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MONITORING OF FOREST CONDITION IN EUROPE

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

Introduction

1. Forest condition in Europe has been monitored over 20 years by ICP Forests in close cooperation with the European Commission. Large-scale variations of forest condition over space and time have been assessed on 6,000 plots systematically spread across Europe in relation to natural and anthropogenic factors. This large-scale monitoring intensity was referred to as level I. Intensive monitoring was carried out on 860 level II plots in order to detect how various stress factors influence forest ecosystems.

2. Air pollution effects were the particular focus of the programme. The activities required technical equipment for a larger number of surveys, for example, crown condition, foliar chemistry, soil and soil solution chemistry, tree growth, ground vegetation, atmospheric deposition, ambient air quality, meteorology, phenology, litterfall and remote sensing. With its large number of plots and parameters and the participation of 40 countries, the programme has operated one of the world's largest biomonitoring networks.

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3. The objectives of the monitoring programme are to:

(a) Provide a periodic overview on the spatial and temporal variation in forest condition in relation to anthropogenic and natural stress factors for a European and national large-scale systematic network (level I);

(b) 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 spread over Europe (level II);

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

(d) 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) Compile information on forest ecosystem processes and to provide policy makers and the public with relevant information.

I. NITROGEN AND SULPHUR DEPOSITION ON LEVEL II PLOTS

A. Methods

4. ICP Forests started to implement deposition measurements on level II plots in the mid-1990s. Deposition was measured in open field (bulk deposition) and within forest stands (throughfall). Stemflow measurements were of particular importance in beech stands where considerable amounts of rainwater reached the forest floor running down the smooth bark of the trees. In open field samples, wet and some dry deposition could be directly quantified. Deposition in forest stands was usually higher compared to open fields due to the filtering effects of tree canopies. However, the measurements had to be interpreted with care, as rainwater washed certain elements (e.g. potassium) from the foliage when percolating through the canopies (leaching). Other compounds (e.g. nitrogen) were taken up by leaves and needles (canopy uptake). In comparison to nitrogen compounds, leaching or canopy uptake of sulphate was low.

5. Complete quality-checked data sets for throughfall and bulk deposition for nitrate ($N\text{-}NO_3$), ammonium ($N\text{-}NH_4$), and sulphate ($S\text{-}SO_4$) on 169 plots in 1996–2001 were used to calculate annual mean depositions. For the same period, slopes of plotwise linear regressions were tested for significance. Plot-specific means were calculated for the period 1999 to 2001. In the mapping, all plots that had complete data sets of the depicted compound were included.

B. Results

6. Between 1996 and 2001, sulphate deposition decreased from 7.4 to 5.9 kg S ha^{-1} y^{-1} (fig. I). The annual mean was calculated from 169 open field measurement stations located mainly in central Europe. Forest trees clean the air by filtering pollutants. Therefore in nearby forest stands deposition was on average twice as high as in open fields. A pronounced 40% decrease in sulphate throughfall illustrated that emission reductions benefit forest ecosystems. Annual mean throughfall of ammonium and nitrate decreased as well. In open field measurements, nitrate inputs fluctuated rather than decreased. Despite the last years' reductions, deposition was still above critical loads on many plots. Pollutants were deposited on forest soils for several decades and dynamic models showed that even partial recovery might also take decades (chapter III).

