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URBAN ECOSYSTEM SERVICES: TREE DIVERSITY AND STABILITY OF PM_{10} REMOVAL IN THE METROPOLITAN AREA OF ROME

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Abstract – Urban vegetation, and particularly urban forests, are known to provide important ecosystem services, such as urban air quality improvement by removing gaseous and particulate pollutants. The amount of PM_{10} removed by urban and periurban trees of the metropolitan area of Rome (evergreen broadleaves, deciduous broadleaves and conifers) was estimated by considering the minimum and maximum PM_{10} concentration values recorded in the Municipality of Rome during the years 2003 and 2004. The results of these simulations have been used to map the Ecosystem Service of PM_{10} removal by the three functional groups in the five Sanitary Districts of the Municipality. Given the spatial uniformity of PM_{10} levels in the urban area, the highest amount of PM_{10} deposition rates, during the whole period, are those of the Sanitary District with the largest vegetation cover (RMD). It is also interesting to highlight that the highest deposition fluxes, for the three functional groups, were estimated for the 2004 summer period, in concurrence with the highest mean values of Leaf Area Index. Our results confirm the crucial role of vegetation in supporting significant Ecosystem Services as air quality improvement, highlighting the importance of biodiversity and green infrastructures in sustain and enhance benefits provided by trees.

Keywords: Ecosystem Services, Urban forests, Air quality improvement, Particulate Matter Mapping, Metropolitan area of Rome, tree diversity

Introduction

Economic activities related to the use and conversion of energy are generally coupled to emissions of air pollutants, causing a negative impact on the environment, particularly for the urban areas (Vlachokostas et al., 2009). In cities, air pollution causes many important health risks through the inhalation of gases and particles. Atmospheric particulate matter (PM) originated from anthropogenic sources is considered to cause cardiovascular and respiratory diseases (WHO, 2013; EEA, 2013). This findings are based on epidemiological studies carried out in Europe, showing an increases both in mortality and morbidity associated with air pollution (Powe e Willis, 2004; Manes et al., 2008; Manes et al., 2012a). In this sense, air pollution represents a serious threat for human health and well-being of citizens, which in turn lead to an increased interest, among researches and policy-makers, in developing tools for assessing and quantifying the impact on health, in particular of urban population. Current studies point out how urban green spaces and green infrastructures may promote citizens health and well-being improving the air quality and mitigating the heat island effect and reducing temperature increase due to climate change (Litschke and Kuttler, 2008; Nowak et al., 2006; Manes et al., 2012 a, b; Nowak et al., 2013). Presence and structure of urban parks and forests may affect ecosystem functions, which provide ecosystem services that sustain and promote human health.

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The deepening of the knowledge about the potential role of different urban vegetation types in mitigating Particulate Matter (PM) pollution levels, could provide best practices regarding the selection of most effective trees in abating PM concentration and in managing and recovering of large degraded urban and peri-urban areas. PM particles are captured mainly by foliage, remaining there until a rainfall event can wash them out from plant surfaces (Novak, 1994; Ould-Dada and Baghini, 2001; Robertson and Taylor 2007). The capture efficiency of the particulate by the vegetation is linked to the structural characteristics of the plant, such as for instance, morpho-anatomical characteristics of the leaves. Important studies carried out on the relationship between leaf physiology and PM deposition, pointed out how leaf hairs and waxes may represent species traits with a positive correlation with the capability of plant to abate airborne particulate (Sæbø et al., 2012). Therefore, urban green spaces and urban forest as a multifunctional system can play a significant role for sustainable development, providing important ecosystem services for human and wellness. Moreover, vegetation may contribute to increase urban biodiversity in the global change context, aiming to protect local diversity of flora and fauna and stability/functionality of the whole ecosystems (Maes et al., 2012a; Manes et al., 2012a).
Overall there is the need to increase vegetation cover in abandoned urban sites, both built and non built, aimed to maintaining local biodiversity structure and functions. In this study we applied a simplified deposition model suggested by Escobedo and Nowak (2009), with the objective to estimate the potential role of vegetation in abating airborne PM_{10}, in the metropolitan area of Rome. In Europe, the EU Biodiversity Strategy to 2020 calls on the member states to map and assess ecosystems and their services by 2014 (Action 5, Maes et al., 2012b). In this context, we propose a map for the studied area, highlighting the PM removal function of urban trees and periurban forests. The findings of this research confirmed and strengthened the role of biodiversity in supporting essential Ecosystem Services provided by forest ecosystems, as air quality improvement in particular related to the abatement of airborne particulate pollution.

