. Reg Environ Change 111,73–86. doi: 10.1007/s10113-010-0120-x

ISPRA, 2010. Verso una gestione ecosistemici delle aree verdi urbane e peri-urbane. Analisi e proposte. http://www.areeurbane.isprambiente.it/it/pubblicazioni/pubblicazioni-correlate/verso-una-gestione-ecosistemica-delle-aree-verdi-urbane-e-peri-urbane/view. In Italian,

Ji W, Ma J, Twibell RW, Underhill K, 2006. Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics. Comput Environ Urban Syst 306,:861-879. doi:10.1016/j.compenvurbsys.2005.09.002

Jim CY, 2013. Sustainable urban greening strategies for compact cities in developing and developed economies. Urban Ecosystems 164,:741-761

Johnson MP, 2001. Environmental impacts of urban sprawl: A survey of the literature and proposed research agenda. Environ. Plan. A 33, 717–735.

Kabisch N, Haase D, 2014. Green justice or just green? Provision of urban green spaces in Berlin, Germany. Landsc. Urban Plan. 122, 129-139.

Kabisch N, Strohbach M, Haase D, Kronenberg J, 2016. Urban green space availability in European cities. Ecol. Indic. 70, 586–596.

Kaczynski AT, Koohsari, MJ, Stanis SA., Bergstrom R, Sugiyama T, 2014. Association of street connectivity and road traffic speed with park usage and park-based physical activity. Am. J. Heal. Promot. 28, 197–203.

Kang S, Kim JO, 2015. Morphological analysis of green infrastructure in the Seoul metropolitan area South Korea. Landscape Ecol Eng 112,:259-268

Karhu J, 2011. Green Infrastructure Implementation: Proceedings of the European Commission Conference, 19

Kasanko M, Barredo JI, Lavalle C, McCormick N, Demicheli L, Sagris V, Brezger A, 2006. Are European cities becoming dispersed?: A comparative analysis of 15 European urban areas. Landscape Urban Plan 77:111-130

Koohsari MJ, Kaczynski AT, Giles-Corti B, Karakiewicz JA, 2013. Effects of access to public open spaces on walking: Is proximity enough? Landsc. Urban Plan. 117, 92-99.

Kornai J, 2006. The great transformation of central eastern Europe. Econ transit 142,: 207–244. doi:10.1111/j.1468-0351.2010.00396.x

Kubeš J, 2013. European post-socialist cities and their near hinterland in intra-urban geography literature. Bull Geogr 19:19-43. doi:10.2478/bog-2013-0002

Kuhlman T, Farrington J 2010,. What is sustainability? Sustainability. 2.11: 3436–3448.

La Rosa D, 2014. Accessibility to green spaces: GIS based indicators for sustainable planning in a dense urban context. Ecol. Indic. 42, 122–134.

Lafortezza R, Davies C, Sanesi G, Konijnendijk CC, 2013. Green Infrastructure as a tool to support spatial planning in European urban regions. iForest-Biogeosci. For. 6 3,, 102–108.

Lambin EF, Meyfroidt P, 2010. Land use transitions: Socio-ecological feedback versus socio-economic change. Land use Policy 272,:108-118. doi:10.1016/j.landusepol.2009.09.003

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J, 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environ Change 114,: 261-269. doi:10.1016/S0959-378001,00007-3

Landscape Institute, 2009. Green infrastructure: connected and multifunctional landscape. Landscape Institute.

Lindenmayeret DB, Fisher J, 2006. Habitat Fragmentation and Landscape Change: An Ecological and Conservation Synthesis. Covelo, California: Island Press. 352p.

Liu Y, Feng Y, Zhao Z, Zhang Q, Su S, 2016. Socioeconomic drivers of forest loss and fragmentation: A comparison between different land use planning schemes and policy implications. Land use Policy 54:58-68. doi:10.1016/j.landusepol.2016.01.016

Low S, 2013. Public space and diversity: Distributive, procedural and interactional justice for parks. In G. Young, & D. Stevenson Eds.,, The Ashgate research companion to planning and culture pp. 295–310,. Surrey: Ashgate Publishing.

Luck M, Wu J, 2002. A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. Landscape Ecol 174, 327–339. doi:10.1023/A:1020512723753

Macionis JJ, Parrillo VN 2004. Cities and Urban Life. 3rd ed. Upper Saddle River, NJ: Pearson Education. 395p.

