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EDITORIAL

Editorial-ozone and plant life: the Italian state-of-the-art

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It is the Editorial Policy of *Environmental Science and Pollution Research* to periodically publish a Special Issue to communicate to a broad constituency of the scientific community timely information about specific topics in the environmental sciences. A Special Issue consists of assembled papers that both identify and describe the status and extent of our knowledge concerning new or existing ecotoxicological problems. This is the case of ground-level ozone, primarily an air pollutant, which is of high concern in Europe due to its effects on human health, vegetation and materials. Ozone is not directly emitted into the atmosphere; instead, it is formed from chemical reactions in the presence of sunlight, following emissions of precursor gases. Meteorological conditions play essential rules in these reaction chains and also influence the transport of ozone and its precursors, so that year-to-year differences in pollution levels may be relevant (EEA 2016).

On November 24, 2016, the Italian scientific community involved in the study of the interactions between plants and tropospheric ozone gathered at the Department of Agriculture, Food and Environment of the University of Pisa. This event took place 10 years later another meeting on the very same topics, hold at the same University. Attendance was high, with more than 150 selected participants, belonging to around 20 institutions scattered nationwide. The objective of the conference was to provide a technical and scientific get-together for the academicians and scientists for reciprocating the specific advances/recent findings in the areas of ecology, plant physiology, phytopathology, applied botany, atmospheric chemistry/physics, environmental modelling and allied disciplines.

The Italian scientific production on the subjects dealing with the relationships between plants/ecosystems and ground-level ozone is relevant. As an example, the *Scopus* database (updated at mid November 2016) lists, for the period 2007–2016, more about 4000 documents when the keyword strings "*ozone plant*" and/or "*O_3 plant*" are queried: about 130 of them are produced by Italian scientists. So doing, Italy is at the third place worldwide, behind USA and China. Forest plants and shadow urban trees are the most investigated groups of plants; very poor attention is payed to fruit species. Investigation protocols span from free controlled exposure systems to open-top chambers, fumigation chambers in walk-in controlled-environment conditions and cuvette; study areas cover from the molecular to the ecosystem level the ecophysiology of stressed plants, tritrophic relationships, secondary metabolism, emission of volatile compounds and gas fluxes, quality of products, in addition to ozone metrics and biological monitoring, with related campaigns of environmental education.

A general debate was started during the conference. As an end point, a position paper was launched, whose outstanding points are hereunder reported.

(i) *At least eight out of the 17 goals selected by the United Nations for a Sustainable Development - 2016-2030 action*, "to end poverty, protect the planet, and ensure prosperity for all" *(UN 2016) deal more or less directly with ozone air pollution. They include climate action, human health and well-being, economic growth and fight against poverty, sustainable cities, the quality of life on land and natural capital. No doubts that ground-level ozone causes as much more damage to plants than all other pollutants combined. As an example, a recent study (Gaude* et al. 2014*) demonstrated that in India yield loss due to this pollutant under the present emission scenario would be sufficient to feed 94 million people living below poverty line.*

(ii) *The presence of ground-level ozone is even more a major threat for all forms of life also in Italy (*Fig. 1*), as well as in many areas of the world, such as the Mediterranean basin. Pollution levels recorded in many agricultural*

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and forest areas systemically trespass quite a lot threshold values fixed by international bodies for the protection of vegetation; they elicit concern for their impact on major crops (in terms both of yield loss, quality and nutritional profiles), on the performance of forest and semi-natural vegetation, on biodiversity, on the ability of plant communities to ensure those ecosystem services which are fundamental for our well-being and economic development.