Materials and methods

PM_{10} concentration data

The mitigating role of urban vegetation for PM_{10} was estimated by considering the minimum and maximum PM_{10} concentration values (C) recorded in the Municipality of Rome during the years 2003 and 2004. These were based on PM_{10} yearly time series recorded by air quality monitoring stations located in Piazza Fermi and in Villa Ada, respectively (Figure 1 a, b). “Fermi”, the station showing the highest PM_{10} values, is a urban traffic station, while “Villa Ada”, the station showing the lowest PM_{10} values, is classified as urban background station, and is located inside the historical park of Villa Ada, a large green area in the city centre. In Fig. 2, the number of exceedance of the daily limit value for PM_{10} (50 μg/m^3) during the years 2003-2004, is reported for the two considered stations. Moreover, regarding PM_{10} air concentration, 2004 was generally worse than 2003. The data also show that natural events, as transport of Desert Dust and Sea-salt aerosol, may be responsible for a relevant fraction of PM_{10} exceedance, particularly measured by non-traffic stations. For the Kriging model of PM_{10} distribution in the Municipality of Rome, data from four air quality monitoring station were used.

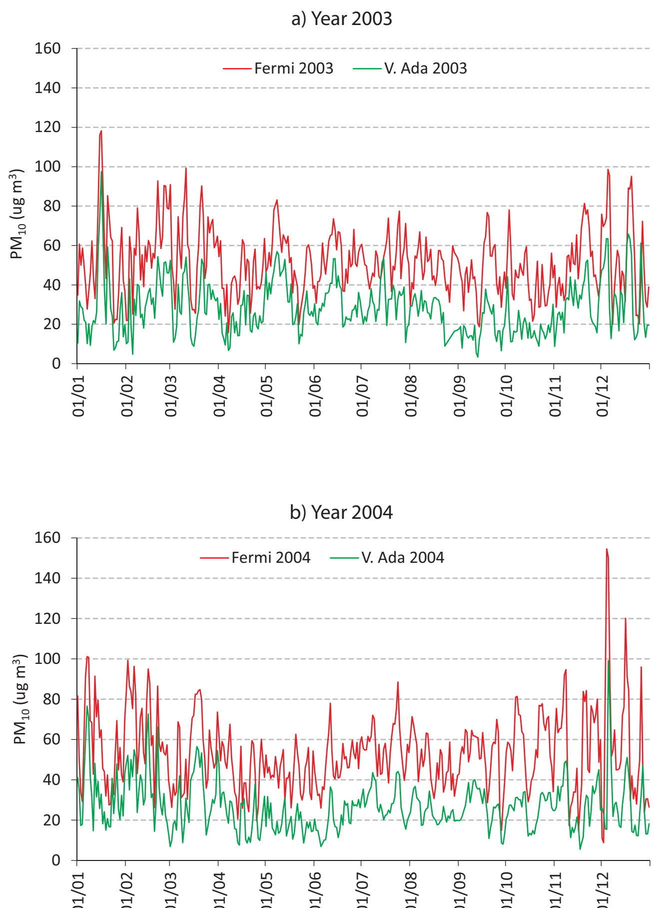

Fig. 1. Annual series of mean daily concentrations of PM_{10} recorded, during the years 2003 (a) and 2004 (b), in two air quality monitoring stations within the Municipality of Rome: “Fermi” was the station with the highest values and “Villa Ada” showed the lowest ones.

