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Understanding the Benefits from Green Areas in Rome: The Role of Evergreen and Deciduous Species in Carbon Dioxide Sequestration Capability

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Abstract

Urban areas are a major source of anthropogenic carbon dioxide (CO_2) emissions because of road traffic and local heating with natural gas, oil or coal. Rome is among the largest European cities (129,000 ha) with a large volume of green areas (69.6% of the total Municipality area). The CO_2 sequestration (CS) capability for the greenery extending for about 300 km^2 inside the area delimited by the Great Ring Road (GRA) in Rome was calculated combining satellite data with CS data measured in the field. Data from Sentinel-2 were collected and the Normalized Difference Vegetation Index (NDVI) was computed on a pixel-base. Three plant classes homogeneous in terms of annual NDVI profile were identified: deciduous trees (DT), evergreen trees (ET) and meadows (M) covering an area of 14,142.027 ha within the GRA, of which M had the highest percentage (48%), followed by DT (27%) and ET (25%). CS ranged from 428,241,492.9 Tons CO_2 year^{-1} (ET) to 263,072,460.6 Tons CO_2 year^{-1} (M). The total CS of the greenery inside the GRA was 1049,490,355.4 Tons CO_2 year^{-1} resulting in an annual economic value of \$772,424,901.6/ha. The CO_2 sequestration capability of the considered plant classes could be incorporated into the national greenhouse gas emission budget to calculate the contribution of CO_2 sequestration to the economy of Rome.

Keywords

CO_2 Sequestration, Green Areas, Cities, Evergreens, Deciduous Species, Meadows

1. Introduction

Nowadays, a target of air quality monitoring is addressed to greenhouse gases concentration responsible for global air temperature increasing [1]. Among greenhouse gases, carbon dioxide (CO_2) is the most abundant owing to fossil fuel combustion and deforestation worldwide [2] [3]. The United Nations Framework Convention on Climate Change (UNFCCC) led to an agreement to reduce rising levels of CO_2 and other greenhouse gases in the atmosphere, and the Kyoto Protocol proposed carbon (C) reduction through decreasing fossil fuel emission or accumulating C in vegetation and soil [4]. Urban areas are a major source of anthropogenic CO_2 emissions [5] because of road traffic and local heating with natural gas, oil or coal [6]. CO_2 concentration in urban areas is more than 50% compared to extra-urban areas [7] [8] [9]. It has been hypothesized that CO_2 emissions from road traffic will increase worldwide by 92% between 1990 and 2020 [10] [11] [12]. As it is estimated that currently 55% of the world's population lives in urban areas, and this percentage will be around 70% in 2030 [13], the forecasted increase of CO_2 concentration in cities can be considered not only an environmental issue but also a social issue [14] [15]. However, the CO_2 atmospheric concentration mitigation requires a complex strategy involving multiple actions at political, economic, social and ecological level. Urban green areas have recently gained popularity as a climate change adaptation/mitigation measure, and many city governments have adopted policies promoting tree-planting, the preservation of urban green spaces and, more recently, green architecture (*i.e.* green roofs and facades) [15]. The research on urban vegetation over the past decades has advanced our understanding of this resource and its impact on the society, which includes many ecosystem services, such as lowering air temperature, reducing building energy use, improving air and water quality, lowering noise level and enhancing social well-being [16]-[21]. Much less evidence is available to demonstrate the direct removal of CO_2 from the atmosphere by urban vegetation [15]. From an ecological point of view, CO_2 sequestration by plants is considered an offset mechanism for CO_2 emissions [22]. However, the lack of data and models evaluated with observations, which covers the large variability among cities in term of plant species, urban morphology and climate setting impedes a proper assessment of current green programs [15]. Moreover, plants contribute differently to CO_2 sequestration according to their habitus. Few data are available for CO_2 sequestration capability by deciduous and evergreen species growing in the same area as those characterized by Mediterranean climate. It is important to consider that deciduous species have a CO_2 sequestration capability from spring to the beginning of autumn while evergreens all year long, due to their continuous photosynthetic activity [23]. Thus, urban greenery reveals the extent and variation of this resource across a city [24]. There is the need to increase knowledge on the role of urban greenery in environmental quality improvement to select the more suitable species which can be planted [18] [25] [26] [27]. In this context, a useful tool to expand our knowledge on plant species CO_2 sequestration capability is to map spatial patterns and distribution of different species [28] though digital cartographies based on the GIS use [29]. Nevertheless, until now GIS-based maps have been developed for producing geo-referenced estimates of C sink and stock potential to process model inputs (*i.e.* land cover and soil texture), and to visualize results [30] [31], while few studies integrate plant species CO_2 sequestration calculated directly throughout photosynthesis measured in the field and based on photosynthesis measurements with GIS to create CO_2 sequestration maps [28]. It is important to increase such types of studies to have spatially explicit patterns of C sink for different vegetation types. The results may be used for political decision maker and administrators to apply an efficient management strategy for urban greenery, especially in cities such as Rome (Italy) characterized by a large presence of green areas. Rome (41˚54'N, 12˚29'E) is among the largest European cities (129,000 ha and 2873.494 inhabitants). Green areas in Rome (89,000 ha) are 69.6% of the total Municipality area, including agricultural areas (43,271 ha), protected natural areas (*i.e.* urban parks, oasis, reserves, wetland, Natura 2000 sites, agricultural parks, SIC, areas managed by Rome Natura, for a total of 41,500 ha), historical parks (820 ha), large urban parks (1780 ha), green equipped covers (1150 ha) and urban furniture (330 ha) (ISPRA 2017). Since a large part of the tree species growing in the historical parks and avenues were planted at the beginning of the XVIII century [32] they have also an historical value.

