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RECENT RESULTS AND UPDATING OF SCIENTIFIC AND TECHNICAL KNOWLEDGE

2008 RESULTS OF MONITORING FOREST CONDITION IN EUROPE

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

INTRODUCTION

1. In 2008, the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) continued its large-scale and intensive monitoring of forest condition. Results are available for 4,837 level I plots (2007 assessment) and 671 level II plots (2005 assessment). The parameters monitored included crown condition, foliar chemistry, soil and soil solution chemistry, tree growth, ground vegetation, atmospheric deposition, ambient air quality, meteorology, phenology and litterfall (Lorenz et al. 2008, Fischer et al. 2008). The results are presented here in accordance with item 3.4 of the 2008 workplan for the implementation of the Convention (ECE/EB.AIR/91/Add.2), adopted by the Executive Body at its twenty-fifth session.

I. SPATIAL AND TEMPORAL VARIATION OF DEPOSITION

2. Bulk deposition and throughfall deposition data have been available from approximately 500 level II plots since the second half of the 1990s. The analysis covered sites which had been operational for the whole period 2000–2005, allowing a maximum of one month of missing data per year. Deposition for the missing periods was calculated from the average daily deposition of the remainder of the year. To take into account the variability of deposition, the plotwise mean deposition for a three-year period (2003–2005) instead of a single year, was evaluated. The slopes of linear regressions over three years for each plot were calculated and tested for significance to quantify temporal developments.

3. Mean nitrogen (N) throughfall deposition ranged from 9.1 to 11.0 kg ha^{-1} $year^{-1}$ measured in 2000–2005 for about 220 plots in Europe (figure 1). Mean annual values fluctuated. Ammonium deposition ranged from 4.6 to 5.3 kg ha^{-1} $year^{-1}$. Nitrate deposition ranged from 4.6 to 5.7 kg ha^{-1} $year^{-1}$. The plotwise evaluations showed that 93% of the plots did not show any significant changes in N throughfall deposition. Depositions were mostly higher on plots in Central Europe than in Alpine, Northern and Southern European regions.

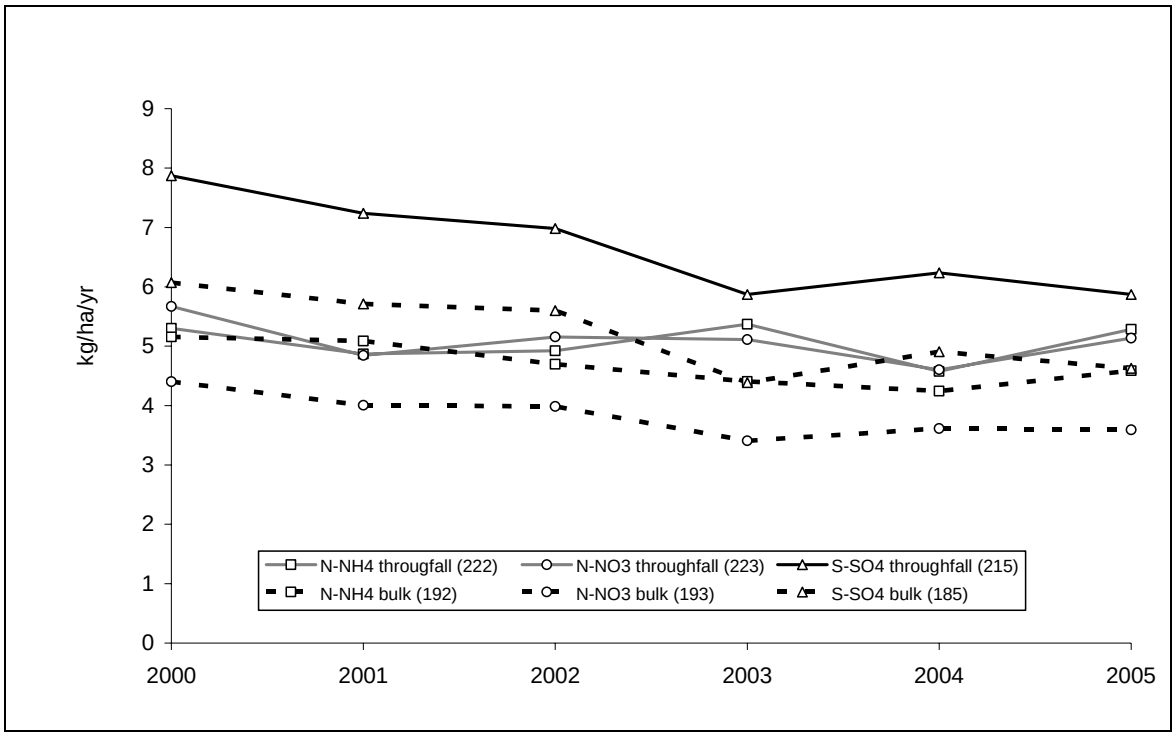

Figure 1. Annual mean bulk and throughfall deposition of sulphate ($S\text{-}SO_4$), nitrate ($N\text{-}NO_3$) and ammonium ($N\text{-}NH_4$) in the period 2000–2005.