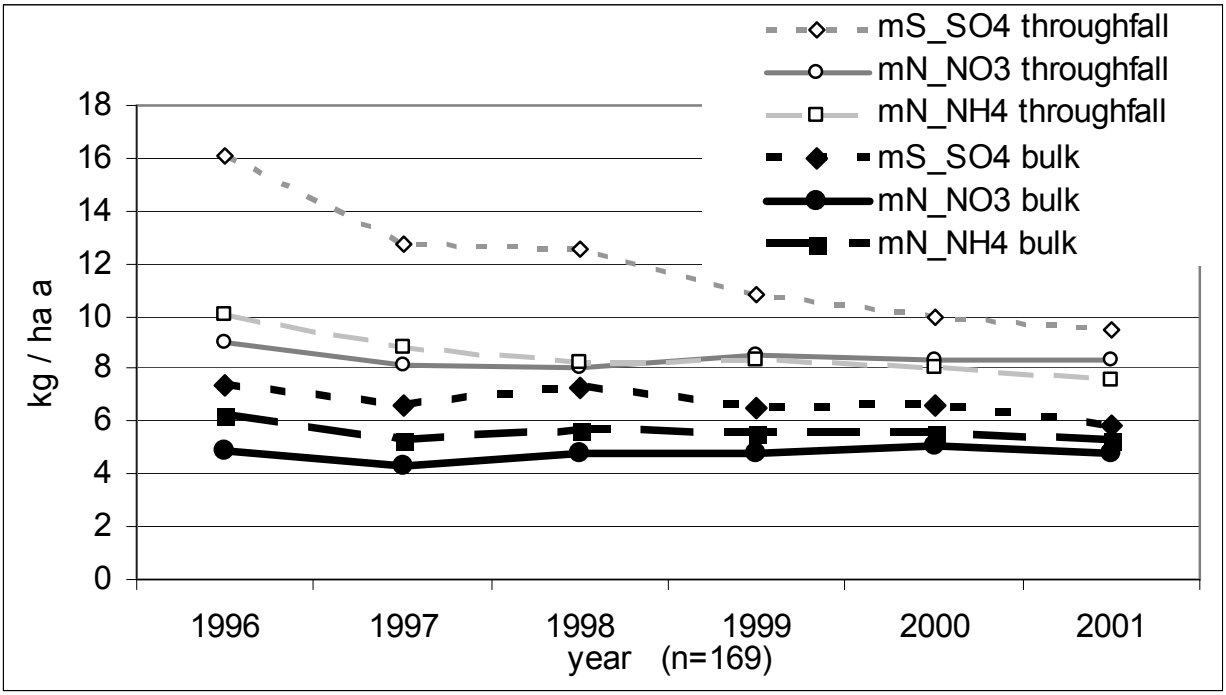

Figure I. Annual mean bulk deposition and throughfall of sulphur ($S\text{-}SO_4$) nitrate ($N\text{-}NO_3$), and ammonium ($N\text{-}NH_4$) in 1996–2001 from 169 plots

C. Levels and trends of deposition are varying over Europe

7. High nitrate deposition was common on plots in central Europe from the north of Italy to southern Scandinavia (fig. IIa). Plots with decreasing open field inputs were in general prevailing but plots with a significant increase existed (fig. IIb). In a few cases this increase took place on plots that already showed high mean inputs. Sulphate bulk deposition decreased at 75% of the plots (fig. IIIb). This decrease was significant at 21.8% of the plots and reflected largely the success of clean air policies. With regard to the continuing high nitrate and ammonium deposition, the implementation of the 1999 Protocol to Abate Acidification, Eutrophication and

Ground-level Ozone that entered into force on 17 May 2005 needs to remain high on the political agenda. Annual fluctuations of atmospheric depositions were often due to variations in precipitation. High sulphate inputs on plots near coasts could be of natural maritime origin (fig. IIIa). The high variability of plot situations and forest types across Europe underlined the necessity of a broad monitoring approach.

