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Working Group on Effects

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Item 4 of the provisional agenda
Recent results and updating of scientific and technical knowledge

Effects of air pollution on natural vegetation and crops

Report by the Programme Coordinating Centre of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops

Summary

The present report is being submitted for the consideration of the Working Group on Effects in accordance with the request of the Executive Body for the Convention on Long-range Transboundary Air Pollution in the 2012–2013 workplan for the implementation of the Convention (ECE/EB.AIR/109/Add.2, items 3.1 (c) and 3.5).

The report of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops presents the results of ozone impacts on ecosystem services and biodiversity, and the results of the pilot study on mosses as biomonitors of persistent organic pollutants as part of the European moss survey conducted in 2010/11.[1] In addition, the results of the workplan items common to all programmes are presented.

[1] Results on the spatial patterns (2010/11) and temporal trends (1990–2010) of heavy metal and nitrogen concentrations in mosses are presented in document ECE/EB.AIR/WG.1/2013/13.

Contents

I. Introduction

1. Recent results on the effects of ozone on vegetation, and progress with the European moss survey on heavy metals, nitrogen and persistent organic pollutants (POPs), are presented here in accordance with items 3.1 (c) and 3.5 of the 2012–2013 workplan for the implementation of the Convention on Long-range Transboundary Air Pollution (ECE/EB.AIR.109/Add.2), adopted by the Executive Body for the Convention at its twenty-ninth session in December 2011.

II. Workplan items common to all programmes

A. Further implementation of the Guidelines

2. Table 1 below provides an overview of the monitoring and modelling effects reported by the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation), according to the Guidelines for Reporting on the Monitoring and Modelling of Air Pollution Effects (ECE/EB.AIR/2008/11).[2]

Table 1
Monitoring and modelling effects reported by ICP Vegetation

Parameter	*Ozone*	*Heavy metals*	*Nitrogen*	*Persistent organic pollutants*
Growth and yield reduction	X			
Leaf and foliar damage	X			
Exceedance critical levels	X			
Climatic factors	X			
Concentrations in mosses		X	X	X

B. Report on ideas and actions to enhance the involvement of countries in Eastern and South-Eastern Europe, the Caucasus and Central Asia, and on cooperation with activities outside the Convention

3. Table 2 provides an overview of the participation of countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia and countries outside the United Nations Economic Commission for Europe (ECE) region in the activities of ICP Vegetation. Whereas countries of this subregion primarily participate in the European moss survey, countries outside it primarily participate in research on the impacts of ozone on vegetation. There is a clear need to enhance participation of countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia in research on the impacts of ozone on vegetation. ICP Vegetation therefore aims to establish links with ozone experts in more countries of these countries in the near future. In the coming year, ICP Vegetation will report on the deposition of air pollutants to and the impacts on vegetation specifically in countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia, as well as South Asia.

[2] The Guidelines were adopted by the Executive Body at its twenty-eighth session (ECE/EB.AIR/96/Add.1, decision 2008/1).

Outreach activities outside the ECE region will be primarily focused on ozone impact on vegetation, acknowledging the fact that ozone is a hemispheric pollutant.

Table 2
Participation of countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia and countries outside the ECE region in ICP Vegetation activities over the past five years, including attendance at task force meetings

Countries of Eastern Europe, the Caucasus and Central Asia	*Countries of South-Eastern Europe*[a]	*Countries outside the ECE region*
Belarus (M)	Albania (M)	Brazil (O_3)
Russian Federation (M)	Bulgaria (M)	China (O_3)
Ukraine (M, O_3)	Croatia (M, O_3)	Cuba (O_3)
	Greece (O_3)	Egypt (O_3)
	Macedonia (M)	India (M, O_3)
	Romania (M)	Japan (O_3)
	Serbia (M)	Niger (O_3)
	Slovenia (M, O_3)	Pakistan (O_3)
	Turkey (M)	South Africa (O_3)

Abbreviations: M = moss survey; O_3 = ozone impacts on vegetation.
[a] Kosovo (United Nations administered territory, Security Council resolution 1244 (1999)) also participated in the moss survey.