Madureira H, Andresen T, Monteiro A, 2011. Green structure and planning evolution in Porto. Urban For Urban Green 10:141–149

Marchetti M, Vizzarri M, Lasserre B, Sallustio L, Tavone A, 2015. Natural capital and bioeconomy: challenges and opportunities for forestry. Ann Silvic Res 382,:62-73

Maricchiolo C, Sambucini V, Pugliese A, Munafò M, Cecchi G, Rusco E, 2005. La realizzazione in Italia del progetto europeo Corine Land Cover 2000. Rapporti APAT 36, Roma

Masek JG, Lindsay FE, Goward SN, 2000. Dynamics of urban growth in the washington DC metropolitan area, 1973-1996, from landsat observations. Int J Remote Sens 2118,:3473-3486. doi:10.1080/014311600750037507

Musacchio LR, 2009. The scientific basis for the design of landscape sustainability: a conceptual framework for translational landscape research and practice of designed landscapes and the six Es of landscape sustainability. Landscape Ecology. 24.8: 993–1013.

Nardo M, Saisana M, Saltelli A, Tarantola S, Hoffman A, Giovannini E, 2005. Handbook on constructing composite indicators: methodology and user guide. OECD Statistics Directorate Paris. https://www.oecd.org/std/42495745.pdf. Accessed 4 October 2016

Neuvonen M, Sievänen T, Tönnes S, Koskela T, 2007. Access to green areas and the frequency of visits - A case study in Helsinki. Urban For. Urban Green. 6, 235–247.

Niemelä J, 1999. Is there a need for a theory of urban ecology? Urban Ecosystems 3.1: 57–65.

O'Brien L, De Vreese R, Kern M, Sievänen T, Stojanova B, Atmiş E, 2017. Cultural ecosystem benefits of urban and peri-urban green infrastructure across different European countries. Urban For. Urban Green. 24, 236-248.

Oh K, Jeong S, 2007. Assessing the spatial distribution of urban parks using GIS. Landsc. Urban Plan. 82, 25–32.

Ostapowicz K, Vogt P, Riitters KH, Kozak J, Estreguil C, 2008. Impact of scale on morphological spatial pattern of forest. Landscape Ecol 23:1107–1117

Ottoni C A, Sims-Gould J, Winters M, Heijnen M, McKay HA, 2016. Benches become like porches: Built and social environment influences on older adults' experiences of mobility and well-being. Soc. Sci. Med., 169, 33-41.

Ozus E, Tur SS, Dokmeci V, 2011. Urban restructuring of Istanbul. Eur. Plan. Stud., 192,, 331-356.

Pacione M, 2009. Urban geography: A global perspective. New York: Routledge.

Parysek JJ, 2006. Processes affecting the development and transformation of towns in central european states: The case of poland. Quaestiones Geographicae 25:29-36.

Paulsen K, 2014. Geography, policy or market? New evidence on the measurement and causes of sprawl and infill, in US metropolitan regions. Urban Studies 5112,:2629-2645. doi:10.1177/0042098013512874

Pendall R, 1999. Do land-use controls cause sprawl?. Environ Plan B 264,:555–571.

Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WC, Costanza R, 2001. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annual Review of Ecological Systems 32.1: 127–157.

Pili S, Grigoriadis E, Carlucci M, Clemente M, Salvati L, 2017. Towards Sustainable Growth? A Multi-criteria Assessment of Changing, Urban Forms. Ecol. Ind. 76, 71-80.

Pirnat J, Hladnik D, 2016. Connectivity as a tool in the prioritization and protection of sub-urban forest patches in landscape conservation planning. Landscape Urban Plan 153:129-139

Poleman H, 2016. A walk to the park? Assessing access to green urban areas in Europe's cities. European Commission, Brussels. Retrieved from http://ec.europa.eu/regional_policy/it/information/publications/working-papers/2016/a-walk-to-the-park-assessing-access-to-green-urban-areas-in-europe-s-cities. accessed May 2017,.

Potschin M, Haines-Young R, 2006. "Rio+ 10" sustainability science and landscape ecology. Landscape and Urban Planning. 75.3: 162–174.

Power A, 2013. Hovels to high rise: State housing in Europe since 1850. London: Routledge.