In such context, the main objective of this research was to map the CO_2 sequestration capability for the greenery developing inside the area delimited by the Great Ring Road (GRA) in Rome, by combining satellite data with CO_2 sequestration data measured in the field at plant level, and referred to the carbon uptake rate over the year through photosynthesis. In particular, the contribution of evergreen species, deciduous species and meadows to the total CO_2 sequestration capability of the greenery inside the GRA was calculated. The monetary value of the CO_2 sequestration capability for the greenery inside the GRA was also calculated.

2. Materials and Methods

2.1. The Study Area

The study was carried out in the city of Rome, in the area delimited by the Great Ring Road (GRA), which is part of the Rome Municipality area. This area extends for 300 km^2 (*i.e.* approximately one fifth of the total surface of the Municipality of Rome) (**Figure 1**).

The climate of Rome is of Mediterranean type. The mean minimum air temperature (T_{min}) of the coldest months (January) was 4.72˚C ± 1.09˚C, the mean maximum air temperature (T_{max}) of the hottest months (July and August) was 31.85˚C ± 0.12˚C and the yearly mean air temperature (T_m) was 16.76˚C ± 6.57˚C. Total annual rainfall was 818.74 mm, most of which occurring in autumn

Figure 1. The Great Ring Road (GRA) in the city of Rome.

and winter. Dry period was from June to August (86.62 mm of total rainfall) (Data collected by the Regional Agency for the Development and Innovation of Agriculture for the Latium, Arsial Meteorological Station, Lanciani Street, for the period 2006-2017).

2.2. CO_2 Sequestration Map

The CO_2 sequestration map of Rome was developed by three steps. First, data from satellite images were used to identify the greenery developing inside the GRA. In particular, data from Sentinel-2 (10 m of pixel size and 5 days of revisiting period) were collected for the year 2016. The Normalized Difference Vegetation Index (NDVI) was computed on a pixel-base. A monthly NDVI maximum value composite was performed for each pixel in order to overcome the influence of cloud coverage and to guarantee the use of the best dataset available. A k-means (kM) cluster analysis was performed to derive a vegetation cover map. Three vegetated classes homogeneous in terms of annual NDVI profile were identified: deciduous trees (DT), evergreen trees (broadleaves and needle leaves) (ET) and meadows (prairies and pastures) (M). Mixed pixels (*i.e.* scattered trees or small hedges within a built-up area) were excluded from the analysis. Second, the CO_2 sequestration (CS, Tons CO_2 $year^{-1}$) capability for DT, ET and M classes was determined starting for the database related to data from historical green parks in Rome (Villa Pamphilj, Villa Ada Savoia, Villa Borghese and Villa Torlonia) in [18] and in Gratani *et al.* (data not published and related to the Botanical Garden of Rome) of different size, location and vegetation types. In particular, Villa Pamphilj (41˚53'N; 12˚27'E) extends over 184 ha in the south of the city, Villa Ada Savoia (41˚55'N; 12˚30'E) over 160 ha in the north of the city, Villa Borghese (41˚54'N; 12˚29'E) over 74 ha in the city centre, Villa Torlonia (41˚91'N; 12˚30'E) over 14 ha at east of the city, the Botanical Garden of Rome (41˚53'53''N; 12˚28'46''E; 53 m a.s.l.) over 12 ha in the city centre. The considered database was created by calculating CS for the different plant categories as described in [18]. Since the considered plant categories included the most representative species developing in Rome [33] [34], data were suitable for quantifying CS of the greenery inside the GRA. Third, the database was processed in order to extrapolate CS data for DT, ET and M identified classes by satellite images. The distribution of the three classes inside the GRA is shown in **Figure 2**. Then, the obtained CS values were weighted for the total extension of each class in order to obtain the total CS (TCS) inside the GRA.

