



## REMOVAL OF AIRBORNE PARTICULATE MATTER BY VEGETATION IN AN URBAN PARK IN THE CITY OF ROME (ITALY): AN ECOSYSTEM SERVICES PERSPECTIVE

SILLI V.<sup>1,2</sup>, SALVATORI E.<sup>1,\*</sup>, MANES F.<sup>1</sup>

<sup>1</sup> *Department of Environmental Biology, Sapienza University of Rome, P.le Aldo Moro, 5 - 00185 Rome (Italy)*

<sup>2</sup> *ISPRA - Institute for Environmental Protection and Research, Nature Conservation Department NAT-SOS, Via V. Brancati, 48 - 00148 Rome, ITALY*

\* *Corresponding Author: Tel: +39 0649912451; e-mail: [elisabetta.salvatori@uniroma1.it](mailto:elisabetta.salvatori@uniroma1.it)*

(RECEIVED 10 MARCH 2015; RECEIVED IN REVISED FORM 13 APRIL 2015; ACCEPTED 15 APRIL 2015)

**ABSTRACT** – Pollution, in particular airborne particulate matter (PM), has been recognized as serious threat to human health. Vegetation may contribute to reduce PM concentration, improving environmental and life quality of inhabitants, especially of those living in urban areas, also delivering important Ecosystem Services to human communities. Here are presented some results of a more extensive research project, aimed to explore the effect of urban vegetation on PM concentrations. The study has been carried out in the year 2012 in Villa Ada, a historical park located north of Rome, surrounded by densely built areas and by high-traffic density roads. An experimental measurements campaign of PM concentrations was conducted. We adopted a simplified model for the estimation of the potential PM<sub>10</sub> deposition to vegetation. The results showed that trees may effectively abate suspended particles, with evergreen broadleaved trees being most effective in the summer, reducing the average air concentration of PM<sub>10</sub>. During the year 2012, the woody vegetation of Villa Ada removed in total 4417.2 kg of PM<sub>10</sub>, and the gross value of this benefit can be estimated as equal to \$ 80746. This study confirms the strategic role played by green infrastructures in supporting and improving the provision of important Ecosystem Services in urban areas.

**KEYWORDS:** REGULATING ECOSYSTEM SERVICES, AIR QUALITY IMPROVEMENT, PARTICULATE MATTER (PM) CONCENTRATION, METROPOLITAN AREA OF ROME, FUNCTIONAL BIODIVERSITY, GREEN INFRASTRUCTURES, URBAN VEGETATION, TREES DIVERSITY

### INTRODUCTION

Particulate Matter (PM) is a dangerous air pollutant for human health. Epidemiological studies highlight robust evidences of the link between the increase in airborne PM concentrations, and growing mortality and morbidity for major cardiovascular and respiratory diseases, as well as lung cancer and stroke (Pope et al., 2002; Mannocci et al., 2014). PM in the atmosphere is usually monitored as PM<sub>10</sub>, including all particles with a size smaller than 10 µm, and PM<sub>2.5</sub>, that includes particles with an aerodynamic diameter smaller than 2.5 µm. The latter represent the most harmful fraction for human health, because their diameter and their

anthropic genesis and the possibility to contain heavy metals and carcinogenic compounds. From the PM aerodynamic diameter depends in fact the particles ability to penetrate into the respiratory system, which acts as a selective filter for different grain sizes of PM: larger particles can reach only the upper respiratory tract, while the breathable fraction includes the fine fraction (PM<sub>2.5</sub>), that can reach the lungs and alveolar regions, as well as the ultrafine fraction (PM<sub>1</sub>), capable to enter directly into the blood stream (Perrone et al., 2013 and reference cited therein).

There is, therefore, the urgent need to develop new strategies

to control and abate the environmental concentrations of this pollutant, especially in urban areas, where both pollution concentrations and exposed population are highest (EEA, 2013). At this regard, many studies have confirmed that vegetation can have a relevant role in the amelioration of air quality in urban areas, through its capability to act as a sink for both gaseous and particulate air pollutants (Barò et al., 2014; Song et al., 2015), thus contributing to improve human health and wellbeing (Manes et al., 2008; 2012; 2014; Nowak et al., 2013; 2014). The improvement of air quality is considered as one of the most important Ecosystem Services provided by vegetation in urban areas (Escobedo et al., 2011), and its importance has been demonstrated especially at local level. In particular, urban forest patches such as urban parks and gardens have proven to be effective tools for air pollution mitigation within a city (Cavanagh et al., 2009; Yin et al., 2011; Cohen et al., 2014; Aromolo et al., 2015).

Particles impacting on green surfaces are captured mainly by foliar organs, and rather than being detoxified as for gaseous pollutant, they are re-suspended or washed away by a climatic event (such as wind or rain) (Nowak, 1994, Ould-Dada and Baghini, 2001). The capture ability of the vegetation for the particulate, i.e. the percentage of particles deposited on leaf surfaces in respect to those suspended in the air (Beckett et al., 2000), is related to different factors, many of which belong to the so-called species traits (both morphological and physiological) (Freer-Smith et al., 2005; Sæbø et al., 2012; Nguyen et al., 2015). Among these, the most important are the shape and structure of the leaf blade (smaller leaves with a complex silhouette can capture more PM than larger leaves with regular simple edges), the phyllotaxis and the presence of hairs or epicuticular structures such as waxes, resins or secretion, that may increase the efficiency of retention of the particles on the leaf surfaces (Räsänen et al., 2013; Sgrigna et al., 2014). Even twigs, branches and trunk can capture PM, but in small quantities compared to the foliage. Therefore, grouping vegetation into functional classes such as evergreen broadleaves, deciduous broadleaves and conifers, each one with its intrinsic auto-ecological characteristics and seasonal physiological and phenological dynamics, can help to better understand the effects of urban parks on local air quality, as well as to develop cost effective management strategies aimed to improve the Ecosystem Services provision by urban vegetation.

In previous studies (Manes et al., 2012; 2014), we have estimated the potential capacity of urban trees and periurban forests to reduce air pollution ( $O_3$  and  $PM_{10}$ ) within the metropolitan area of Rome. Here, by using both a modelling approach and experimental measurements in the field, we have investigated the impact of a large urban park located in the city centre (Villa Ada Savoia) on the local levels of  $PM_{2.5}$ ,  $PM_{10}$  and Total Suspended Particles (TSP).