4. Regarding the European moss survey, the ICP Vegetation Programme Coordination Centre is currently discussing with the Russian Federation how its role can be increased in the coordination of the moss survey in the future. The expert in the Russian Federation has been very active in the past in enhancing the participation of countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia in the moss survey. The next European moss survey is provisionally scheduled for 2015/16. In 2013, a short leaflet was produced on the results of the 2010/11 European moss survey, which was translated into Russian for distribution in the countries of Eastern Europe, the Caucasus and Central Asia.

C. Report on impacts of air pollution on biodiversity and ecosystem services

5. The ICP Vegetation Programme Coordination Centre coordinated the production of the summary report on the benefits of air pollution control for biodiversity and ecosystem services (ECE/EB.AIR/WG.1/2013/14), the full biodiversity report (informal document No. 1) and a short booklet on the same subject. The booklet was made available as informal document No. 9 for the fifty-first session of the Working Group on Strategies and Review (Geneva, 30 April–3 May 2013) and was presented at the "Clean Air for Nature" workshop at the Directorate-General for Environment of the European Commission (Brussels, 20 March 2013), as well as at the fifth Stakeholder Expert Group meeting for the review of European air pollution policy (Brussels, 3 April 2013). A review from ICP Vegetation on

the impacts of ozone pollution on ecosystem services and biodiversity[3] was incorporated in both documents. Further details of the contribution from ICP Vegetation are provided in section III below.

III. Report on the ozone impacts on ecosystem services and biodiversity (new activity)

6. Until recently, much of the research on ozone impacts has focused on quantifying the effects on ecological processes rather than considering the implications for ecosystem services that provide benefits for human well-being. Now, for the first time, ICP Vegetation has placed current process-based knowledge within the context of ecosystem services and reported on the potential for impacts of ozone on ecosystem services and biodiversity (see para. 5 above).

7. **Supporting services**. Ozone pollution impacts directly or indirectly on many of the fundamentally important ecological processes that provide supporting services and underpin almost all ecosystem services, these include:

(a) *Primary productivity and carbon cycling*: Ozone reduces whole plant photosynthesis by directly impacting on the photosynthetic machinery, reducing leaf area by promoting early senescence and leaf abscission, diverting carbon (C) use into detoxification and/or repair metabolism, changing conductance of the leaf pores (both increases and decreases have been noted, see below) and altering C allocation in favour of the above-ground parts rather than below-ground parts. Carbon flux to and from the soil is also altered by changes in leaf litter quality, altered deposition of C in the rooting zone, changes in soil microbial community composition and altered soil processes;

(b) *Nutrient cycling:* Tropospheric ozone has the capacity to impact on nutrient cycling by both direct and indirect mechanisms by altering the chemical composition of plant tissue and the quantity (and quality) of litter fall, impacting on below-ground plant biomass and root exudates and indirectly altering microbial community composition(s) and functioning, as well as the soil processes and the chemical properties. All of these have the capacity either, independently or in concert, to ultimately reduce the long-term sustainability of ecosystems;

(c) *Stomatal (leaf pore) functioning and water cycling:* Tropospheric ozone is known to alter leaf pore responses to environmental stimuli. In the short term (at higher concentrations) ozone can cause leaf pores to close; however, under prolonged chronic exposure (at lower concentrations) many scientific papers document ozone-induced leaf pore opening or loss of leaf pore sensitivity to closing stimuli, such as drought, light and humidity. No clear patterns emerged from the literature for the ozone concentration range for the different responses, except perhaps a tendency for opening to occur at lower concentrations than closure, particularly in trees.

