

AIR POLLUTION AND VEGETATION IN THE MEDITERRANEAN AREA

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Air quality is an important ecological factor for forests, native ecosystems and agricultural crops. Atmospheric pollutants may cause biochemical and physiological damages which lead to reduction of growth and yield (Treshow, 1984). An impairment of competitive and reproductive performance may also occur, which causes changes in species diversity and composition at ecosystem level (Westman, 1985).

The interactions between air quality and vegetation in the Mediterranean area received so far only little attention from the scientific community, in spite of the threat that air pollution may represent. The high temperature and solar radiation which occur during the hot season facilitate the production and accumulation of ozone in the lower troposphere. The precursors involved in the photochemical production of O₃ are nitrogen oxides (NO_x) and volatile hydrocarbons, emitted in large amounts in the region especially in summer, due to the influx of tourists from central and northern european countries. The instruments for the analysis of atmospheric ozone are not numerous in the Mediterranean basin, but the available data, coming from physicochemical and biological monitoring, clearly indicate the occurrence of significant concentrations of this pollutant at ground level over large urban and rural areas (Lorenzini, 1992).

The analysis of the historical records of O₃ has revealed a more than two fold increase over the last century (Volz and Kley, 1988). On the basis of present estimates, the global tropospheric concentrations of ozone will continue to increase at a rate faster than during the past 100 years, as a consequence of the continuous increase of the emissions of precursors (Hough and Derwent, 1990). Other air pollutants have, at least in some Mediterranean countries, a different trend.

This is the case for sulphur dioxide (SO₂), whose emissions have been decreasing over the last decade in Italy, France and Spain (EMEP, 1990). In this paper the available information on the impact of air pollutants on plants in the Mediterranean area is briefly reviewed, and the main research requirement on the subject are outlined.

Abstract

The Mediterranean area is densely populated and has high emission rates of air pollutants. Among these, nitrogen oxides and volatile hydrocarbons are precursors of highly phytotoxic photochemical oxidants like ozone (O₃). The production and accumulation of ozone in the lower troposphere is increased by the high temperature and solar radiation which characterize the Mediterranean climate during summer. In several localities O₃ concentrations above the thresholds for phytotoxicity frequently occur. Significant losses of yield attributable to ambient ozone have been observed in Spain in the Ebro delta region and in Italy at urban and rural sites in the Po plain. The available information on the influence of ambient air pollution on forests, natural species and ecosystems is still very slight. Typical O₃ injury symptoms have been observed on *Pinus halepensis* in Israel, Greece and Spain. Information on other species is almost completely lacking. An increase in research on this topic is urgently needed.

Résumé

L'aire méditerranéenne est très peuplée et les taux d'émission des polluants atmosphériques sont élevés. L'oxyde d'azote et les hydrocarbures volatiles sont les précurseurs des oxydants photochimiques phytotoxiques, tels que l'ozone. La formation et l'accumulation d'ozone dans les couches superficielles de l'atmosphère sont favorisées par les températures élevées et par les radiations solaires caractérisant le climat méditerranéen. Dans nombreuses localités des concentrations d'ozone supérieures aux limites de phytotoxicité sont fréquemment décelables. Des réductions de la production agricole attribuables à l'ozone des couches superficielles ont été observées en Italie dans des aires urbaines et rurales de la plaine du Po. Les informations disponibles sur l'influence que la pollution des couches atmosphériques superficielles a sur les forêts, les espèces naturelles et les écosystèmes sont limitées. De symptômes typiques attribuables aux dégâts provoqués par l'ozone ont été observés sur le *Pinus halepensis* en Israël, en Grèce et en Espagne. Les informations sur d'autres espèces manquent presque totalement, l'où une recherche plus approfondie s'avère nécessaire.

