ICP Forests

# Forest Conditions

ICP FORESTS 2016 EXECUTIVE REPORT

2016

THÜNEN

# FOREST CONDITIONS

## ICP FORESTS 2016 Executive Report

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

www.icp-forests.net

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# CONTENTS AND SUMMARIES

Soil and freshwater acidification was a main concern when international clean air initiatives under the umbrella of the UNECE started in the 1970s and 1980s. While human-activity-generated deposition has declined over the past decades, we still need to consider legacy effects of acidifying substances that have accumulated in forest soils. Monitoring and evaluating soil acidification - in Europe and in individual countries - is therefore still highly relevant for current and future forest management decisions.

Although an essential nutrient for all living organisms, nitrogen can be harmful in many ecosystem types if available in excess. Forest soils in parts of central Europe, an area once highly loaded by inorganic nitrogen deposition, show now the first signs of recovery. However, large parts of Europe still suffer from inorganic nitrogen inputs above critical levels. Its control is therefore absolutely necessary. Only efficient monitoring systems can provide sufficient accurate information in order to maintain forest ecosystems in an appropriate condition.

Current ozone ($O_3$) levels are high enough to negatively affect vegetation and may become worse in the future. To provide a scientifically-sound basis for decision-makers, a comprehensive knowledge of spatial and temporal patterns of ozone concentration and its effects on vegetation is crucial. Therefore, long-term measurements of environmental drivers such as ozone concentrations that may affect forest conditions across Europe are essential to derive cause-effect relationships for a proper risk assessment under climate change.

# PREFACE

It is a pleasure for me to introduce the 2016 Executive Report of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The Ministry of Sustainable Development and Infrastructure of Luxembourg supports and encourages the ongoing work of the programme and has hosted this year's Task Force meeting.

Since the "Waldsterben" was identified occurring in the early 1980s, we have recognized how vulnerable our forests are. Alarming changes such as crown damage, dead trees and the acidifications of soils were observed in Central Europe. Over the years, a degradation of forest health was detected. In this context it is our task and obligation to adopt the best strategies aimed at protecting and developing our forests.

However, pollution inputs are still too high at many forest sites, especially in Central Europe. Critical loads are still being exceeded and models predict that it will be decades before forests recover from earlier pollution inputs even if the 'clean air' policies continue to be applied.

Meanwhile new questions are bothering policy-makers, forest managers and the public: How does climate change impact our forests? How will the forests respond to higher temperatures and changes in the water regime? How well prepared are they for the expected, far-reaching changes? How can we support the forestry sector in adapting to climate change?

In order to manage our forests to their full potential, we need to have up-to-date information on the condition of these ecosystems, the species present on site and future trends. We aim to achieve this through a systematic programme of surveys and monitoring. This is why it is so important that ICP Forests has been monitoring the condition of the European forests for the past 30 years.

I am convinced that based on the well-proven expertise and established infrastructure, ICP Forests will respond to these requirements and I encourage ICP Forests to continue this important work and wish continued success for the future.

Camille Gira

Secretary of State
for Sustainable Development
and Infrastructure, Luxembourg

Seidling

# 1 FOREST SOIL ACIDIFICATION IN EUROPE TODAY

## Status, trends, management implications

Human activity during the second half of the 20th century caused an increase in levels of sulphate and inorganic nitrogen from air pollution, which contributed to soil acidification across large parts of Europe. Temperate and more northerly (boreal) forests often grow on acidic soils that are sensitive to the effects of an increase in levels of acidity. Because of its effects on the balance between chemical elements in the soil and weathering of minerals, an increase in acidity allows greater quantities of important plant nutrients (base cations – calcium, magnesium, potassium, sodium) and aluminium to dissolve from soil into soil solution. This in turn increases the rate at which these nutrients are leached from the soil with seepage water, and increases the risk of aluminium having a toxic effect on fine roots. The levels of these chemicals dissolved in the soil (soil solution) monitored within ICP Forests under the Working Group on Effects of the UNECE Convention on Long-range Transboundary Air Pollution thus reflects the impact of sulphate and inorganic nitrogen deposition on levels of acidity in forest soils. Examining soil solution can therefore be used to follow up soil recovery processes, providing "real time" information on the response of soils to reductions in polluting emissions.

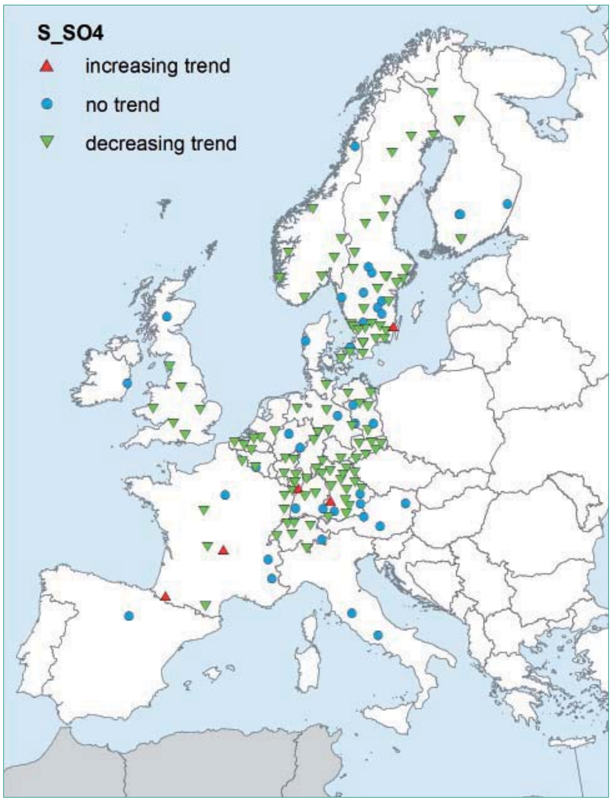
**Forest monitoring indicates that the rate at which sulphate is deposited has strongly decreased in Europe over the past two decades.** Inorganic nitrogen deposition has also decreased in Western and Central Europe, but to a lesser extent than sulphate, and in parts of Northern and Eastern Europe it has even slightly increased. These results complement measurements of emissions from the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP). The following four examples, presented at the Scientific Conference of ICP Forests in Luxembourg in 2016, illustrate the effects of declining levels of acid deposition on soils and soil solution at national and European scales.

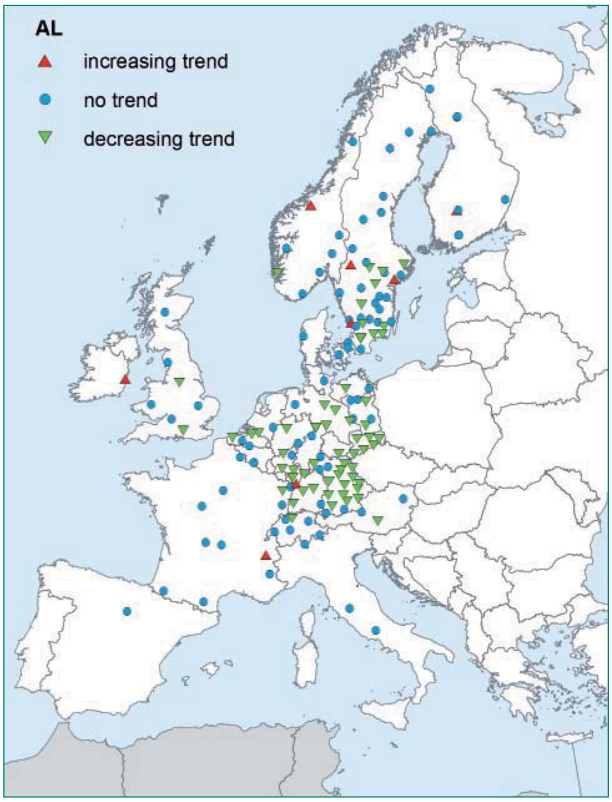
(i) **Sulphur emission reductions have significantly reduced the rate at which key nutrients and aluminium dissolve from soils into soil solution.** The response of soil solution to changes in deposited acidity from the atmosphere was evaluated for 177 European Level II ICP Forests intensive monitoring sites at which soil solution had been collected for at least 10 years. Results indicate a strong significant decline in the concentration of sulphate (S-SO4), total aluminium (Al) and base cations (BC) in soil solution at the European scale (Figure 1-1, Table 1-1).