8. **Provisioning services**. Impacts of ozone pollution on provisioning services include impacts on:

(a) *Crop production:* The key components of the food system that ozone interferes with are the productivity of crops, their nutritional value and the stability of food

[3] Gina Mills, Serena Wagg and Harry Harmens, eds., *Ozone pollution: Impacts on ecosystem services and biodiversity* (Bangor, United Kingdom: ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, 2013). Available from http://icpvegetation.ceh.ac.uk/publications/thematic.html.

supplies, as ozone concentrations, and therefore impacts, vary from year to year. Some of the world's most important staple food crops are sensitive (wheat, soybean and other pulses) or moderately sensitive (maize, rice, potato) to ozone, and effects on the yield of these crops are of global significance. A recent report by ICP Vegetation[4] for the first time quantified ozone impacts on wheat yield in Europe using the flux-based methodology and predicted that losses would be 9 per cent in 2020, amounting to €2 billion in the 27 member States of the European Union (EU-27) plus Norway and Switzerland. Current ambient ozone levels in South Asia are also considered to be reducing crop yield and quality for a range of important crops in the region, commonly within the range of 10 to 20 per cent;

(b) *Timber production:* A recent meta-analysis has suggested that the increase in ozone since the industrial revolution has been responsible for a reduction in photosynthesis of approximately 11 per cent in trees, which may have reduced tree productivity by approximately 7 per cent. In general, deciduous trees tend to be more sensitive to ozone than coniferous trees, with ozone-sensitive species present across most of Europe. Using national forest age class statistics, ozone response relationships for different species and ages, a model of stem increment growth and national mean accumulated ozone over a threshold of 40 $\mu g/m^3/h$ (40AOT40) values, it was estimated that losses in C stocks in the living biomass of trees averaged 10 per cent across 10 Northern European countries, with the highest losses predicted for the Czech Republic, Germany and Poland.

9. **Regulating services**. Impacts of ozone pollution on regulating services include impacts on:

(a) *C sequestration and global warming:* If ozone concentrations are high enough to reduce photosynthesis (i.e., carbon dioxide (CO_2) fixation) and/or above-ground plant growth, then less CO_2 and ozone will be absorbed by the leaves of vegetation, leading to a positive feedback to atmospheric CO_2 and ozone concentrations and therefore more global warming. ICP Vegetation recently conducted the first flux-based assessment of effects of ozone on C sequestration in the living biomass of trees in Europe, focusing on 2000 and 2040 effects.[5] This study showed that applying the flux-based methodology using a climate-region specific parameterization for 2000 revealed C reductions of 14 per cent in the living biomass of trees. Predictions for 2040 indicated that the reduction of C storage is expected to decrease considerably compared with the reduction in 2000, mainly as a result of a predicted reduction in atmospheric ozone concentrations across Europe (see ECE/EB.AIR/WG.1/2012/3 and ECE/EB.AIR/WG.1/2012/8);

(b) *Air quality:* Globally, it has been estimated that ozone deposition to vegetation (by reaction with plant surfaces and uptake through the leaf pores) reduces tropospheric ozone concentrations by as much 20 per cent. This is an especially significant function of vegetation given that ozone is the third most important greenhouse gas causing global warming. Under drought conditions, however, plants close leaf pores to conserve water and uptake of ozone is substantially reduced, with one study indicating that the European summer heat wave in August 2013 led to a 20 to 30 parts per billion (ppb) increase in ozone concentration. A further level of complexity involves ozone-induced

[4] Gina Mills and Harry Harmens, eds., *Ozone pollution: A hidden threat to food security* (Bangor, United Kingdom: ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, 2011). Available from http://icpvegetation.ceh.ac.uk/publications/thematic.html. See also ECE/EB.AIR/WG.1/2011/3, ECE/EB.AIR/WG.1/2011/8 and ECE/EB.AIR/WG.1/2012/3.