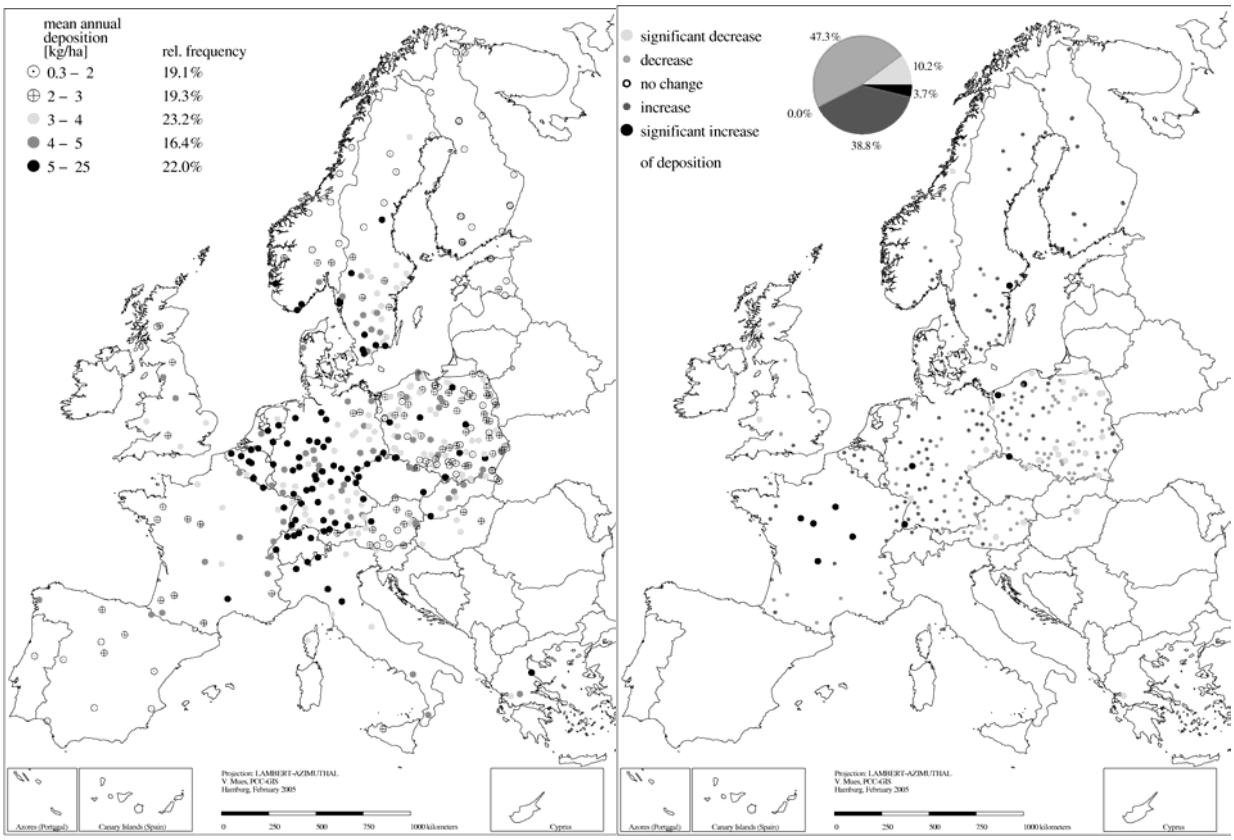

Figure II. (a, left) Mean nitrate (N-NO3 bulk) deposition in1999–2001 on 409 plots and (b, right) trend of nitrate (N_NO3 bulk) deposition in 1996–2001 on 294 plots

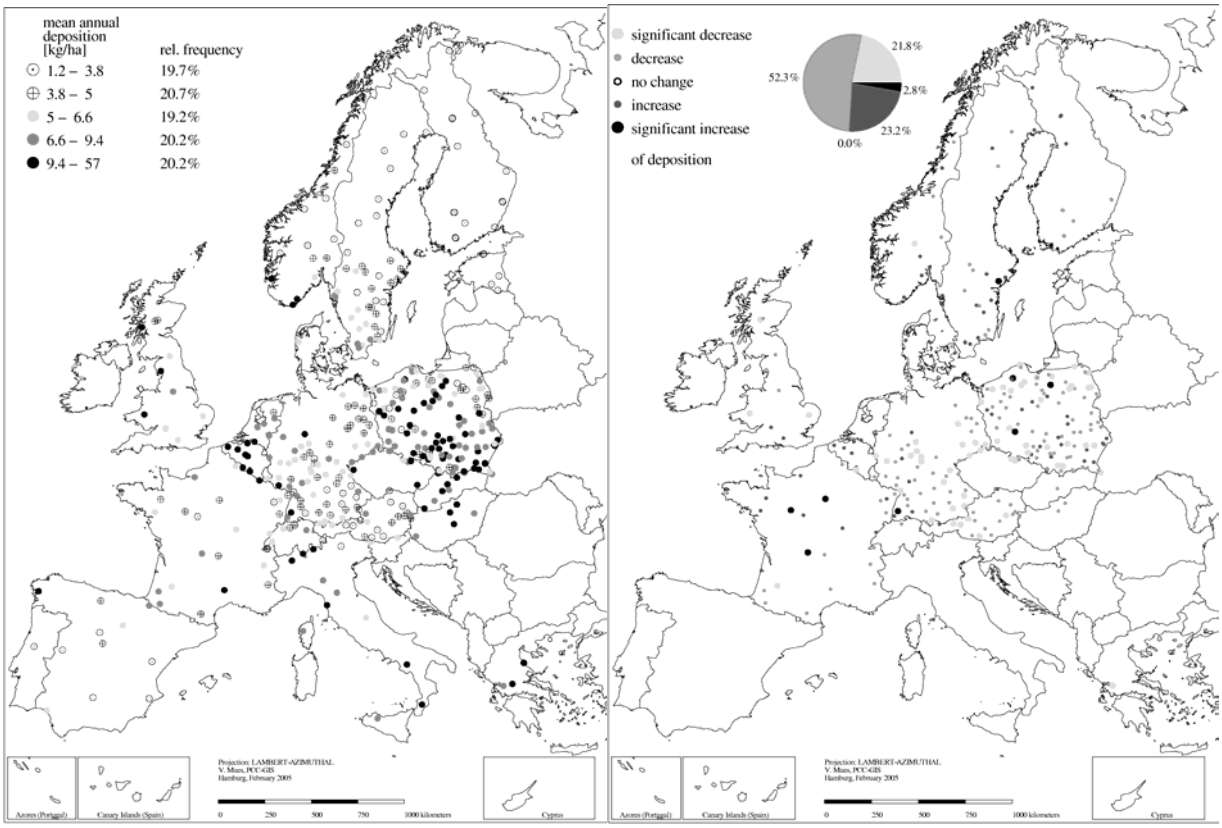

Figure III. (a, left) Mean sulphate (S-SO4 bulk) deposition in 1999–2001 on 401 plots and (b, right) trend of sulphate (S-SO4) bulk deposition in 1996–2001 on 285 plots

II. LEACHING OF NITROGEN DEPOSITION INTO GROUNDWATER

A. Introduction

8. Nitrogen emissions by agriculture and fossil fuel combustion have remained a major problem in central Europe. On average, nitrogen deposition decreased slowly or remained at the same level on the forest plots (chapter I). Over the last decades deposition contributed to increased storage of nitrogen in the organic matter and soil and ultimately enhanced nitrogen concentrations in surface water runoff and groundwater. Data from 121 level II plots together with additional large-scale data were the basis for assessing the impact of high nitrogen deposition on forest soils in central and northern Europe. This research was supported by European Union (EU) projects DYNAMIC and CNTER.

