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MONITORING OF FOREST CONDITION IN EUROPE

Summary report by the Coordinating Centre of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests

Introduction

1. Forest condition in Europe has been monitored for over 17 years jointly by the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) under the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe (UNECE) and the European Union. Spatial and temporal variations in forest condition on a large scale have been assessed on 6 000 plots systematically spread across Europe in relation to natural and anthropogenic factors (large-scale monitoring network – level I). Causal relationships are studied through intensive monitoring on 860 plots covering the most important forest ecosystems in Europe (intensive monitoring plots – level II). Both monitoring levels are complementary to one another. With active participation of 39 countries and a large number of plots and monitored parameters, the programme operates one of the world's largest biomonitoring networks.

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2. The objectives of the monitoring programme are:

(a) To provide periodic overviews of the spatial and temporal variation in forest condition in relation to anthropogenic and natural stress factors for European and national large-scale systematic networks (level I);

(b) To contribute to a better understanding of the relationships between the condition of forest ecosystems and stress factors, in particular air pollution, through intensive monitoring of a number of selected permanent observation plots across Europe (level II);

(c) To contribute to the calculation of critical levels, critical loads and their exceedances in forests;

(d) To collaborate with other environmental monitoring programmes in order to provide information on other important issues, such as climate change and biodiversity in forests, and thus contribute to the sustainable management of European forests;

(e) To compile information on forest ecosystem processes and to provide policy makers and the public with relevant information.

I. SIMULATION OF LONG-TERM IMPACTS OF ATMOSPHERIC NITROGEN AND ACIDITY DEPOSITION ON FOREST SOIL SOLUTION CHEMISTRY

3. The results of critical loads calculations for level II plots were already presented in 2002 (EB.AIR/WG.1/2002/7). For the first time dynamic models have now been applied, using the pan-European level II data set, to simulate future reactions of soils to deposition reductions. The models integrate dynamic soil processes such as cation exchange, sulphate adsorption and nitrogen retention. Deposition scenarios were based on the 1999 Gothenburg Protocol. The evaluations were carried out in close cooperation with ICP on Modelling and Mapping and ICP on Integrated Monitoring. The results were considered as an important step towards the future goal of applying dynamic models not only on individual plots but at a Europe-wide scale.

A. Methods

4. Both chemical element input through deposition and element concentrations in the soil solution were regularly measured at about 200 intensive monitoring plots. At these plots a dynamic soil acidification model was applied to see whether measured soil solution concentrations could be reproduced by the model. Existing data were used to optimize certain process parameters in the model. For most plots, the agreement was reasonable to good.

5. Once the model was optimized, the impacts of the expected deposition changes were simulated for the 1970-2030 period. It was assumed that if the model was able to reproduce the soil solution measurements over a number of past years, it could also provide plausible results in simulating future situations.

B. Results

6. The scenario analysis for all simulated level II plots (fig. I) shows a sharp decrease in the median sulphate soil solution concentration caused by the large reductions in sulphur emissions in Europe. It also shows that reductions in nitrogen emissions would lead to lower nitrate

concentrations in the soil. Additional evaluations show that reductions will most probably occur on plots which today have high nitrate concentrations. Some plots will continue to have high nitrate values also in the future. The decrease in acid deposition leads to an improvement of the chemical status of the plots as pH increases and the accompanying aluminium concentrations decrease. It has to be taken into account that these results reflect only chemical reactions of the soil water. Reactions of the soil solid phase are always slower and will take decades or even centuries.

