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Urban green and its relation with air pollution: ecological studies in the Metropolitan area of Rome

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Abstract

Abstract: Tropospheric ozone (O_3) and Particulate Matter (PM) have become a major concern in most European cities. In particular, in Italy the O_3 concentrations exceed the limits established for the protection of both human health and vegetation. More integrative studies are revealing that urban trees could concretely help in improving air quality, not only because of their well known aesthetic and recreational benefit, but also for their capability to reduce air temperature and to remove air pollutants. This reduction takes place both directly, by dry deposition to plant surfaces and uptake through stomata, and indirectly, by mitigation of the urban heat island intensity by canopy transpiration and building shading, that lowers the activity of chemical reactions that led to the formation of photochemical pollutants in air. This is of particular importance especially for those cities located in the Mediterranean Basin, whose urban vegetation is often characterized by VOC-emitting species that can contribute significantly to the O_3 formation and destruction dynamics. The aim of this paper is to present a short review of ecological research performed on vegetation of the metropolitan area of Rome, at different spatial and temporal scale, in order to evaluate the functional role of urban green to monitor and improve urban air quality. In the frame of the project HEREPLUS (EU FP7), all of this information, opportunely integrated with climatic and pollutant data, will be implemented in a GIS and, by the use of geo-statistical methods, the ameliorating effect of urban vegetation will be quantified and mapped.

Key words: urban vegetation; air quality improvement; O_3, PM, pollutants uptake; GIS

Introduction

Ozone (O_3) and Particulate Matter (PM) pollution have become of major concern in most European cities, mainly for those located in the Mediterranean basin, where climatic conditions favour the formation of O_3 during the summer period [1]. Current European legislation on ozone (Directive 2008/50/EC) sets the limit for the protection of human health to the reference value of 120 μg/m^3 averaged over 8 hours (long-term objective), based on studies carried out on restricted groups of exposed population. However, ozone concentrations in Italy frequently exceeds this threshold [2,3]. Furthermore, the O_3 levels measured during the 2002 – 2004 years were well above of the European average and, as a consequence the effects on health of Italian citizens were proportionality high [4]. The World Health Organization has recently estimated that, in Italian cities, 0.6% of total acute mortality, plus 0.8% of acute cardiovascular deaths, as well as an 1% of total respiratory-related hospital admissions for people older than 65 years of age, were attributable every year to ozone, as measured with the SOMO35 (sum of means over 35 ppb) indicator [4]. Moreover, some epidemiological studies have shown a major adverse effect of PM during the summer period, pointing out a possible combined role of PM, ozone and high temperature [5,6].

Tropospheric ozone is also regarded as the main air pollutant that negatively affects both natural and cultivated vegetation in developed countries [7]. Currently, the O_3 risk assessment for vegetation in Europe and in Italy is conducted accordingly to the standard experimental procedures developed by the UN/ECE CLRTAP Working Group on Effects, which considers two approaches for the quantifications of the O_3 Critical Levels (CL) for vegetation: concentration-based approach (CLe_c), and flux-based approach (CLe_f). The former considers the cumulated exposure to O_3 over a defined threshold (AOTx indices, such as AOT40 – O_3 concentration over the threshold of 40 ppb during daylight hours, cumulated over the growing season), while the latter considers the real ozone dose uptaken by plants through stomata, that is influenced not only by O_3 levels, but also by plant status and environmental parameters [8, 9].

The aim of this paper is to present a short review of ecological researches performed on vegetation of the metropolitan area of Rome, at different spatial and temporal scale, in order to evaluate the functional role of urban green to monitor and improve urban air quality. Bioindication and biomonitoring studies are related to biochemical, eco-physiological and remotely sensed data. Moreover, an integrated multidisciplinary approach has been developed in the frame of the HEREPLUS European Project (EU FP 7), with the purpose to evaluate the relations between epidemiological data, relative to cardio respiratory diseases, tropospheric ozone and particulate matter concentrations, and urban green function.

Air pollution effects on urban vegetation in the metropolitan area of Rome

Rome, the capital of Italy, is one of the most important cities of Southern Europe. It is characterized by high levels of urban traffic and urbanization rates, that have largely increased in the last years: in 2007, the Municipality of Rome counted 2,718,768 resident inhabitants on a surface of 1,308 km² (density: 2,069 inhabitants/km²) [10], and a metropolitan area of about 4 million inhabitants spread over a surface of more that 5,000 km², that make it Italy's largest and most populous city. Figure 1 shows the land use map of the Metropolitan area of Rome, obtained by the classification of a Landsat 5 TM image (21/07/1999), while in Table 1, the different types of land cover and their extensions are reported [11]. Due to the characterizing Mediterranean climate [12], this city is particularly susceptible to episodes of photochemical smog; the ozone limit for human protection has been exceeded in 26.75 days in 2003, thus causing a concrete risk to population.

