ICP FORESTS
BRIEF #3
2018

ICP Forests

Ozone concentrations are decreasing but exposure remains high in European forests

KEY MESSAGES

1. Ozone is a gaseous air pollutant present in remote areas at levels causing visible symptoms in plants

2. Despite a significant reduction, ozone levels at ICP Forests sites still exceed the threshold value for adverse effects

3. Ozone-induced foliar symptoms have been observed on woody plant species all across Europe

4. Further observational and long-term monitoring studies are needed to better quantify dose-response relationships and a potential impact on forest growth

THÜNEN
WSL
wge Working Group on Effects of the Convention on Long-range Transboundary Air Pollution
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LRTAP Long-range Transboundary Air Pollution

This ICP Forests brief describes the current status of ground-level ozone concentrations and effects on forest vegetation across Europe since 2000.

Measuring air pollutants in forests is important for evaluating the risk for vegetation in areas not covered by conventional air quality monitoring networks. Within ICP Forests, ozone measurements are carried out at 233 forest monitoring sites in 18 countries under the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone. Data are also collected on ozone-related visible symptoms and other ecosystem properties such as tree growth, nutrition, and biodiversity, as well as climate. This makes ICP Forests long-term monitoring essential for impact assessment and air pollution modelling, offering vast research opportunities across disciplines.

Why is ozone an issue for forest ecosystems?

The 'ozone layer' is a band of high ozone concentrations in the stratosphere that protects life on Earth by absorbing ultraviolet radiation from the sun. In contrast, however, high ozone concentrations at ground level can be harmful to people, animals, plants and materials. Ground-level ozone concentrations are of particular concern for crops and forests because concentrations are often higher in rural/remote areas. Impacts include biochemical, physiological and morphological responses – damaging leaves and needles of sensitive plants and affecting plant growth, reproduction, hydrology, and response to co-occurring stressors. While the direct effects of ozone exposure on woody species are apparent in terms of foliar symptoms, indirect effects on tree growth and vitality are far less clear and – on the basis of ICP Forests data – general conclusions cannot yet be drawn. The role of interacting factors (such as nitrogen deposition, climate, tree age, site conditions and tree-/species competition) should also be considered.

A slight but significant decline

Trend analysis of ICP Forests data reveals a slight but significant decrease in growing season (April–September) ozone concentrations between 2000 and 2014 (0.63 ppb per year).

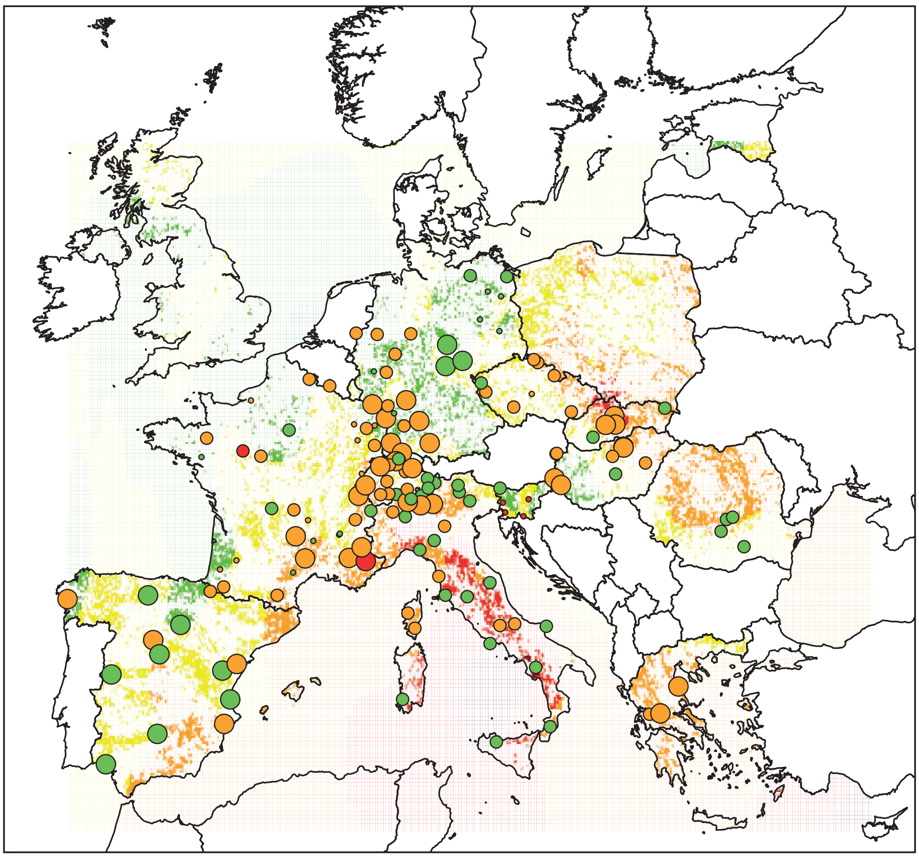
These findings are consistent with those of the European Environment Agency (EEA), the European Monitoring and Evaluation Programme (EMEP) and other studies of ground-level ozone trends in air reporting a decline in peak ozone concentrations, combined with a slight increase or stabilisation of annual mean ozone concentrations.