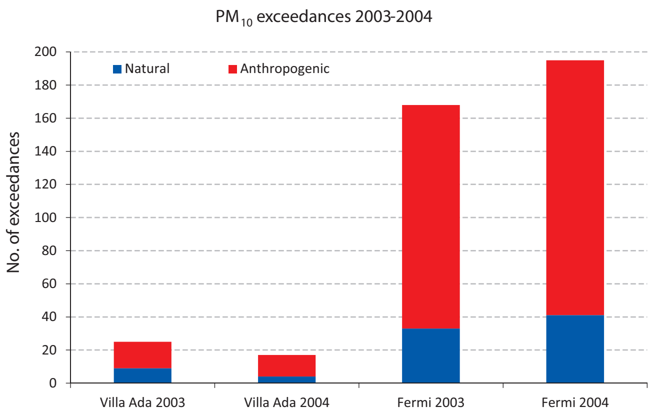

Fig. 2. Number of exceedance of the daily limit value for PM_{10} (50 µg/m^3) during the years 2003-2004 for the stations "Fermi" and "Villa Ada".

Urban forest in the city of Rome

As detailed in Manes et al. (2012a), for physiological modelling purposes the woody vegetation within the borders of the Municipality of Rome has been divided into three groups , based on leaf type:

- Evergreen broadleaves (*Quercus ilex* and *Quercus suber* prevalent)
- Deciduous broadleaves (*Quercus* spp., *Platanus* spp.)
- Conifers (*Pinus pinea*)

A Landsat 5 TM image (recorded in date 21/07/1999), with spatial resolution of 30×30 m, was used to assess the distribution of the three functional groups above mentioned, across the city of Rome. The area covered by each category has been estimated by a Geographic Information System (GIS) analysis, using ESRI ArcGIS software. Deciduous broadleaves represent the most abundant functional group (3474 ha), followed by evergreen broadleaves (2121 ha) and conifers (1605 ha). The area covered by the three categories sums up to 7198 ha, corresponding to 5.6% of the Municipality area of Rome (Manes et al., 2012).
Physiological and structural parameters of the three vegetation groups have been simulated using the MOCA-Flux model (Modelling of Carbon Assessment and Flux), implemented within the object-oriented software package STELLA II (High Performance Systems Inc., USA) (Manes et al., 2012a; Manes et al., 2010). The model has been parameterised for the three vegetation categories, by using values of input physiological and structural variables derived from available field measurements, collected in different sampling sites within the Metropolitan area of Rome. Among the physiological variables simulated by the model, the Leaf Area Index (LAI, $m^2_{leaf}\ m^{-2}_{soil}$), has been used as input data for estimating the PM_{10} deposition rates.

Modelling PM_{10} deposition to woody vegetation

In order to calculate the amount of PM_{10} deposition on woody vegetation in Rome municipality, the equations reported by Novak (1994) were applied. According to this model, the removal of particulate in a specific site and during a given time period has been calculated as follows:

$$Q = F \times L \times T$$

where Q is the amount of a particular air pollutant removed by trees in the time period, F is the pollutant flux, L is the total canopy cover in that area, i.e. the Leaf Area Index, LAI ($m^2\ m^{-2}$), estimated by the MOCA-Flux Model for each functional group, and T is the considered time period.
The pollutant flux F is calculated following the Nowak methodology (1994):

$$F = V_d \times C$$

where V_d is the dry deposition velocity of a given air pollutants and C is its concentration in air. The mitigating role of urban vegetation for PM_{10} was calculated by considering the minimum and maximum C values recorded in the Municipality of Rome. The deposition velocity V_d was set to an average value of 0.0064 m/s based on a LAI = 6 and then adjusted to actual LAI, as suggested by Escobedo and Nowak (2009).
The deposition fluxes where then calculated for each of the three functional groups.
The total amount of PM_{10} removed by woody vegetation in 2003 and 2004 was obtained by integrating the mean daily deposition flux over the annual series as follow:

$$Q_{PM10} = \sum_{i=1}^{365} Vd_i \times C_i \times 24 \times 3600 \times LAI_i \times 0.5$$

where 0.5 is the resuspension rate of particles coming back to the atmosphere (Zinke, 1967) and LAI_i was the variable used to refer the removal to 1 m^2 of soil covered by the given functional group.
The total amount of PM_{10} removed by woody vegetation in Rome Municipality was estimated for the years 2003 and 2004, by applying the following equation to the total area covered by each vegetation category:

$$Total\ PM_{10}\ removed = Q_{PM_{10}}\ x\ A_i$$

where A_i is the area covered by the ith functional group expressed in m^2, within the Rome Municipality. The same method was used for estimating PM_{10} removal simulating as

if, in both years all the trees, had belonged to one single functional group. In the three scenarios, one for each group, the total area covered by tree vegetation within the Municipality of Rome (7198 ha) was attributed to each one of them. For this simulation, an average between the maximum and minimum PM_{10} deposition values (t ha^{-1}) were considered; estimates was carried out on seasonal base, by using the C values recorded by the air quality monitoring stations of Fermi and Villa Ada, respectively.
This approach was used because, as shown by PM_{10} maps despite the complex pattern over time of this pollutant and the high values of standard error, the overall spatial variability in the city of Rome, is almost negligible. Thus, interpolation by geostatistical methods did not provide an adequately effective result, also due to the low spatial density and not homogeneous distribution of PM_{10} monitoring stations. However, examples of PM_{10} map in winter 2003 for Rome, produced by the Kriging approach, is provided (Fig. 3a), in order to evaluate both the excessively low sampling density and the consequently high error of geostatistical interpolations (Fig. 3b).

a) b)

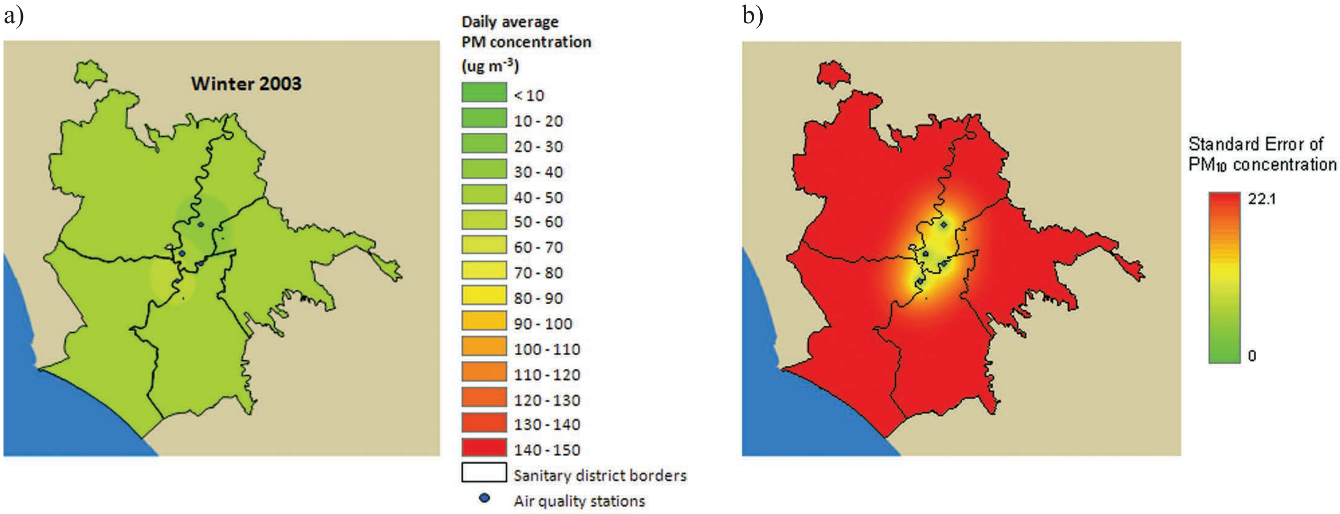

Fig. 3. a) Kriging model of PM_{10} distribution in the Municipality of Rome in Winter 2003. The localization of the air quality monitoring stations equipped for PM data acquisition are also indicated; b) Standard error maps of the kriging model.