2.3. Monetary Value of CO_2 Sequestration

The monetary value of CO_2 sequestration capability for DT, ET and M classes inside the GRA in Rome was estimated, assuming a monetary value of $0.00334/lb (*i.e.* $0.00736/kg) for sequestered CO_2, according to [35]. The monetary value referred to TCS was also calculated.

3. Results

3.1. CO_2 Sequestration Map

The satellite images covered a total green area of 14, 142.027 ha within the GRA of which M had the highest percentage (48%) and ET the lowest (25%) (**Figure 2**, **Table 1**).

As shown in **Figure 2**, evergreen species are mainly distributed along the main river valleys and in forested areas in the western and northwestern sectors of the city. Note that, due to both ecological and historical drivers, the north-south course of the Tiber River constitutes a major barrier between the deciduous forest vegetation of the western part of the city and the southeast where vegetation is mainly composed by evergreen species, pastures and fallow areas (Celesti-Grapow and Pignatti 1995). Here, vegetation forms a green corridor that connects the rural-urban interface with the archaeological sites in the city center (Ricotta *et al.* 2001). In the northeastern part of the city, vegetation is much more fragmented, and scattered remnants of pastures and evergreen vegetation are mainly distributed at the rural-urban interface, whereas patches of deciduous forests are found along the course of the Aniene River.

The yearly CS for the considered plant lasses expressed per hectare (Tons CO_2 $ha^{-1}\cdot year^{-1}$) is shown in **Table 2**. The table highlighted that one hectare of ET had the highest CS, followed by DT and M.

The obtained CS for DT, ET and M were weighted for the total extension of each class inside the GRA (**Table 3**). CS ranged from 428,241,492.9 Tons CO_2 $year^{-1}$ (ET) to 263,072,460.6 Tons CO_2 $year^{-1}$ (M). TCS of the greenery inside the GRA was 1049,490,355.4 Tons CO_2 $year^{-1}$ to which ET contributed for 40.80%, DT for 34.13% and M for 25.07%.

3.2. Monetary Value of CO_2 Sequestration

CS resulted in an annual monetary value of 315,185,738.8/ha, $263,617,831.8/ha, $193,621,331.0/ha for ET, DT and M, respectively. TCS for all the classes growing inside the GRA resulted in an annual economic value of $772,424,901.6/ha.

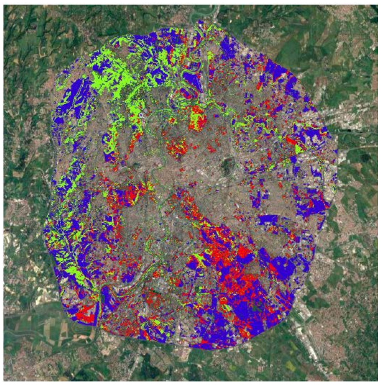

Figure 2. Spatial distribution of the three plant classes inside the Great Ring Road (GRA) in Rome. Red = evergreen trees (broadleaves and needle leaves); green = deciduous trees; blue = meadows (prairies and pastures).

Table 1. Surface area covered by the considered three plant classes inside the Great Ring Road (GRA) in Rome: deciduous trees (DT), evergreen trees (broadleaves and needle leaves) (ET) and meadows (prairies and pastures) (M).

Classes	ha	%
ET	3521.702	25
DT	3822.587	27
M	6797.738	48
Total	14,142.027	100

Table 2. Yearly CO_2 sequestration (CS) capability, expressed per hectare for each of the considered plant classes inside the Great Ring Road (GRA) in Rome: deciduous trees (DT), evergreen trees (ET) and meadow (M).

lasses	CS (Tons CO_2 $ha^{-1} \cdot year^{-1}$)
ET	121.60 ± 24.61
DT	93.70 ± 76.64
M	38.70 ± 21.57

Table 3. Total carbon sequestration (TCS) (Tons CO_2 $year^{-1}$) of the considered plant classes inside the Great Ring Road (GRA) in Rome: deciduous trees (DT), evergreen trees (ET) and meadows (M).