Prastacos P, Chrysoulakis N, Kochilakis G, 2012. Spatial Metrics for Greek cities using land cover information from the Urban Atlas. In: Gensel, J.; Josselin, D.; Vandenbroucke, D. Eds.,: Multidisciplinary Research on Geographical Information in Europe and Beyond: Proceedings of the 15th AGILE International Conference on Geographic Information Science, 261–266

Quatrini V, Barbati A, Carbone F, Giuliarelli D, Russo D, Corona P, 2015. Monitoring land take by point sampling: Pace and dynamics of urban expansion in the metropolitan city of rome. Land Urb Plan 143:126-133. doi:10.1016/j.landurbplan.2015.06.012

Ramm F, Topf J, Chilton S, 2011. OpenStreetMap: using and enhancing the free map of the world. UIT Cambridge Cambridge.

Ramos-Gonzalez OM, 2014. The green areas of San Juan Puerto Rico. Ecol Soc 193,:21

Raymond CM, Frantzeskaki N, Kabisch N, Berry P, Breil M, Nita RM, Geneletti D, Calfapietra C, 2017. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ. Sci. Policy. 77, 15-24.

Richter B, Grunewald K, Meinel G, 2016. Analyse von Wegedistanzen in Städten zur Verifizierung des Ökosystemleistungsindikators. Erreichbarkeit städtischer Grünflächen 472–481. doi:10.14627/537622063.Dieser. (in German)

Ruangrit V, Sokhi BS, 2004. Remote sensing and GIS for urban green space analysis – A case study of Jaipur city, Rajasthan, India. J. Inst. of Town Plan. India, 12, 55–67.

Sallustio L, Quatrini V, Geneletti D, Corona P, Marchetti M, 2015. Assessing land take by urban development and its impact on carbon storage: Findings from two case studies in Italy. Environ. Impact. Asses. 54, 80–90.

Salvati L 2013, Urban containment in action? Long-term dynamics of self-contained urban growth in compact and dispersed regions of southern Europe. Land Use Policy 35:213–225

Salvati L, Ferrara C, Mavrakis A, Colantoni A, 2016. Toward forest “sprawl”: monitoring and planning a changing landscape for urban sustainability. J For Res 271,:175-184

Salvati L, Sateriano A, Bajocco S, 2013. To grow or to sprawl? Land Cover Relationships in a Mediterranean City Region and implications for land use management. Cities, 301,:113-121. doi:10.1016/j.cities.2012.01.007

Salvati L, Zitti M, 2009. The environmental "risky" region: Identifying land degradation processes through integration of socio-economic and ecological indicators in a multivariate regionalization model. Environ Manage 445,:888-898. doi:10.1007/s00267-009-9378-5

Salvati L, 2013. Urban containment in action? Long-term dynamics ofself-contained urban growth in compact and dispersed regions of southern Europe. Land Use Policy 35, 213–225.

Salvati L, Munafo M, Morelli VG, Sabbi A, 2012. Low-density settlements and land use changes in a Mediterranean urban region. Landsc. Urban Plan. 105, 43–52. doi:10.1016/j.landurbplan.2011.11.020.

Salvati L, Quatrini V, Barbati A Tomao A, Mavrakis A, Serra P, Sabbi A, Merlini P, Corona P, 2016. Soil occupation efficiency and landscape conservation in four Mediterranean urban regions. Urban For. Urban Green. 20, 419–427.

Salvati L, Tombolini I, 2013. Cropland vs Forests: Landscape Composition and Land-use changes in Peri-urban Rome 1949-2008,WSEAS Trans. Environ. Dev. 9, 278–289.

Sanesi G, Colangelo G, Lafortezza R, Calvo E, Davies C, 2016. Urban green infrastructure and urban forests: a case study of the Metropolitan Area of Milan. Landscape Res 422,:164-175

Sanesi G, Chiarello F, 2006. Residents and urban green spaces: The case of Bari. Urban For. Urban Green. 43-4,, 125-134.

Saunders DA, Hobbs RJ, Margules CR, 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology.; 5.1: 18–32.

Saura S, Vogt P, Velázquez J, Hernando A, Tejera R, 2011, Key structural forest connectors can be identified by combining landscape spatial pattern and network analyses. Forest Ecol Manag 2622,:150-160

Savard JPL, Clergeau P, Mennechez G, 2000. Biodiversity concepts and urban ecosystems. Landscape and Urban Planning. 48.3: 131–142.

Schipperijn J, Stigsdotter UK, Randrup TB, Troelsen J, 2010. Influences on the use of urban green space–A case study in Odense, Denmark. Urban For. Urban Green. 91,, 25-32.

Schneider A, Woodcock CE, 2008. Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Stud. 45, 659–692.