The decline was more evident in coniferous forests and in areas with the greatest reduction in rates at which sulphate is deposited. These results suggest that reductions in sulphur emissions have significantly reduced the rate at which key nutrients (base cations), as well as total aluminium, are dissolved from soils into soil solution. The parallel reduction of deposition of base cations has also contributed to a reduction of dissolved base cations in the soil solution.

| | **Soil depth interval** | |
|---|---|---|
| **variable** | **Mineral, 10-20 cm** | **Mineral, 40-80 cm** |
| pH | no trend | no trend |
| Log[Ca] | negative trend, $p < 0.001$ | negative trend, $p < 0.01$ |
| Log[Mg] | negative trend, $p < 0.05$ | negative trend, $p < 0.05$ |
| Log[K] | negative trend, $p < 0.01$ | negative trend, $p < 0.01$ |
| Log[Na] | no trend | no trend |
| Log[Cl] | no trend | no trend |
| Log[N-NO$_3$] | no trend | no trend |
| Log[S-SO$_4$] | negative trend, $p < 0.001$ | negative trend, $p < 0.001$ |
| Log[Al] | negative trend, $p < 0.01$ | negative trend, $p < 0.05$ |
| Log[BC] | negative trend, $p < 0.001$ | negative trend, $p < 0.01$ |
| Log[DOC] | no trend | negative trend, $p < 0.001$ |

*Table 1-1: Trends over time in [logarithmic] soil solution concentrations of elements or compounds sampled by tension lysimeters in upper (10-20 cm) and deeper (40-80 cm) mineral soil at investigated European Level II plots for at least 10 years; negative = decreasing trend; p: level of statistical significance.*





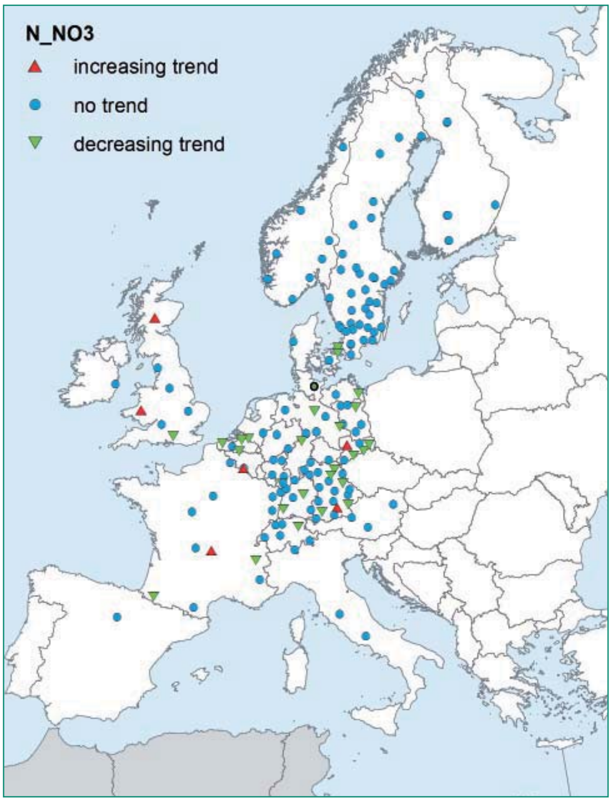


*Figure 1-1: Significantly decreasing, increasing, or no trend for [logarithmic] concentrations of sulphate (S-SO4), total aluminium (Al), and nitrate (N-NO3) in soil solution of the mineral soil at 40-80 cm depth at investigated Level II plots over at least 10 years.*

Nutrient losses from the soil with seepage water are therefore reduced likewise. Nitrate concentrations remain elevated in many parts of Western Europe and are still an important factor driving levels of acidity in soil there.

(ii) **Soil solution sulphate fluxes declined in Flanders.** Between 1994 and 2010, atmospheric deposition of inorganic nitrogen and sulphate strongly decreased at five Level II plots in Flanders, Belgium. Rates at which sulphate and ammonium were deposited by rain or other precipitation reaching the forest floor through the canopy (throughfall) decreased by 56-68% and by 40-59% respectively. Rates at which nitrate was deposited by throughfall decreased by 17-30% in the three deciduous forest plots, but remained stable in the two coniferous forest plots. Rates at which base cations (calcium, potassium, magnesium) were deposited by throughfall decreased at matching rates, resulting in a 45-74% overall net decrease in acid deposition.

Soil solution sulphate fluxes declined in all five plots, but less than expected from the observed decrease in sulphate deposition. A net release of sulphate was found only at two deciduous forest plots. Nitrate fluxes in the mineral soil decreased significantly at most soil depths in all Flemish plots.

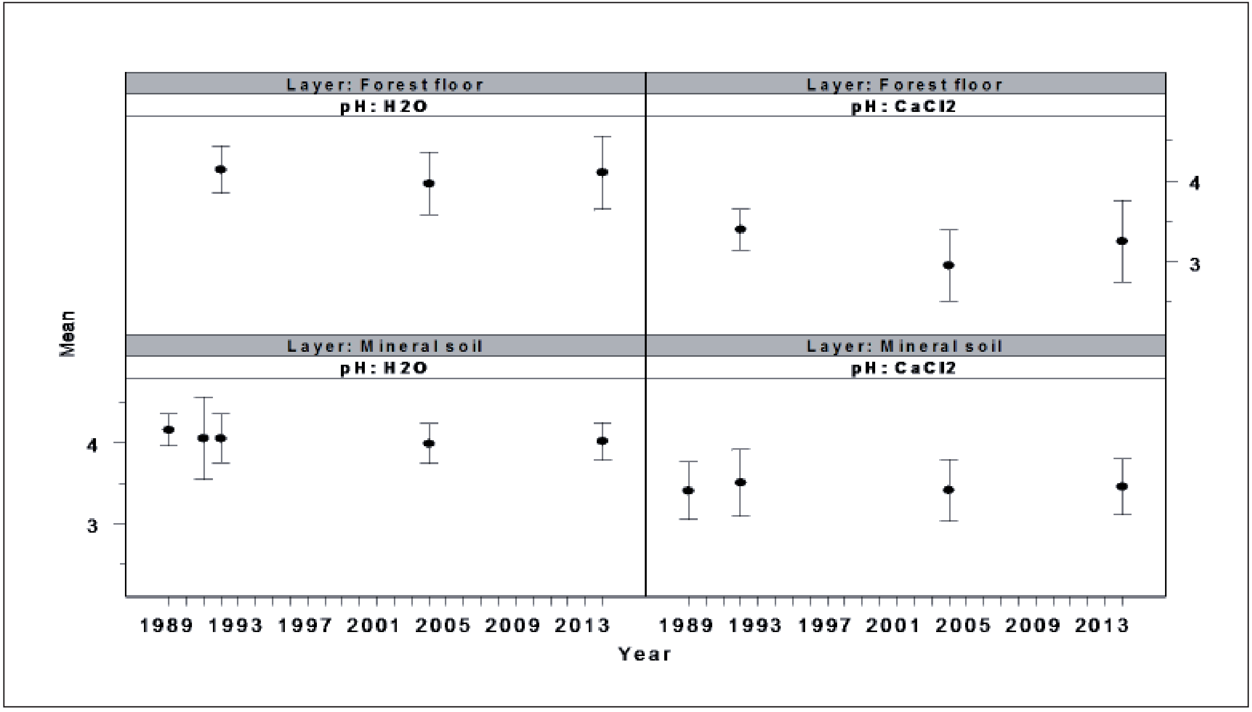


*Figure 1-2: Average (mean) pH measured in water (H2O) and mean pH measured in calcium-chloride (CaCl2) for the mineral soil layers and the forest floor sampled on 11 Level II monitoring plots in Flanders, Belgium.*

(iii) **Slight increase in soil pH in the forest floor indicates recovery from acidification.** More recently, data from the forest floor and mineral soil of eleven Flemish Level II plots sampled between 1989 and 2014 were compared. All plots are located on acidic forest soils with a topsoil pH measured in water around 4.0, within either the exchangeable cation or aluminium buffer range. Between 1990 and 2004 there was a slight decrease, and between 2004 and 2014 a slight increase, in soil pH in the forest floor, both significant (Figure 1-2). In the mineral soil layers respected effects can hardly be seen.