[5] Harry Harmens and Gina Mills, eds., *Ozone pollution: Impacts on carbon sequestration in Europe* (Bangor, United Kingdom: ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, 2012). Available from http://icpvegetation.ceh.ac.uk/publications/thematic.html.

emission of biogenic volatile organic compounds (BVOCs) from plants, which can either react with ozone to reduce concentrations or lead to ozone formation;

(c) *Methane emissions:* There is evidence that ozone may influence emissions of the greenhouse gas methane from wetlands, although the results are less conclusive than for CO_2 effects. Global estimates of carbon sequestration in peat-lands are in the region of 20–30 g C m^{-2} yr^{-1}, and thus any effects of increasing ozone are of global significance for climate regulation. Results from experiments are rather mixed, with some studies indicating methane increases, while others show a decrease. The inconsistencies in these effects are most probably due to differences in species present and concentration and duration of ozone exposure;

(d) *Water cycling:* As described in paragraph 7 (c) above, there are two main responses of the leaf pores to ozone, each potentially having an opposite effect on the water cycle: ozone-induced closure will preserve water within soils, while ozone-induced opening will increase water loss from vegetation and soils. Global climate modellers have until recently assumed the former mechanism is dominant, but very recently the implications of increased water loss as a result of chronic ozone exposure are beginning to be considered within such models. Extensive measurements of a southern Appalachian forest in the United States of America have indicated an enhancement of the amplitude of daily water loss from native trees with increasing ambient ozone exposure, resulting in a reduction of water run-off and river flow rates in the catchment;

(e) *Flowering, pollination and insect signalling:* Reported ozone-induced changes in the number of flowers and timing of flowering will play an important role in the reproductive success of plants, particularly for species in which flowering is closely synchronized with pollinating species. A recent meta-analysis of ozone effects on plant reproductive growth and development indicated that current ambient ozone concentrations significantly reduce seed number (16 per cent), fruit number (9 per cent) and fruit weight (22 per cent), while there was a trend towards increasing flower number and weight. Floral scent trails, important in pollinator attraction and plant defences against herbivorous insects, have also been shown to be destroyed or transformed by ozone. These ozone-induced changes in flowering timing and signalling could have large ecological impacts;

(f) *Plant biodiversity and species balance:* Typical effects of ozone on sensitive species include accelerated aging and changes in biomass, resource allocation and/or seed production. Each of these can impact on the vitality of component species of plant communities, potentially altering plant biodiversity as well as that of the animals, fungi, bacteria and insects that live in close association with plants or in nearby soils. In so doing, ozone-induced changes in species diversity or shifts in species balance will impact on many ecological processes, thereby impacting on ecosystem services, flows, goods and values. Effects on species balance have been widely reported from controlled exposure experiments, but a less clear picture emerges from field-based studies with long established communities and from field surveys. Although more studies are needed, it is clear that impacts of ozone are of particular concern for global biodiversity hotspots, such as the Mediterranean basin.

10. To enable a comprehensive quantitative assessment of ozone impacts on ecosystem services, including an economic valuation, the following further research is recommended:

(a) A systematic review and data mining exercise for each ecosystem service to derive generic response functions for calculation of effects;

(b) Experimental work for those ecosystem services for which there is insufficient experimental information available to derive response functions (e.g., quantification of below-ground impacts of ozone on C sequestration in roots and soils; decoupling between photosynthesis and leaf pore conductance; responses in a future climate, including elevated CO_2; and large-scale field-exposure experiments on intact ecosystems, including impacts on biodiversity and species balance);

(c) Spatial analysis of ozone impacts on ecosystem services (using appropriate spatial data);

(d) Further research on economic valuation methods and, where possible, cost-benefit analysis for future air pollution and climate scenarios.

