Tropospheric ozone (O₃) is a gaseous air pollutant that can impact forest vegetation, causing effects ranging from visible injury to reduced carbon sink strength of forest trees, and it is thus a priority for the UNECE Convention on Long-range Transboundary Air Pollution. Emissions associated with the burning of fossil fuel and biomass have approximately doubled the mean global tropospheric ozone concentrations, and further increases are expected over the course of the twenty-first century.

**Ozone concentrations, exposure and trends**

Most recent results from measurements made using passive samplers located on ICP Forests Level II sites across Europe reveal that seasonal mean ozone concentrations recorded in April-September from 2000 to 2013 ranged from 19 to 64 ppb, with an apparent north-south gradient (Fig. 4.1).

AOT₄₀ ozone exposure (Accumulated concentrations Over a Threshold of 40 ppb, the regulatory air quality standard used in Europe to estimate the potential risk posed to vegetation) was assessed. Mean values of AOT₄₀ for 2000-2013 ranged from 2 to 67 ppm h. The AOT₄₀ threshold of 5 ppm h set to protect forests from adverse effects was exceeded in almost all countries (Fig. 4.2).
The overall decreasing trend of 0.35 ppb per year during the time period 2000 to 2013 (Fig. 4.3 and 4.4) matches the latest findings of the European Monitoring and Evaluation Programme (EMEP), which indicates that modelled maximum values decreased by 0.1 to 0.5 ppb per year for the April-September period in most of Europe during 2000 to 2012. This is also consistent with a number of studies reporting a flattening or even reduction in the ozone levels, most pronounced in summer. However, there are also European reports showing that there are no downwards trends in ground-level ozone concentrations.

The differing outputs from various trend reports demonstrate the difficulty of modelling concentration trends. This underlines the great value of long-term air pollution measurements made at the very forest site as a means of ensuring the greatest possible accuracy and in situ model validation.

Figure 4.3: Scatter plot for ozone concentration (ppb) from passive samplers exposed in 20 countries from 2000 to 2013, showing a faint but significant decrease of 0.35 ppb per year (n = 29,356; p = 0.000).

Figure 4.4: Spatial distribution of significant trends in weighted mean concentrations (ppb) on 214 sites with at least 6 years and 120 days per season data coverage between 2000 and 2013. Empty circles identify those plots for which trends could not be calculated (< 6 years of validated data).
Risk assessment at remote forest sites

Risk assessment at remote sites is often constrained by the limited availability of in situ data to estimate ozone exposure. Conventional monitoring of ground-level ozone is possible and affordable only on a very limited number of sites, and conventional monitoring located in urban areas cannot be readily used to infer risks to forests. ICP Forests data offers a unique opportunity in this respect. There have been several attempts to estimate risk to European forests using ICP Forests data.

In a former European study with passive samplers placed on 81 Level II plots, concentrations during 2000–2004 ranged from 30–45 ppb at most of the stations. The highest ozone concentrations occurred in southern Europe, especially in northern Italy, southern Switzerland, and Spain. From 2000 to 2002, the AOT40 threshold of 5 ppb h to protect forests was exceeded at 77–100% of the same forest sites across France, Italy, Spain and Switzerland.

More recently, in the mountainous environment of Trentino in Italy, geo-statistical modelling and mapping has been applied on the basis of ozone concentration data collected from 2007 to 2011 by means of passive sampling on ICP Forests Level I plots over an area of 6207 km2. Mean (May–July) concentrations ranged from 29.5-86.1 ppb, and the AOT40 risk threshold of 5 ppb h was exceeded on 90% of the study area. Considerable variability was found between AOT40 values at individual sites, even within the same EMEP grid cell.

Another study conducted in the Jizerské hory mountains in northern Italy, used Viburnum lantana as an in situ bio-indicator to assess the impact of ambient ozone on plants growing on site in the forest. Foliar symptoms were observed only on Rubus idaeus and Fagus sylvatica, two species for which the role of confounding factors such as heat and high radiation can also be important.

One way of disentangling the complex interactions between species-specific sensitivity and environmental factors in order to assess the actual “net impact” of ambient ozone on plants growing on site in the forest may be the use of single species in situ bio-indicators. Studies conducted in Trentino, a mountainous region in northern Italy, used Viburnum lantana as an in situ bio-indicator to assess the frequency and temporal development of visible symptoms (Fig. 4.5) at sites subjected to different levels of ozone and plant response under real conditions in the field.

Figure 4.5. Typical ozone-induced symptoms on Viburnum lantana.

Visible foliar symptoms are usually the first sign of the presence of phytotoxic ozone levels, and their measurement is a method of monitoring the potential impact of ozone on vegetation. From 2000 to 2002, a total of 65 species representing 52 genera were seen to be manifesting symptoms of ozone damage in Spain, Italy and Switzerland. Species showing symptoms were found on 47% of the common monitoring plots in 2001, and on 38% in 2002. However, the complex set of interactions (ozone levels, factors controlling the uptake, and defensive mechanisms) sometimes makes it difficult to establish a clear dose-response relationship between ozone and plant response under real conditions in the field.
30 years of monitoring the effects of long-range transboundary air pollution on forests in Europe and beyond
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United Nations Economic Commission for Europe (UNECE)
Convention on Long-range Transboundary Air Pollution (CLRTAP)
International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)

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ISSN 1020-587X
e-ISSN 2198-6541

Recommended form of citation: Sanders TGM, Michel AK, Ferretti M (2016) 30 years of monitoring the effects of long-range transboundary air pollution on forests in Europe and beyond UNECE/ICP Forests, 67 p.

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EDITING
Tessa Feller, Lohr am Main

LAYOUT
Werbeagentur Herrmann, Eberswalde

PRINTED BY
Spree Druck Berlin GmbH

Printed in Germany
For further information please visit our website: www.icp-forests.net