Marked north-south gradient

The long-term mean ozone concentrations in the growing season (April–September) showed an increasing trend from north to south in forests across Europe for the period 2000 to 2014 (average: 36.2 ppb, ranging from 14.5 to 70.1 ppb). The highest concentrations occurred in Italy, southern Switzerland, the Czech Republic, Slovakia, Romania and Greece.

Exposure and risk

ICP Forests data for the period 2002–2014 reveal that ozone-induced symptoms in woody plant species occur every summer on many plots and species across Europe. The relationship between ozone exposure and visible symptoms is not straightforward, however. Ozone-induced symptoms may be found on plots with low summer background concentrations (20–30 ppb) while infrequent (or even no) symptoms may be found on plots with high concentrations (>50 ppb). This reflects the various species-specific sensitivities of trees to ozone and the influence of environmental factors such as nutrition, water availability and climate. Foliar symptoms are the only ozone-specific visible diagnostic tool readily usable in the field. They provide a way to detect potential ozone effects on natural vegetation on a qualitative basis. Quantitative estimates of risk (e.g. reduced tree growth – which can occur even in the absence of visible symptoms) require complex modelling approaches, including the calculation of ozone fluxes into leaves/needles (such as the phytotoxic ozone dose – see page 4).



▲ Spatial distribution of April–September mean ozone concentrations interpolated from 18,464 passive samplers on 206 plots in 15 countries for the period 2000–2014 (background colour) and occurrence of ozone-induced foliar symptoms on 155 plots in 11 countries for the period 2002–2014 (coloured dots).

Ozone-induced symptoms in European tree species

▲ European beech (*Fagus sylvatica* L.)

▲ European ash (*Fraxinus excelsior* L.)

▲ Poplar (*Populus* x *berolinensis* Dippel)

▲ Wayfarer (*Viburnum lantana* L.)

Future developments

Additional experimental and long-term monitoring studies are needed to further the understanding of ozone effects on forest ecosystems and the impacts of ozone on tree growth under real conditions. Upscaling these results to longer timescales and wider geographical areas will require the development of appropriate physiological and ecosystem modelling tools, from the tree to the landscape level.

Suggested reading

Cailleret M et al., 2018: Ozone effects on European forest growth - towards an integrative approach. Journal of Ecology. doi:10.1111/1365-2745.12941.

Calatayud V, Schaub M, 2013: Methods for measuring gaseous air pollutants in forests. In: Ferretti M, Fischer R (eds), 2013: Forest Monitoring: Methods for terrestrial investigations in Europe with an overview of North America and Asia. pp. 375-384. Elsevier.

Ferretti M et al., 2018: Scarce evidence of ozone effect on recent health and productivity of Alpine forests – A case study in Trentino, N. Italy. Environmental Science and Pollution Research, 25. doi:10.1007/s11356-018-1195-z.

Mills G et al., 2017: Flux-based critical levels of ozone pollution for vegetation: Overview of new developments 2017. ICP Vegetation Programme Coordination Centre, CEH, UK, 8 pp.

Schaub M, Calatayud V, 2013: Assessment of visible foliar injury induced by ozone. In: Ferretti M, Fischer R (eds), 2013: Forest Monitoring: Methods for terrestrial investigations in Europe with an overview of North America and Asia. pp. 205-221. Elsevier.

Ground-level ozone is formed in the air by the reaction of UV radiation (sunlight) and nitrogen oxides, carbon monoxide, and volatile organic compounds.

This may happen hundreds of kilometres from the emission source.

Mean ozone concentrations are highest in late spring/summer and peak around midday with a seasonal (April–September) average of around 30–100 µg m^{-3} or 15–50 ppb.

Ozone concentrations have been monitored in ICP Forests since 2000 using passive samplers at intensive monitoring plots. Because the impact of ground-level ozone on plants depends not only on concentration and exposure, but also (and mainly) on uptake by plants, three metrics are currently applied to describe risk:

Ground-level ozone concentration

Reported as volume per volume, in parts per billion (ppb), or as mass per volume, µg m^{-3}. 1 ppb = 1.96 µg m^{-3} under standard conditions.