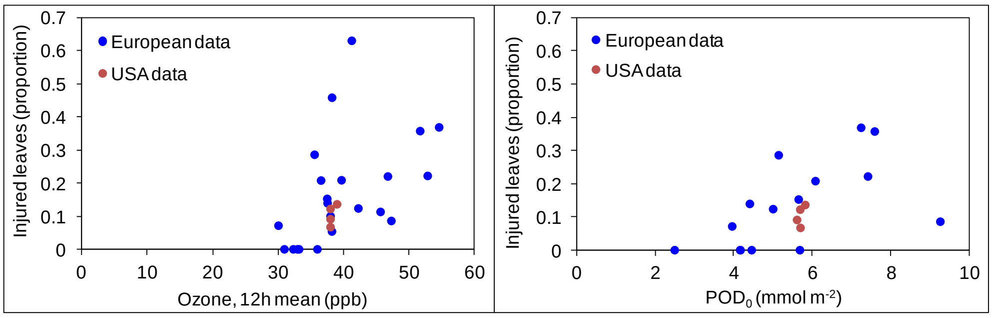
IV. Supporting evidence for ozone impacts on vegetation (ongoing activity)

11. The data from the 2008–2012 biomonitoring and ozone exposure experiments with beans were combined into a database for dose-response analysis.[6] Over 3,000 leaf pore conductance measurements were made and used to generate an ozone flux model for beans. Over the course of the two-to-three month experiment, hourly accumulated ozone flux (phototoxic ozone dose (POD_0)) ranged from 4.4 (Bangor, United Kingdom of Great Britain and Northern Ireland) to 18.9 (Seibersdorf, Austria) mmol m^{-2}. Visible ozone injury (bronze stippling) regularly occurred across the network. Using the data for sites where ozone injury had occurred within the first four weeks on the ozone-sensitive variety and less than 15 per cent of leaves were injured on the resistant variety of bean, there was an indication of a threshold for the proportion of injured leaves of a 12 hour (h) mean of circa (ca.) 35 ppb and a POD_0 of ca. 4 mmol m^{-2} (figure 1).

12. The analysis conducted so far has not found a clear dose-response relationship between ozone parameters such as the 12h mean or POD_0 for the yield biomass ratio between the ozone-sensitive and resistant variety. Overall, the bean biomonitoring system does seem to provide a good indication of the occurrence of ozone concentrations that are high enough to visibly damage plants. As such it is very valuable for use in countries just joining the ICP Vegetation programme, as proof or otherwise that ozone levels are causing damage. However, ICP Vegetation is concerned that differences between the sensitive and resistant varieties are not strong enough for continued application as a biomonitor for yield effects.

Figure 1

Relationships between proportion of leaves injured on ozone-sensitive bean plants after four weeks exposure to ambient air and 12h mean ozone concentration (left) and stomatal flux (POD_0) (right) at the sites



[6] Harry Harmens and others, *Air Pollution and Vegetation: ICP Vegetation Annual Report 2012/2013* (Bangor, United Kingdom: ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, 2013). Available from http://icpvegetation.ceh.ac.uk/publications/annual.html.

V. Report on the pilot study of mosses as biomonitors of persistent organic pollutants (new activity)

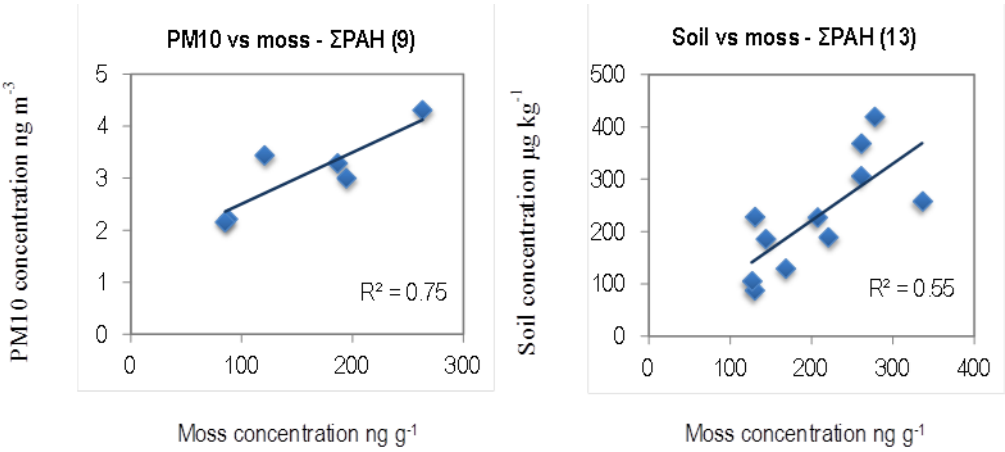
13. A recent review study[7] by ICP Vegetation has shown that mosses are suitable organisms to monitor spatial patterns and temporal trends of atmospheric concentrations or deposition of POPs, including polycyclic aromatic hydrocarbons (PAHs), polychlorobiphenyls (PCBs), dioxins and furans (PCDD/Fs), and polybrominated diphenyl ethers (PBDEs) (i.e., flame retardants). Six countries conducted a pilot study in 2010 on the application of mosses to monitor atmospheric deposition of POPs: France, Norway, Poland, Slovenia, Spain and Switzerland, with only Norway analysing other compounds in addition to PAHs (Harmens et al., 2013b).[8]

