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Monitoring land take by point sampling: Pace and dynamics of urban expansion in the Metropolitan City of Rome

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HIGHLIGHTS

- Coupling point sampling and mapping is tested to monitor the growth of urban areas.
- Statistical estimators concerning urban areas are derived for a case study in Italy.
- Straightforward and rigorous method for monitoring rapidly expanding urban areas.
- Reliable information source for urban growth management.

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ABSTRACT

Land take due to the rapid growth of urban areas is an issue of global concern. It calls for sound monitoring methodologies to quantify the phenomenon, with a view to verify the effectiveness of urban growth management strategies. To this end, we propose an integrated statistical approach, coupling point sampling and mapping techniques, to estimate the number and size of urban areas, in a given territory, on successive occasions. Urban areas classification is based on all land cover classes contributing to urban structure, and is more comprehensive than assessments based on sealed surfaces only. The devised approach is here tested to quantify land take by urban expansion during 1990–2008 in the Metropolitan City of Rome (Central Italy). Urban areas coverage increased from 15.4% in 1990 to approximately 20.4% in 2008. During this period, 11,000 ha, mainly agricultural land, were taken by urban sprawl in Rome's municipality. This occurred despite the fact that population had remained stable. Our findings also indicate that the average land take per-capita in Rome municipality is about four times higher than the average value of urban residential area per capita of mid-to-large European cities. We therefore discuss the potential of the proposed method for a reliable monitoring of urban expansion, in order to support sustainable urban management and to highlight factors underpinning unregulated urban development.

1. Introduction

The expansion of urban areas and population growth appear to be inextricably linked. Urbanization, defined as the growth in the proportion of the population inhabiting towns and cities, is recognized as a key factor in the increase of urban land cover on a global scale (Angel, Parent, Civco, Blei, & Potere, 2011).

Today, 54% of the world's population lives in urban areas. Africa and Asia are urbanizing faster than other regions of the world and are expected to become 56% and 64% urban, respectively, by 2050 (UN, 2014). Accordingly, urban land cover is reckoned to double by 2050 the area covered in 2000 in developed countries, and to increase fourfold in developing ones (Angel, Parent, Civco, & Blei, 2011).

The growth of built-up areas (residential, commercial, industrial, infrastructures) leads to urban *soil sealing*, i.e. the covering of the soil surface by impervious materials, which results in the soil no longer being able to perform the range of its ecological functions (European Commission, 2012). *Land take* refers to

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this irreversible process and results in a loss of fertile soils for agriculture and forestry. The expansion of built-up areas also triggers a series of negative environmental impacts, such as the shrinkage of farmland for food production (Gardi, Panagos, Van Liedekerke, Bosco, & de Brogniez, 2015; He et al., 2013), the loss of biodiversity (Mcdonald, Kareiva, & Forman, 2008), and the degradation of ecosystem services (Estoque & Murayama, 2012; Hutyra, Yoon, Hepinstall-Cymerman, & Alberti, 2011; Polasky, Nelson, Pennington, & Johnson, 2011). In more general terms, the ecological footprint of urbanization can seriously jeopardize the quality of life of urban dwellers, especially in developing countries (Cilliers, du Toit, Cilliers, Drewes, & Retief, 2014; de Hollander & Staatsen, 2003; Konteh, 2009; Xiang, Stuber, & Meng, 2011).

Three parameters are crucial for monitoring the pace of urban expansion and its links with population growth worldwide (Angel, Parent, Civco, & Blei, 2011): (i) the total land area occupied by urban land cover; (ii) the ratio between the surface covered by urban areas within a given administrative unit and its population; (iii) the amount of open space in and around cities, fragmented by built-up areas.

Open space fragmentation notably represents the outcome of urban sprawl, a recent pattern of land take characterized by a low density expansion of built-up areas mainly in the surrounding countryside. Contrary to what happens with compact cities, in sprawling cities the fragmented open space indicates inefficiency in the use of land for development (EEA, 2006). Urban sprawl is experienced both by regions with a long history of urbanism, such as Europe (Kasanko et al., 2006; Poelmans & Van Rompaey, 2009) or North-America (Hamidi & Ewing, 2014; Terando et al., 2014; Theobald, 2005), and rapidly urbanizing countries, such as China (Schneider, Chang, & Paulsen, 2015), India (Bhatta, Saraswati, & Bandyopadhyay, 2010) and Nigeria (Agunbiade, Rajabifard, & Bennett, 2012). The latter three countries are believed to account for 37% of the global urban population increase, which is expected to take place by 2050 (UN, 2014).