B. Nitrogen input and nitrogen status of the soils leaching fluxes

9. As reported in earlier publications, high leaching of nitrogen was largely related to high nitrogen throughfall deposition. When rainwater contained large quantities of nitrogen, there was a higher probability of nitrogen leaching into the groundwater. This general relationship was

specifically true for sites where the forest floor was already nitrogen-enriched ("high-N status") (fig. IV). Neither the soil nor the plants were capable of retaining much additional nitrogen and let it pass through rather quickly.

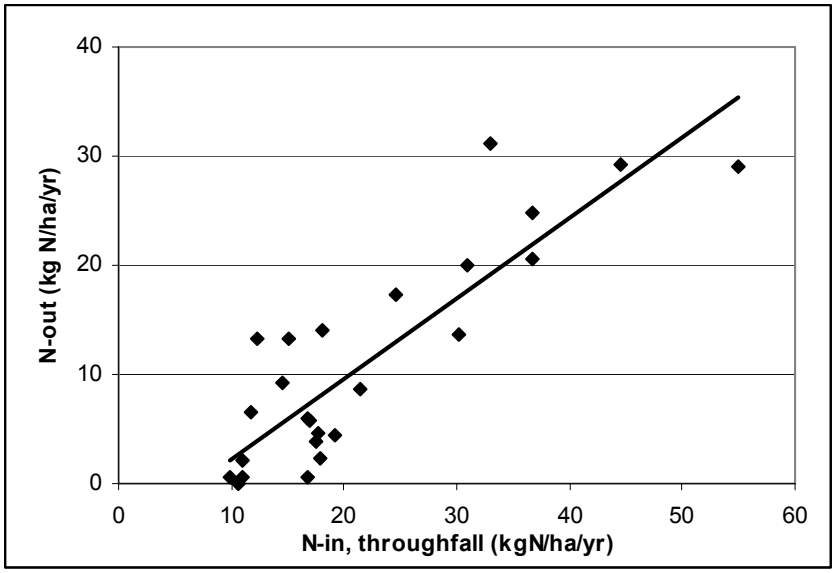

Figure IV. Nitrogen leaching against input in throughfall at nitrogen enriched sites

10. At sites that were rather nitrogen-poor ("low-N status"), mean annual temperature was an important determinant for nitrogen leaching. For any given nitrogen input, model calculations showed that nitrogen output was highest at a mean annual temperatures of 7.5° C. At higher temperatures nitrogen leaching was lower. A possible explanation was that warmer temperatures were linked to enhanced vegetation productivity and higher nitrogen uptake. Lower leaching rates also occurred at lower temperatures, probably due to microbial domination of nitrogen cycling.

III. FOREST ECOSYSTEM RECOVERY CAN TAKE DECADES – THE APPLICATION OF DYNAMIC MODELS

A. Introduction

11. Monitoring results showed that sulphur deposition significantly decreased on many plots, whereas nitrogen inputs were in general either fluctuating or decreasing. But what were the medium-and long-term effects of previous decades with high air pollution? Could we again proceed as if nothing had happened once the inputs decreased below critical loads? Dynamic soil chemistry models such as SAFE (Soil Acidification in Forest Ecosystems) and VSD (Very Simple Dynamic) showed the effects on soils and soil solution of acid deposition and forestry measures, for example harvesting and liming. They offered process-oriented tools to estimate the recovery time for forest ecosystems and level II data provided good input for the models. In

previous reports results of the SMART model were presented. Here the first results of the VSD model and the more complex SAFE model are presented. The application to a larger number of plots will be carried out in the coming year.

B. Results

12. Dynamic models were applied to level II data by national focal centres of Bulgaria, Germany, Norway, Sweden, Switzerland and United Kingdom:

(a) SAFE simulations on 84 plots in Germany predicted that in over 90% of the cases the critical pH limits would be exceeded in 2010 and recovery processes would be very slow;

(b) At 16 sites in Sweden slow recovery of soil chemistry was predicted assuming implementation of the 1999 Gothenburg Protocol. In 2100, still 44% of the sites might have soil layers with a base cation to aluminium ratio below the critical value of 1;

(c) Critical loads for sulphur and nitrogen were not exceeded at any of the three plots in Bulgaria;

(d) Soil base saturation levels at any of the modelled sites would not reach pre-industrial levels in the next 50 years even assuming a maximum feasible emission reduction scenario.