14. In Norway, the observed geographical distribution of the concentration of selected POPs (PCB, dichlorodiphenyltrichloroethane (DDT), PAHs and PBDEs) in mosses indicated that the concentration in mosses reflect the atmospheric deposition patterns well. For most of the POPs the concentration in mosses decreased with northern latitude (similar to heavy metals), indicating that long-range atmospheric transport contributes to the higher concentrations observed in southern Norway.

15. In Switzerland, high concentrations of PAHs were found in mosses sampled in the region of Basel (chemical industry), while low concentrations were observed in the western part of the central plateau where the population density is relatively low. There was a good correlation between the summed PAHs concentration in mosses and the concentration in coarse particulate matter (PM_{10}) and soil (figure 2).

Figure 2

Relationship between the sum (Σ) of PAHs concentration in mosses and PM_{10} (left) and soil (right) in Switzerland



16. The total PAHs concentrations in mosses was significantly lower in Navarra, a rural area in Spain, than in Île-de-France (metropolitan area of Paris) and in Switzerland, particularly in the Basel region. The concentration of heavy PAHs in mosses varied partly with the level of urbanization in a 10 kilometre radius. This was not the case for lighter PAHs, as they are mainly emitted by road traffic. Hence, mosses sampled in Navarra were

[7] H. Harmens and others, "Terrestrial mosses as biomonitors of atmospheric POPs pollution: A review", *Environmental Pollution*, vol. 173 (February 2013), pp. 245–254.

[8] Harry Harmens and others, *Air Pollution and Vegetation: ICP Vegetation Annual Report 2012/2013*.

characterized by a low percentage of heavy PAHs due to the low degree of urbanization in Navarra. Specific correlations with heavy metal concentrations in mosses confirmed that the main PAH emission sources in Switzerland and Navarra were industrial activity and road traffic, respectively. The total PAHs concentration in mosses was the lowest in Norway and Slovenia and the highest in Poland.

VI. Final report on the European heavy metals and nitrogen in mosses survey 2010/11 (ongoing activity)

17. For details on the European heavy metals and nitrogen in mosses survey 2010/11 see the ICP Vegetation report, “Heavy metals and nitrogen in mosses: spatial patterns in 2010/11 and long-term temporal trends (1990–2010) in Europe” (ECE/EB.AIR/WG.1/2013/13) and *Heavy metals and nitrogen in mosses: spatial patterns in 2010/2011 and long-term temporal trends in Europe*.[9]

VII. Meeting of the Programme Task Force

18. The twenty-sixth meeting of the ICP Vegetation Programme Task Force was held in Halmstad, Sweden, from 28 to 30 January 2013. The meeting was hosted by the IVL Swedish Environmental Research Institute and the Department of Biological Sciences, Gothenburg, with financial support from the Swedish Environmental Protection Agency. The meeting was attended by 63 experts from 21 countries, including 17 Parties to the Convention and guests from Brazil, China, Japan and Pakistan.

[9] Harry Harmens and others (Bangor, United Kingdom: ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, 2013). Available from http://icpvegetation.ceh.ac.uk/publications/thematic.html.