Results and discussion

Figure 4 shows the seasonal trend of PM_{10} deposition fluxes simulated for the three functional groups using the methodological approach of Escobedo and Nowak (2009).
The results of these simulations for each functional group, show maximum values of PM_{10} deposition in the year 2003 equal to 0.125 t/ha_{soil} year for evergreen broadleaves, 0.032 t/ha_{soil} for deciduous broadleaves, and 0.088 t/ha_{soil} year for conifers. In the year 2004, the maximum estimated values of PM_{10} deposition were 0.120 t/ha_{soil} for evergreen broadleaves, 0.149 t/ha_{soil} for deciduous broadleaves and 0.094 t/ha_{soil} for conifers (Table 1).
Our results are comparable with the results reported by Yang et al. (2005) in the Beijing area of, China, for the year 2002.

Table 1. PM_{10} deposition fluxes calculated for the Rome woody vegetation in 2003 and 2004. Yearly cumulated values (t ha^{-1} of soil covered by the given vegetation leaf-type.) are reported for the three leaf types, based on daily Leaf Area Index estimated by the MOCA-Flux model. LAI data are used to calculate deposition velocity following the methodological approach of Escobedo and Nowak, 2009. For each estimation, minimum and maximum values are provided, based on PM_{10} yearly time series recorded by air quality stations of Fermi and Villa Ada, respectively.

Total PM_{10} removed (t/ha_{soil} per year) - Rome municipality				
	2003		2004	
	minimum	maximum	minimum	maximum
Evergreen	0.068	0.125	0.060	0.120
Deciduous	0.016	0.032	0.072	0.149
Conifers	0.048	0.088	0.047	0.094