## MATERIALS AND METHODS

### Study area

The studied area is located inside the Villa Ada urban park, placed in the northern part of Rome, and surrounded by intense traffic roads. Figure 1 shows a map of Villa Ada, obtained by a Landsat 5 TM supervised classification (Manes et al., 2012). This Villa, with a total extension of 160 ha, is one of the largest urban parks in the Rome city centre (Alessio et al., 2002). It is composed by artificial pastures, water bodies and sparse trees, but its inner part is marked by a large forest stand prevalently covered by *Pinus pinea* L. (domestic pine) and *Quercus ilex* L. (holm oak). Deciduous species, such as *Quercus cerris* L. (turkey oak) and *Castanea sativa* Mill. (chestnut) are also present. Table 1 shows the surface cover of each woody vegetation type inside the Villa Ada urban park, while the meteorological conditions recorded inside the Villa during the year 2012 are shown in Figure 2.

Table 1. Surface cover (ha) of the three considered woody vegetation types inside Villa Ada.

Woody vegetation type	Surface cover (ha)
Evergreen broadleaves	38.50
Deciduous broadleaves	35.70
Conifers	42.20
<b>Total</b>	<b>116.40</b>

### Estimate of potential $PM_{10}$ deposition

In this study, a simplified version of the model presented by Nowak (1994) and Escobedo and Nowak (2009) was applied to estimate the potential  $PM_{10}$  deposition to woody vegetation within Villa Ada, in the year 2012:

$$Q = F \times L \times T \quad (1)$$

where Q is the amount of the air pollutant (in our case  $PM_{10}$ ) removed by trees in a certain time, F is the pollutant flux, L is the total canopy cover in that area, i.e. the Leaf Area Index (LAI,  $m^2_{leaf} m^{-2}_{soil}$ ), for each vegetation leaf-type, and T is the time period. The pollutant flux F is calculated as:

$$F = V_d \times C \quad (2)$$

where  $V_d$  is the dry deposition velocity of a given air pollutant, and C is its concentration in air. The deposition velocity  $V_d$  for  $PM_{10}$  was set to an average value of  $0.0064 m s^{-1}$  based on a LAI = 6, and then adjusted to the actual LAI,

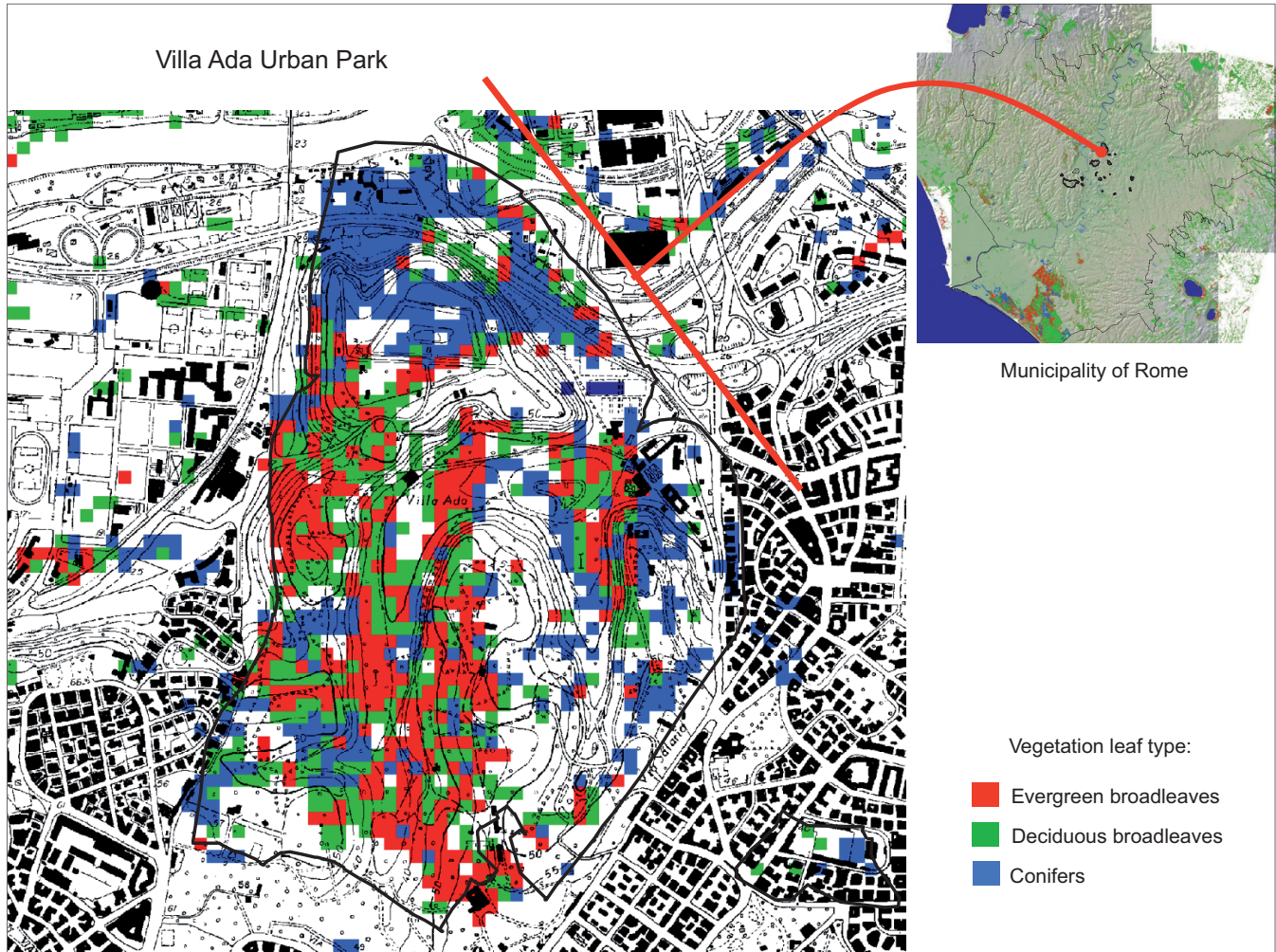


Figure 1. Vegetation map of the Villa Ada Urban Park, and its position inside the Municipality of Rome.

as suggested by Escobedo and Nowak (2009). As for  $C$ , the  $PM_{10}$  time series ( $\mu\text{g m}^{-3}$ ) recorded during the year 2012 by the urban background monitoring station of Villa Ada was used. The deposition fluxes were then calculated for each of the three functional groups. The total amount of  $PM_{10}$  removed by woody vegetation in 2012 was obtained by integrating the mean daily deposition flux over the annual series as follows:

$$Q_{PM_{10}} = \sum_{i=1}^{365} Vd_i \times C_i \times 24 \times 3600 \times LAI_i \times 0.5 \quad (3)$$

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  $1 \text{ m}^2$  of soil covered by the given functional group.