(iii) *Ozone is a secondary pollutant, its formation resulting from complex interactions among primary pollutants (notably nitrogen oxides and volatile organic compounds, emitted by both anthropogenic and biogenic sources) and natural components of the atmosphere, under the crucial influence of solar radiation. Plants are essential players in this context: they are a primary target of ozone toxicity, but-at the same time-they remove it from the atmosphere (mainly through stomatal absorption during their physiological gas exchange activity), so doing protecting human health; but many trees themselves emit organic volatile compounds which enter the troposphere and take part to the whirlwind of reactions which bring to photochemical smog and ozone formation. On the other hand, ozone is also a greenhouse gas and a driver of climate change and a key agent in atmospheric chemistry.*

(iv) *Ozone formation and distribution are deeply influenced by the environment and by its climate change-driven factors. Extreme meteorological conditions such as summer heat waves and protracted droughts will be even more frequent in the near future and will contribute to the build-up of enduring episodes of high ozone pollution (Lorenzini* et al. 2014*;* Fig. 2*), with relevant impact on human beings and ecosystems health, not to mention effects on manufactured products and artefacts. Available studies (EAA 2016) indicate that projected mid-century climate change will increase surface ozone over the vast majority of continental Europe; the increase is particularly robust, for instance, over the Po Valley.*

(v) *On the basis of the abovementioned points it is believed that policy- and decision-makers should undertake proposals in order to appoint and sustain proper research projects aimed to focus the information required to develop a congruent action plan to tackle and mitigate the environmental and sanitary questions represented by ozone pollution.*

At the end of the meeting, a great consensus was developed on the challenge of preserving the experiential explicit knowledge assets which had been proposed by the authors: the option of editing a special issue of a first-class specialised journal, such as *Environmental Science and Pollution Research* was immediately accepted. So, the present issue hosts the majority of the presentations offered at the conference; besides them the dossier benefits from the input of some other external contributions recently produced by Italian colleagues, also focused on the same topics. Out of the 16 reports here compiled (in addition to the present editorial), 11 are in form of research articles, four of review articles and one of short research and discussion article. An overall turnkey indication of the state-of-the-art of the Italian scientific community is so available. All the items have been subjected to the canonical peer-review procedures on the initiative of the editorial staff of the journal.

The special issue is opened by an introductory report (Nuvolone et al. 2017) dealing with the sanitary (i.e. human health) aspects of ozone pollution, with special regard to the Italian scenario. Air pollution is the single biggest environmental health risk in Europe, causing hundreds of thousands of premature deaths, shortening people's lifespan and contributing to serious illnesses such as heart disease, respiratory problems and cancer. According to the more recent estimates produced by the European Environmental Agency (EEA 2016), in Italy, in 2013, 3380 premature deaths (equivalent to 36,500 years of life lost) are estimated to be attributable to ozone exposure, the highest values among the 41 European countries.

The other papers may be grouped under five thematic headings.

(i) The first group deals with intimate mechanisms of lichen response to ozone. Lichens are interesting organisms, due to their ability to absorb everything present in their atmosphere, especially pollutants, and to their aptitude of growing also in the leftover spots of the natural world that are too harsh or limited for most other organisms. So, Bertuzzi et al. (2017) investigated the hypothesis that lichens are ozone-tolerant thanks to the constitutive antioxidant systems, intimately related to their poikilohydric life-style. Vannini et al. (2017) elucidated the physiological and ultrastructural effects induced by ozone in *Xanthoria parietina*, putting in evidence the role of parietin in promoting the recovery after the damage.

(ii) The effects of ozone exposure on forest plants in manipulative experiments under controlled conditions represent a further grouping. Hoshika et al. (2017a) tested a ratio of photosynthesis to ozone uptake as an index for the assessment of foliar visible injury in Oxford poplar. The same team (Hoshika et al. 2017b) investigated in a free-air controlled exposure facility the ozone dose-response relationships for three European oak species under a range of soil water availability. Physiological and biochemical responses to long-term exposure to ozone of two Italian provenances of *Fraxinus excelsior*