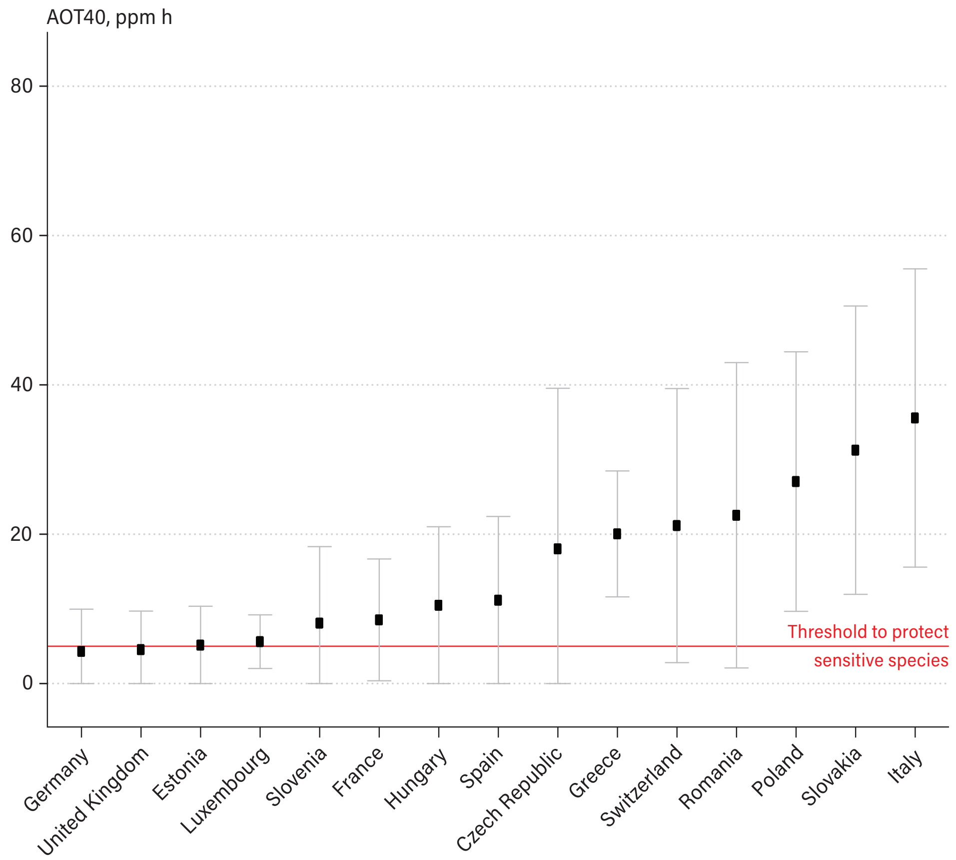
Ozone exposure

Reported as the length of time and the amount by which ozone concentrations are accumulated over a threshold of 40 ppb (AOT40), in ppm h.

Phytotoxic ozone dose (POD)

Ozone taken up by leaves/needles above a species-specific threshold y nmol m^{-2} s^{-1} (PODySPEC) in mmol m^{-2} plant leaf area.

High ozone exposure in forests across Europe



Between 2000 and 2014, accumulated ozone exposure over a threshold value of 40 ppb (referred to as 'AOT40') ranged from 4.3 to 35.5 ppm h. The AOT40 threshold of 5 ppm h – set to protect sensitive tree species from adverse ozone effects – was exceeded in 13 out of 15 countries.

◀ Mean AOT40 for 15 countries based on April–September ozone concentrations measured with passive samplers (n = 18,464 samples) for the period 2000–2014 at 206 ICP Forests intensive monitoring plots.

United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (Air Convention) International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)

The data underlying this Brief were collected through ICP Forests. Monitoring sites are maintained by the ICP Forests member states and a wide range of environmental parameters and ecosystem responses are regularly assessed. See ICP Forests Brief #1 for further details.

For further information, please contact:
Programme Co-ordinating Centre of ICP Forests
Dr Walter Seidling, Head
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde, Germany
Email: pcc-icpforests@thuenen.de
http://icp-forests.net

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Authors: Marcus Schaub[1,2], Matthias Haeni[1,2], Vicent Calatayud[3], Marco Ferretti[1,2], Elena Gottardini[4]

[1]Swiss Federal Research Institute WSL, Switzerland, [2]SwissForestLab, Switzerland, [3]Fundación CEAM, Spain, [4]Research and Innovation Centre, Fondazione Edmund Mach, Italy

Series editors: Alexa K Michel, Walter Seidling
Copy editor: Carolyn Symon, carolyn.symon@btinternet.com
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