The total amount of  $PM_{10}$  removed by woody vegetation in Villa Ada was then estimated by multiplying  $Q_{PM_{10}}$  to the total area covered by each vegetation category within the Villa (Manes et al., 2014). The distribution of three functional groups of woody vegetation, namely Evergreen broadleaves (*Quercus ilex* and *Quercus suber* prevalent), Deciduous broadleaves (*Quercus* spp., *Platanus* spp.) and Conifers (*Pinus pinea*) within Villa Ada, has been assessed by using a Landsat 5 TM image (recorded in date 21/07/1999), with spatial resolution of  $30 \times 30 \text{ m}$ . The area covered by each category has been estimated by a Geographic Information System (GIS) analysis, using ESRI ArcGIS software (Table 1). As described in Manes et al. (2012), this information was used to estimate day by day and seasonally,  $PM_{10}$  deposition to each functional group. 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

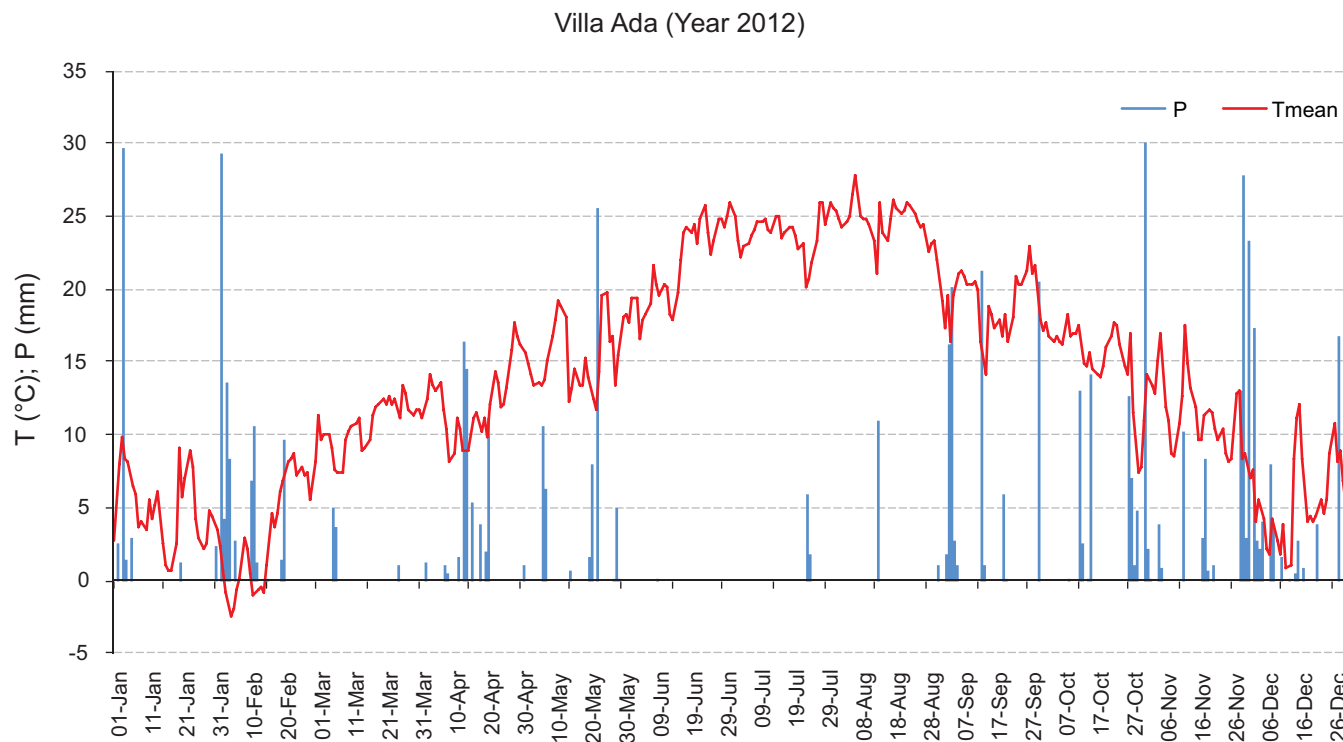


Figure 2. Daily trends of average air temperatures (T, °C) and total precipitations (P, mm), recorded during the year 2012 by the meteorological station located inside Villa Ada (50 m a.s.l.). Data by Arpa Lazio, Regional Centre for Air Quality (<http://www.arpalazio.net>).

group. In the three scenarios, one for each group, the total area covered by tree vegetation within Villa Ada (116.40 ha) was attributed to each one of them.

### Measurements campaigns of PM<sub>2.5</sub>, PM<sub>10</sub> and TSP

Measurements campaigns were carried out in two sites inside the Villa, “green” site and “bare” site. The “green” sampling site is located in the mixed pine-oak evergreen forest, at approximately 50 m of distance from the main road (SS4 “Via Salaria”, about 10,000 vehicles in the 5 rush hours, Alessio et al., 2002), while the “bare” sampling site is located at the same distance from the road, 30 m away from the “green” site on an artificial pasture. In both sites PM measurements were carried out at 1.5 m height from the ground.

The experimental measurement campaign was carried out in the morning and early afternoon (from 10:00 to 14:00 CET) during selected days of 2012 by using optical particle counters (OPC) Aerocet 531 (Metone, USA). These instruments work on light scattering principle (nephelometry) and allow to measure different PM fractions (PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>7</sub>, PM<sub>10</sub> and Total Suspended Particles, TSP)

simultaneously. Measured values of PM<sub>2.5</sub>, PM<sub>10</sub> and TSP were corrected for the air water content, by an appropriate equation, depending on relative humidity (Sioutas et al., 2000). Finally, data have been processed, validated, and analyzed by descriptive statistics (Statistica, Statsoft Ltd).