Schwoertzig E, Poulin N, Hardion L, Trémolières M, 2016. Plant ecological traits highlight the effects of landscape on riparian plant communities along an urban–rural gradient. Ecol Indic 61:568–576. doi:10.1016/j.ecolind.2015.10.008

Selman P, 2006. Planning at the Landscape Scale. Oxon: Routledge. 225p.

Selman P, 2008. What do we mean by "sustainable landscape"? Sustainability: Science, Practice, and Policy. 4: 23–28.

Selman P. Landscape and Sustainability at the National and Regional Scales. 2007: 104–117. In: Benson, J.F., Roe, M. Eds., Landscape and Sustainability. 2nd ed. Taylor & Francis. 2007. 336p.

Simberloff D, 1997. Biogeographic approaches and the new conservation biology. In Pickett STA, Ostfeld RS, Shachak M, Likens GE eds, The ecological basis of conservation. Heterogeneity, ecosystems, and biodiversity. Chapman and Hall, New York, New York, USA, pp 274-284

Soille P, 2003. Morphological Image Analysis: Principles and Applications, 2rd edn. Springer-Verlag, New York

Soille P, Vogt P, 2009. Morphological segmentation of binary patterns. Pattern Recognit Lett 30:456–459.

Solon J, 2009. Spatial context of urbanization: Landscape pattern and changes between 1950 and 1990 in the Warsaw metropolitan area, Poland. Landsc Urb Plan 933,:250–261. doi:10.1016/j.landurbplan.2009.07.012

Stanilov K, 2007. Taking stock of post-socialist urban development: A recapitulation. In Stanilov K Ed, The post-socialist city: Urban Form and Space Transformations in Central and Eastern Europe after Socialism, pp3–17. Springer.

Stanners D, Bourdeau P, 1995. The urban environment. In: Stanners, D., Bourdeau, P. Eds.,, Europe's Environment: The Dobˇr´ıs Assessment. European Environment Agency, Copenhagen. Retrived from https://www.eea.europa.eu/publications/92-826-5409-5

Stathakis D, Tsilimigkas G, 2013. Applying Urban Compactness Metrics on Pan-European Datasets. In: ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XL-4/W1, No. 2: 127–132

Sugiyama T, Francis J, Middleton NJ, Owen N, Giles-Corti B, 2010. Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces. Am. J. Public Health 100 9,, 1752–1757.

Sutton PC, 2003. A scale-adjusted measure of "urban sprawl" using nighttime satellite imagery. Remote Sens Environ 863,:353-369. doi:10.1016/S0034-425703,00078-6

Tarzia V, 2003. European Common Indicators: towards a local sustainability profile. Ambiante Italia Research Institute, Milano, Italy, 211

Terkenli TS, Bell S, Živojinović I, ... , O'Brien L, 2017. Recreational Use of Urban Green Infrastructure: The Tourist's Perspective. In: Pearlmutter D, Calfapietra C, Samson R, O'Brien L, Krajter Ostoić S, Sanesi G, Alonso del Amo R eds, The urban forest: cultivating green infrastructure for people and the environment. Springer International Publishing, Cham, pp 191–216

Termorshuizen JW, Opdam P, Van den Brink A, 2007. Incorporating ecological sustainability into landscape planning. Landscape and Urban Planning. 79.3: 374–384.

Thomas RJ, Akhtar-Schuster M, Stringer LC, Marques MJ, Escadafal R, Abraham E, Enne G, 2012. Fertile ground? Options for a science-policy platform for land. Environ Sci Policy 16:122-135. doi:10.1016/j.envsci.2011.11.002

Tölle A, 2010. Urban identity policies in Berlin: From critical reconstruction to reconstructing the wall. Cities 275,:348-357. doi:10.1016/j.cities.2010.04.005

Tomao A, Quatrini V, Corona P, Ferrara A, Lafortezza R, Salvati L, 2017. Resilient landscapes in Mediterranean urban areas: understanding factors influencing forest trends. Environ Res 156:1–9

Tomao A, Secondi L, Corona P, Giuliarelli D, Quatrini V, Agrimi M, 2015. Can composite indices explain multidimensionality of tree risk assessment? A case study in an historical monumental complex. Urban For Urban Green 14:456–465

Tosics I, 2005. City development in Central and Eastern Europe since 1990: The impact of internal forces. In Hamilton FEI, Dimitrowska-Andrews, K and Pichler-Milanovich Eds, Transformation of Cities in Central and Eastern Europe, pp 44–78. Tokyo: UNU Press.