Classes	TCS (Tons CO_2 $year^{-1}$)	%
ET	428,241,492.9	40.80
DT	358,176,401.9	34.13
M	263,072,460.6	25.07
Total	1049,490,355	

4. Discussion

The high biodiversity of urban landscapes resulting from variable land use creates a great variability of ecological conditions for plants [34] [36]. Nevertheless, the rapid expansion of cities affects urban species composition and functioning. Urban areas are projected to more than double between 2010 and 2060, which will impact agricultural lands, as well as expand the importance of urban forests in relation to environmental quality and human well-being [37]. Literature [38] [39] provides valuable insights into how humans interact with urban greenery. The benefits of the contact with nature concern mental and physical health. In particular, urban green areas play a key role from a social perspective by promoting physical activity and increasing people interaction [40]. Moreover, urban forests encompassing trees, shrubs, meadows and other vegetation types in cities provide a variety of ecosystem services to city-dwellers, such as air purification, temperature regulation, noise reduction, runoff mitigation and recreational opportunities [41] [42] [43]. In particular, urban plants contribute to decrease atmospheric CO_2 concentration, which has increased dramatically since the start of the industrial revolution. Close to 280 ppm in 1870, the average global concentration surpassed 400 ppm in 2015, and this acceleration is similar to the rise in fossil CO_2 emissions, due to the use of fossil fuels. According to [44], the CO_2 concentration significantly increased in Rome from 1995 (367 ± 29 ppm) to 2004 (477 ± 30 ppm) (data referred to daily peak in the early morning when traffic is the highest) and a further increase was monitored in 2016 (560 ± 27 ppm). During the year, CO_2 concentration in Rome peaks in winter, 18% higher than in summer in relation to traffic density [17] [44].

Concerning the area inside the GRA in Rome, [34] highlighted that the most widespread vegetation types are deciduous woods dominated by *Quercus cerris* L. on volcanic soils and by *Quercus pubescens* Willd. on less mature soils, evergreen woods dominated by *Quercus suber* L. on sand and by *Quercus ilex* L. on the steepest slopes. The results highlight that deciduous species (DT) cover 3822.587 ha inside the GRA, evergreens (ET) 3521.702 ha and meadows (M) 6797.738 ha. In particular, numerous residual forest patches are scattered in the protected areas in the western and northwestern sectors of the city, such as Insugherata, Monte Mario, Pineto and Infernaccio. Significant remnants of forest vegetation are also located along the Tiber River and in the main Urban Parks (Villa Ada, Villa Borghese and Villa Pamphilj). In addition, the riparian forest patches in the Natural Reserve of the Aniene Valley are very important for preserving the natural vegetation in the northeastern sector of the city. In the southeast, the Appia Antica, Centocelle and Acquedotti protected areas host an important network of green areas which extends from the archaeological site of the Roman Forum in the city center to the pastures and fallow areas at the rural-urban interface. All of these areas have a historical and conservation value for the preservation of urban vegetation.

It is important to highlight that the evergreen species have a CO_2 sequestration capability all year long having, as a consequence, an important role especially in autumn and winter when CO_2 emissions from road traffic are the highest in Rome [44]. Recognition of the need to stabilize the CO_2 concentration in the atmosphere has been manifested in a number of international and national agreements and policies, such as the Kyoto Protocol, the Paris Agreement, the EU climate policy (e.g., [1]) and the Cop 24 in Katowice (Polonia 2018). The results show that the total CS inside the GRA corresponds to 10.49% of the total greenhouse gases emission of Rome for 2010 [45]. These findings may be of relevance in an international discussion related to the ongoing rise in the CO_2 concentration and its implications in the context of the hypothesized global change. The evaluation of urban greenery in both aesthetic and monetary terms can be an important tool to assist planners in protecting this resource [46]. Thus, the evaluation of the monetary value of urban greenery is a potential investment in the form of CO_2 sequestration. The results highlight that CS for the greening inside the GRA in Rome results in an annual economic value of $772,424,901.6/ha to which evergreens contribute for 40.80%, deciduous trees for 34.13% and meadows for 25.07%.

The CO_2 sequestration capability of the considered plant classes can be incorporated into the national greenhouse gas emission budget to calculate the contribution of CO_2 sequestration to the economy of Rome. Whereas the importance of C allocation is undisputed, there is little consensus on how it should be modelled [47]. In the future, based on the remote sensing images, data, and use of large-scale quadrats, the existing database can be updated via GIS, and an inversion model suitable for the actual situation in each region will provide a direction for developing more accurate assessment of regional forest C sequestration [48], including greenery in the cities. Through proper planning and management, urban greenery can be sustained and environmental and human health values improved. Healthy urban vegetation and proper management can reduce some of the environmental issues associated with urbanization (e.g., increased air temperature and energy use, reduced air and water quality, increased human stress) and ultimately, help humans living within and around urban areas [37]. This methodology can be applied to other cities in Italy and in other countries, characterized by different plant species, according to the different geomorphology and climate, and incorporated in a geographic information system to monitor spatial changes of CO_2 sequestration over time.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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