## RESULTS AND DISCUSSION

### Estimate of potential PM<sub>10</sub> deposition

The PM<sub>10</sub> concentrations in Villa Ada show a typical seasonal trend for the city of Rome, with higher values especially in Winter and Fall (Cattani et al., 2010) (Figure 3). Lower values were instead measured in Spring, when the contribution of domestic heating is missing.

The yearly trend of PM<sub>10</sub> deposition simulated for the three woody vegetation types (Figure 4) shows that deposition is maximum on evergreen broadleaves and conifers during winter and fall, when deciduous broadleaves do not contribute being in the leaf-off season (Manes et al., 2014). Moreover, deciduous broadleaves show lower deposition values than evergreen broadleaves and conifers, during summer, due to their lower LAI values in the water limited



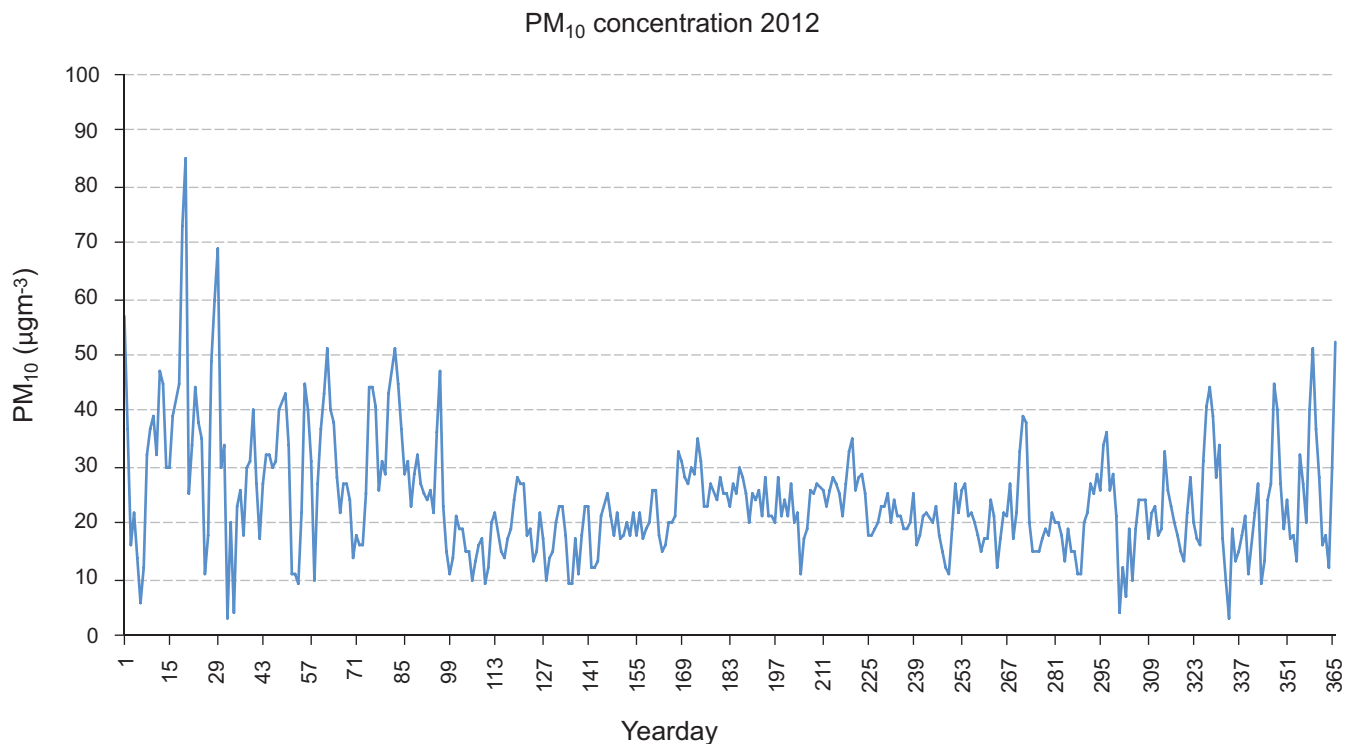


Figure 3. Daily trend of PM<sub>10</sub> concentrations measured by the air quality monitoring station of Villa Ada (urban background station) during the year 2012. Data by Arpa Lazio, Regional Centre for Air Quality (<http://www.arpalazio.net>).

season. The particular water scarcity conditions, affected more the deciduous trees, while the evergreen and conifers vegetation of the Villa show a better adaptation to the drought conditions (Manes et al., 2012).

Table 2 (a, b) summarizes the seasonal cumulated deposition ( $\text{g m}^{-2}$ ) and the total deposition on the whole area covered by

vegetation (116.40 ha), estimated for the year 2012. These values are in agreement with those estimated for the urban and periurban vegetation of the whole Rome Municipality (Manes et al., 2014), as well as with those reported in other cities in different urban areas of the world (Yang et al., 2005; Escobedo e Nowak, 2009). During the year, the highest total