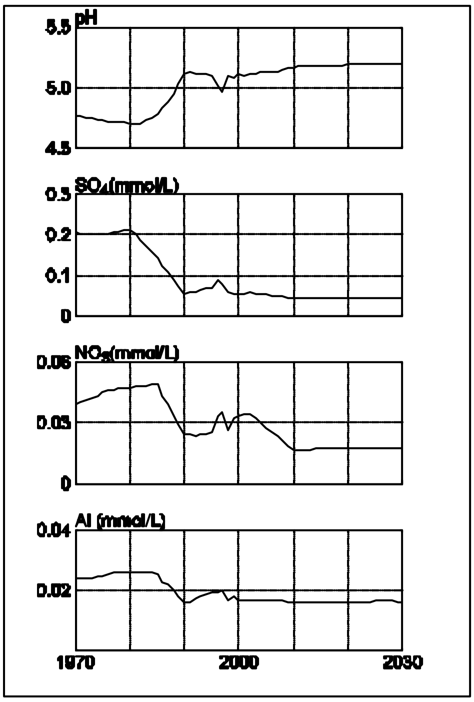

Figure I. Simulation of pH and median sulphate (SO_4^{2-}), nitrate (NO_3^-), and aluminium (Al) concentrations in the soil solution of 200 intensive monitoring plots for the 1970 to 2030 period under an emission scenario following the Gothenburg Protocol. The non-smooth behaviour of the lines between 1996 and 2000 reflects the use of year-specific data within this period, whereas for the other years average values were used

7. The geographical distribution of simulated soil solution SO_4 concentrations shows a high spatial variability with the highest values in Central Europe. For aluminium it mainly shows that where concentrations are above critical values, these are strongly reduced over time. Initially, aluminium concentrations were above a critical value of 0.2$mol_c.m^{-3}$ on about 20% of the plots. Simulations taking into account the Gothenburg Protocol show that in the future this percentage will be considerably reduced to around 5%.

II. OZONE CONCENTRATIONS IN FORESTS

8. Ozone is currently regarded as a one of the most pervasive air pollutants affecting forests. In view of the fact that most of the ozone data at a European level are currently derived from urban and sub-urban areas, in 2001 ICP Forests launched a test phase to explore the monitoring of ozone

at its mostly remote forest plots. The test phase focused on air concentrations measurement by means of passive samplers and the assessment of visible ozone injury. Around 100 intensive monitoring plots located in nine countries were included.

A. Passive sampling

9. The passive samplers tested proved to provide a reliable and comparatively cheap method to gain information on ambient air quality, specifically in remote forest areas where no other technical facilities are available. Mean values from April to September 2001 showed higher concentrations in Southern Europe, with 58% of the Spanish sites and 63% of the Italian sites having a 6-month time-weighted average concentration in the range of 46-60 parts per billion (ppb). Also in Greece and Switzerland comparatively high concentrations occurred. In Germany, France, the United Kingdom and Austria, the sites showed lower average concentrations. It should be kept in mind that in 2001 ozone concentrations were generally rather low compared to most previous years.

B. Visible ozone injury assessment

10. Ozone leaves no elemental residue that can be detected by analytical techniques. Therefore, visible injury on needles and leaves from major tree species and on ground vegetation was assessed in 2001 on 72 plots in nine countries. A web site, including a photograph gallery with examples of ozone symptoms on leaves and needles, was made available to support the determination of ozone injury (http://www.gva.es/ceam/ICP-forests). Several training courses were conducted to build up the necessary expertise in this field and to harmonize methods. Special microscopical methods were developed to validate symptoms in doubtful cases. Visible injury on trees was reported from 17 plots. In Central Europe the investigations focused on common beech. For this important tree species, injury was reported on 24% of the investigated plots. Many of the ground vegetation species that showed visible ozone injury in the field were not known to be ozone-sensitive before.

C. Achievements and outlook

11. During the test phase an ozone monitoring system for forests at the European scale has been initiated and proven to be operational. Expertise on passive sampling was built up in many countries. The assessment of ozone injury on major tree species as well as on ground vegetation has to be considered as a first phase to implement a unique effects monitoring system on a European scale, based on validated field observations. It will also broaden knowledge on ozone-sensitive species. It is planned to refine the methods and to continue the passive sampling activities. Information from both surveys will be linked using a geographic information system (GIS). This will help to understand the effects of ozone on forest vegetation better and will also provide a good basis for calibrating models of ICP Forests and of other programmes under the Convention.

III. THE INFLUENCE OF NITROGEN DEPOSITION ON CURRENT CARBON SEQUESTRATION IN EUROPEAN FORESTS

12. The uptake of carbon in forests (sequestration) delays the rise of CO_2 concentrations in the atmosphere and thus slows down the rate of climate change. Elevated nitrogen deposition on

forests is suspected to have played a large role in carbon sequestration, due to the stimulation of wood production and the accumulation of soil organic matter. Other possible contributing factors are forest management and increases in atmospheric CO_2 concentrations and temperatures. Data from 120 intensive monitoring plots and 6 000 level I plots were used to work on these issues.