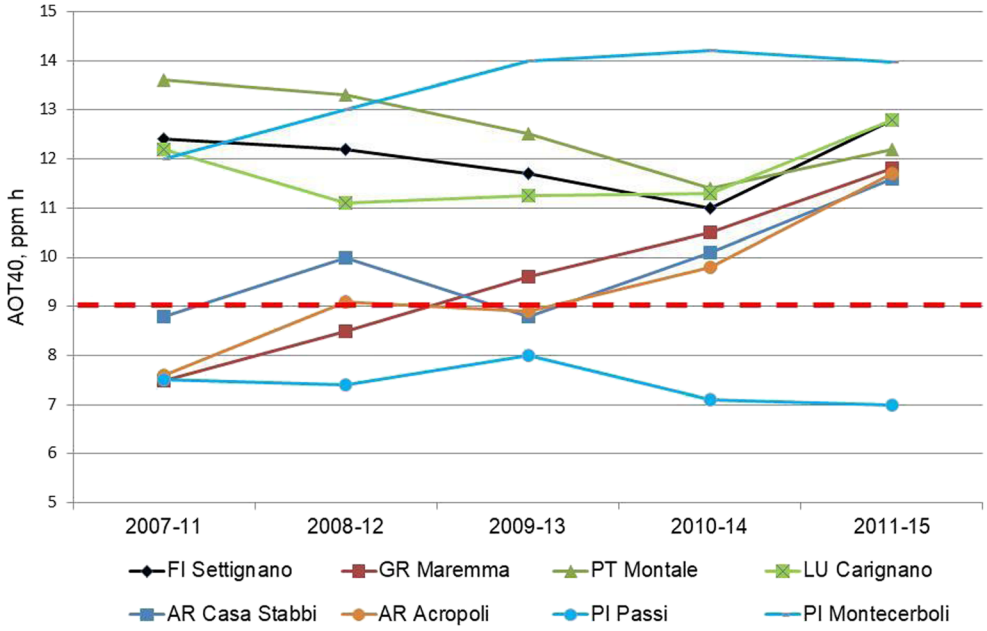

Fig. 1 AOT40 (Accumulated exposure Over a Threshold of 40 ppb*(v)* O_3, expressed in ppm h) 5-y running averages (only values measured between 08:00 and 20:00 CET each day from May to July are used for the calculation) as observed in 8 Tuscan monitoring stations (Data source: Tuscan Regional Environmental Agency, ARPAT, Florence). The dashed horizontal line shows the EC target value for the protection of vegetation (9 ppm h). GR-Maremma is a rural site; AR-Casa Stabbi is rural/background; AR-Acropoli, FI-Settignano, PT-Montale, LU-Carignano, PI-Passi, PI-Montecerboli are suburban

were the focus of the paper presented by Cotrozzi et al. (2017a). Pellegrini et al. (2017) reported about the detoxification mechanisms underlying ozone sensitivity in tulip tree, *Liriodendron tulipifera* and Cotrozzi et al. (2017b) talked about the comparison between an evergreen isohydric oak species (*Quercus ilex*) and a sympatric, deciduous and anisohydric species (*Q. pubescens*) under long-term ozone stress.

(iii) The interactions among ozone levels and peculiar environmental stress factors challenging Mediterranean crops, such as soil salinity and drought, with special regard to their influence on stomatal behaviour were the issue covered by Fagnano and Maggio (2017) and De Biasi et al. (2017) discussed the complex interactions among zinc availability and response to ozone in durum wheat plants.