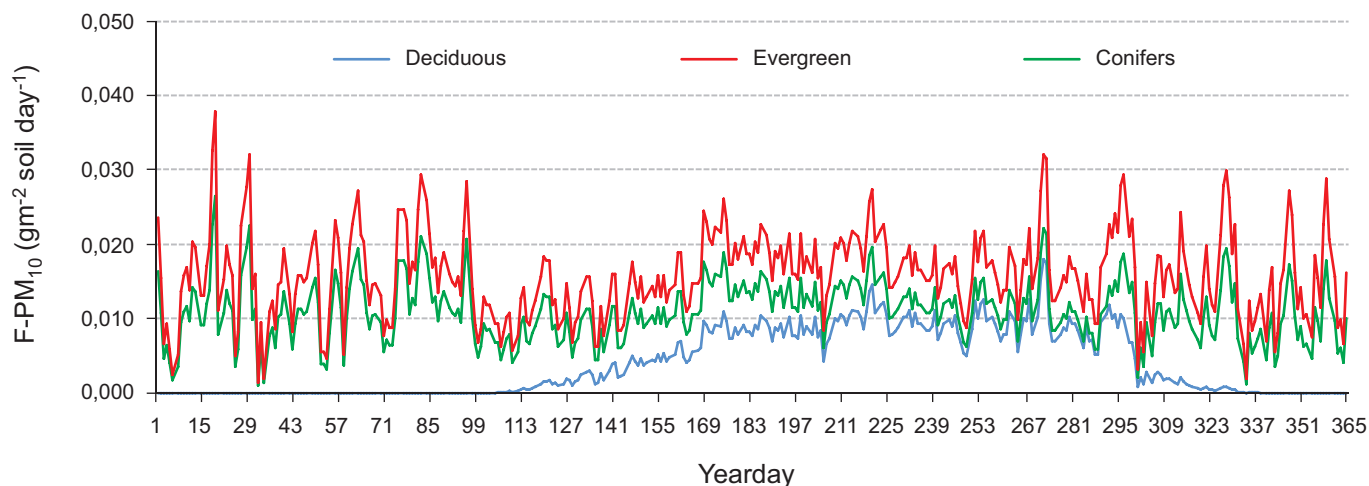


Figure 4. Daily PM<sub>10</sub> deposition fluxes estimated for Evergreen broadleaves, deciduous broadleaves and conifers on the basis of PM<sub>10</sub> concentrations reported in Figure 3.

deposition of PM<sub>10</sub> was showed by evergreen broadleaves (2213.3 kg), followed by conifers (1692.6 kg) and deciduous broadleaves (511.2 kg). The total PM<sub>10</sub> removal performed by the three vegetation types altogether was higher during summer (Tab. 2, b), coherently to what was reported by Baró et al. (2014) in a study carried out in the Mediterranean city of Barcelona.

Table 2. a) Seasonal accumulated deposition (g m<sup>-2</sup>), and (b) total yearly depositions (kg) of PM<sub>10</sub> estimated for deciduous broadleaves, evergreen broadleaves and conifers in Villa Ada. The total yearly value is based on the vegetation cover reported in Table 1.

a) PM<sub>10</sub> accumulated seasonal deposition (g m<sup>-2</sup>)

	Evergreen broadleaves	Deciduous broadleaves	Conifers	Mean
Winter	1.418	0.000	1.006	0.808
Spring	1.271	0.294	0.920	0.828
Summer	1.645	0.873	1.176	1.231
Fall	1.414	0.265	0.909	0.863
Year 2012	5.749	1.432	4.011	3.731

b) PM<sub>10</sub> total seasonal deposition (kg)

	Evergreen broadleaves	Deciduous broadleaves	Conifers	Total
Winter	545.8	0.0	424.4	970.2
Spring	489.5	105.0	388.1	982.6
Summer	633.5	311.5	496.4	1441.4
Fall	544.5	94.7	383.7	1023.0
Year 2012	2213.3	511.2	1692.6	4417.2

In the Villa Ada Urban park in Rome, we have also simulated the air quality improvement due to vegetation sink capacity for PM<sub>10</sub> (Figure 5). Four seasonal scenarios for the “real” case (actual vegetation cover for evergreen broadleaves, deciduous broadleaves and conifers), and “no vegetation” (bare soil replacing woody vegetation at all locations), are reported. The ratio vegetation/bare soil depositions was calculated for each vegetation leaf-type. The results show a conspicuous contribution of all the three vegetation leaf-types in removing pollutants from the urban atmosphere. It is interesting to notice, during the particularly dry condition of year 2012, (Figure 2), that evergreen broadleaves were more effective than conifers and deciduous broadleaves in removing PM<sub>10</sub>.

Millward and Sabir (2011) have quantified the benefits provided by an urban park in Toronto, Canada, in terms of air quality improvement. In particular, these authors have attributed an economic value of \$18.28 to each kg of PM<sub>10</sub> removed by vegetation. According to this work, the Ecosystem Service of PM<sub>10</sub> removal in Villa Ada during the year 2012 can be valued to \$ 9345.3, \$ 40459.3 and \$ 30941.6 for deciduous broadleaves, evergreen broadleaves

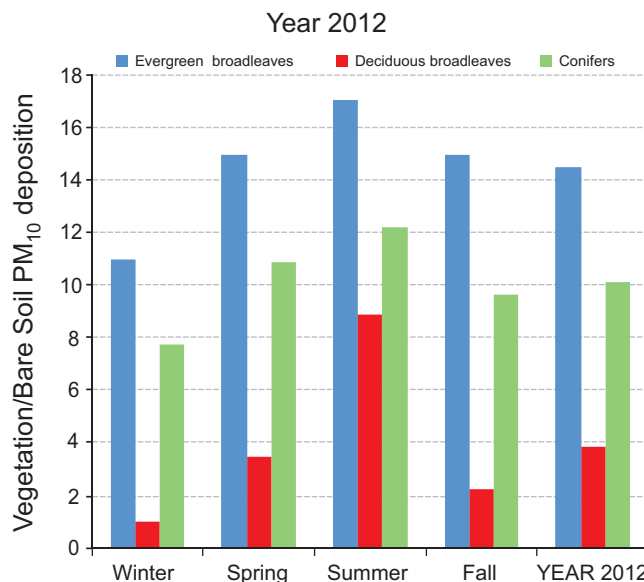


Figure 5. Mitigating role of urban vegetation. Ratio between PM<sub>10</sub> deposition to each vegetation leaf type (“real case”), and PM<sub>10</sub> deposition to bare soil (“bare soil scenario”), in the Villa Ada green area (116.40 ha of woody vegetation), during winter, spring, summer and fall 2012.

and conifers, respectively. The benefit of PM<sub>10</sub> removal provided by the urban trees of Villa Ada in the year 2012 can therefore be estimated as equal to \$ 80746.2 in total. This is, however, a gross value, which does not consider the annual costs of managing the urban park and its trees (eg. irrigation, pruning, maintenance), as well as the climatic benefits or the removal of gaseous air pollutants.

Finally, Figure 6 confirms that evergreen broadleaves alone have the highest potential PM<sub>10</sub> removal (6689.9 kg) followed by conifers (4667.6 kg); both functional types keep their leaves/needles through the whole year, and also during winter, when PM concentrations are highest. In case of the need of increasing the tree cover of an urban park, this functional differences in the Ecosystem Service provision should be taken into account by stakeholders and urban green managers. It is worth noting, however, that in the case in which the vegetation cover of the urban park includes all the three functional types (Real Case), the removal is still high (4417 kg), thus indicating that functional biodiversity plays a crucial role in the provision of the Ecosystem Service of PM<sub>10</sub> removal, as already highlighted in the case of O<sub>3</sub> removal (Manes et al., 2012).