Impact of air pollutants on plants in the Mediterranean basin

Traits of Mediterranean vegetation relevant to air pollution effects

The study of air pollution effects on crops, forests and natural ecosystems in the Mediterranean area (figure 1) must take into consideration the biological features of the different species, which reflect their adaptation to the climate. The mild temperatures which occur in winter allows the growing season to extend over the whole year. It is therefore clear that the concept of a «seasonal concentration mean», calculated over a fixed time interval (usually spring and summer) cannot be easily applied to Mediterranean ecosystems: the exposure to pollutants should rather be calculated on an annual basis for the ecosystem as a whole. For single species the actual duration of the growing season should be considered. The high temperatures and drought which characterize the summer may cause severe heat and water stress, which is counteracted with different strategies. Some species (e.g. *Euphorbia dendroides*) lose their foliage and start dormancy at the beginning of summer; others have evergreen sclerophyllous leaves which can close their stomata during the hot hours of the day in order to reduce the loss of water by trans-

piration (water savers, e.g. *Quercus ilex*); others have an extremely developed root system which can provide sufficient water for keeping the stomata open all day (water spenders, e.g. *Pistacia terebinthus*) (Levitt, 1980). The response to water stress, in particular the closure of the stomata during the central hours in summer may influence the uptake of photochemical pollutants, which usually reach their maximum concentrations during the hot hours of day. On the other hand, air pollutants themselves may interfere with the behavior of the stomata and with other biological processes relevant for adaptation to drought, causing a loss of tolerance to this stress (Kasana, 1992).

Crops

Visible injury to crops from several air pollutants (e.g. fluoride, sulphur dioxide, hydrochloric acid) has been locally observed around industrial sources in the Mediterranean area. The information available for Italy has recently been reviewed by Schenone and Lorenzini (1990). Visible injury from ambient photooxidants at the regional scale has been detected on several crops in different countries. In Greece Velisariou et al., (1992a) report the case of a farm where tobacco (*Nicotiana tabacum*) cultivation was stopped partly because of a «disease» which was later identified as O₃ lesions. The comparison of old and new greek

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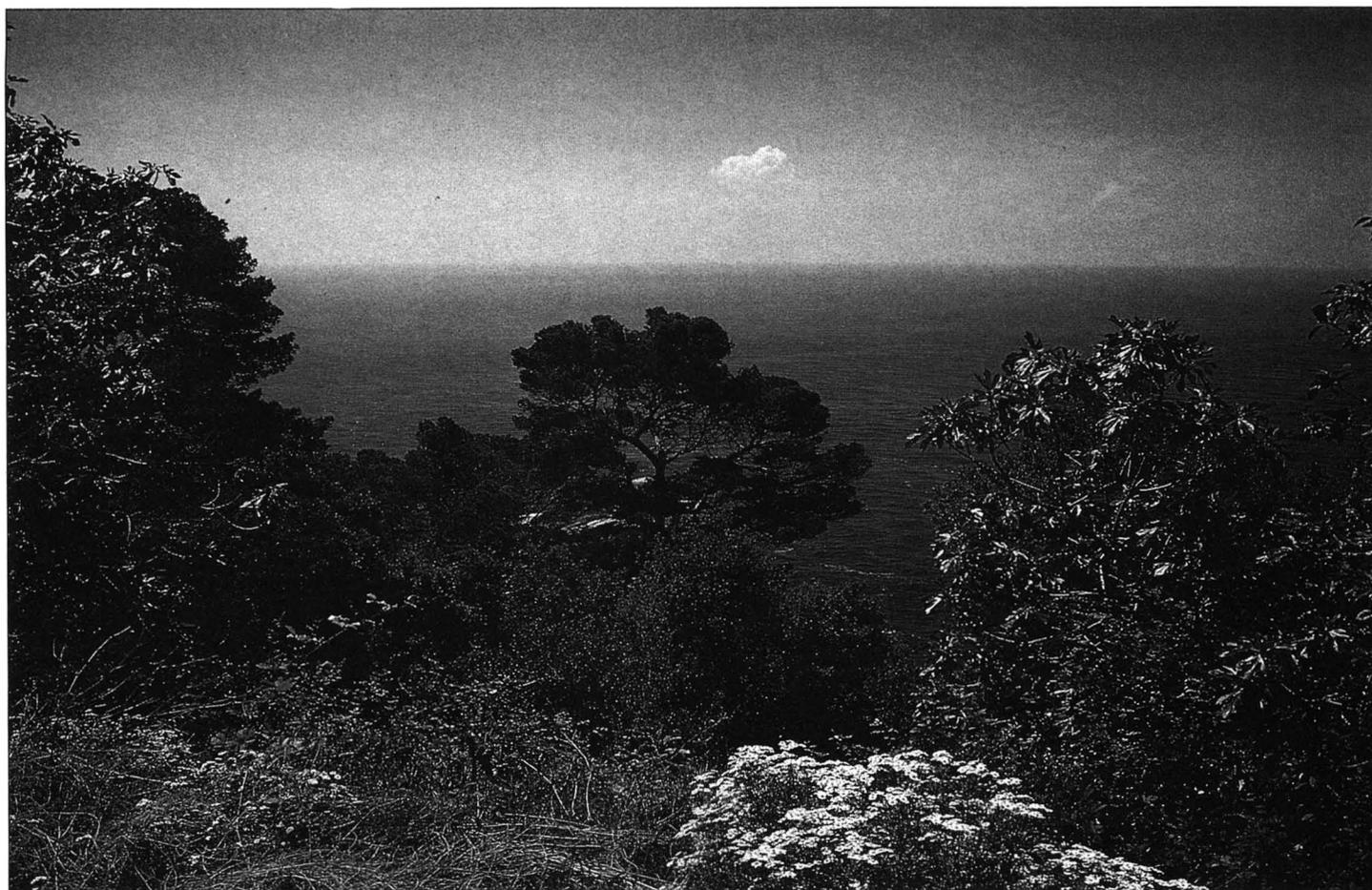