A. Methods

13. For 120 intensive monitoring plots with a comprehensive database, carbon pools in stem wood and soil were calculated directly. It was also possible to establish statistical relations to transfer the carbon pools to 6 000 level I plots assuming them to be representative of approximately 2.0 million km^2 of forests in Europe. 1960 was used as the reference year for nitrogen deposition and the impact of additional nitrogen deposition until the year 2000 was calculated. At the intensive monitoring plots (level II) changes in tree carbon pools were directly derived from repeated growth inventories. Carbon changes in the soil were computed from nitrogen retention (deposition minus leaching), nitrogen uptake and a C/N (carbon to nitrogen) ratio assumed to be constant at different nitrogen input levels. For the level I plots nitrogen deposition was derived from model estimates. Nitrogen uptake by above-ground biomass was calculated from yield estimates as a function of site quality. For below-ground carbon pools and changes, nitrogen retention fractions in level I plots were related to measured C/N ratios, using a relationship derived from level II plots.

B. Carbon pool changes on intensive monitoring plots

14. The results at the intensive monitoring plots show that annual uptake of carbon in trees is generally 5-7 times higher than the estimated carbon pool changes in the soil (see fig. II). As expected, the changes in the carbon pool in trees due to forest growth increase from Northern to Central Europe.

C. Carbon pool changes in European forests and the impact of nitrogen deposition

15. Modelled results based on 6 000 level I plots estimate the total carbon uptake in tree wood due to growth as 0.3 $Gton.yr^{-1}$ for European forests during the 1960-2000 period. This value is similar to the results of other research projects. Estimating carbon losses due to forest fires and wood harvesting with an overall European average ratio of two thirds the net carbon sequestration was calculated as 0.1 $Gton.yr^{-1}$ for European forests. The contribution of nitrogen deposition to this annual increase of carbon in standing biomass was 0.005 $Gton.yr^{-1}$ (fig. II), accounting for around 5% additional carbon uptake due to enhanced nitrogen input since 1960. For Europe as a whole, nitrogen deposition thus had a comparatively small impact on carbon sequestration in trees, but in areas with high nitrogen deposition, the local impact can be substantial. The calculation of net carbon sequestration based on the soils of 120 intensive monitoring plots shows that, in total,
only 0.0138 Gtons were sequestered in 2000. Carbon uptake in the soil is more difficult to calculate. Further research is needed to substantiate the role of forest soils in carbon sequestration.

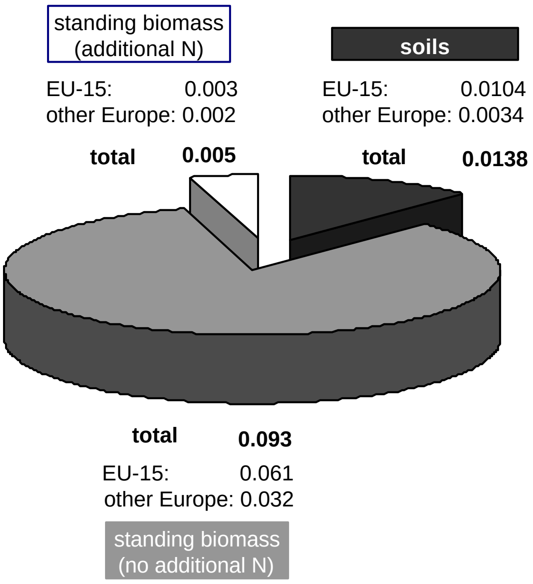

Figure II. Annual net carbon sequestration of standing biomass and soils in European forests in Gton.ha^{-1}.yr^{-1}. Carbon sequestration in standing biomass caused by additional nitrogen inputs is comparatively small. (EU-15: 15 Member States of the European Union)

D. Achievements and outlook

16. Overall, the contribution of nitrogen deposition to carbon sequestration by tree wood and forest soil is likely to be low. Assuming an even smaller influence of elevated CO_2 concentrations and increasing temperature, this implies that the most likely cause for the increased carbon pools in standing biomass in Europe is the fact that overall timber removal is less than overall increment in existing and newly afforested stands. This hypothesis will require substantiation in the coming years.

