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Regulating Ecosystem Services of forests in ten Italian Metropolitan Cities: Air quality improvement by PM_{10} and O_3 removal

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ABSTRACT

Urban and periurban forests, which are integrated within the concept of Green Infrastructure, provide important Ecosystem Services, including air purification. In this study, we quantified the Ecosystem Service of particulate matter (PM_{10}) and Ozone (O_3) removal from urban and periurban forests in ten metropolitan cities in Italy, and its total monetary value. In order to gain a better understanding of how Ecosystem Services can be regulated on a wider scale, the vegetation ecosystem types were grouped into Physiognomic-Structural Categories of Vegetation according to morphofunctional criteria. The pollution removal was mapped using a remote sensing and GIS approach, by applying a deposition model and a stomatal flux model. We estimated, for the ten metropolitan cities, an overall pollution abatement of 7150 Mg of PM_{10} and 30,014 Mg of O_3 in the year 2003, which was an extremely hot year. Our findings indicate that structural characteristics (i.e. Leaf Area Index) and functional diversity, linked to stomatal conductance, exert a marked influence on the provision of the regulating Ecosystem Services, whose total monetary value was estimated to be equal to 47 and 297 million USD for PM_{10} and O_3 removal, respectively. This study represent the first national-scale assessment of the Ecosystem Services of air pollution removal in Europe, thus providing information that may be useful to stakeholders to manage Green Infrastructure more efficiently.

1. Introduction

According to the Global Health Observatory data (GHO, 2016), more than 50% of the population in 2014 lived in urban areas, and this percentage is expected to increase in the coming decades. In Europe, cities continue to grow rapidly, expanding into the surrounding areas (EEA, 2006). The inhabitants that are concentrated in such areas are exposed to environmental pollution and increasing risk factors resulting from land degradation. Indeed, a vast body of literature has documented how inhabitants of urban areas are exposed to high levels of air pollution, resulting in both short- and long-term adverse effects on public health, ranging from altered lung function to increased mortality (EEA, 2014; Martuzzi et al., 2006; WHO, 2013). Currently, Particulate Matter (PM) and Tropospheric Ozone (O_3) are the most threatening pollutants in the European Union (Guerreiro et al., 2014). In 2011, 20% and 30% of the people living in European cities were exposed respectively to O_3 and PM_{10} levels above EU air quality standards, and more than 90% were exposed to O_3 and PM_{10} concentrations exceeding World Health Organization (WHO) air quality guidelines (EEA, 2013). There is a growing awareness that nature can play an important and effective role in coping with these environmental problems in Europe, where nature-based solutions are implemented within Horizon 2020 goals. Nature-based solutions are defined by the European Commission as "solutions that are inspired or supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience" (EC, 2016). Urban and periurban forests

Abbreviations: GI, Green Infrastructures; ES, Ecosystem Services; PSVC, Physiognomic-Structural Vegetation Category; PM, Particulate Matter; O_3, tropospheric ozone; LAI, Leaf Area Index; g_s, stomatal conductance; MC, Metropolitan City.