Figure 1 - The effects of air pollution on Mediterranean vegetation are almost unknown. The tree near the centre of the picture is an Aleppo pine (*Pinus halepensis*), a species highly sensitive to photochemical smog. (Photo courtesy of Dr. C. Margiocco).

cultivars of wheat (*Triticum aestivum*) showed surprisingly that recent varieties are more sensitive to ozone than older ones (Barnes et al., 1990). In this case the sensitivity to ozone was associated with some other favourable characteristics which breeders have specifically selected for over the years; further studies in fact showed that modern greek cultivars have higher rates of photosynthesis, associated with greater stomatal conductance. This may contribute to the greater O_3 sensitivity of modern cultivars, although this may not be the only factor involved. The large scale use of agrochemicals for protecting against pests, some of them having a significant antiozonant activity, may have reduced for the modern cultivars the disadvantage due to greater ozone sensitivity (Velissariou et al., 1992b). In the Ebro delta region in Spain ambient oxidants were suspected to cause severe foliar flecks to watermelon (*Citrullus lanatus*); a subsequent experiment performed with open-top field chambers showed that the removal of ambient air pollution by filtration could prevent the leaf damage and increase the yield. The 7h O_3 mean during the experiment was 50 nanolitres per litre (nll^{-1}), with 800 hours exceeding that concentration, and a maximum value of 90 nll^{-1} (Reinert et al.,

1990). In Spain visible ozone injury has also been noticed on several other crops, like bean (*Phaseolus vulgaris*), peanuts (*Arachis hypogea*), commercial tobacco, tomato (*Lycopersicon esculentum*) and grape (*Vitis vinifera*) (Salleras et al., 1989). In Tuscany (central Italy) oxidant stipples have been observed on grape, bean, soybean (*Glycine max*) and tomato (Lorenzini et al., 1984). In this region 7h O_3 concentrations up to 60 nll^{-1} have been recorded for the May-September period, with hourly maxima above the American standard of 120 nll^{-1} (Lorenzini et al., 1988). In the Po plain (northern Italy) visible injury attributable to ambient ozone has been observed on bean (Panattoni et al., 1990), courgette (*Cucurbita pepo*) (Schenone and Lorenzini, 1992), soybean and hybrid poplar (*Populus deltoides x Maximowiczii*) (G. Schenone, unpublished) (figure 2).