IV. CROWN CONDITION IN 2002 AND THE PAST DEVELOPMENT

17. ICP Forests provides a regular overview of forest condition in Europe using the 16 km x 16 km systematic large-scale monitoring grid and the annual crown condition survey is its main large-scale activity. Within this survey, lack of foliage is described as defoliation for each sample tree. In 2002, more than 130 000 trees on approximately 6 000 permanent sample plots in 30 European countries were assessed following harmonized methods. In many countries additional assessments on denser grids were performed.

A. Results

18. In 2002, 21.3% of all trees assessed were classified as moderately or severely defoliated or dead. Crown condition in the European Union Member States was slightly better than in Europe as

a whole. Of the four tree species most frequently occurring in the plots, European and sessile oak were the most severely defoliated species (see fig. III).

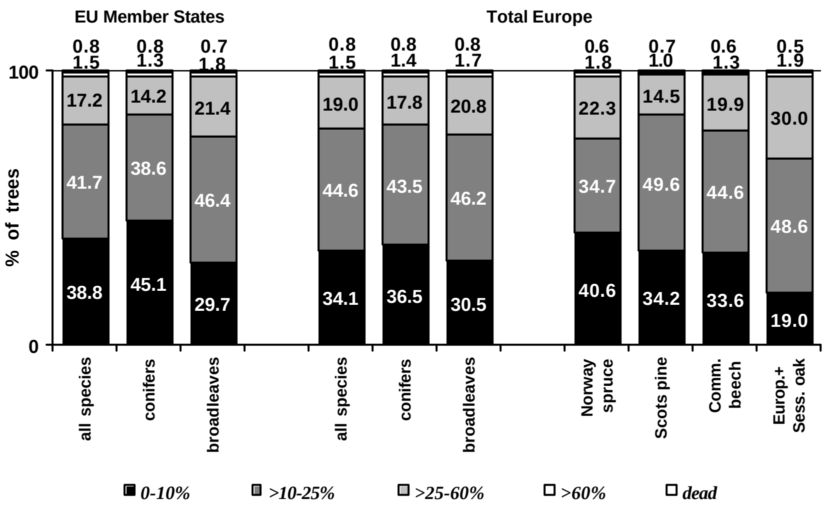

Figure III. Percentage of trees in different defoliation classes for main tree species. Total Europe and the European Union Member States, 2002

19. The temporal development of defoliation was analysed using the sample of continuously monitored trees. The continuously monitored silver fir trees had the highest mean defoliation in all years. In general, mean defoliation values fluctuated considerably (see fig. IV). The proportion of damaged and dead trees (defoliation classes 2-4) of all species was highest in 1995 (25.6%) and decreased in the following two years (not depicted). Since then a steady but slow increase in damage has been recorded.

20. The proportion of plots with a significant increase of mean plot defoliation from 1994 to 2002 was higher (15.8%) than the share of plots where mean defoliation decreased (11.9%). Plots with deteriorating crown condition are clustered along the northern and western coast of the Iberian peninsular, in southern Finland and Estonia, in the alpine region of Austria and in Slovenia and Croatia. Regions where plots are mainly improving are southern Poland and the coastline of Estonia. In 2003 specifically, defoliation of Norway spruce and European and sessile oak has been evaluated.

<u>Norway spruce</u>

21. In central Norway, mean defoliation of spruce is relatively high. The situation is mainly explained by needle rust and root rot fungi. Damage was particularly high due to climatic stress. In the past five years the situation has slightly improved. In large regions of Sweden defoliation has increased since 1997, most likely due to causes similar to those responsible for defoliation in Norway. In Belarus, an improvement was registered, but in the Baltic region and southern Germany defoliation worsened on most plots.

European and sessile oak

22. The deciduous oak trees showed a large variation in both mean defoliation and its temporal variation. In some regions of France, the defoliation was rather high with improvements in the south and west of the country, but no country-wide uniform causes of damage were identified. In central Germany, the large-scale improvement was explained by a recovery of oak trees after years of severe insect damage.