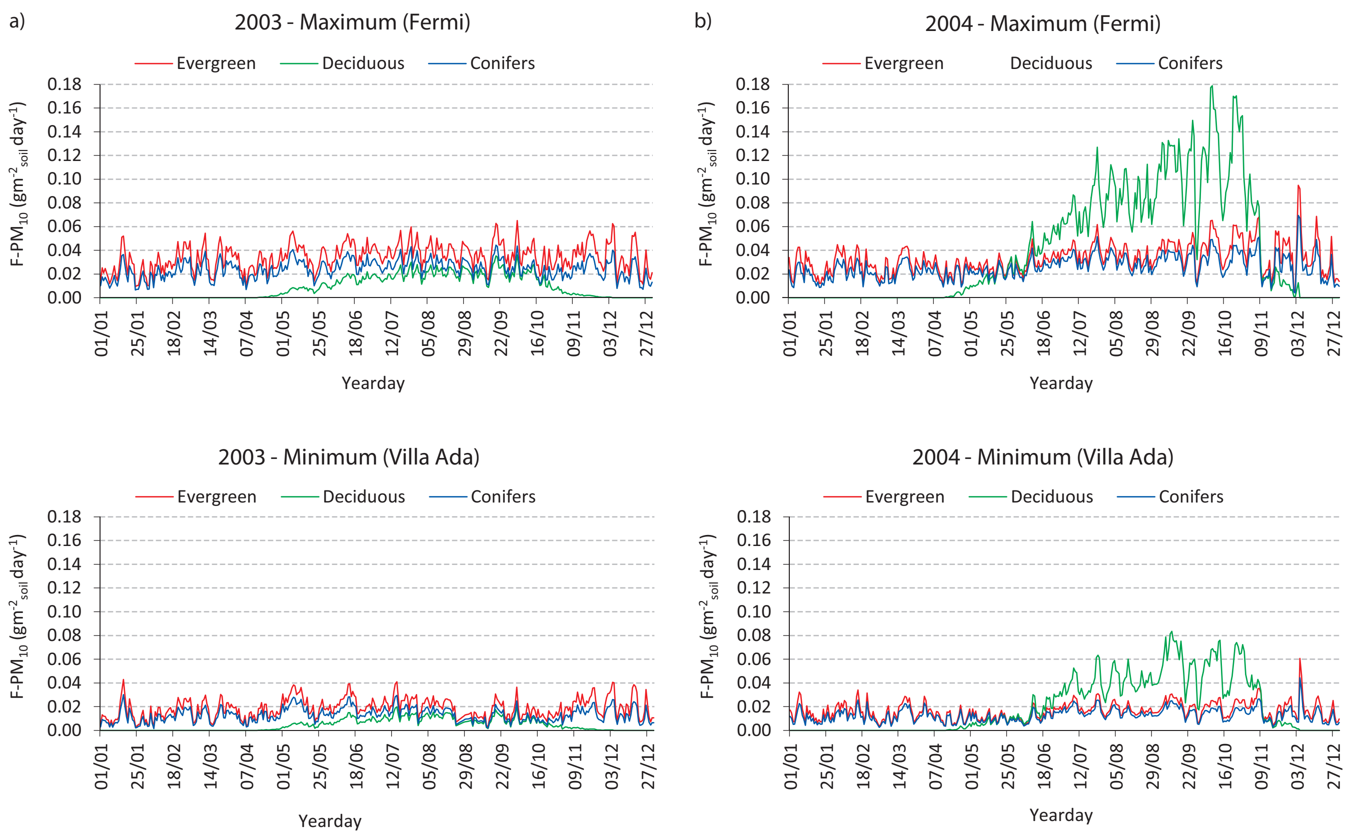

Fig. 4. Trend of maximum and minimum daily means of PM_{10} deposition fluxes, modeled for the years 2003 (a) and 2004 (b) for evergreen broadleaves, deciduous broadleaves, conifers, according to the methodological approach of Escobedo and Nowak (2009).

These Authors reported a total pollutants removal by urban vegetation of 0.275 t/ha; PM_{10} was said to represent 61% of this amount, i.e 0.167 t/ha. However, for this comparison we took into account the following aspects: a) the climate of the years 2003 and 2004, that affected Leaf Area Index values particularly for deciduous broadleaved species (lower LAI, i.e. lower PM_{10} removal, in 2003); b) the different PM_{10} levels between Rome and Beijing. The average monthly concentration of PM_{10} in Beijing in the year 2002, was higher than 150 µg/m^3, with maximum in February over 220 µg/m^3; the monitoring station of Fermi in the centre of Rome recorded, during the year 2003, an average monthly concentration of 51 µg/m^3, with a maximum in February of 59 µg/m^3, approximately 3-4 times lower than in Beijing. Moreover, a proper comparative analysis should be based on data referred both to m^2 of soil, whereas the results by Yang et al. were expressed for m^2 of canopy area. The total amount of PM_{10} removed by woody vegetation in Rome Municipality is showed in Table 2.

The PM_{10} deposition to woody vegetation in each sanitary district of the Rome municipality has been estimated in order to map the Ecosystem Service of PM_{10} removal by the three

Table 2. Total PM_{10} removed in 2003 and 2004 by woody vegetation in the Rome Municipality. Minimum and maximum values are provided, based on the cumulated deposition fluxes (t/ha $_{soil}$ per year), and based on the area covered by each functional group (in brackets).

