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Carbon sequestration of four urban parks in Rome

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ABSTRACT

Urban parks form the largest proportion of public green spaces contributing to both physical and mental well-being of people living in urban areas. CO_2 sequestration capability of the vegetation developing in parks of four historical residences (Villa Pamphjli, Villa Ada Savoia, Villa Borghese and Villa Torlonia) in Rome and its economic value were analyzed. Villa Pamphjli and Villa Ada Savoia having a larger vegetation extension (165.04 ha and 134.33 ha, respectively), also had a larger total yearly CO_2 sequestration per hectare (CS) (780 $MgCO_2$ ha^{-1} $year^{-1}$ and 998 $MgCO_2$ ha^{-1} $year^{-1}$, respectively) than Villa Borghese (664 $MgCO_2$ ha^{-1} $year^{-1}$) and Villa Torlonia (755 $MgCO_2$ ha^{-1} $year^{-1}$), which had a lower vegetation extension (56.72 ha and 9.70 ha, respectively). CS was significantly correlated with leaf area index (LAI). The calculated CS for the four parks (3197 $MgCO_2$ ha^{-1} $year^{-1}$), corresponding to 3.6% of the total greenhouse gas emissions of Rome for 2010, resulted in an annual economic value of $ 23537 /ha.

1. Introduction

Carbon dioxide (CO_2) has been recognized as a major driver of global climate change accounting for over 80% of all greenhouse gas emissions in the European Union (EEA, 2009). CO_2 has increased from 280 ppm at the beginning of the industrial revolution to the present level of 385 ppm (Zhonglin et al., 2013). This increase is not a result of the world's natural cycle but of the people activity (Sevik et al., 2015). Greenhouse gases contribute to increasing air temperature by trapping certain wavelengths of radiation in the atmosphere (Nowak and Crane, 2002). According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the global mean air temperature for the period 2016–2035, relative to 1986–2005, will likely be in the range 0.3–0.7 °C (IPCC, 2014). Concern over global warming has resulted in an international investigation into methods of ameliorating the greenhouse effects and reducing atmospheric CO_2 concentration (Gomi et al., 2010).

It has been estimated that urban areas consume 67% of the global energy and emit 71% of the energy-related CO_2 emissions (IEA, 2008). This is due to artificial surfaces, fossil fuel combustion and traffic volume (Idso et al., 2001; Koerner and Klopatek, 2002; Gratani and Varone, 2005). Moreover, urban canyons created by tightly spaced building and roadways can change airflow patterns and increase down-welling long-wave radiation by reducing the sky view factor (Briber et al., 2013). The problem is emphasized in those urban areas where a high dependence on private transportation significantly contributes to increase gas emission rates. In cities, CO_2 emission is the highest during the day (Kordowski and Kuttler, 2010) peaking in rush hours as attested by the correlation between traffic density and CO_2 concentration (Gratani and Varone, 2005). It has been hypothesized that CO_2 emissions from road traffic will increase worldwide by 92% between 1990 and 2020 (Gorham, 2002) posing a direct and serious hazard to humans (Maleki et al., 2010; D'Amato et al., 2010; McPherson et al., 2011). Nevertheless, despite the importance of atmospheric CO_2 concentration, the exact magnitude and spatial distribution of emissions in urban areas remains poorly quantified (Nemitz et al., 2002; Kordowski and Kuttler, 2010). Only recently, the use of plants to ameliorate urban air quality has become a focus of research (Novak et al., 2006; Gratani and Varone, 2007, 2014; Yin et al., 2011).

Urban vegetation (i.e. public and private parks, gardens, hedges and tree-lined avenues) has an important role in offseting CO_2 concentration by acting as a sink for atmospheric CO_2 via photosynthesis and by storing carbon through the growth process (Nowak and Crane, 2002; Gratani and Varone, 2006; Novak et al., 2006; Liu and Li, 2012). Urban parks form the largest proportion of public available green spaces for urban dwellers (Oleyar et al., 2008; Nagendra and Gopal, 2011). They provide clean air, buffer microclimatic variations, lower noise levels and water flow regulation (Chiesura, 2004; Nagendra and Gopal, 2011; Gratani and Varone, 2014). There is a growing evidence that green spaces contribute to both physical and mental well-being of people living in urban areas. Moreover, urban green spaces increase the attractiveness of

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communities as well as neighborhood desirability, which has been quantified in a real estate value as a "willingness to pay" (Millward and Sabil, 2010). The higher sale prices commanded by houses close to parkland can be used to measure the value buyers place on the benefits associated with proximity to treed properties (Peper et al., 2007). Thus, green spaces contribute multiple valuable social, environmental and economic ecosystem services to cities (McPherson et al., 2005; Conway and Urban, 2007; Escobedo et al., 2008). Climate change mitigation by enhancing CO_2 sequestration through vegetation may be a relatively low-cost option and would likely yield other environmental benefits (Gorte, 2009). Thus, policies dealing with management and implementation of green areas in cities should be stressed. Authorities should efficiently manage vegetation in order to secure a better quality of the life (Torres and Pinho, 2011; Millward and Sabir, 2011).

The city of Rome is characterized by a large extent of the urbanized area (128,736 ha), 2,872,021 inhabitants and a large movement of public and private means of transport (3,513,942, ACI, 2014). Rome ratified the Aalborg Commitments, which deals in promoting the sustainability of European cities through strategies concerning the decrease of greenhouse gas emissions and transport activity. Rome has many green areas (86,000 ha, 67% of the total surface area, data from Rome Municipality), which includes protected areas, urban parks and gardens. In particular, a large part of the "urban green areas" (578 ha, data from Rome Municipality) is covered by historical residences with large parks.