### Experimental campaigns

The trends of the PM<sub>2.5</sub>, PM<sub>10</sub> and TSP measured in both “green” and “bare” sites (Figure 7, a), showed higher values

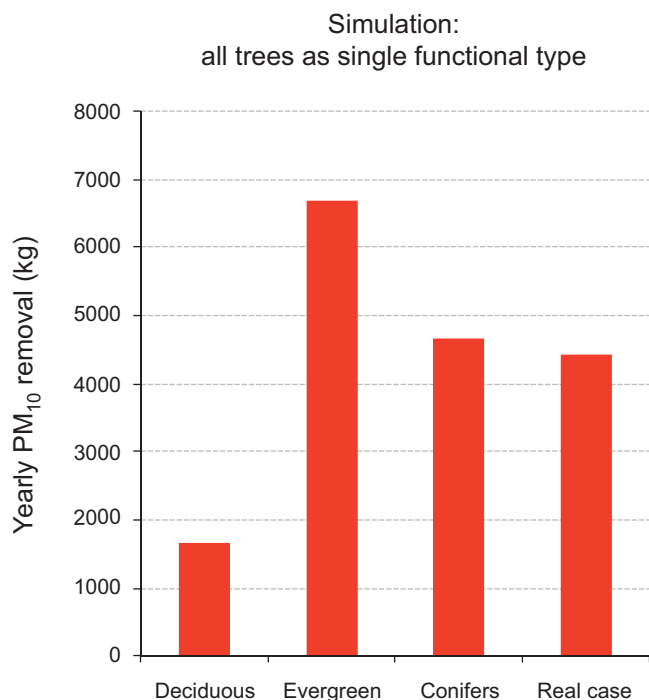


Figure 6. Simulation of yearly PM<sub>10</sub> deposition (kg) that would have occurred in Rome in 2012 if all urban trees would belong to one single functional group.

between 10:00 and 12:00, corresponding to a daily peak of vehicular traffic and related pollutants emissions; it is interesting to note that particles concentration data observed in the “green” area (shrubs and trees) were often lower than those recorded in the “bare” site inside the Villa, characterized by artificial pasture. These results could be explained by the capacity of the woody vegetation in the “green site” to remove PM. However, the contribution of the natural phenomena of deposition and dispersion of PM cannot be considered negligible (Cohen et al., 2014). The average concentrations of PM inside the Villa were, as usually occurs, below the city average values (Cattani et al., 2010; Silli et al, 2014; Fusaro et al., 2015). In particular, PM<sub>2.5</sub> always showed lower values of concentrations compared to coarser ones (PM<sub>10</sub> and TSP). This may indicate a contribution to the suspended PM within Villa Ada by soil erosion and biological particles as fungal spores and pollen (Cariñanos et al., 2008).

The highest contribution of vegetation to PM abatement was observed for PM<sub>10</sub> and TSP (average values: 11.84% and 22.25%, respectively); for these fractions, in fact, it is evident the vegetation flattening effect on the peak concentrations, while the smallest contribution of vegetation was observed in the reduction of the fine fraction PM<sub>2.5</sub> (2.56%) (Table 3 and Figure 7, b). These results are consistent with those observed from similar studies performed in other major countries in urban parks, as Yin et

al. (2011) in China, whose measured reduction values of the green, between area characterized by trees and shrubs (green) and area without vegetation (bare), in the range of 2 to 35% for the total fraction of PM (TSP).

It is interesting to highlight that the negative values of abatement observed in Figure 7, b, might indicate an emission of dust from the ground, or a re-suspension of particles from plant surfaces caused by wind or other environmental factors present in the site.

Table 3. Average concentration of PM<sub>2.5</sub>, PM<sub>10</sub> and TSP measured on bare soil (bare) and vegetated soil (green) by using Aerocet analyzers. The average difference (%) of concentration between green and bare for the different PM fraction is also reported.

	PM <sub>2.5</sub>	PM <sub>10</sub>	TSP
Average concentration bare (µg m <sup>-3</sup> )	1.54	7.21	10.15
Average concentration green (µg m <sup>-3</sup> )	1.40	6.23	7.69
Average difference (green vs. bare) (%)	2.56	11.84	22.25

## CONCLUSIONS

The results of this research confirm the key role played by the urban forest in supporting and improving the stability of natural systems and of related significant Ecosystem Services, such as the enhancement of air quality, in particular in urban areas. Green infrastructures and their biodiversity, represent therefore a valuable resource to be safeguarded, enhanced and developed, in order to improve the quality of life and of the environment, especially in densely populated metropolitan areas characterized by a high dwelling density.

The estimation of the vegetation effects on PM concentration in natural and urban environments, may be particularly critical, due to the large temporal and spatial environmental variability of all factors that can affect the mechanisms by which the vegetation capture and retains air particulate pollution especially in urban areas. The value of this reduction may be variable and usually higher for the coarse fractions (namely PM<sub>10</sub> and TSP), while, for the fine ones (PM<sub>2.5</sub> in particular) the abatement seems to be significantly lower and more related to structure and type of vegetation and by environmental context. The application of numerical models to entire plant communities appears to be a valid option to estimate the potential deposition of PM on vegetation, allowing a comparison with results obtained in studies carried out in other large cities. The obtained data, highlight the ecophysiological response of the three considered types (evergreen broadleaves, deciduous broadleaves and conifers); this may provide particular case studies to build a response scenario in the context of the