Total PM_{10} removed (t per year) - Rome municipality				
	2003		2004	
	minimum	maximum	minimum	maximum
Evergreen (2120 ha)	144.3	265.8	127.6	255.3
Deciduous (3477 ha)	56.3	111.3	250.3	519.1
Conifers (1601 ha)	76.1	140.2	75.5	151.3
Total	**276.7**	**517.3**	**453.4**	**925.6**

functional groups (Fig. 5). A high variability of abatement level between functional types, in the two years, can be observed. Given the spatial uniformity of PM_{10} levels in the urban area (Fig. 3), the highest amount of PM_{10} deposition rates, during the whole period, are those of the Sanitary District with the largest vegetation cover (RMD, Fig. 5). It is also interesting to highlight that the highest deposition fluxes, for the three functional groups, were estimated for the 2004 summer period, in concurrence with the highest mean values of Leaf Area Index (Fig 4). The total amount of PM_{10} removed by woody vegetation in the year 2003 within the Sanitary District RMD, was about 363 t. The approach developed by Escobedo and Nowak (2009), taking into account the real annual trend of LAI, allows to estimate accurately the influence of inter-annual climate variability on leaves growth.

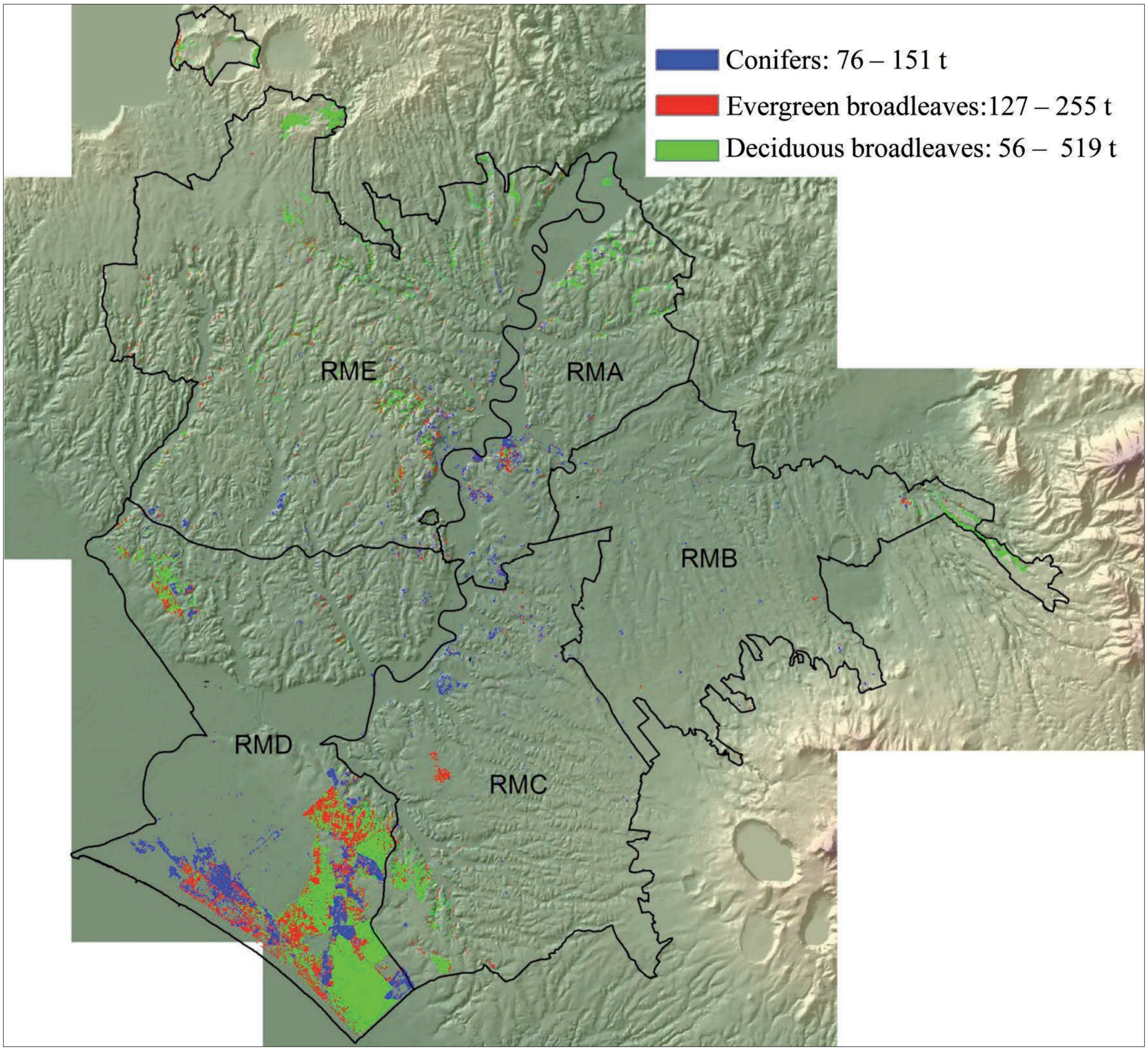

Fig. 5. Map of the Ecosystem Service of PM_{10} removal (min/max, t per year) by the three functional groups in the Municipality of Rome during the years 2003-2004, highlighting the difference in the air quality ameliorating capability of the groups. The borders of the five Sanitary District (RMA, RMB, RMC, RMD, RME), as well as that of the whole Municipality, are marked in black.

Figure 6 shows the amount of PM_{10} removed in 2003 and in 2004 by the urban woody species, in four different scenarios: current species composition (real case) and simulating a green cover composed exclusively by evergreen broadleaves, or deciduous broadleaves, or conifers respectively. It is interesting to note how the broadleaf evergreen species exhibit a greater efficiency to remove particulate with a limited interannual variability. Conversely deciduous species show a higher interannual variability with a higher abatement level than evergreen broadleaves under conditions of good water availability as during summer-fall 2004.