In the mineral soil, base (alkaline) saturation was measured between 1989 and 2014. Although the measurements include some uncertainties as a result of changes in some of the laboratory methods over time, the trends in base saturation in the mineral soil layers on these plots seem to confirm recovery from acidification. The average (mean) base saturation increased consistently in the same time span even if there is considerable variation across different locations (Figure 1-3).

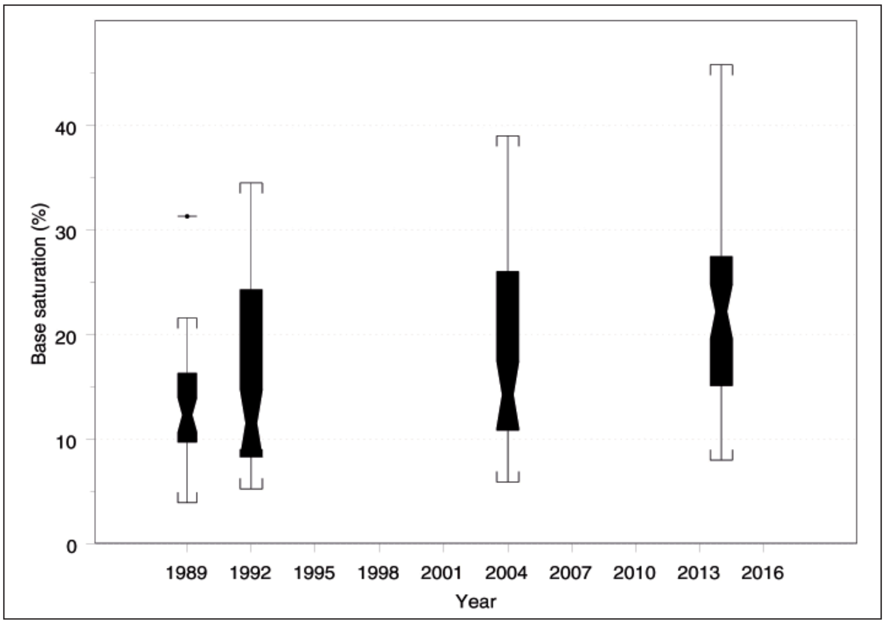


*Figure 1-3: Increase of the mean base saturation in the mineral soil between 1989 and 2014 on 11 Level II plots in Flanders, Belgium.*

## Securing nutritional sustainability

The fourth example highlights a situation that evolved in many countries, where levels of nutrients removed from the soil by harvesting of plants as a result of the increased demands for woody biomass are rising, while high amounts of sulphate and nitrate from earlier deposition are still moving through forest soils with seepage water. Forming strong negative ions (anions), they are accompanied by essential nutrients, which take the form of positive ions (base cations), and respective losses are unavoidable. To secure nutritional sustainability, sites with high nutrient losses caused by surplus nitrogen and sulphate must therefore be identified and managed accordingly.

(iv) **Sulphate still responsible for 40% and nitrate for 25% of the nutrient (cation) losses.** The output of nitrate, sulphate, and base cations with seepage was determined for more than 1,100 sites of a national forest soil survey in Germany using models based on data from ICP Forests Level II plots and other seepage water studies. In order to compare nutrient losses from seepage with nutrient removal by harvest, the average annual level of elements removed by harvesting was estimated for more than 50,000 German forest inventory plots, accounting for tree species composition and quantities of wood produced (yield class).

Figure 1-4 demonstrates that nitrate losses with seepage water varied quite considerably, but exceeded potential harvest exports of nitrogen for about 15% of the plots. Sulphur outputs were dominated by soil water fluxes and reflected the huge amount of sulphate still stored in forest soils. Magnesium losses with seepage clearly surpassed the assumed harvest exports. For calcium, harvest exports were dominant on acid soils, whereas both water seepage and losses through harvesting proved to be equally important on fertile but carbonate free soils. High seepage water output of calcium on chalky soils (high levels of calcium carbonate) was indicated by weathering of carbonates. Potassium was mainly removed by the harvesting of biomass, while losses with seepage water were low by comparison.

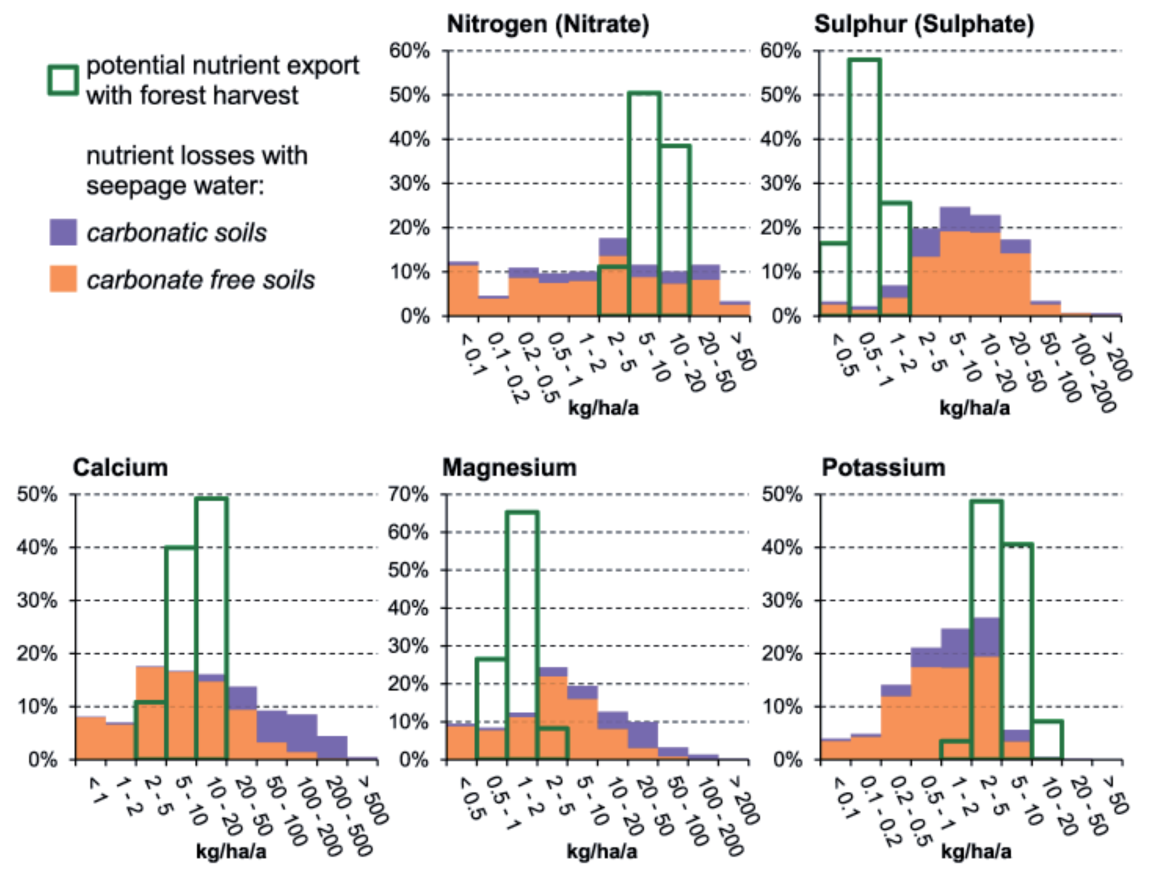


*Figure 1-4: Comparison between potential nutrient losses with harvest and nutrient losses with seepage water in German forests (both frequency distributions in percent and referring to one year; please note the unequal divisions on the x-axis).*

Considering seepage water output only, the striking result was that on average, sulphate was still responsible for 40% and nitrate for 25% of the cation losses on sites not dominated by carbonates. Even on chalky soils, sulphate and nitrate contributed almost 10% each to removal of nutrients. Despite decreased deposition of sulphur and nitrogen, the effects of acidifying deposition are thus still visible and will continue to affect element cycling in forest ecosystems.