Multiple influences on crown condition

23. Multiple linear models confirmed that weather, insects and atmospheric deposition influence the condition of tree crowns in Europe. The evaluations showed that a high precipitation level is related to relatively healthy tree crowns. These findings for spruce and deciduous oak support those reported for Scots pine and beech in last year's report (EB.AIR/WG.1/2002/7). The influence of insect damage was also consistently reflected in the statistical evaluations for the four most frequently occurring tree species. Fungi showed varying relations. Sulphur deposition of the current year was consistently related to high or increasing defoliation. As can be shown there was no uniform Europe-wide trend, but varying conditions on different plots. Age and country were relevant causal factors explaining the spatial variation but did not influence time trend evaluations.

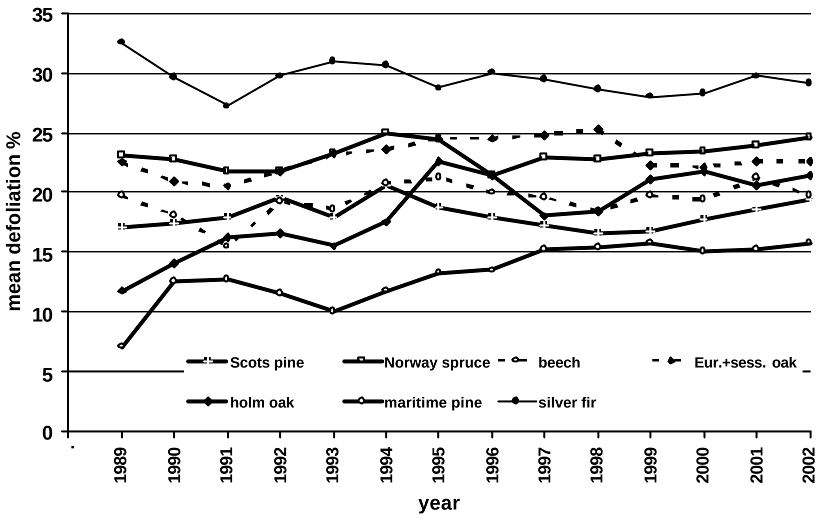

Figure IV. Trends over time in mean defoliation of the main European tree species, calculated for continuously monitored trees. Sample sizes vary between 1 237 trees for European and sessile oak and 2 988 for spruce (silver fir: 289 trees)

V. ELEMENTAL FOLIAR COMPOSITION

24. Chemical analyses of tree needles and leaves give valuable insights into tree nutrition, which in turn reflects environmental change. Since 1987, the elemental foliar composition has been determined annually on 36 Finnish and 71 Austrian level I plots. These countries were selected for evaluation because they have the most comprehensive foliar chemistry data sets.

25. During the past 15 years, the needle sulphur concentrations have been low in both Austria and Finland. Even at this low level the needle sulphur concentrations decreased, reflecting the success of sulphur emission reduction programmes (see fig. V). In some remote areas in Finland the needle sulphur concentrations have dropped to a level normally found in pristine forests. In Austria, however, 7% of the sampled forests had concentrations above specific national thresholds.

26. Needle nitrogen concentrations in most parts of Finland and Austria have generally remained low. This is particularly true for Austrian forests located in alpine regions. Trees with higher needle nitrogen concentrations were often found close to agricultural and industrial areas. Taking into account the normal ageing effect of the monitored trees, a decrease in nitrogen concentrations would have been expected at constant input loads. Such a decrease has not been observed, so it is assumed that nitrogen is also becoming more available in remote areas. Increased availability of nitrogen can have adverse effects on forest ecosystems.