In northern Italy the effects of ambient air pollution on crops have been investigated with open-top field chambers, a technique which allows control of the air pollution content of the atmosphere while keeping the plants in near-field conditions. The experiments were performed at two sites in the Po Plain; one site was within the urban area of Milano (urban site), and the second was in the countryside along the Po river

90 km south-east of Milano (rural site). The crops were cultivated in the field under standard agronomic conditions and were exposed to either filtered or nonfiltered air in the open-top chambers until final harvest. The results showed significant yield losses for various crops in the chambers receiving ambient nonfiltered air compared to the filtered ones. No relevant differences between the two sites were noticed. For winter wheat the yield reduction in nonfiltered air averaged 23% over three years at the urban site and 21% at the rural site. Phytotoxic levels of ozone were measured at both sites during the two months before harvest. For dry bean the yield losses over two years and three cultivars were 27% at the urban site and 23% at the rural site. During the experiments with bean 7h O_3 means up to 50 nll^{-1} were recorded, with maxima up to 100 nll^{-1} . Significant reduction of yield were also observed for barley (*Hordeum vulgare*) in 1989. For bean the effects on yield were associated with visible injury to leaves, while for wheat no symptoms were noticed. An experiment with courgette gave a nonsignificant yield reduction of 10%, although visible interveinal foliar flecking occurred in plants grown in nonfiltered air (Schenone and Lorenzini, 1992; Schenone et al., in press). The effects of O_3 on herbaceous and woody crops are studied with open-top chambers at a field site near Viterbo, in central Italy. A prelimi-

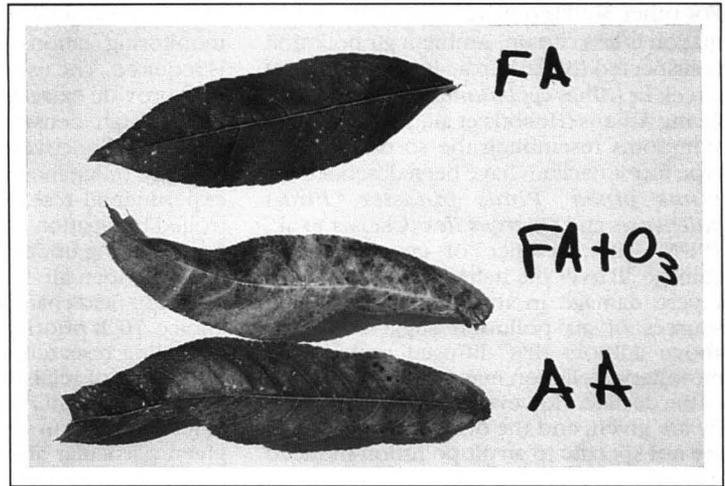
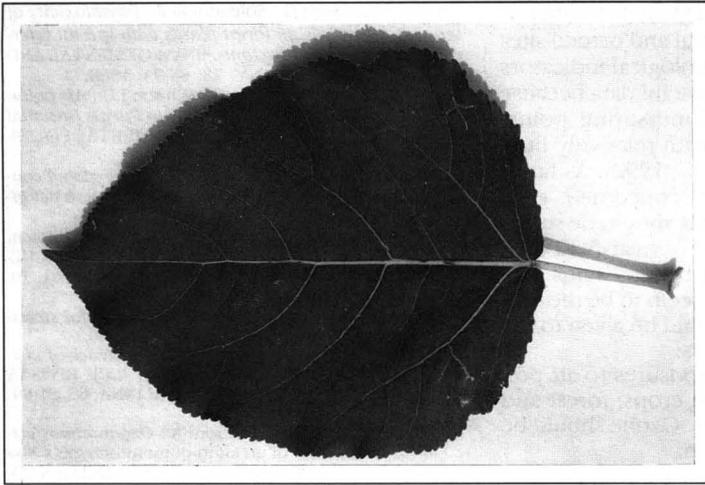


Figure 2 - Leaf of hybrid poplar (*Populus deltoides* x *Maximowiczii*) grown at a rural site in the Po Plain, northern Italy. The leaf shows interveinal stippling on the upper surface, a typical symptom of ozone injury for most deciduous trees.