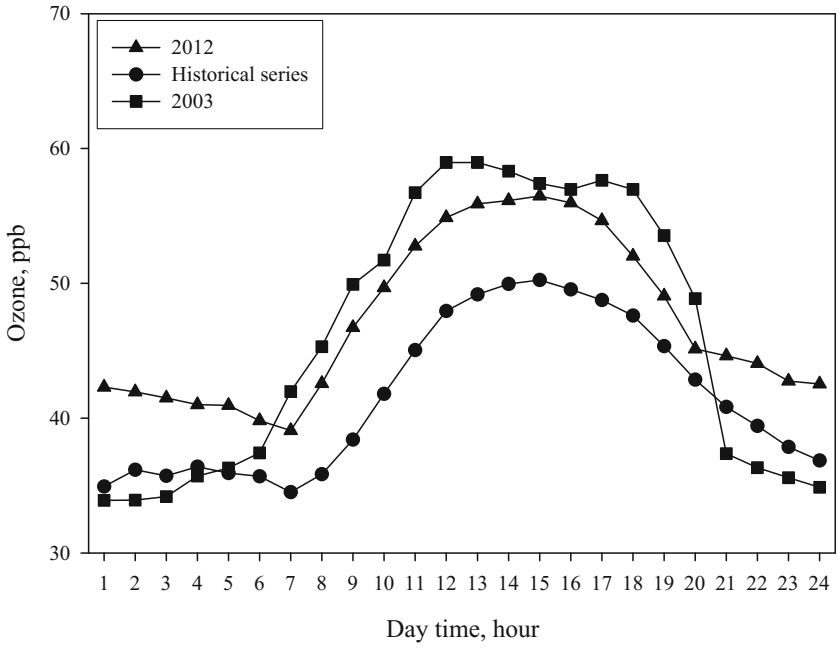

Fig. 2 Diurnal variation of ozone hourly concentration in the rural/background monitoring station of Casa Stabbi (Arezzo Province) (1 July–15 August) in 2003 and 2012 (2 years with dramatic summer heat waves), in comparison with an historical series (1999–2002 + 2004–2011) (after Lorenzini et al. 2014)

(iv) Ozone uptake by vegetation was the major issue of another couple of papers. Fusaro et al. (2017) modelled ozone fluxes in the urban and peri-urban forest coverage of the Metropolitan City of Rome and their role in terms of ecosystem services, while Fares et al. (2017) explored the importance of micrometeorological techniques in association with latent heat flux measurements in the field for the partition of ozone fluxes into the stomatal and non-stomatal sinks along the soil-plant continuum.

(v) Three publications fall under the heading of estimate of ozone effects on forests. The first paper (Gottardini et al. 2017) describes the results of a 5-year long multidisciplinary project aimed at providing explicit responses to key answers such as: "*is there a potential risk placed by ozone to forests in Trentino (Northern Italy)?*", or, "*are there specific ozone symptoms on vegetation, and are they related to pollution levels?*". Ferretti et al. (2018) investigated the significance of tropospheric ozone as a factor explaining recent tree health and productivity in selected Alpine forests in Trentino (N. Italy). On the other hand, Paoletti et al. (2017) used a unique database of stand volume growth from hundreds *Fagus sylvatica* stands distributed across Italy to assess the effects of ambient ozone, as described by several metrics.

Finally, a methodological essay (Cotrozzi et al. 2017c) tackles the potential of reflectance spectroscopy, a novel approach to monitor the impact of air pollution on the vegetation status in the Mediterranean environment.

Taken together, the contribution to this special issue highlight both the progress and the still existing bottlenecks for the full knowledge of the interactions between ground-level ozone and plant life in a typical Mediterranean context. They all lead to the conclusion that exposure to environmental concentrations of ozone of today-and even more of tomorrow-reduces plant performances and fitness; they also pave the way for new research to answer many questions which remain to be elucidated such as the real role of vegetation in detoxification processes in different environmental conditions and a more reliable environmental risk assessment, with special regard to the combined effects of ozone pollution and climatic change. Policy makers would intensely benefit these first-hand information, even if many questions remain to be clarified or further emphasised and the road ahead is still long and winding.

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Author contributions GL and CN co-wrote this Editorial based on the various contributions to this research topic.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Cristina Nali received her PhD in Phytotoxicology by the University of Pisa, Italy, in 1997. During this time and thereafter, she worked as a researcher on plant pathology, with special regard to the interactions between fungal diseases and gaseous air pollutants. Throughout this time, she was also engaged in biological education projects, with particular regard to biological monitoring of ground-level ozone; another major field of interest has been the study of the effects of environmental pollutants upon qualitative performances of agricultural, forest and medicinal plant species and the study of physiological and molecular bases for their differential response to the oxidative stress. Currently, she is Full Professor at the Department of Agriculture, Food and Environment of the University of Pisa.