4. Mean bulk ammonium deposition for about 200 plots decreased from 5.2 kg in 2000 to 4.2 kg in the year 2004 and reached 4.6 kg N ha^{-1} $year^{-1}$ in 2005. An overall decrease from 2000 to 2005 was significant on 10% of the plots, whereas a significant increase was observed on 2%

of the plots. Bulk nitrate inputs decreased from 4.4 in 2000 to 3.6 kg N ha^{-1} $year^{-1}$ in 2005. A significant decrease was observed on 8% of the plots. A significant increase was observed on 1% of the plots.

5. Mean throughfall sulphate inputs decreased from 7.8 to 5.9 kg ha^{-1} $year^{-1}$ in the period 2000–2005 (figure 1). 23% of the plots showed significantly decreasing sulphur (S) inputs, whereas only one plot showed an increase. Comparatively low sulphate throughfall deposition was measured on plots in the Alpine region, Scandinavia and the Iberian Peninsula. Mean bulk sulphate deposition decreased continuously from 6.1 in 2000 to 4.4 kg S ha^{-1} $year^{-1}$ in 2003 and reached 4.6 kg S ha^{-1} $year^{-1}$ in 2005.

II. EXCEEDANCE OF CRITICAL LOADS AND ECOSYSTEM RESPONSES

6. Based on the results of deposition measurements at level II sites, critical loads for acidity and N as well as their exceedance were presented in the previous report (Lorenz et al. 2007). The exceedance of critical loads as well as deposition and soil information were now related to tree crown defoliation as an important ecosystem response variable. Calculations were carried out for the main tree species and are based on about 130 level II plots.

7. For the total sample of all main tree species, there were no significant relations to critical load exceedance. When analysing the main tree species separately, higher defoliation estimates coincided with higher exceedance of nitrogen deposition for common beech (figure 2). For Scots pine (figure 3), European and sessile oak and Norway spruce, there were no systematic relationships. As is typical with the use of highly aggregated parameters in interference analyses, it was not easy to identify an underlying causal mechanism for the relationship found in beech. Respective interference analyses between defoliation and exceedance of critical loads for acidity did not reveal any significant statistical relationships for the four species respectively species aggregates.

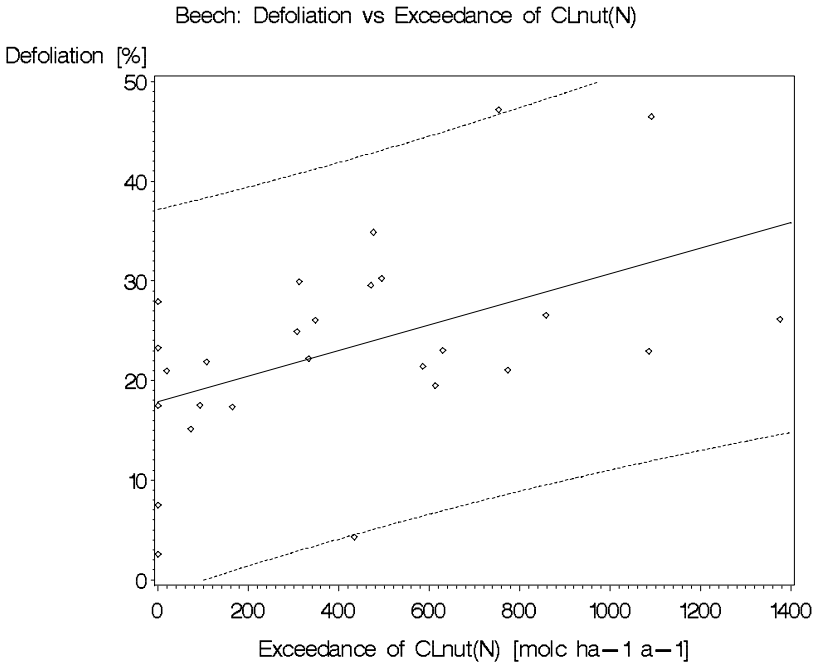

Figure 2. Linear regression (including the 95% confidence intervals for predicted values) with defoliation of beech (*Fagus sylvatica et moesiaca*) as response parameter and exceedance of critical loads for nutrient N as predictor (n = 27, R^2 = 0.24, p > F = 0.0099).