Significant effects of air pollution on urban vegetation in this city have also been reported. Tripodo et al [13] measured peroxidise activity and sulphate content in leaves of *Pinus pinea* L. and *Quercus ilex* L. inside two urban parks in Rome, and found an higher peroxidise activity in trees at closest distance from a road with heavy

Figure 1. Land use map of the Metropolitan area of Rome, obtained by the classification of a Landsat 5 TM image (21/07/1999). [11]

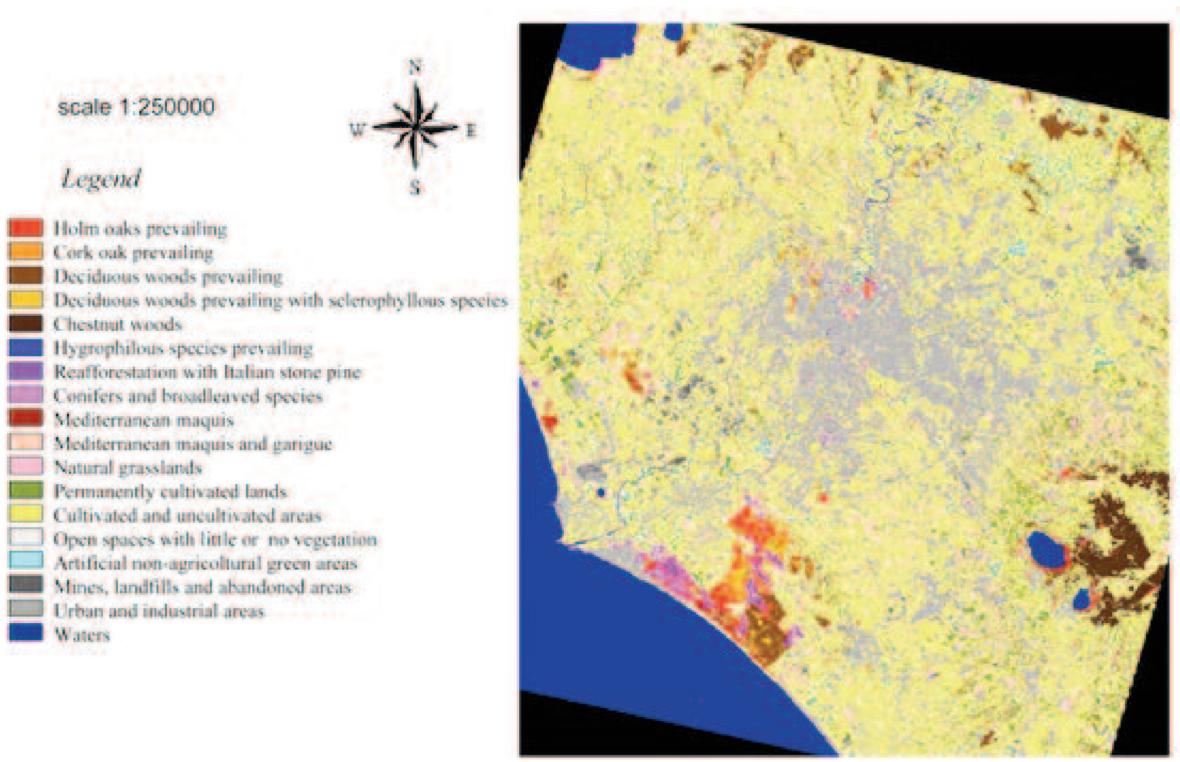

Table 1. Different types of land cover and their extensions of the Metropolitan area of Rome, obtained by the classification of a Landsat 5 TM image (21/07/1999). [11]

Typology	Covered surface (ha)	Covered surface (%)
Holm oaks prevailing	3397	1.31
Cork oak prevailing	78	0.03
Deciduous woods prevailing	6099	2.36
Deciduous woods prevailing with sclerophyllous species	2451	0.95
Chestnut woods	3665	1.42
Hygrophilous species prevailing	1260	0.49
Reafforestation with Italian stone pine	1580	0.61
Conifers and broadleaved species	705	0.27
Mediterranean maquis	553	0.21
Mediterranean maquis and garigue	12721	4.92
Natural grasslands	17245	6.67
Permanently cultivated lands	17280	6.69
Cultivated and uncultivated areas	126512	48.95
Open spaces with little or no vegetation	760	0.29
Artificial non-agricoltural green areas	3570	1.38
Mines, landfills and abandoned areas	3395	1.31
Urban and industrial areas	57170	22.1
Waters	-	-
Total	**258441**	**100**

motor vehicle traffic.