C. A beech forest example

13. At the level II plot in Freising, Germany (fig. V) a forest clear-cut, documented in the stand history, led to a collapse of soil solution pH over several years in the mid-19th century. Increasing air pollution contributed to a continuous decrease of pH since then. At the end of the 20th century this decline was rather extreme across the mineral soil layers above 45 cm. The emission reduction scenario resulted in a recovery of deeper soil layers supported by cations from the weathering of rather nutrient rich parent materials. For the upper soil layers, the cation supply from deeper soil was not sufficient in relation to acid deposition and the pH was predicted to remain below the critical limit as indicated for the layer 25–45 cm. The critical limit was defined by requiring the pH of the soil body below 10 cm soil depth in pre-industrial time not to change significantly. The calculations relied on level II data and historic deposition rates available from the literature. Future deposition scenarios were based on emissions of the 1999 Gothenburg Protocol as calculated by the Centre for Integrated Assessment Modelling.

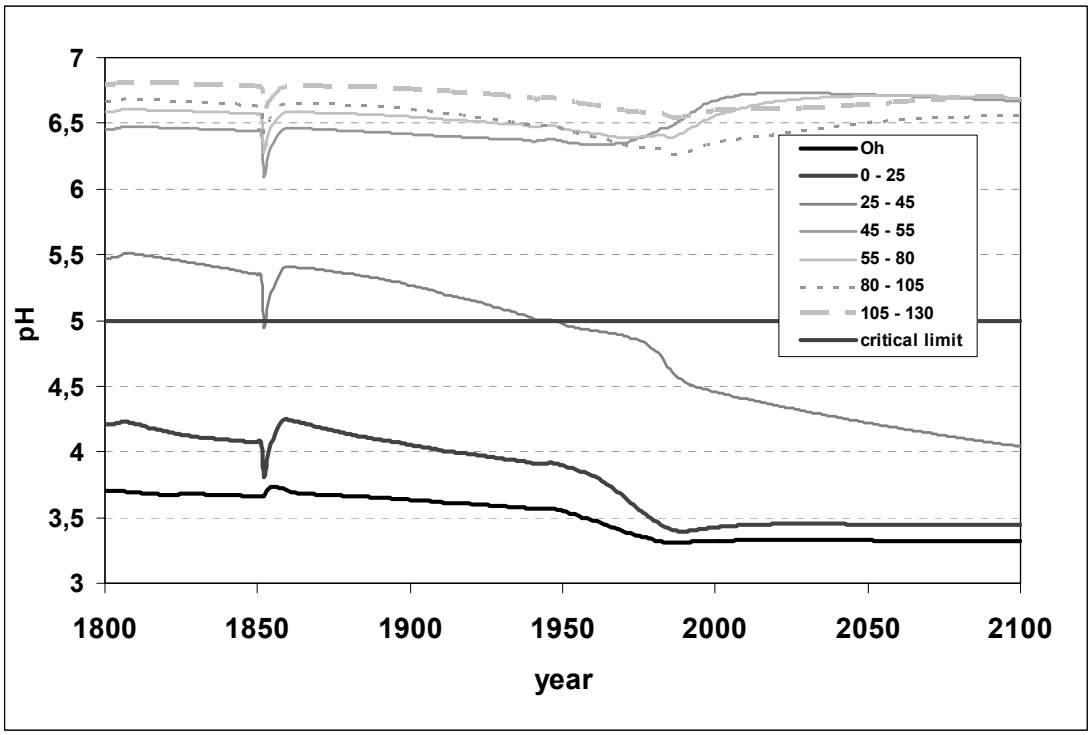

Figure V. Application of the SAFE model for the level II plot in Freising, Germany

D. Conclusions and outlook

14. Emission reductions based on the 1999 Gothenburg Protocol and the EU National Emission Ceilings Directive resulted in some soil recovery on most of the plots. Further emission reductions were necessary to ensure a soil status of long-term ecosystem stability. The soil solid phase chemistry, fauna and flora reacted slower than the soil solution and recovery could take many decades. Future efforts will be directed towards the application of SAFE to a larger number of level II plots and towards still more sophisticated models, which are able to simulate reactions of plant communities and forest growth to changing environmental parameters.

IV. IMPLEMENTATION OF OZONE MONITORING

A. Introduction

15. Ground-level ozone is regarded as one of the most important greenhouse gases. Its formation in the atmosphere is aggravated by air pollutants such as nitrogen dioxide. As ozone data from remote and forested areas were not readily available, ICP Forests started a test phase for passive samplers at its level II plots in 2001. This produced information on monthly, fortnightly or weekly mean concentrations for more than 100 plots and supported the determination of visible ozone injuries on plant leaves and needles. Data up to 2003 were evaluated.

B. Results

16. On most of the surveyed plots, ozone concentrations were higher in 2003 compared to 2002 (fig. VI). This was particularly evident in Germany, Greece and Italy, where many plots reached ozone mean concentrations above the critical limit of 45 parts per billion (ppb) (Directive 2002/3/EC). The increase reflected different weather conditions of both years. Year 2002 was rainy and stormy with exceptional flood episodes in central Europe, whereas 2003 was characterized by exceptionally high temperatures and drought problems in large parts of Europe. The long and intensive sunshine periods in 2003 resulted in high ozone concentrations as sun radiation is a prerequisite for ozone formation in the atmosphere.