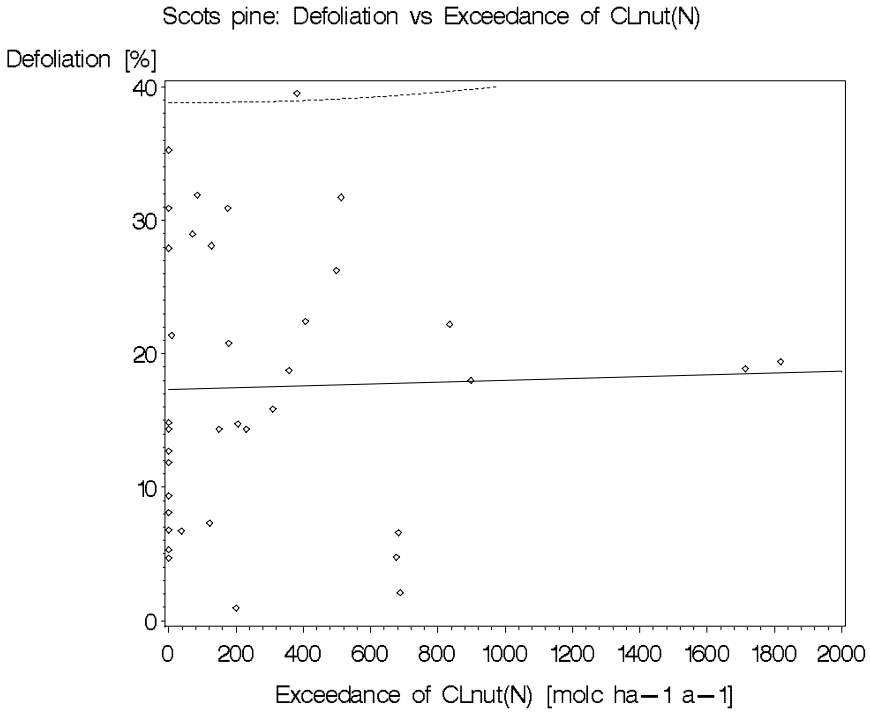

Figure 3. Linear regression (incl. 95% confidence intervals for predicted values) with defoliation of Scots pine (*Pinus sylvestris*) as response parameter and exceedance of critical loads for nutrient N as predictor (n = 37, R^2 = 0.001, p > F = 0.865).

8. Multiple linear models were calculated with defoliation as response variable to take into account the multiple influences on tree condition and the interdependencies between different predictor variables. Again, beech defoliation was related to exceedance of critical loads for nutrient N, whereas there were no such relationships for the other main tree species. It should be noted that the critical loads concept is a long-term model for ecosystem development. Therefore, exceedance of critical loads may not evoke immediate responses within particular ecosystems. Only if specific critical thresholds (limits) of organisms (e.g. trees) within certain ecosystems are exceeded is a respective response to be expected. Even though it proved challenging to show direct relations between critical loads exceedance and tree crown defoliation, there were relations between deposition and forest ecosystem condition. These were statistically shown by a larger number of correlations between N deposition and defoliation of Norway spruce, Scots pine and beech.

III. DYNAMIC MODELLING OF DEPOSITION EFFECTS ON PLANT SPECIES DIVERSITY

9. Three level II plots were selected for applying the biodiversity model on the bioindication for ecosystem regeneration towards natural conditions (the BERN model, Schlutow and Hübener 2005). The BERN model was applied in addition to the geochemical very simple dynamic (VSD) model in order to comprehend the vegetation changes in the past and future. The VSD model, inter alia, builds on historical deposition data. Based on the results of time series modelled with VSD for base saturation and carbon-nitrogen ratio (C/N), the BERN model functioned as an add-on model and helped to predict vegetation changes in relation to changing deposition and related soil conditions. The model was applied on sites in Austria, the Czech Republic and Poland.

10. At the Austrian and Czech sites, the results of the VSD model showed a dramatic decline of base saturation between 1910 and 1930, probably caused by foresting spruces instead of the native beeches. After 1930, eutrophying N deposition was the main cause for a strongly decreasing C/N. Changes in base saturation and C/N ratio led to drastic changes in the site conditions and thus to altered natural vegetation types as predicted by the BERN model. According to the modelled predictions, the recovery of natural forest vegetation is being prevented by an unbalanced nutrient supply up to the end of the modelling period in 2050. Recommendations for adapted forest management included amelioration of soil properties and selection of adapted tree species.