Figure 3 - Leaves of peach tree (*Prunus persica*) exposed to charcoal-filtered air (FA), filtered air plus ozone (FA + O₃) and ambient air (AA) at a semirural site in near Viterbo, central Italy. On this species ozone causes diffusion of red pigments from injured tissue into surrounding tissue. Visible injury which occur in ambient air can be prevented by removing the air pollutants by filtration; the same symptoms can be reproduced by adding ozone to filtered air. (Photo courtesy of Dr. M. Badiani).

nary experiment performed with peach tree (*Prunus persica*) suggests the occurrence of negative effects of ambient levels of O₃ on this species (figure 3). A synergistic interaction between ozone and a pathogenic fungus has in addition been observed (Badiani et al., 1992).

Forests, native species and ecosystems

The research on effects of ambient air pollution on Mediterranean forests, native species and ecosystems has been mainly performed as field observations. Most references deal with the direct impact of vehicle exhausts or other forms of pollution and lack quantitative data on air quality for the «clean» and «polluted» sites. Very little is known about the impact of photochemical air pollution at regional scale. A first case-study which can be mentioned here is the severe damage which occurs to coastal forest ecosystems along the Tyrrhenian beachfront, especially in the proximity of river mouths. The typical symptom is foliar necrosis of the side of the crown directed to the sea; the growth is reduced and the plants often die. The damaged leaves have a high content of chloride. There is now convincing evidence that the disorder is caused by the polluted marine aerosol with a synergistic action between sodium chloride and detergents (Gellini et al., 1985; Guidi et al., 1988). The elemental analysis of leaves of evergreen oak (*Quercus ilex*) growing under the influence of urban air pollution at Naples has indicated a high load of trace metals, whose concentration was positively correlated with the traffic intensity (Alfani et al., 1989). In leaves of *Laurus nobilis* at the botanical garden of the univer-

sity of Naples, the content of chlorophyll and nitrogen was found to be inversely related to the amount of sulphur, suggesting a negative influence of ambient levels of SO₂ (Alfani et al., 1983). The ultrastructural and biochemical analysis of leaves of *Pinus pinea* collected within the urban area of Rome and in the surrounding rural areas indicated faster and higher degradation of epicuticular waxes, higher levels of peroxidase activity and sulphate contents in plants sampled in Rome; these effects may be attributed to the direct action of vehicle exhausts (Manes et al., 1989). Analogous studies carried out in Greece on *Laurus nobilis*, *Olea europea* and *Eucalyptus camaldulensis* demonstrate that sclerophyllous trees growing in a heavily polluted urban environment generally present harder and thicker leaves in comparison to plants living in rural areas. Nevertheless the structure of cell organelles is not damaged, and the trees maintain their photosynthetic activity (Christodoulakis and Fasseas, 1990;

Christodoulakis and Koutsogeorgopoulou, 1991). The authors therefore conclude that these species must be regarded as «injury resistant»; the observed thickening and hardening of the leaf external structures lead to a more xeromorphic habitus, which can be related to the hot and dry urban microclimate. As mentioned before, the information on the effects of photochemical air pollution on Mediterranean native species and ecosystems is very slight. Chlorotic mottling and banding of needles of *Pinus halepensis* and *Pinus pinea* have been observed in Israel in the Shaar Hagai canyon, along the road leading to Jerusalem. The symptoms were identical to those described for *Pinus ponderosa* in the San Bernardino mountains in California and attributed to ozone.

The ozone damage is accompanied by severe infestation by *Matsucoccus josephy* scales and Scolitidae beetles (Naveh et al., 1980). *Pinus halepensis* is also severely damaged by ambient photooxidants in the greater Athens basin in Greece (figure 4) (Velissariou et al., 1992a). The lesions were visible in all but the current year needles in the cooler months; in summer the needles were very chlorotic, possibly due to photooxidation of chlorophylls mediated by heat or drought, and the O₃ symptoms were masked. Ozone damage to Aleppo pine has also been noticed in Spain (Gimeno et al., in press).