The examples from the intensive ICP Forests monitoring and related surveys underline two applied aspects of forest monitoring: On one side, it delivers benchmark values for levels of acidic chemicals deposited from the atmosphere to be used in further clean air policies. On the other side, forest management gets information on the sustainable use of forest soils for future management decisions, which can be highly topical in view of green energy policies.


Gehrmann

**Further Reading:**

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Seidling

# 2 NITROGEN IN EUROPEAN FORESTS – ARE SETTINGS CHANGING?

## Nitrogen in deposition, soil and soil solution

During the second half of the 20th century, European forests received high inputs of nitrogen (N) from combustion processes, as well as husbandry and fertilisation of arable farmland. This caused significant changes to the way nitrogen cycles through both the biological and geological environment. Although nitrogen is an essential plant nutrient, its overload might be detrimental to ecosystems for several reasons. The intensive monitoring of forest ecosystems by ICP Forests not only records nitrogen deposition, but tracks it through the compartments of forest ecosystems.

While sulphate deposition has sharply decreased during the past two decades in Europe (see chapter 1), the rate at which inorganic nitrogen is deposited has declined more slowly, and critical loads and limits are still exceeded at about a third to half of ICP Forests Level II sites. Nitrogen saturation is thus still a major concern. Status and changes of nitrogen deposition, soil status and fluxes have been recently evaluated at the ICP Forests monitoring plots in different European countries.

The following four examples suggest changes in the forms of nitrogen emissions, reflected by changes in the way nitrogen is deposited. In part, this represents some recovery from the impacts of inorganic nitrogen deposition, but also shows signs of nitrogen saturation at sites that have historically received high levels.

(i) **Nitrogen deposition in Czech forests: increasing importance of $NH_4^+$**. A study of spatial patterns and temporal changes of inorganic nitrogen deposition in Czech forests was conducted based on long-term monitoring data of the Czech air quality network. Inorganic nitrogen deposition in the Czech forests has generally decreased over the longer term. Referring to the relative contribution of wet and dry nitrogen forms, the wet nitrogen deposition decreased more compared to the dry forms. Dry nitrogen deposition was exclusively recorded by the measurement of nitrogen oxides ($NO_x$); ammonia ($NH^3$) was not measured regularly, though it may contribute substantially to dry nitrogen deposition. Therefore, the ratio between ammonium nitrogen ($N\text{-}NH_4^+$) and nitrate nitrogen ($N\text{-}NO_3^-$) in wet deposition may reflect the share of different emission sources, pollution climate, and atmospheric chemistry. This ratio, both in precipitation and wet deposition has changed in the long-term at most sites, with an increasing importance of $NH_4^+$ (Figure 2-1).

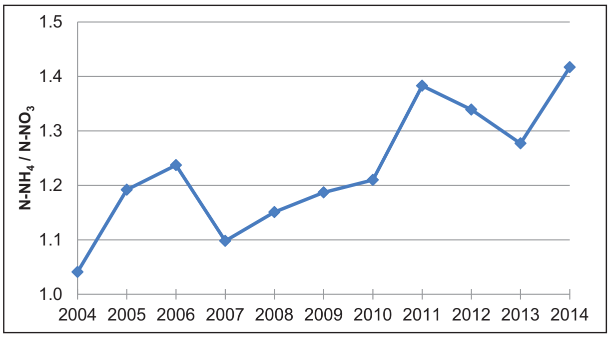

*Figure 2-1: Trend in $N\text{-}NH_4^+/N\text{-}NO_3^-$ ratio in wet atmospheric deposition between 2004 and 2014, calculated for the Czech forested area by using a GIS system.*

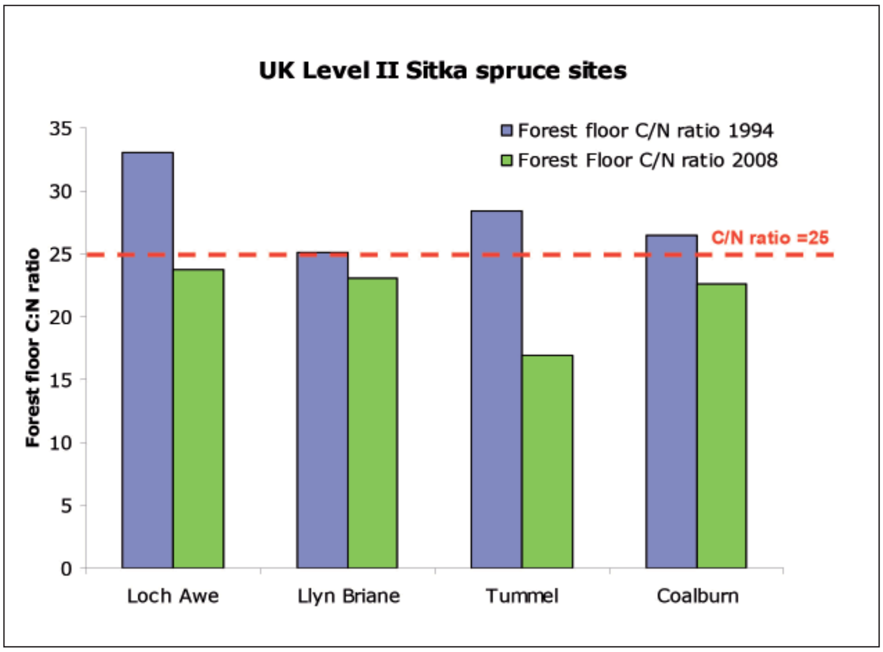

*Figure 2-2: Changes in forest floor C/N ratio from 1994 to 2008 at 4 Sitka spruce Level II sites in the UK; C/N ratio < 25 are considered as nitrogen saturated.*

(ii) **Excessive nitrogen leaching exceeding the deposition input.** As in other countries, there is growing concern in the UK that some forests are approaching nitrogen saturation. These concerns led to the evaluation of the balance of nitrogen levels within each plot using more than 10 years of monitoring data for all of the UK's ICP Forests intensive monitoring plots.

Long-term total nitrogen deposition across the UK sites varied between 3 and 17 kg of nitrogen per hectare/year with leaching losses between 2 and 51 kg of nitrogen per hectare/year and net nitrogen uptake by trees between 7 and 39 kg of nitrogen per hectare/year. About 30% of the nitrogen was unaccounted for and likely to originate from other sources, such as atmospheric nitrogen fixation by microbes and nitrogen mobilisation from litter and organic substance in soils. Gaseous nitrogen releases from soils have also been quantified at some sites, which suggest higher nitrous oxide ($N_2O$) gas fluxes at sites with higher rates of nitrogen deposition.