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play a key role in enhancing environmental quality because they provide important Ecosystem Services (ES) (Costanza et al., 1998; de Groot et al., 2002; Millennium Ecosystem Assessment (MA), 2005; Gómez-Baggethun and Barton, 2013), with economically measurable benefits for urban dwellers (Costanza et al., 2014; Escobedo et al., 2011; Manes et al., 2012, 2014; Millward and Sabir, 2011; Silli et al., 2015). The main benefits in urban areas comprise air purification, including the mitigation of near-road air pollution impact, urban temperature regulation, run-off mitigation, noise reduction and recreation (Baró et al., 2014; Bolund and Hunhammar, 1999; Dobbs et al., 2011; Tong et al., 2016). Considering the dramatic loss of green spaces as a result of urbanization in Europe, the maintenance of healthy urban green areas that are rich in biodiversity is essential to the well-being of humans (Fuller and Gaston, 2009). Indeed, tree diversity appears to be a key factor in maximizing and stabilizing the provision of ES (Manes et al., 2012, 2014; Millward and Sabir, 2011; Nowak et al., 2006). The relationship between ES and green areas is unified and expressed in the concept of Green Infrastructure (GI) (Lafortezza et al., 2013; Tzoulas et al., 2007), which is defined as an interconnected network of green spaces that conserves natural ecosystem values and functions and provides associated benefits to human populations (Benedict and McMahon, 2002). Vegetation, particularly urban and periurban forests, can consistently reduce pollution levels through both the adsorption of particulate matter on the surface of leaves and the uptake of gaseous pollutants such as O_3 through stomatal fluxes (Nowak et al., 2014). The provision of ES depends on the extent of the underlying processes (de Groot et al., 2002), which in turn depends on complex interactions between biotic and abiotic environmental factors, concentrations of pollutants, structural and functional characteristics of vegetation, which can be inferred through parameters such as the Leaf Area Index (LAI) and stomatal conductance (g_s). The extent of the functions by which the ES provision capacity is determined also varies according to the species composition of ecosystems. In order to understand this issue, it is of fundamental importance to analyze biodiversity on an appropriate spatial scale. However, how structural and physiognomic features of vegetation or latitudinal gradient could affect ES provisioning, is currently poorly investigated (Escobedo et al., 2011). Furthermore, the knowledge of the factors underlying the provision of services in particular from urban ecosystems is still quite limited (Niemelä et al., 2010; Niemelä, 2014). In recent years, an increasing interest has focused on spatially explicit indicators of the distribution of ecosystem functions and services (Alcaraz-Segura et al., 2013; Alamgir et al., 2014; de Araujo Barbosa et al., 2015; Maes et al., 2012; Maes et al., 2016; Xie and Ng, 2013). Several studies have been conducted on biological diversity and related services in metropolitan areas of the US (McPhearson et al., 2014; Miller, 2008; Parker, 2014; Puth and Burns, 2009), where large-scale analysis already exist (Nowak et al., 2006, 2014). An increasing amount of attention is being focused on the metropolitan dimension of biodiversity and its related issues in Europe as well (Borgström et al., 2006; Schewenius et al., 2014), particularly on the definition of ecological networks and GI (Blasi et al., 2008; Capotorti et al., 2015b; Gómez-Baggethun and Barton, 2013; Lafortezza et al., 2013; Manes et al., 2012; Silli et al., 2015) within the broader field of sustainable urban planning (EC, 2004; DG Environment, 2012), though the need remains to implement such researches on a national scale, owing to the heterogeneity of environmental conditions and ecosystems, particularly those in the Mediterranean area (Capotorti et al., 2014). Indeed, in Europe only studies on urban ES at the city-level have been made (Baró et al., 2014; Manes et al., 2012, 2014). According to Baró et al. (2014), although the contribution of urban forests to air quality is significant for citizens' health on the local scale (Maas et al., 2006; Nowak et al., 2014), more efforts are needed to quantify the contribution of GI on a broader territorial spatial scale. Furthermore, despite the extensive efforts made, using increasingly complex techniques, to investigate ES, there are not yet enough studies that provide stakeholders with readable instruments, as well as simulations of possible policy maneuvers that can help in the management of GI (Tong et al., 2016). Lately a multi-scale modeling that provide applicative strategies for policy makers, as the Integrated Assessment modeling approach (Oxley et al., 2013; Vedrenne et al., 2015), were developed. In this study, the extent of PM_{10} and O_3 removal by the main Physiognomic-Structural Vegetation Categories (PSVCs) was assessed in ten metropolitan cities in Italy. The main objectives of this study were: (i) to investigate the influence of urban and periurban forest structural characteristics and functional diversity on the extent of the ES of air pollution abatement, (ii) to perform an economic evaluation of the benefits associated with the ES of pollution removal, and (iii) to provide documentary evidence that is useful to decision-makers within a GI management perspective. The mapping and modeling of the regulating ES was performed by integrating remotely sensed data in a Georaphic Information System (GIS) environment. The underlying hypothesis is that species composition and green cover extension, which depend on city-specific ecological conditions and the land use of the metropolitan areas being considered, are the factors that affect the pollution removal service to the greatest extent. In the present work, a wide range of dataset types and procedures that have been consolidated at both the national and international levels were combined for the first time, thus representing a novel methodological approach to the assessment of regulating ES in metropolitan areas. Our study aims to help policy-makers in the management of GI as a nature-based solution by providing information on the main features affecting GI capacity to provide ES, according to specific environmental conditions found in different metropolitan areas.

2. Methods

2.1. Methodological setting

The Italian Metropolitan Cities (MCs) were legally defined in 2014 (State Law 56/2014), and represent wide contiguous urban areas of important towns with their respective neighboring municipalities. In order to analyze ES, the forest ecosystems of the MCs were divided into Physiognomic-Structural Categories of Vegetation (PSVCs). The concentration fields of PM_{10} and O_3 for the year 2003 in the metropolitan areas were estimated by means of the air quality modeling system MINNI, which is widely used in air quality regulatory interventions and policies at the national level (Mircea et al., 2014). In order to parameterize the PM_{10} deposition model, the MODIS Leaf Area Index (LAI) was acquired and averaged, and any missing data filled by means of the Per Class Mean (PCM) procedure (Borak and Jasinski, 2009). The year 2003 was chosen on account of the exceptionally long heat wave and photochemical episode that occurred in August throughout Western Europe, which led O_3 concentrations to peak, causing severe health problems (Vautard et al., 2005), even though this impact is less evident on the annual mean values. The methodological approach adopted to estimate the regulating ES is shown in Fig. 1. The estimated ES were then related to the structural and physiognomic parameters of vegetation (Leaf Area Index, number of different PSVCs) and environmental variables (pollutant concentrations) using a regression analysis.

2.2. Study areas

Besides their socioeconomic functions, MCs have acquired responsibilities regarding land planning and sustainable local