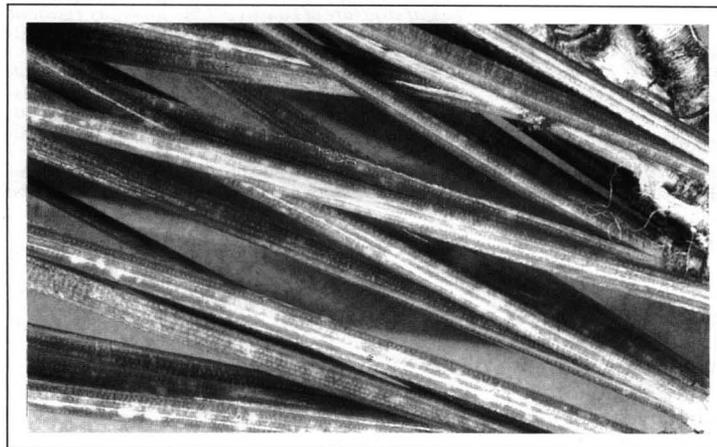


Figure 4 - Chlorotic mottling on needles of Aleppo pine (*Pinus halepensis*) exposed to ambient ozone near Athens. Mottling is a typical symptom of ozone injury to conifers. (Photo courtesy of Dr. D. Velissariou).

For other Mediterranean species the information is less certain. Ambient air pollution is suspected to play a role in the decline of Greek fir (*Abies cephalonica*) on the slopes facing Athens (Heliotis et al., 1988). In Italy symptoms resembling the so called «new type forest decline» have been described for *Pinus pinea*, *Pinus pinaster*, *Pinus halepensis* and *Quercus ilex* (Clauser et al., 1989). The presence of generally mild damage all over the Italian territory, and of severe damage in the vicinity of strong sources of air pollution suggests to the above authors that diffused regional atmospheric pollution may be the main cause of the decline. However, no data on air quality are given, and the described symptoms are not specific to an air pollution-induced damage.

Critical levels for effects of air pollutants on vegetation

The recently introduced concept of critical level allows a practical approach for estimating the sensitivity of ecosystems to air pollution. The critical level of a certain pollutant is intended as the threshold concentration (or the dose) above which harmful effects to sensitive receptors may occur. An extremely useful feature of this approach is that the critical levels can be mapped (UNECE, 1988). In these maps the more sensitive areas have lower values of critical level. The comparison of the critical level maps with the concentration maps obtained from instrumental monitoring allows identification of the areas where the critical levels are exceeded, and where the abatement of pollutant concentrations is needed. The critical levels for European crops, forests and natural vegetation have been established by the United Nations Economic Commission for Europe (UNECE), and are now being updated following new knowledge coming from research. However, the above overview indicates that the present knowledge on the responses of crops, forests and natural vegetation to air pollutants in the Mediterranean basin is absolutely insufficient and that a greater research effort is needed in order to identify and map the critical levels for air pollutants in this region.

Research requirements and conclusions

The research so far carried out has found evidence of clear effects of ambient air pollution on plants in the Mediterranean basin. The instrumental and biological monitoring of air quality has demonstrated the occurrence of phytotoxic concentrations of ozone at regional scale over large urban and rural areas, with a trend towards a further increase. Nevertheless, the data on air quality for the Mediterranean area are still insufficient, especially for O_3 , and reliable maps of pollutant concentration can not be drawn. A better knowledge of air quality is

therefore essential, and a greater number of monitoring stations at rural and natural sites is required. The use of biological indicators may provide extremely useful data because of the high density of measuring points which can be covered with relatively little expense (Mignanego et al., 1992). As far as experimental research is concerned, controlled fumigation systems should be set up for operating under field or near-field conditions: open-air fumigation systems and open-top field chambers seem to be the best choice. High priority should be given to the following research topics:

— Effects of realistic exposures to air pollutants on Mediterranean crops, forest and natural vegetation species. Ozone should be given particular attention.

— Interactions between air pollutants and other stress factors, both physical (water stress, heat), and biological (insects, diseases).

— As far as natural vegetation is concerned, the experimental work in fumigation chambers should be accompanied by field surveys for evaluating the extent and spatial distribution of specific symptoms of air pollution damage on sensitive species (e.g. O_3 -induced chlorotic mottling on conifer needles).

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