Currently three conifer sites out of nine monitoring sites are showing signs of nitrogen saturation such as low C/N (carbon versus nitrogen) ratios (Figure 2-2) and excessive nitrogen leaching, exceeding the deposition input (Figure 2-3). There were no signs of nitrogen saturation at the broadleaved sites.

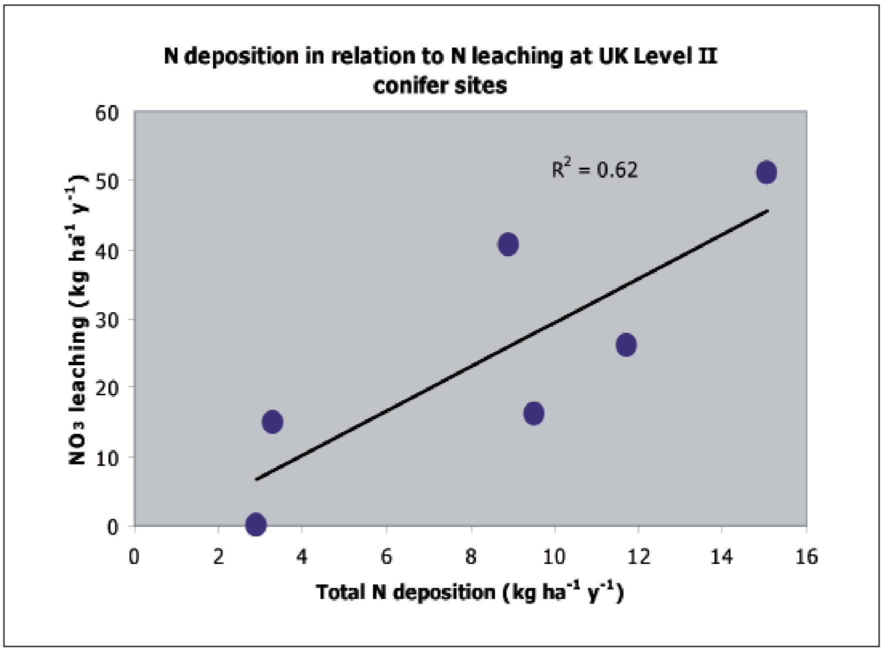

*Figure 2-3: $N-NO_3$ leaching fluxes (kg per hectare/year) against total nitrogen deposition (wet and dry) at the conifer Level II sites in the UK. All sites with nitrogen deposition above 8 kg per hectare/year have forest floor C/N ratio < 25.*

(iii) **Initial recovery effects found in soil solution in areas of high deposition.** At five Level II plots in Flanders, Belgium, samples of deposition by precipitation (rainfall etc), throughfall (reaching the forest floor through the canopy) and stemflow (reaching the forest floor by flowing down trunks and stems) were examined, and soil solution from the forest floor and three depths in the mineral soil was collected. Concentrations of dissolved organic carbon (DOC), dissolved organic nitrogen (DON), nitrate (NO$_3^-$) and total dissolved nitrogen (TDN) were determined, and trends in the DON/TDN (organic nitrogen versus total nitrogen) ratios and DOC/NO$_3^-$ (organic carbon versus nitrate) ratios were evaluated. Nitrate concentration in soil solution of the intermediate mineral layer (the B horizon) strongly decreased, while organic carbon and organic nitrogen concentrations increased, which resulted in significant increases in the ratio of organic nitrogen to total nitrogen and the ratio of organic carbon to nitrate (Figure 2-4).

Along with the deposition of sulphate, the deposition of inorganic nitrogen, particular ammonium (NH$_4^+$), strongly decreased in Flanders between 1994 and 2010 (see chapter 1, example ii). These findings suggest that the observed changes in soil solution could at least partly be explained by recovery from acidification (pH of soil solution increased by circa 0.5 units between 2005 and 2014) and partly by initial recovery from nitrogen saturation.

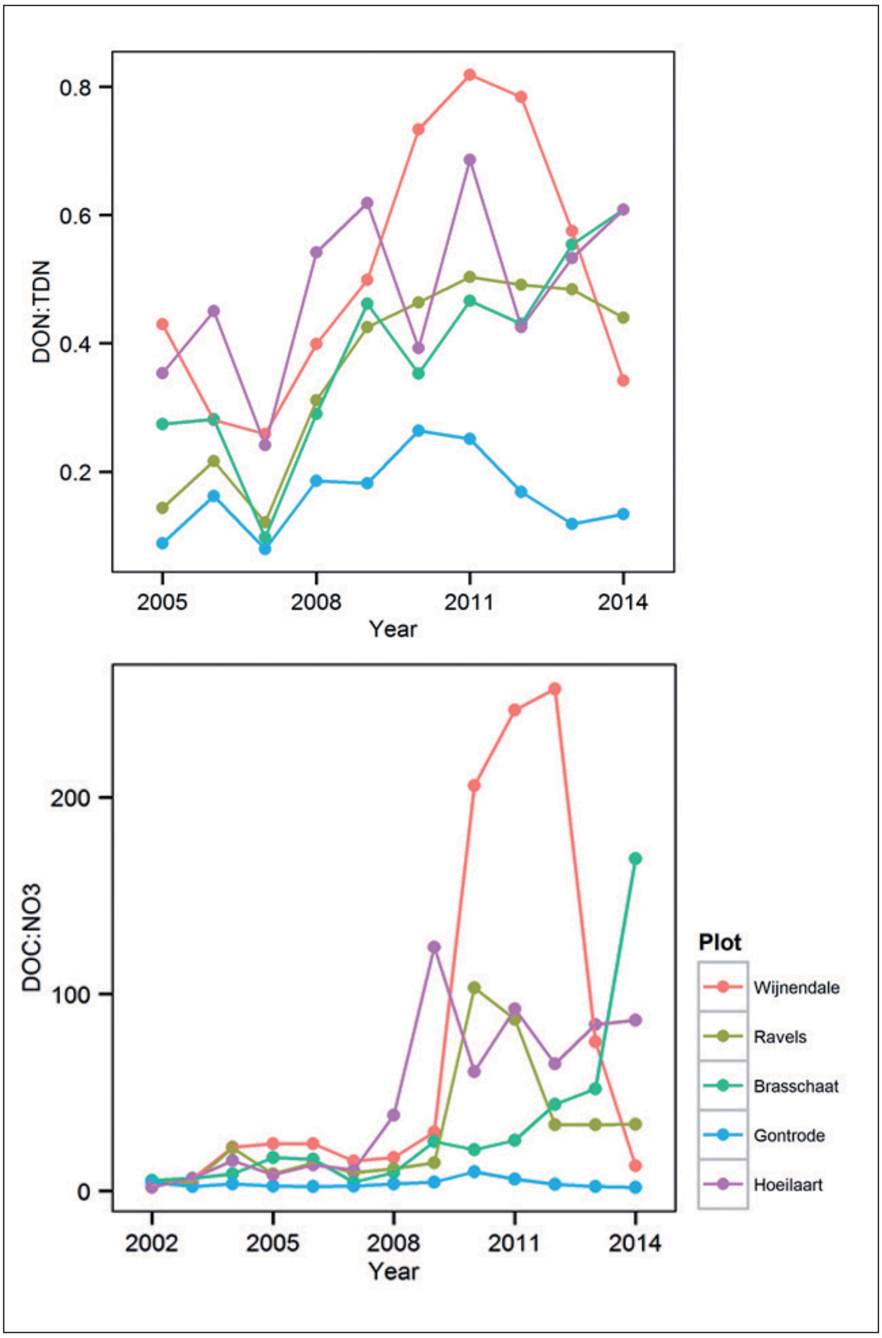

*Figure 2-4: Average (mean) annual DON/TDN ratio (left) and DOC/NO$_3^-$ ratio (right) in the B horizon (intermediate mineral soil layer) of five Level II plots in Flanders, Belgium.*