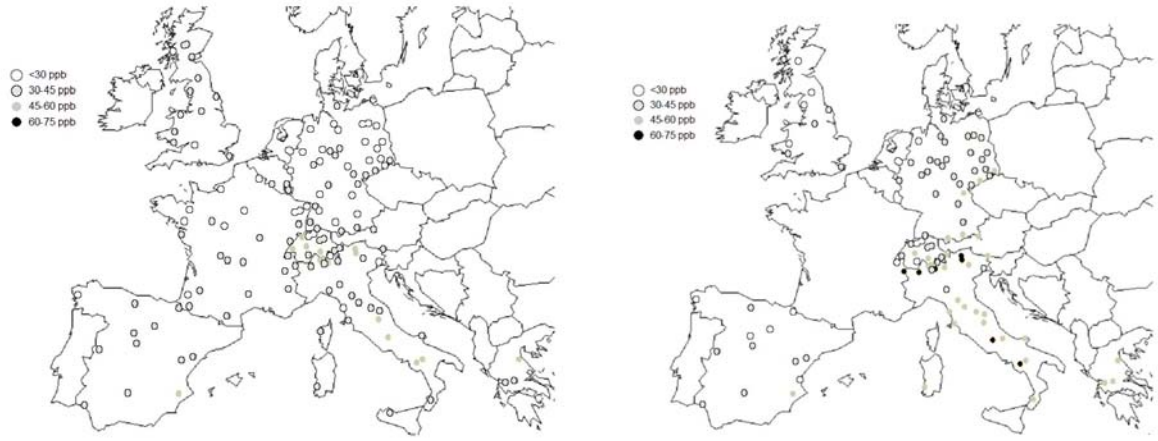

Figure VI. Mean ozone concentrations from April to September in 2002 (left) and 2003 (right). Data for plots with measured values for more than 50% of the days between April and September were presented

17. Ozone concentrations were related to the latitude and altitude of the plots. Plots with higher ozone concentrations were located in southern Europe and at higher altitudes. Highest concentrations were measured in southern Switzerland and northern Italy. During spring and summer, ozone-rich layers are regularly formed and re-circulated in the Mediterranean basin for several days. This explained the high ozone concentrations observed in southern Europe.

18. Six countries submitted data on visible injury during the test phase in 2001–2003. Across Europe, countries reported 108 different plants showing symptoms. Visible ozone injury was reported for beech (13 plots) and for ash (8 plots). The number of species showing symptoms decreased from 2002 to 2003 in Spain and Switzerland but increased in Italy. More symptomatic species were detected in 2003 than in 2002 in Hungary, however, there were no ozone concentration measurements. A clear link between hot summers and more injury could not be demonstrated. Decreased water availability for the plants reduces gas exchange through leaves

and needles and consequently ozone uptake. Thus, high ozone concentrations in dry summers were not necessarily linked to more damage.

C. Conclusions and outlook

19. The ozone monitoring test phase of ICP Forests provided concentration data from remote areas. Long series of ozone measurements and ozone injury assessments would help to draw more definite conclusions on the effects of ozone in European forests. This is particularly necessary under changing climatic and environmental conditions with a predicted increase in summer temperatures and a higher frequency of drought episodes. The comparison between 2002 and 2003 showed that under such climate scenarios higher ozone levels were to be expected.

V. STATE OF EUROPE'S FORESTS IN 2004 AND CHANGES OVER TIME

A. Introduction

20. Defoliation was assessed in 2004 on 135,372 trees on 6,133 plots in 31 countries in the large-scale transnational 16x16 km grid as a fast reacting indicator for numerous natural and anthropogenic factors affecting tree vitality. In many countries, additional assessments were performed in denser national grids. Here results are reported on four tree species, which are represented most frequently in the transnational grid, i.e. Scots pine, Norway spruce, common beech as well as European and sessile oak.

B. Results

21. The share of trees classified as damaged or dead was 23.3% in the whole of Europe and 24.2% in the participating EU member States. These figures involved a share of dead trees of 0.7 % in both cases. European and sessile oak had the highest and Scots pine the lowest defoliation (fig. VII).