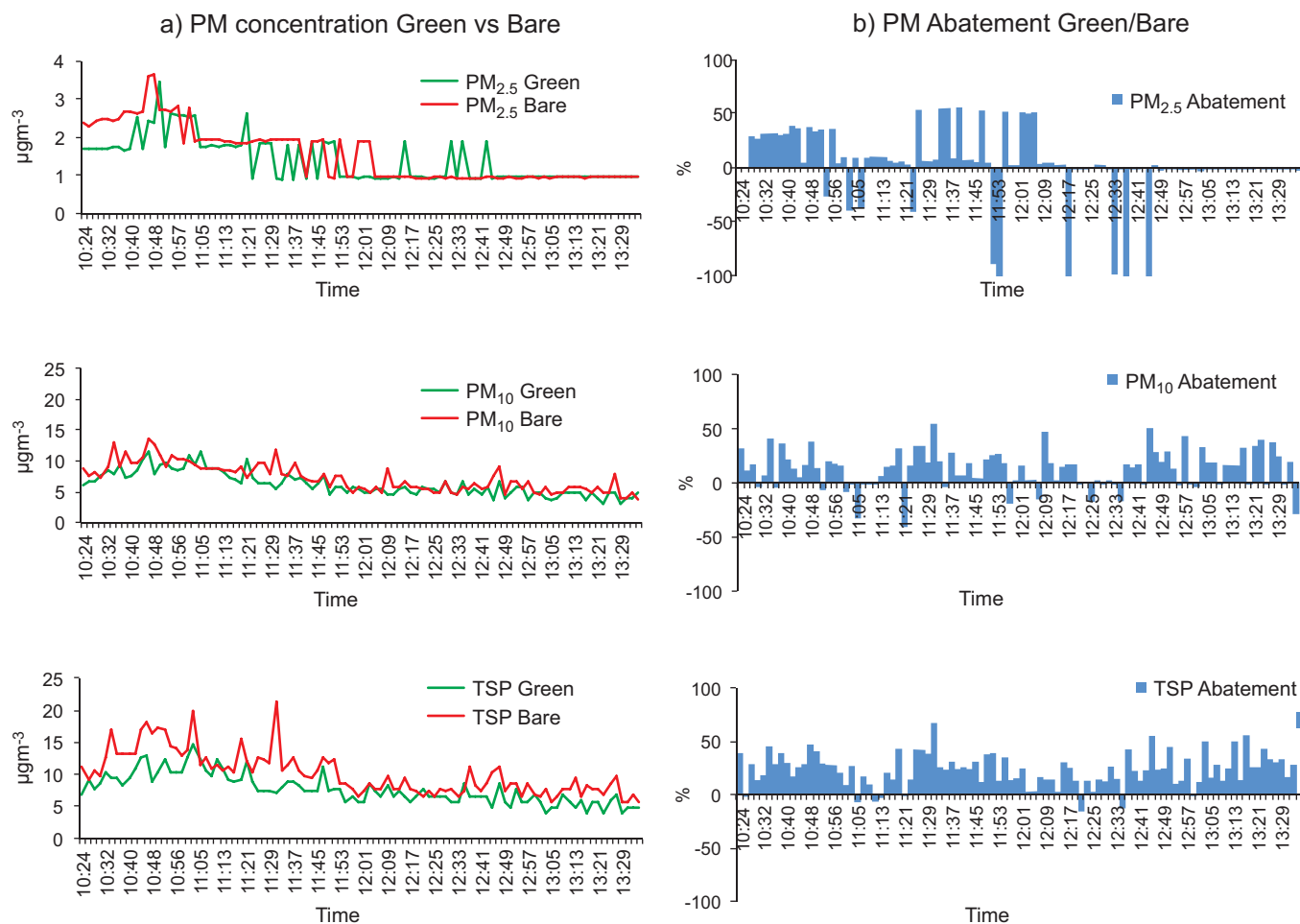


Figure 7. a) Hourly trend of  $PM_{2.5}$ ,  $PM_{10}$  and TSP measured in the “green” and “bare” sites in the Villa Ada Urban park; b) the corresponding percentage reduction of  $PM_{10}$  concentration of “green” vs “bare” site.

global climate change. Deciduous species seem to be the more vulnerable to the water scarcity and to high temperatures that characterize the summer period in the Mediterranean area, particularly in 2012, compared to the other two types. Evergreen broadleaves instead, being characterized by physiological and morphological adaptations to drought, showed no functional deficits during the dry period, maintaining high values of leaf surfaces (and corresponding high PM abatement). Even conifers have shown a good degree of functional adaptation to summer water stress, but seem to be more sensitive to water reduction, decreasing the production of leaf biomass and consequently decreasing the ability to abate  $PM_{10}$ , mainly in the dry season.

However further researches are needed to improve these estimates, and to increase the knowledge for vegetation planning at local scale (Nowak et al., 2013), aiming to minimize human exposure to PM and other harmful pollutants in the urban environment.

## ACKNOWLEDGEMENTS

This research was funded by the following grants: Ministero della Salute, Centro Nazionale per la Prevenzione ed il Controllo delle Malattie - CCM, project: “Metodi per la valutazione integrata dell’impatto ambientale e sanitario (VIAS) dell’inquinamento atmosferico”, and by MIUR, Rome, project PRIN 2010-2011 “TreeCity”.

## REFERENCES

Alessio M., Anselmi S., Conforto L., Improta S., Manes F., Manfra L., 2002. Radiocarbon as a biomarker of urban pollution in leaves of evergreen species sampled in Rome and in rural areas (Lazio - Central Italy). *Atmospheric Environment* 36, 5405-5416.