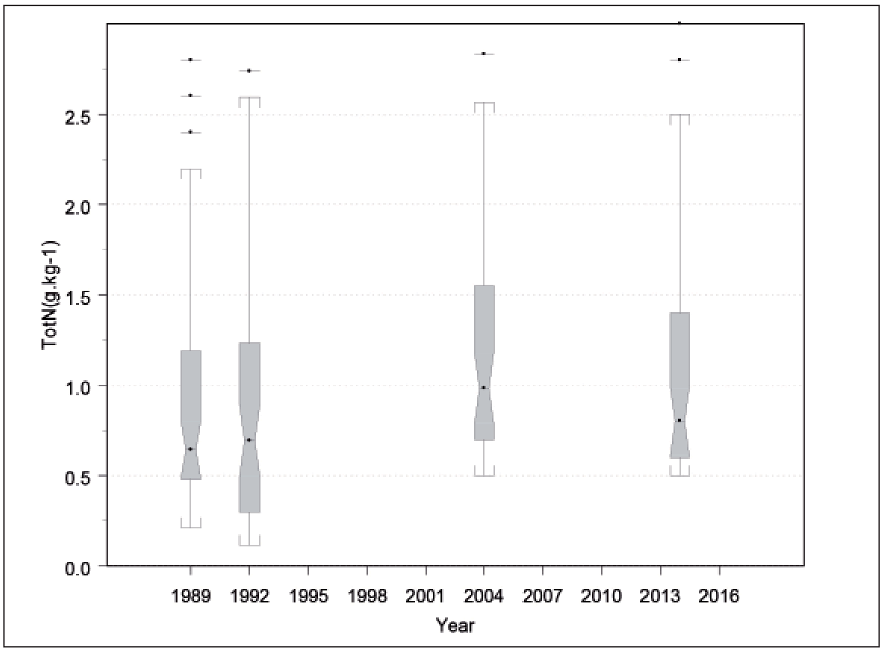

*Figure 2-5: Total nitrogen concentrations in the mineral soil at five sampling depths (0–5 cm, 5–10 cm, 10–20 cm, 20–40 cm and 40–80 cm) of 11 Level II plots in Flanders, Belgium, measured between 1989 and 2014.*

(iv) **Recovery effects hold off in the solid soil phase.** On eleven Flemish Level II plots, solid soil was sampled between 1989 and 2014; in each of the four sampling campaigns the total nitrogen concentration was determined. Comparisons between the samples taken at each of the plots in different years revealed that in the solid soil the nitrogen concentrations in 2004 and 2014 were higher compared to those in 1989 (Figure 2-5). An increase in nitrogen concentrations in organic topsoil was also observed in four Sitka spruce sites from the UK Level II network between 1994 and 2008, which contributed to the forest floor carbon versus nitrogen ratios declining to a level associated with potentially higher nitrogen leaching losses (Figure 2-2).

These recent studies highlight qualitative and quantitative long-term shifts of atmospherically-borne nitrogen in deposition, in soil solution, and in the solid soil phase. In the Czech forest sites, a more pronounced reduction in the deposition of oxidised nitrogen compounds was found, as compared to reduced nitrogen forms. This necessitates a higher awareness of ammonia emissions from agriculture in future clean air policies. At the same time, signs of recovery in high deposition areas like the UK and Flanders can be observed. However, responses are quite variable and depend highly on local circumstances. Thus forest authorities and managers need to consider these soil-related processes in their planning, but monitoring has to be continued to further elucidate ongoing forest ecosystem developments.

**Further Reading:**

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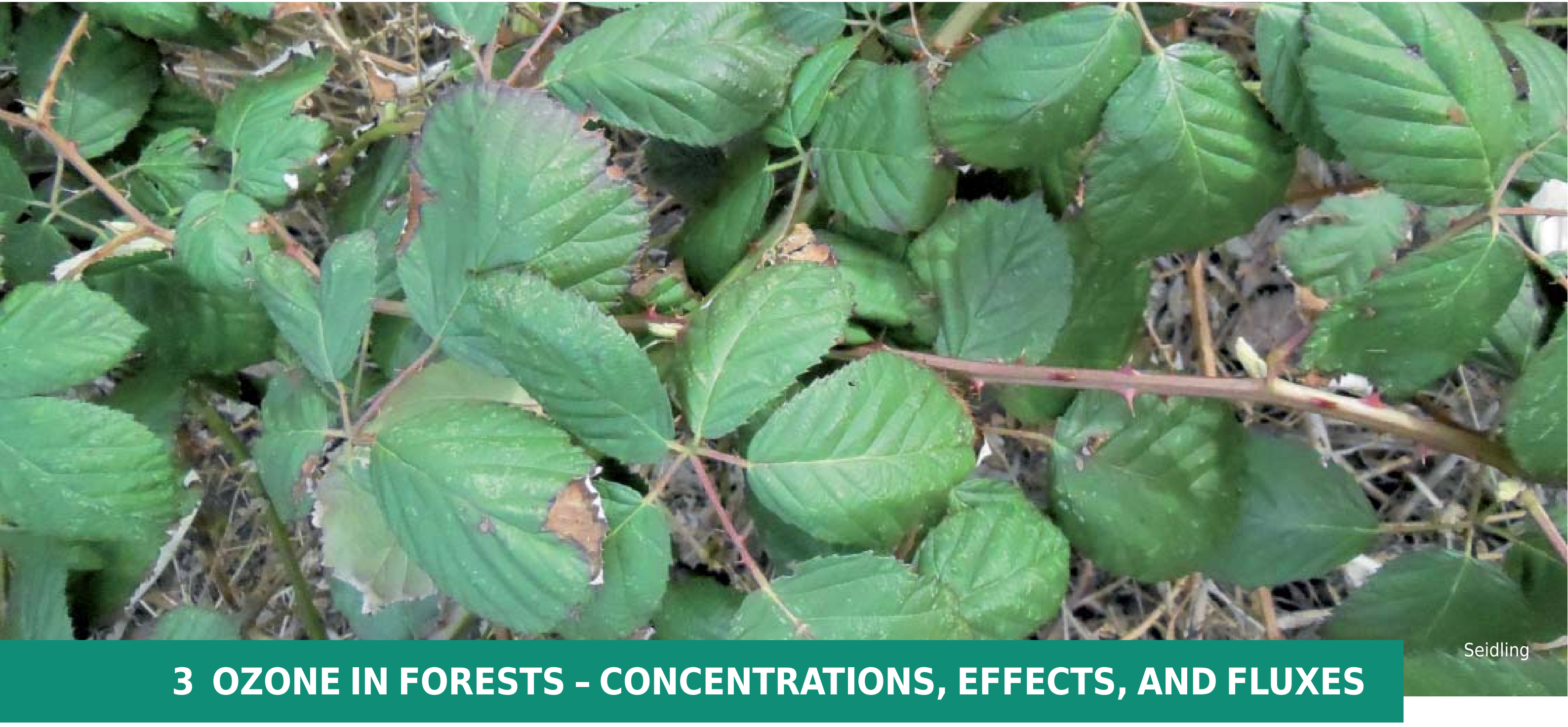

Seidling

# 3 OZONE IN FORESTS – CONCENTRATIONS, EFFECTS, AND FLUXES

Ozone ($O_3$) pollution, unlike fluoride or sulphur dioxide pollution, leaves no elemental residue that can be detected by analytical techniques. Therefore, ozone-induced visible injury on needles and leaves is the only easily detectable evidence in the field.  This comes about as a result of oxidative stress, leading to a cascade of adverse physiological and morphological effects. In combination with the measurement of ozone concentrations and the modelling of $O_3$ metrics such as exposures and ozone uptake, the assessment of ozone visible injury can be valuable to estimate the potential risk for European ecosystems that are exposed to elevated ambient ozone concentrations.