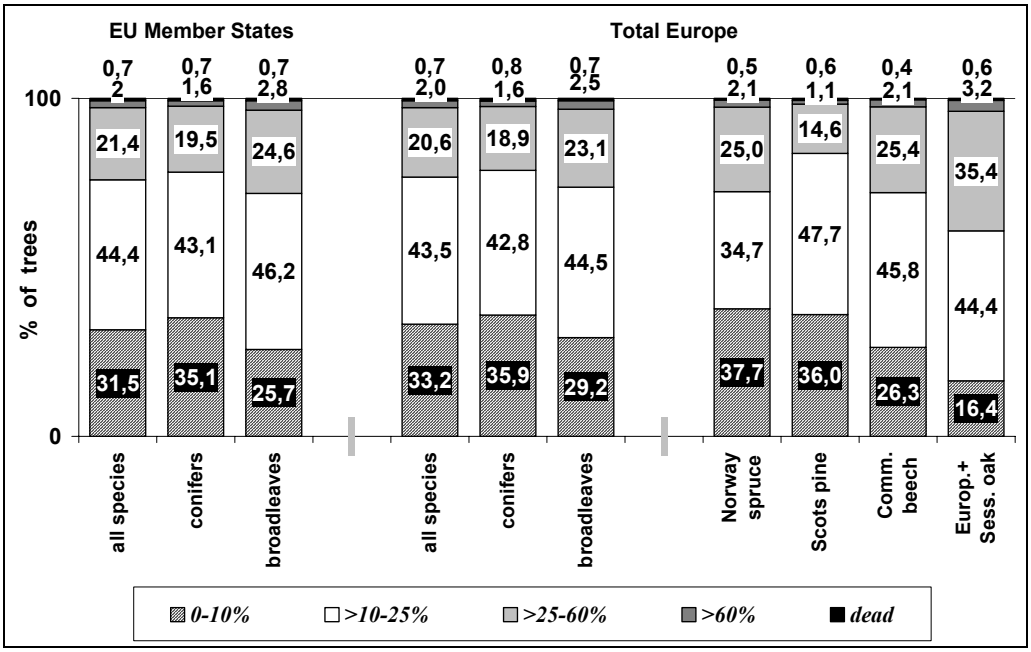

Figure VII. Percentage of trees in different defoliation classes in whole Europe and in participating EU member states in 2004

22. Mean defoliation of common beech, of European and sessile oak and to a smaller degree also of Norway spruce increased during an evaluation period from 1990 to 2004. These three species had recovered from high defoliation in the mid-1990s, but showed a clear increase in defoliation between 2002 and 2004 (fig. VIII). All species except holm oak and Scots pine showed a sharp increase in defoliation in 2004 and partly started in 2003. Defoliation in Scots pine has decreased since 1995.

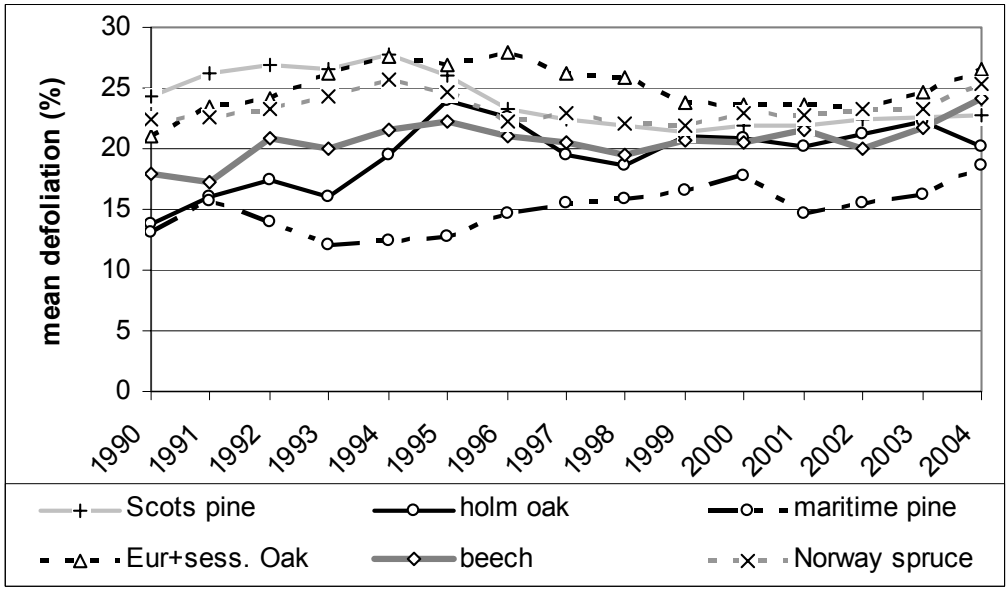

Figure VIII. Development of annual mean defoliation of six main tree species in Europe. Sample sizes varied between 11,924 and 2,332 trees per year and species. Results are based on data from 12 countries with continuous data submission

23. The trends in defoliation varied considerably across Europe. On 18.8% of plots a statistically significant increase in defoliation was observed in 1997–2004. This reflected the deterioration of crown condition of the main tree species described above. A decrease in defoliation occurred on only 12.4% of the plots. These were largely Scots pine concentrated in Belarus and in parts of Poland and the Baltic countries.

24. Common beech deteriorated in all regions monitored in 2004, except in eastern parts of Europe (fig. IX). Deterioration was less obvious for European and sessile oak because of their higher defoliation in earlier years. For Norway spruce the deviation from the medium-term mean defoliation showed a high spatial variation. Defoliation was higher than average in eastern Austria and central Sweden, whereas it was lower than average in large regions of central, eastern and northern Europe.