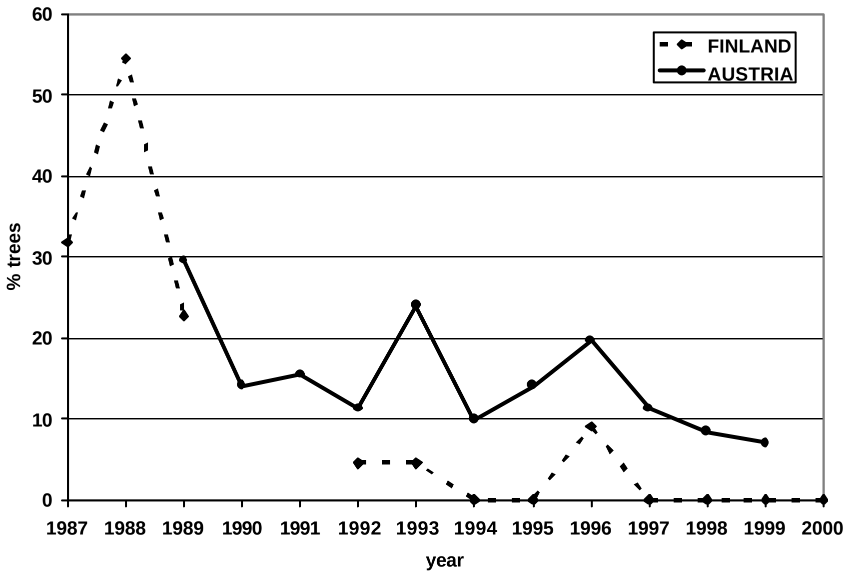

Figure V. Proportion of stands with foliar sulphur concentrations above 1.1 mg $S.g^{-1}$ in Finland and Austria

VI. CONCLUSIONS

27. The main findings are that:

(a) Forests in Europe react to changing environmental conditions. Air pollution is one of the causes for changing forest condition. Different indicators reflect these changes:

(i) Defoliation of the main tree species remained high in 2002, with one fifth of the assessed trees classified as damaged. Defoliation was mainly related to unfavourable weather conditions, biotic factors and air pollution;

(ii) Decreasing sulphur concentrations in pine and spruce needles reflect decreased sulphur deposition in recent decades;

(b) Scenario analyses assuming emission reductions according to international agreements predict a decrease in sulphur and nitrogen concentrations in the soil solution. The soil solid phase recovery can take much longer, indicating that forest ecosystems will suffer for a long time from high deposition loads;

(c) The first evaluations of ozone measurements on the forest plots confirm high ozone concentrations in Southern Europe. Ozone injury was visible on leaves of some major tree species such as beech as well as some ground vegetation species that were not known to be ozone-sensitive before;

(d) At the European level, increased forest growth due to nitrogen deposition resulted in a 5% increase in annual carbon sequestration. Annual net carbon sequestration in trees was found to be 5-7 times as high as in forest soils. Extrapolation to the forest area of Europe corrected for harvesting and fire yield an average rate of 0.1 Gigatons per year.

28. The condition of European forests is changing under present environmental conditions. ICP Forests in close cooperation with the European Union is managing one of the world's largest biomonitoring networks in order to quantify these changes and to contribute to the understanding of cause-effect relationships.

29. Air pollution is one of the causes of changing forest condition and assessing its effects is the programme's main monitoring activity. Recent results reflect the success of sulphur emission reduction measures of the past decades. Scenario analyses based on the 1999 Gothenburg Protocol also predict a decrease in nitrate concentrations in the soil solution of most plots. However, in many regions with developing industries, atmospheric deposition is still increasing, requiring its continued monitoring and the sharing of information and expertise. In this context the achievements of ICP Forests and the European Union have been acknowledged by the United Nations Forum on Forests at its third session in 2003 and its monitoring methods have also been recommended for other regions of the world.

30. Ozone concentrations above critical levels and rising carbon dioxide concentrations have become a threat to forest ecosystems. In 2002, the percentage of trees with damaged crowns remained high and visible ozone injuries were detected on many plots. It is still unclear how forest ecosystems on a large scale respond to rising concentrations of greenhouse gases and climate change, and the complex interactions between them. However, open air research already shows interactions between carbon dioxide and ozone. The results of the programme show the effect of nitrogen deposition on carbon sequestration. With its unique system of monitoring plots and its database, the programme is in a strong position to provide a sound basis for future environmental policies in these fields.

31. The programme will continue its regular overviews of forest condition in Europe. It will focus on policy-relevant key information in the field of air pollution and forests, and will also contribute information needed on climate change and forest biodiversity. Thus the monitoring activities will provide a sound basis for clean air and environmental policy in the future.