Turner MG, Donato DC, Romme WH, 2013. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. Landscape Ecology. 28.6: 1081–1097.

Turner MG, Gardner RH, O'Neill RV, 2001. Landscape Ecology in Theory and Practice: Pattern and Process. New York: Springer-Verlag. 404p.

United Nations, 2014. World urbanization prospects: The 2014 revision highlights. Department of economic and social affairs. Population Division United Nations. [online]. Retrieved from: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf

Uy PD, Nakagoshi N, 2008. Application of land suitability analysis and landscape ecology to urban green space planning in Hanoi, Vietnam. Urban For Urban Green 71,:25-40

Van den Bosch M, Sang ÅO, 2017. Urban natural environments as nature-based solutions for improved public health–A systematic review of reviews. Environ. Res., 158, 373-384.

Van Herzele A, Wiedemann T, 2003. A monitoring tool for the provision of accessible and attractive urban green spaces. Landsc. Urban Plan. 63, 109–126

Van Herzele A, 2001. Challenges of neighbourhood participation in city-scaled urban greening. In: Proceedings of the Paper Presented at the Changing Role of Forestry in Europe-Between Urbanisation and Rural Development, International Policy Research Symposium, Wageningen, pp. 11-14, November 2001.

Vogt P, Riitters K, Estreguil C, Kozak J, Wade TG, Wickham JD, 2007. Mapping spatial patterns with morphological image processing. Landscape Ecol 22:171–177

Walmsley A, 2006. Greenways: multiplying and diversifying in the 21st century. Landscape Urban Plan 761,:252-290

Wickham JD, Riitters KH, Wade TG, Vogt P, 2010. A national assessment of green infrastructure and change for the conterminous United States using morphological image processing. Landscape Urban Plan 943,:186-195

Wilson B, Chakraborty A, 2013. The environmental impacts of sprawl: Emergent Themes from the past decade of planning research. Sustainability, 58,, 3302–3327.

With KA, 2002. Landscape Connectivity and Metapopulation Dynamics, 2002. 208–227. In: Gergel, S.E., Turner, M.G. Eds.,. Learning Landscape Ecology. A Practical Guide to Concepts and Techniques. New York, NY: Springer-Verlag. 316p.

Wu J, 2013. Landscape sustainability science: ecosystem services and human well-being in changing landscapes. Landscape Ecology. 28.6: 999–1023.

Wu J, Hobbs R, 2002. Key issues and research priorities in landscape ecology: an idiosyncratic synthesis Landscape Ecol 174,:355-365

Zipperer WC, 2005. Ecological Assessment and Planning in the Wildland-Urban Interface: A Landscape Perspective In: Vince SW, Duryea ML, Macie EA, Hermansen LA eds, Forests at the wildland-urban interface: conservation and management. Boca Raton, FL: CRC Press. pp 161-174.

Zitti M, Ferrara C, Perini L, Carlucci M, Salvati L, 2015. Long-term urban growth and land use efficiency in southern Europe: Implications for sustainable land management. Sustainability 73,:3359-3385. doi:10.3390/su7033359

Žlender V, Ward Thompson C, 2017. Accessibility and use of peri-urban green space for inner-city dwellers: A comparative study. Landsc. Urban Plan. 165, 193–205.

11. List of papers

Masini E, Barbati A, Bencardino M, Carlucci M, Corona P, Salvati L, 2018. Paths to change: Bio-economic factors, geographical gradients and the land-use structure of Italy. Environ Manage. 61(1):116-31. https://doi.org/10.1007/s00267-017-0950-0.

Masini E, Tomao A, Barbati A, Corona P, Serra P, Salvati L, 2018. Urban Growth, Land-use Efficiency, and the Underlying Socioeconomic Context: a Comparative Analysis of 417 Metropolitan Regions in Europe. Environmental Management, 1-16. https://doi.org/10.1007/s00267-018-1119-1.

Quatrini V, Tomao A, Corona P, Ferrari B, **Masini E**, Agrimi M, 2018. Is new always better than old? Accessibility and usability of the urban green areas of the municipality of Rome Urban Forestry & Urban Greening. ISSN 1618-8667, https://doi.org/10.1016/j.ufug.2018.07.015.

Ferrari B, Quatrini V, Barbati A, Corona P, **Masini E**, Russo D. Conservation and enhancement of the Green Infrastructure as Nature-based solutions for Rome's sustainable development. Urban Ecosystems. (under review).