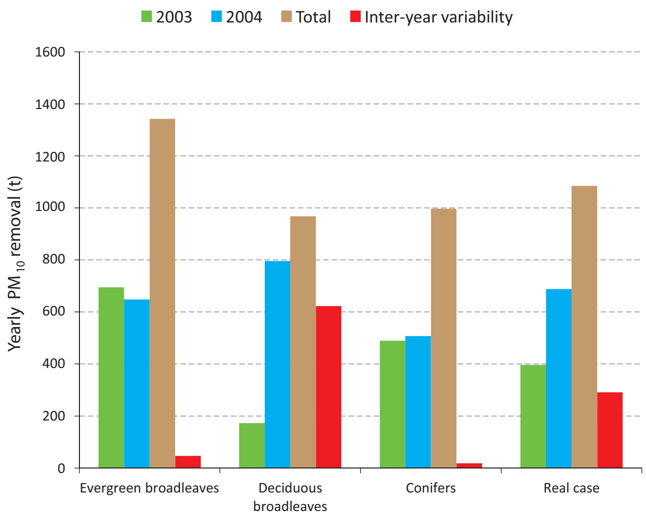

Fig. 6. Simulation of yearly PM_{10} deposition that would have occurred in Rome in 2003 and 2004 if all urban trees would belong to one single functional group.

Conclusions

These results focused the attention to the different functional responses of the three considered vegetation types (evergreen, deciduous and conifers) in different climatic conditions, which may be of particular interest to increase pollution removal performance by green, in the context of global climate change. The synergism observed, being due to the specific seasonal phenological and ecophysiological dynamics of the three leaf types, highlights the need to preserve biodiversity, particularly in urban areas and in the current context of climate change.

Green Infrastructures, natural or semi-natural green spaces and corridors, and their biodiversity, represent an important resource to be preserved, increased and sustained, in aiming to ameliorate the air quality of the whole environment (Zulian et al., 2014), especially in dense populated metropolitan areas. Our results confirm the crucial role of vegetation in supporting significant Ecosystem Services as air quality improvement, highlighting the importance of biodiversity and green infrastructures of sustain and enhance benefits provided by trees (Shagner et al., 2013; Manes et al., 2010; Maes et al., 2013; Istat, 2013). Protection, requalification and increase of both urban green and forested periurban areas, through specific management plans, is therefore essential for a sustainable development of metropolitan areas.

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