As a consequence, urban growth management has become a much-debated subject in the field of urban planning. *Urban containment*, aiming at limiting urban development outside a defined urban area (urban growth boundary or greenbelt), is the prevailing urban planning paradigm adopted in Europe, North America and Asia (Bengston & Youn, 2006; Gennaio, Hersperger, & Bürgi, 2009; Kline, Thiers, Ozawa, Alan Yeakley, & Gordon, 2014; Millward, 2006; Zhao, 2011). The *making room* strategy is proposed as a more feasible alternative to steer urban growth in rapidly urbanizing countries (Angel, Parent, Civco, & Blei, 2011) and represents a different approach to the issue. It lies on the idea that urban areas limits have to be enlarged so to accommodate 20–30 years of urban expansion, according to realistic projections of population growth, and to allow for the selective protection of public open spaces in designated areas of expansion.

In order to evaluate the effectiveness of urban growth management strategies, it is therefore crucial to identify sound methods for monitoring the growth of urban areas. Robust and easily understandable indicators for monitoring urban dynamics are particularly necessary in the European Union, in order to verify the progress towards the target of no net land take by 2050 (Decision No. 1386/2013/EU).

Mapping or sampling are the two main methodological approaches used to assess the growth of urban areas. The cartographic approach allows the production of wall-to-wall maps of urban areas vs. other land cover classes. Satellite-based mapping is widely used to detect the spatial extent urban areas from the global (Schneider, Friedl, & Potere, 2009) to the city scale (Bagan & Yamagata, 2012; Jat, Garg, & Khare, 2008; Olayiwola & Igbavboa, 2014; Zeng, Zhang, Cui, & He, 2015). The reference scale, the minimum mapping unit (MMU), and the thematic content of the classification of urban areas, are all critical factors in the search for a more accurate representation of the spatial pattern of built areas. Therefore, within the framework of the MOLAND project (Monitoring Land Use Dynamics), aimed at producing a long-time series geodatabase of urban land use development in Europe, a MMU of 1 ha for artificial surfaces and of 3 ha for non-artificial surfaces is applied (Barranco, Silva, Marin Herrera, & Lavalle, 2014).

Conversely, if the goal is to derive statistics of urban areas, a sampling-based approach proves more appropriate, when an adequate sample size is used (Corona, Barbati, et al., 2012). This methodology has been recently used in the United States to monitor the effectiveness of urban containment policies (Kline et al., 2014) or to quantify transitions from open to urban areas (Schweizer & Matlack, 2014). However, none of the research conducted has rigorously addressed the topic of deriving uncertainty estimates of urban land cover based on formal statistical procedures, an important advantage of sampling in comparison with mapping methods (Corona, Fattorini, Chirici, Valentini, & Marchetti, 2007).

The accuracy of urban areas estimates can even improve when coupling the benefits of sample-based and mapping approaches in an integrated statistical method. If, on one hand, point sampling allows the random extraction, over a given territory, of a set of sampling points located in urban areas, on the other, mapping is applied to delineate the spatial extent of urban patches around each urban sampling point. In consequence, the total land area occupied by urban land cover, the number of urban patches and their average size can be estimated within a given territorial context.

The devised approach is here tested to monitor urban growth in the territory of the Metropolitan City of Rome (Italy) between the years 1990 and 2008. Rome can be regarded as a semi-compact city which, from the 1990s onwards, has evolved into a more scattered and moderately polycentric urban form (Frondoni, Mollo, & Capotorti, 2011; Salvati, 2013; Salvati, Munafo, Gargiulo Morelli, & Sabbi, 2012). The case study is representative of dynamics of urban expansion common to many cities worldwide, which have experienced higher rates of built-up areas expansion with respect to population growth in the past few decades (Bagan & Yamagata, 2012; Barranco et al., 2014; Jat et al., 2008).

The aim of this paper is to apply the integrated statistical method to address two key issues for urban growth management: (i) how to estimate the pace of urban expansion in the municipalities comprised in the Metropolitan City of Rome, in terms of growth in the number and size of areas under urban land cover; (ii) how to identify municipalities most affected by urbanization processes and tendencies toward sprawl vs. compact urban development across municipalities.

The methodological workflow used to address these questions is illustrated in Fig. 1, fully described in Section 2, and findings are presented in Section 3. The discussion section (Section 4) offers a critical comparison between the estimates of areas under urban land cover and the data derived from coeval land cover maps. Further, the same section highlights how acquired knowledge can help understand the factors underpinning urban sprawl in the considered case study. Final remarks on future prospects of this approach for monitoring the effectiveness of urban growth management strategies are given in Section 5.

2. Materials and methods

2.1. Study area

The territory of the Metropolitan City of Rome, formerly Province of Rome (Fig. 2), covers an area of 5352 km^2, with a total population of 4,061,543 inhabitants living in 122 municipalities