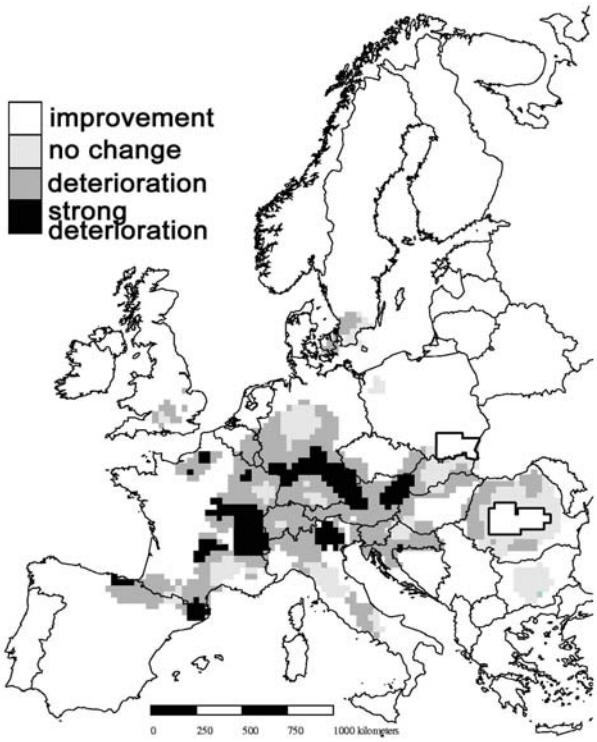

Figure IX. Deviation of annual mean defoliation of common beech in 2004 from the average defoliation in 1997–2003. Data were interpolated with kriging method from 564 plots continuously assessed in 1997–2004

25. The increase of defoliation in 2004 was already anticipated in last year's report in view of the heat and drought stress which occurred in summer 2003. Depending on tree species, there were several reasons explaining continuing or even increasing defoliation after the actual drought year, all involving a weakening of the trees for several years. Beech constituted a classical example for its increasing defoliation due to drought stress. The improvement of crown

condition of Scots pine in central and Eastern Europe was observed for nearly a decade and was attributed to improved weather conditions and decreased air pollution.

VI. SUMMARY AND CONCLUSIONS

26. More than two decades ago Europe was alarmed by scenarios of air pollution causing catastrophic forest damage. The headlines have since changed. Forest condition deteriorated far less dramatically at the European-wide scale than feared in the early 1980s.

27. The provision of a more realistic picture on forest condition in space and time and the establishment of an early warning system for European forests were among the main results of the monitoring under ICP Forests carried out in close collaboration with the European Commission.

28. In many regions various stress factors including air pollution affected forest condition considerably. Extreme drought and heat during the summer 2003 contributed to the pronounced worsening of the condition of many of the main tree species in 2004, notably for beech and especially in Central Europe. Only the defoliation of Scots pine is now clearly lower than in the mid-1990s. Crown condition proved to be a valuable indicator of the condition of trees to estimate in a relatively short time and with low costs.

29. There were various reasons for the different trends in forest ecosystems condition across Europe. The level II plots offered a unique chance for more in-depth insights into ecosystem reactions related to different stress factors. The mean annual nitrogen deposition under the canopy of 169 level II plots, mostly located in central European regions, decreased from around 19 to 16 kg ha^{-1} y^{-1} in 1996–2001. On nearly all plots, nitrogen deposition was considerably higher than sulphur deposition. Mean sulphur deposition was 10 kg ha^{-1} y^{-1} in 2001. The high nitrogen deposition increased the risk of nitrate leaching into the groundwater. This was particularly true for sites that were already nitrogen enriched.

30. The Convention's protocols were negotiated to reduce air pollution effects to ecosystems, materials and human health. Dynamic soil chemistry models predicted some recovery of soil solution chemistry as a consequence of the abatement strategies. However, full recovery of many plots will take decades and depend on further emission reductions.

31. The monitoring test phase for ambient air quality which started in 2001 on 100 level II plots has led to reliable ozone data from remote forested sites. The threat of higher ozone concentrations in repeated warm summer episodes has been substantiated. The assessment of ozone effects on plants has begun. First results showed no clear link between ozone

concentrations and visible ozone injury as gas exchange and thus ozone uptake was limited in dry weather conditions.

32. The results from ICP Forests work during the past two decades has constituted part of the scientific basis of the Convention protocols. In the future, the provision of relevant scientific information to the Convention will remain the highest priority. Nevertheless, the programme will also use its multidisciplinary monitoring approach and data to contribute to other international environmental policy processes. It will provide information on species diversity in European forests and on causes for its changes over time. In addition, harmonized data on carbon sequestration will be contributed by ICP Forests. Close cooperation with the scientific community will assure further mutual benefits and close contact with programmes in other regions such as Eastern Asia and Northern America will help complete a global picture on forest condition.