The main objective of this research was to quantify the CO_2 sequestration of different plant categories occurring inside the parks of four historical residences in Rome. Moreover, we would estimate the economic benefits of CO_2 sequestration by quantifying its monetary value based on a CO_2 fixation price (McPherson et al., 1997; Nowak and Crane, 2002). Quantifying the economical advantages of CO_2 sequestration by urban vegetation may help the decision-makers to make efficient management plans and to project new parks by choosing plant species also on the basis of their CO_2 sequestration capability.

2. Methods

2.1. The study area

The study was carried out in the period June 2013 – June 2014 in the city of Rome (41°53′N; 12°31′E). Rome is under a Mediterranean type of climate. The average total year rainfall is 866 mm most of it distributed in autumn and winter. The average maximum air temperature of the hottest months (July and August) is 31.6 ± 0.2 °C and the average minimum air temperature of the coldest months (January and February) is 4.9 ± 0.1 °C (data provided by the Meteorological Station of Collegio Romano, for the period 1995–2014).

Four parks were selected (Fig. 1): Villa Doria Pamphilj, Villa Ada Savoia, Villa Borghese and Villa Torlonia, characterized by the presence of tree and shrub species, most of them being natural species of the Mediterranean landscape. These parks were selected on the basis of their size and their proximity to the city center. Among them, Villa Pamphilj (41°53′N;12°27′E) is one of the largest urban parks in Rome, extending over 184 ha in the south of the city. Villa Ada Savoia (41°55′N; 12°30′E) extends over 160 ha in the north of the city. Villa Borghese (41°54′N; 12°29′E) extends over 74 ha in the city center, and Villa Torlonia (41°91′N; 12°30′E) extends over 14 ha east of the city (Gratani and Varone, 2014).

2.2. Plant categories

Inside each park, plants were classified into five plant categories: woods, "group of trees", tree-lined avenues, lawns and hedges. In particular, (1) woods (dominated by a single species) or mixed hardwood (with more than one species) refer to trees extending more than 4 ha; (2) "group of trees" refers to trees with an extension less than 4 ha (each "group of tree" is constituted by only one species); (3) tree – lined avenues refer to individual trees placed regularly along a road (each tree – lined avenues is constituted by only one species); (4) lawns refer to a patch of ground covered with grass (Ong, 2003); (5) hedges refer to shrubs characterized by a height ranging from 1 to 2 m, according to Gratani and Varone (2014).

The extension of each plant category was measured by a Quantum Gis (QGIS), an Open Source Geographic Information System (OSGEO4W, version 1.8.0) running on Windows. QGIS determines the acquisition, recording, analysis, visualization and restitution of information by geographical data. The GIS software is useful for the census of urban green areas by the analysis of digital cartographies.

2.3. Plant category structural traits

Leaf Area Index (LAI) was measured by the "LAI 2000 Plant Canopy Analyzer" (LICOR Inc., Lincoln, USA) for all the considered plant categories. The structural traits of each category, excluding lawns and hedges, were measured on representative plants ($n = 10$ per plant category). In particular, tree diameter at breast height (DBH, m) was measured by callipers (Silvanus calliper – 65 cm) and by a DBH tape (length = 20 m) when diameter was greater than 65 cm. Plant height (H, m) was measured by electronic clinometers (Haglöf, Sweden). The total photosynthetic leaf surface area (TPS, m^2) of trees was determined multiplying each LAI value by the ground area covered by the tree crown (Nowak and Crane, 2002; Gratani and Varone, 2006). Ground area covered by a tree crown was calculated from the area of circle that was obtained by projecting the crown to the ground and measuring the length along an axis from edge to edge through the crown centre. In particular, the mean value of four or eight (depending on crown contour) radii was used. The TPS of lawns was calculated multiplying each LAI value by the projected leaf area to the soil. Structural hedge traits were analyzed along a representative track (25 m long) for each hedge type, at 1.00 m from the soil level (Gratani and Varone, 2013). TPS of hedges was calculated multiplying the total number of leaves by the average leaf area (LA, cm^2). The total number of leaves was counted in 10 sections (each of 1 m^2) distributed along the considered hedge track per each hedge type (Gratani and Varone, 2014). LA (excluding petiole) was obtained by the Image Analysis System (Delta–T Devices, UK).

2.4. CO_2 sequestration

The total yearly CO_2 sequestration was calculated multiplying TPS of each plant category by the mean yearly net photosynthesis and the total yearly photosynthetic activity time (in hours), according to Gratani and Varone (2006). Nevertheless, in order to compare CO_2 sequestration of the different plant categories, the total yearly CO_2 sequestration capacity per hectare (CS, Mg CO_2 ha^{-1} y^{-1}) was used.

Net photosynthetic rates (NP, $\mu mol\ m^{-2}\ s^{-1}$) were measured monthly by an open infrared CO_2 gas analyzer (ADC LCA4, UK) equipped with a leaf chamber (PLC, Parkinson Leaf Chamber). Measurements were made in situ on cloud-free days (PAR > 1000 $\mu mol\ m^{-2}\ s^{-1}$), in the morning (from 9:00 am to 12:00 pm) according to Reich et al. (1995) to ensure that near-maximum daily NP were measured. On each sampling occasion, fully sun expanded leaves were used (Varone et al., 2015). The sampled leaves did not show any evidence of injury. Leaves were retained in their natural position during measurements. Moreover, to make the measurements comparable, leaves with a south-east exposure