The seasonal trend of SO_2 concentration exhibited a direct influence of the leaf sulphate content, but no significant correlation was found between leaf sulphate content and distance from the road. Altieri et al [14] analysed micromorphology of the epicuticolar waxes in *Pinus pinea* L. needles by a scanning electron microscope, and found alteration in needles collected at urban sites compared to samples from rural sites, that were related to urban pollution-climate.

Passive biomonitoring experiments that combined the measure of isotopic (^{14}r, δ^{13}c), chemical (Pb concentration) and ecophysiological (gas exchange and leaf fluorescence of chlorophyll a) parameters in leaves of *Quercus ilex* L. and *Pinus pinea* L. along a transect from the bordering road to the interior of an urban park, showed a decreasing pollution gradient towards the inner park [15]. Polati et al. [16], have also used Platanus sp. and *Lolium multiflorum* Lam leaves for passive and active biomonitoring of lead, copper, zinc and cadmium in the urban system of Rome, while other authors [17] have recently shown the possibility to use *Quercus ilex* leaves for long-term monitoring of metal concentration in this urban area, where the species is naturally present, and widely distributed in the landscape. Moreover, active bioindication studies with tobacco and radish plants [18], as well as with clover biomonitoring mini-stations [1] have been used to investigate specifically the ambient O_3 levels in urban areas, urban parks, suburban sites and rural zones outside the city of Rome, showing phytotoxic effects not only at the urban sites, but also in the neighbouring rural zones.

Recently, the amount of ozone taken up by an evergreen mediterranean forest (*Quercus ilex* L.) inside the Presidential Estate of Castelporziano, a protected area located just 22 km away from the city centre, has been quantified by the use of micrometeorological flux measurements [19]; the potential O_3 stomatal fluxes under seasonally varying microclimatic conditions at two levels of the canopy of the same forest, have been also evaluated [20].

Urban vegetation and the formation and degradation of air pollutants in cities: the HEREPLUS Project

The European Commission for the Environment has already advanced a series of actions to promote a strategy for sustainable urban development, and to improve the life quality of the increasing population of the European cities. With regards to this, vegetation could help concretely to improve the quality of the urban environment, not only because of its well known aesthetic and recreational benefits, but also for its capability to reduce air temperature and to remove air pollutants, that could help to match the air quality standards with the required reduction of primary and secondary pollutants [21].

Nowak et al. [22] estimated that urban vegetation in the United States removed a mean of 214,900 t of PM_{10} and 305,100 t of O_3 during 1 year period (1994), while Powe and Willis [23] estimated that, for the whole Britain, the impact in terms of net health effects of trees compared to another land use was 5–7 deaths brought forward and 4–6 hospital omissions per year. McDonald et al [24], McPherson et al. [25, 26] and Broadmeadow and Freer-Smith [27], have demonstrated that trees can remove large quantities of ozone from the atmosphere by downward deposition through stomatal and non stomatal fluxes [28]. The amount of ozone, as well as other pollutants, absorbed by urban trees and shrubs in the vast metropolitan area of Beijing, China, has been estimated by Yang et al. [29], thus quantifying the capability of the so called “urban forest” to ameliorate air quality. Moreover, a preliminary computer simulation carried out for the city of Toronto [30] showed that trees can mitigate the intensity of the urban heat island, thus contributing to the annual energy saving of more than 30% with their shading/ambient cooling effect. The reduction of air temperature by canopy transpiration and building shading, and by other changes in the atmospheric physical environment, can actively contribute to the reduction of secondary air pollutants, such as O_3, by lowering the activity of chemical reactions that led to their formation in the air [31].

Another important aspect that have to be considered is that many ornamental tree species emit volatile organic compounds (VOC) belonging to the isoprenoid family [32]. Isoprenoids are strongly reactive and, in the conditions typical of urban environments, react with nitrogen oxides of anthropogenic origin forming tropospheric ozone, photochemical smog [33] and particulate [34]. However, plant isoprenoids have been very recently demonstrated to effectively take up ozone, therefore contributing to scavenging this pollutant from air [35-3734-36]. An accurate study of the potential emission of isoprenoids by plants growing in the urban environment is therefore urgent.