**Ozone concentration decreases at forest sites in Europe, but exposure remains high.** Based on measurements from 203 ICP Forests Level II sites across Europe in 20 countries, during the period 2000-2013 a trend was found showing overall ozone ($O_3$) decreasing by 0.35 parts per billion (ppb) per year.  Another study in France, carried out on 332 background sites over the period 1999-2012, showed a decrease in average ozone concentrations of 0.12 ppb per year at rural sites and an increasing trend at (sub)urban sites. This study also showed that peak ozone concentrations strongly declined at all sites, and hypothesized that this may be due to the reduction of $NO_x$ (nitric oxide and nitrogen dioxide) and VOC (volatile organic compounds) emissions over the past 20 years. Exposure to ozone, however, remains high on most forest sites across Europe, with potential for harmful effects on vegetation.

**Widespread visible foliage damage in European forest.** Visible injury to foliage is considered one of the most responsive indicators to assess ozone risk for vegetation and to identify potential hotspots for adverse ozone effects on forest ecosystems. Injury data from ICP Forests Level II plots were evaluated over the period of 2002 to 2014 (Figure 3-1). Overall, 285 woody species from 169 plots in 19 countries were recorded, of which 26% were reported as symptomatic. Common beech showed the highest frequency of symptomatic observations (40.5%). When considering plots with at least eight years of records, there was an overall decreasing trend for the frequency of symptomatic species, which parallels the significant decrease of ozone concentrations. Apart from the European-wide survey conducted within ICP Forests, other studies provided evidence of visible injury on forest species: two examples are reported below.

(i) **Wayfarer: an effective in situ bioindicator.** As far as visible foliage damage is concerned, a single-species approach can be helpful in reducing the inherent variability typical of a multi-species approach. Observations were carried out over the period 2010-2015 on 10-30 randomly selected sites over a 6,000 km² area in Trentino, Italy. They showed a consistent spatial and temporal pattern, linking visible foliage damage on wayfarer with ozone concentration modelled and measured by conventional monitors (Figure 3-2). In 2015, in conjunction with a particularly dry summer, injury to foliage was less frequent on dry sites.

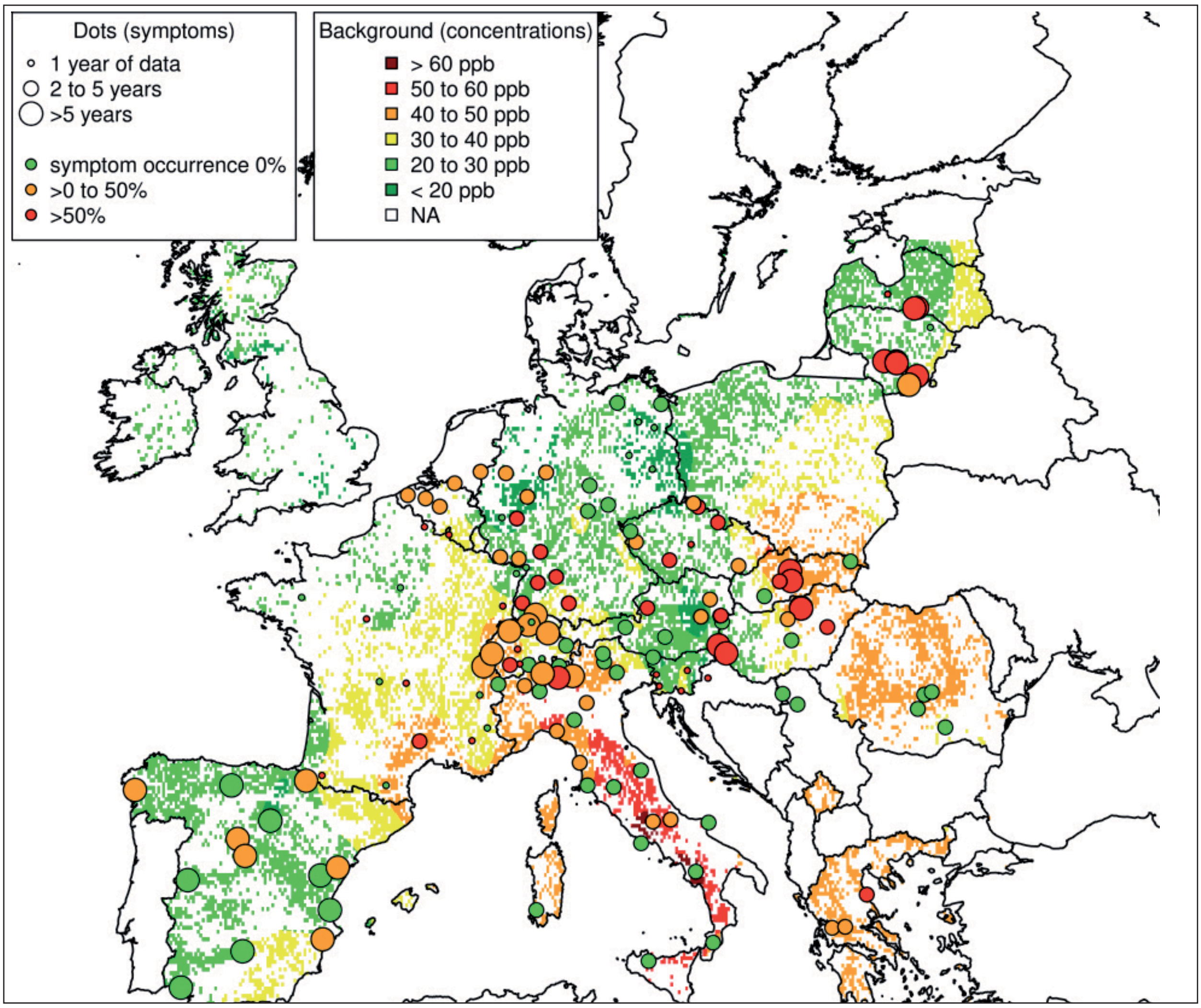

*Figure 3-1: Spatial pattern of plots showing available survey years (size of dots) and the frequency of years when species on the plot were found symptomatic (colour of dots) during 2002-2014 across large parts of Europe against the seasonal mean ozone concentrations (coloured forested areas).*

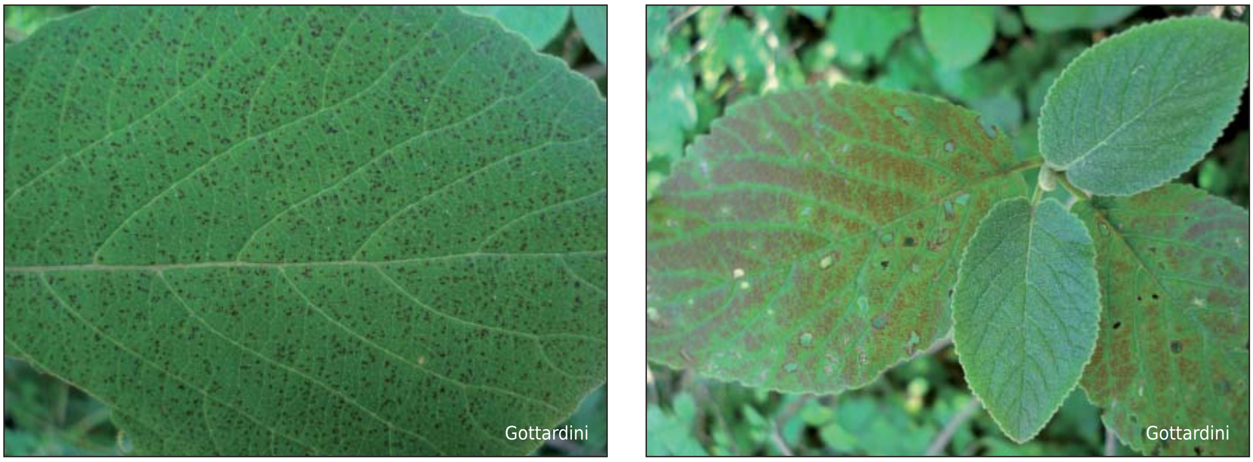

*Figure 3-2: Ozone-induced symptoms on wayfarer (Viburnum lantana) leaves: stippling (left) and bronzing (right).*

**Long-term observation on Aleppo pine.** In south-eastern France, data on forest response indicators (i.e. crown defoliation, crown discolouration, and visible foliage ozone damage) were collected in stands of Aleppo pine and of stone pine over 20 years. Ozone concentrations and meteorological data were also measured. At forest sites, a decline in ozone injury was found, in parallel with declining modelled ozone concentrations. However, defoliation was increasing, likely due to drier and warmer weather. Climatically-caused soil drought may have lowered ozone uptake by tree needles.