- Aromolo R., Savi F., Salvati L., Ilardi F., Moretti V., Fares S., 2015. Particulate matter and meteorological conditions in Castelporziano forest: a brief commentary. *Rendiconti Lincei*, in press. DOI 10.1007/s12210-015-0414-5
- Barò F., Chaparro L., Gòmez-Baggethun E., Langemeyer J., Nowak D.J., Terradas J., 2014. Contribution of Ecosystem Services to Air Quality and Climate Change Mitigation Policies: The Case of Urban Forests in Barcelona, Spain. *AMBIO* 43,466–479.
- Beckett, K.P., Freer-Smith, P., Taylor G., 2000. Effective tree species for local air-quality management. *Journal of Arboriculture*, 26, 1, 12-19.
- Cariñanos P., Galán C., Alcázar P., Dominguez E., 2008. Classification, analysis and interaction of solid airborne particles in urban environments. *Transactions on Ecology and the Environment*, 110, WIT Press, Environmental Toxicology, 317-325. [www.witpress.com](http://www.witpress.com), ISSN 1743-3541 (on-line).
- Cattani G., Di Menno di Bucchianico A., Dina D., Inglese M., Notaro, Settimo G., Viviano G., Marconi A., 2010. Evaluation of the temporal variation of air quality in Rome, Italy from 1999 to 2008. *Annali Istituto Superiore di Sanità* 46(3), 242-253.
- Cavanagh Jo-Anne., Zawar-Reza P., Gaines Wilson J., 2009. Spatial attenuation of ambient particulate matter air pollution within an urbanised native forest patch. *Urban Forestry & Urban Greening* 8, 21-30.
- Cohen P., Potchter O. C., Schnell I., 2014. The impact of an urban park on air pollution and noise levels in the Mediterranean city of Tel-Aviv, Israel. *Environmental Pollution* 195, 73-83.
- EEA, European Environmental Agency, 2013. Air quality in Europe - 2013 report. EEA Report No 9/2013.
- Escobedo F. J., Nowak D. J., 2009. Spatial heterogeneity and air pollution removal by an urban forest. *Landscape and Urban Planning* 90,102-110.
- Escobedo F.J., Kroeger T., Wagner J.E., 2011. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. *Environmental Pollution* 159, 2078-2087.
- Freer-Smith P.H., Beckett K.P., Taylor G., 2005. Deposition velocities to *Sorbus aria*, *Acer campestre*, *Populus deltoides* *trichocarpa* 'Beaupre', *Pinus nigra* and *Cupressocyparis leylandii* for coarse, fine and ultra-fine particles in the urban environment. *Environmental Pollution* 133, 157-167.
- Fusaro L., Salvatori E., Mereu S., Silli V., Bernardini A., Tinelli A., Manes F., 2015. Researches in Castelporziano test site: ecophysiological studies on Mediterranean vegetation in a changing environment. *Rendiconti Lincei*, in press, DOI 10.1007/s12210-014-0374-1.
- Manes F., Silli V., Salvatori E., Incerti G., Galante G., Fusaro L., Perrino C., 2014. Urban ecosystem services: tree diversity and stability of pm10 removal in the metropolitan area of Rome. *Annali di Botanica* 4, 19-26.
- Manes F., Incerti G., Salvatori E., Vitale M., Ricotta C., Costanza R., 2012. Urban ecosystem services: tree diversity and stability of tropospheric ozone removal. *Ecological Applications* 22, 349-360.
- Manes F., Salvatori E., La Torre G., Villari P., Vitale M., Biscontini D., Incerti G., 2008. Urban green and its relation with air pollution: ecological studies in the Metropolitan area of Rome. *Italian Journal of Public Health* 5, 278-283.
- Mannocci A., Salvatori E., Saulle R., Incerti G., Boccia A., Manes F., La Torre G., 2014. Rischi per la salute da inquinamento urbano nei sistemi urbani europei: approfondimento sui risultati dello studio multicentrico HEREPLUS nella città di Roma. *Igiene e Sanità Pubblica* 70, 463-472.
- Marconi A., 2010. Evaluation of the temporal variation of air quality in Rome, Italy from 1999 to 2008. *Annali Istituto Superiore di Sanità* 46, 3, 242-253.
- Millward A.E., Sabir S., 2011. Benefits of a forested urban park: What is the value of Allan Gardens to the city of Toronto, Canada? *Landscape and Urban Planning* 100, 177-188.
- Nguyen T., Yu X., Zhang Z., Liu M., Liu X., 2015. Relationship between types of urban forest and PM<sub>2.5</sub> capture at three growth stages of leaves. *Journal of Environmental Sciences* 27, 3-41.
- Nowak D. J., 1994. Air Pollution Removal by Chicago's Urban Forest. USDA Forest Service Gen. Tech. Rep. NE-186.
- Nowak D.J., Hirabayashi S., Bodine A., Greenfield E., 2014. Tree and forest effects on air quality and human health in the United States. *Environmental Pollution* 193, 119-129.
- Nowak D.J., Hirabayashi S., Bodine A., Hoehn R., 2013. Modeled PM<sub>2.5</sub> removal by trees in ten U.S. cities and associated health effects *Environmental Pollution* 178, 395-402.
- Ould-Dada Z., Baghini N.M., 2001. Resuspension of small particles from tree surfaces. *Atmospheric Environment* 35, 3799-3809.
- Perrone M.G., Gualtieri M., Consonni V., Ferrero L., Sangiorgi G., Longhin E., Ballabio D., Bolzacchini E., Camatini M., 2013. Particle size, chemical composition, seasons of the year and urban, rural or remote site origins as

determinants of biological effects of particulate matter on pulmonary cells. *Environmental Pollution* 176, 215-227.

Pope C. A., Renlund D. G., Kfoury A. G., May H. T., Horne B. D., 2008. Relation of Heart Failure Hospitalization to Exposure to Fine Particulate Air Pollution. *Am J Cardiol.* 102, I9, 1230-1234.

Räsänen J.V., Holopainen T., Joutsensaari J., Ndam C., Pasanen P, Rinnan A., Kivimäenpää M., 2013. Effects of species-specific leaf characteristics and reduced water availability on fine particle capture efficiency of trees. *Environmental Pollution* 183, 64-70.

Sæbø A., Popek R., Nawrot B., Hanslin H.M., Gawronska H., Gawronski S.W. (2012) Plant species differences in particulate matter accumulation on leaf surfaces. *Science of the Total Environment* 427-428, 347-354.

Sgrigna G., Sæbø A., Gawronski S, Popek R., Calfapietra C., 2015. Particulate Matter deposition on *Quercus ilex* leaves in an industrial city of central Italy. *Environmental Pollution* 197, 187-194.

Silli V. (2014). Interactions between plant and atmosphere: air quality and effect of vegetation on distribution and concentration of airborne particulate matter. PhD thesis, Dept. Env. Science University of L'Aquila (AQ) Italy.

Sioutas C., Kim S., Chang M., Terrell L., Gong H. Jr., 2000. Field evaluation of a modified DataRAM MIE scattering monitor for real-time PM<sub>2.5</sub> mass concentration measurements. *Atmospheric Environment* 34, 4829-4838.

Song Y., Maher B.A., L. Feng, Wang X., Sun X., Zhang H., 2015. Particulate matter deposited on leaf of five evergreen species in Beijing, China: Source identification and size distribution. *Atmospheric Environment* 105, 53-60.

Yang J., McBride J., Zhou J., Sun Z., 2005. The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry & Urban Greening* 3, 65-78.

Yin S., Shen Z., Zhou P., Zou X., Che S., Wang W., 2011. Quantifying air pollution attenuation within urban parks: an experimental approach in Shanghai, China. *Environmental Pollution* 159, 2155-2163.

Zinke P.J., 1967. Forest interception studies in the United States. In: *Forest Hydrology* (Sopper W.E. and Lull H.W., eds.). Pergamon Press, Oxford, UK, pp. 137-161.