In spite of this, only limited studies have tried to quantify the role of the main urban vegetation types in the O_3 and PM pollution dynamics in European cities, and there is a particular lack of knowledge for what concerns large urban areas characterized by a Mediterranean-type climate [38]. In this frame, the project HEREPLUS (Health Risk Assessment for Environmental Pollution Levels in Urban Systems), a Coordination Action financed under EU FP7 (Grant Agreement n. 212854), aims to improve the knowledge of the potential role of different urban vegetation types for mitigating the O_3 and PM pollution levels in four different urban areas. Among them, three are located in the Mediterranean area (Rome, Madrid, Athens), while one in Central Europe (Dresden). The HEREPLUS project also intends to provide best practices regarding the choice of the most suitable species and management practices of urban green areas, aimed at maximizing their potential to improve air quality in urban systems.

Methods

During the HEREPLUS Project, physiological models will be applied to plants growing in the green areas of the studied cities in order to estimate the uptake and deposition rates of pollutants (ozone and PM) and thus quantify the role of vegetation as a sink for pollutants and minimizing the pollutant impacts on humans. First, on strong isoprenoid emitting plants, the seasonality of the emission, and its relationships with physiological factors such as photosynthesis and transpiration, or with pollution stress factors, previously assessed by laboratory and field studies, will be simulated in the urban environment. Secondly, the uptake of O_3 and PM by vegetation will be assessed, and related to the possible role of isoprenoids in increasing the O_3 flux to stomata. A process-based model [39] will be used in order to estimate several physiological variables (photosynthesis, transpiration, stomatal conductance to water vapour), Volatile Organic Compounds emission rates, and the Leaf Area Index value, for selected plant species growing in the urban green areas. In detail, the process-based model that will be utilised here is structured in different modules, each calculating and simulating a specific process such as net photosynthesis, transpiration, and total volatile organic compounds emission rates. Object-oriented programming software will be used, which will allow to link well physiological modules to each other and environmental parameters, by following existing functional relationships. VOCs modelling will be based on equations taking into consideration two important environmental parameters such as light and temperature, which are involved for the synthesis and emission of VOCs. Some structural parameters are linked to physiological ones such as the Leaf Area Index, which is an important scaling parameters allowing to up-to-scale leaf physiological processes to the canopy/community scale. These parameters, opportunely integrated with climatic and pollutant data, will define the role of the urban vegetation acting as a sink/source of O_3, and as a sink for PM deposition. The input variables of the model will be taken from previous data-sets.

The modelling exercises will deliver important data (uptake and deposition rates from/to vegetation) that will be implemented in a Geographic Information System (GIS) for the following elaborations linking climate, pollutant distribution, mortality and morbidity distribution and topological information, all constituting several layers of the GIS. Green and non-green areas (streets, buildings etc.) will be topologically defined and distinguished within the municipality borders. All green areas will be censed and the principal woody species and their physiological characteristics will be taken into consideration. Deterministic methods (IDW) and geo-statistical methods (Kriging, Co-Kriging with external drift etc) will be used, since they are the most suitable for an improved estimation of target variables by the integration into Kriging system of supplementary correlated factors such as urban green, microclimatic factors, urban topology model.

In this way, it will be possible to map the ameliorating effect of urban vegetation on air quality, and to produce integrated health risk maps, in GIS environment, for each urban area considered in this project. Formalization of best practices of to improve the sink capacity of urban vegetation, for minimizing the pollutant impact on population (e.g. selection of plant species, management of existing green areas), will be finally carried out.

Conclusions

The HEREPLUS project will provide an important contribution in the field of knowledge of the relationship between urban vegetation and urban air quality. In particular, it is expected to reach an improved knowledge of the actual and potential role of the main urban vegetation types in mitigating O_3 and PM pollution levels, to be correlated with management strategies of the green areas in the different studied cities (Rome, Madrid, Athens and Dresden), characterized by different climate and pollution levels. This will be of particular importance especially for those cities located in the Mediterranean basin, whose urban vegetation is often characterized by VOC-emitting species that can contribute significantly to the O_3 formation and destruction dynamics. The findings will be used to define best practices to improve the sink capacity of urban vegetation in order to minimize the air pollutant impact on population.

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