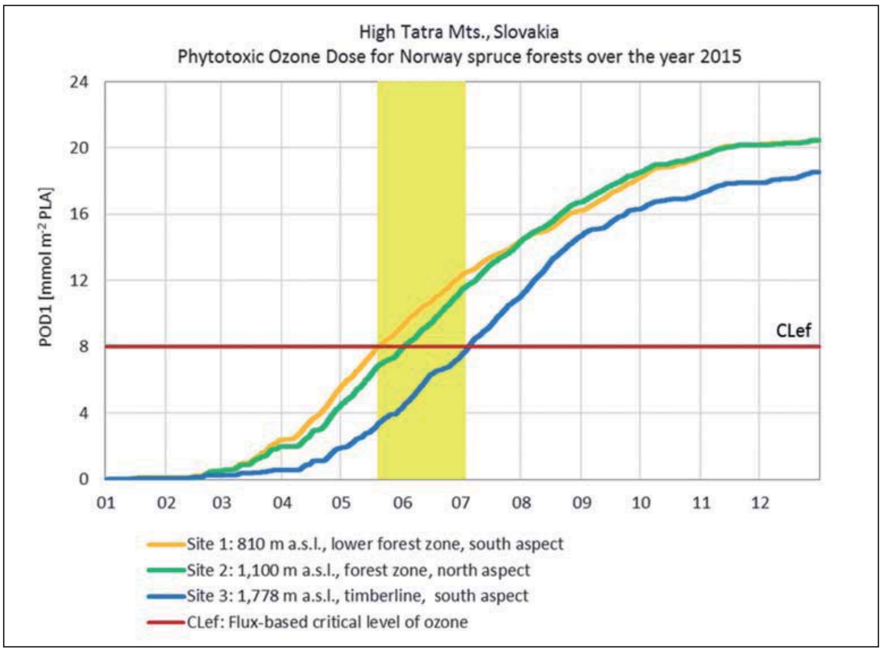

*Figure 3-3: Phytotoxic Ozone Dose above a flux threshold of 1 nmol per m²/second ($POD_1$) for three forest sites in the High Tatra Mts. and instances of exceeding of flux-based critical level of ozone (CLef) over the year 2015 (by month); PLA: projected leaf area; at the lowest altitude during the second half of May CLef was already exceeded.*

**Different ozone metrics to evaluate ozone risk.** The assessment of the risk posed by ozone to vegetation can be assessed according to different metrics: concentration, accumulated exposure along the vegetative season (as discussed above), and uptake by the foliage. The latter is the ozone flux-based approach, which accounts for a series of environmental factors and provides the accumulated Phytotoxic Ozone Dose ($POD_y$) (measured in mmol [$O_3$] per m² of Projected Leaf Area (PLA)). POD can be calculated with threshold (i.e. $POD_1$) or without ($POD_0$). Several studies have been carried out over the past years. Two recent examples are reported:

(i) **Norway spruce in the Tatra Mountains.** POD for Norway spruce was modelled for 2015 in the High Tatra Mountains in Slovakia for three different altitudes between 800 and 1,800 metres. Model outputs were considerably affected by different length of growing seasons, with $POD_1$ values between 15 and 20 mmol per m² PLA (Figure 3-3). A potential high risk for vegetation was estimated.

(ii) **AOT40 and POD in France and Italy.** Modelled exposure-related AOT40 (Accumulated Ozone above the Threshold of 40 parts per billion) and flux-based POD with and without an hourly threshold were correlated with tree response parameters (i.e. defoliation, discolouration, and visible foliage ozone damage) in 2012 and 2013 in south-eastern France and north-western Italy. While AOT40 was more strongly correlated with non-specific indicators of ozone (i.e. crown defoliation and discolouration), the flux-based metrics, especially POD0 were better correlated to visible ozone injury.

The above-indicated ICP Forests long-term and related ICP Vegetation case studies, with both ICPs co-operating under the auspices of the Working Group on Effects (WGE) of the United Nation Economic Commission for Europe (UNECE), were presented at the 5th ICP Forests Scientific Conference in Luxembourg in 2016. They demonstrate the potential of the Central ICP Forests database on the one hand, but also the urgent need for integrated studies across Europe to enable meaningful statements on the state of European forests.

**Further Reading:**

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Sicard P, Serra R, Rossello P (2016) Spatiotemporal trends of surface ozone concentrations and metrics in France. Environmental Research 149:122-144.

32nd ICP Forests Task Force Meeting 2016, Luxembourg; photo byMinistère du Développement durable et des Infrastructures'

# CONCLUSIONS

The examples given from three **important areas of air pollution policies** with regard to forest ecosystems have been taken from the much broader array of contributions displayed and discussed at the Scientific Conference of ICP Forests, which took place back-to-back with the 2016 Task Force Meeting in Luxembourg. Taking distinguished contributions from this prominent event enables a view of the most recent results from ICP Forests monitoring activities itself, and related research activities in other programmes like ICP Vegetation. A recent prominent example is ozone-related research, traditionally based on a broad alliance of scientists with different backgrounds; other such co-operation, such as with the Acid Deposition Monitoring Network in East Asia (EANET) or the Wood Buffalo Environmental Association (WBEA) in Alberta/Canada, should be further intensified in the future.

The Scientific Conference offers the possibility to throw a glance onto further developments of monitoring and research within **ICP Forests, now continuously monitoring** major ecosystem-related parameters **for over 30 years**, and – as importantly – participation from research activities of other forest-related research organizations. Cross-fertilisation among and between various research and monitoring platforms may become a common feature of future activities and enhance common monitoring projects and research initiatives. With such an increasingly broad field of activities, ICP Forests may contribute to the solution of research questions related to the grand societal challenges human society will increasingly be confronted with in the future, such as air pollution, climate change, and biodiversity loss.

The **forest sector** also has an essential and continuous interest in results of forest monitoring. Enhanced model results based on more reliable data should increasingly foster management decisions concerning all kinds of forest-related resources. Soil, as a slow but adamantly changing fundamental of all forest-related decisions, needs well-developed process-based understanding. For instance, enhanced soil acidification as a consequence of the deposition of large quantities of acidifying sulphur and nitrogen compounds during the past century has changed important soil properties and recovery will still take time. During this time, forest ecosystems may lose essential nutrients (cations) and other compounds like dissolved organic carbon (DOC) via seepage, later emerging in freshwater bodies.

This and other processes document the **interconnectivity of ecosystems** at higher levels and make forest ecosystems one of the main ecosystem types to be of high relevance in any global perspective. Historical processes have changed and are changing forest ecosystems, making forests a candidate for both in-depth studies and broad-scale monitoring. Both are covered by the intensive (Level II) and extensive (Level I) monitoring of ICP Forests under the umbrella of the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and its Working Group on Effects (WGE). Collaborations inside and outside are an adequate means to gain both thematically deeper and geographically broader understanding of processes in forest ecosystems.

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