11. The Polish site showed the typical conditions of a forest artificially drained in the past. This comparatively strong influence on the local site condition overlaid possible deposition effects.

IV. OZONE CONCENTRATIONS, IMPACTS ON VEGETATION AND FURTHER DEVELOPMENT OF THE FLUX APPROACH

12. Ozone (O_3) passive sampler data collected from 91 level II sites were used to compare mean summer concentrations for the years 2000–2004. Some of the highest O_3 levels in forest areas of Europe were measured during 2003, a season with one of the hottest summers on record in Europe. Relatively high levels were also recorded in 2001 and 2004. During 2002, a season characterized by a rainy summer, and also during 2000, lower O_3 values were measured. Mean seasonal O_3 levels increased from Atlantic and Northern Europe to the Mediterranean region. Based on a five-year data set, a tendency to increasing ($R^2 = 0.54$, $P < 0.001$) O_3 levels with elevation was confirmed.

13. Based on passive sampler data, values of AOT 40 ((accumulated O_3 concentration above a threshold of 40 parts per billion (ppb)) were modelled for level II sites with at least 80% data completeness and a 1–2 weekly sampling frequency. The methodology was based on Gerosa et al. (2003, 2007). In the different years, respective data were available for between 46 and 71 plots. The critical level for a potential risk for sensitive forest species under sensitive conditions set at 5,000 ppb h (parts per million times hours) was frequently exceeded at many sites and years. The median value in the different years varied between 14,000 and 28,000 ppb h. Relatively low values were observed in 2002, a year with a cool summer, and high peaks during 2003 and 2004 (figure 4).

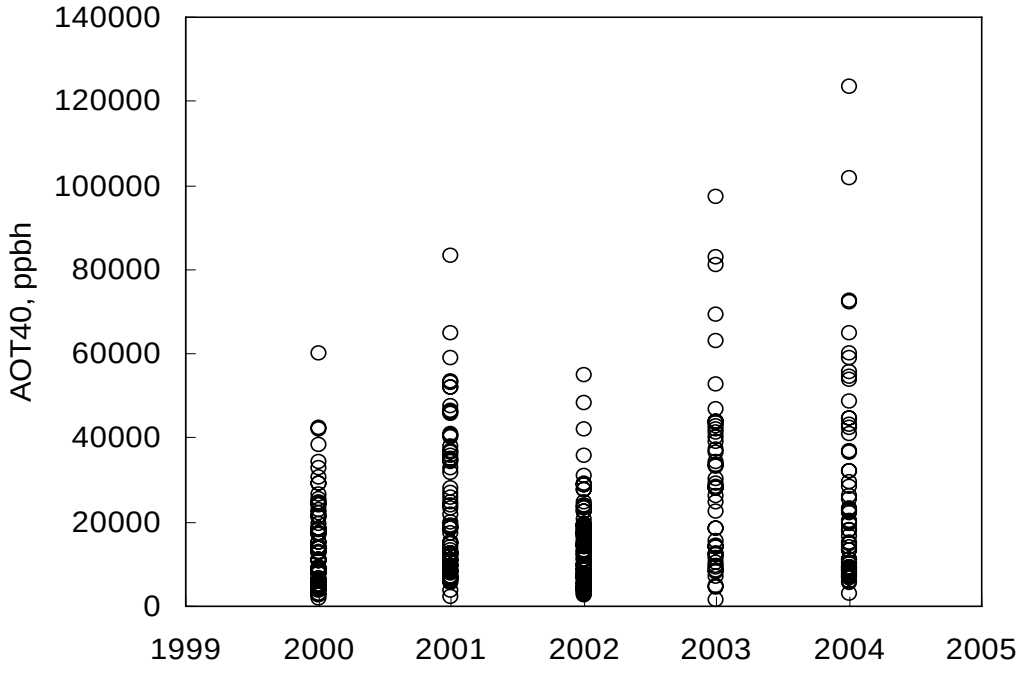

Figure 4. AOT40 (ppb h) estimates obtained for individual level II sites for the period 2000–2004. The number of sites and countries differed from year to year.

14. Since O_3 pollution leaves no elemental residue that can be detected by analytical techniques, visible O_3 injury on needles and leaves is the only easily detectable evidence in the field (Innes et al. 2001, Schaub et al. 2002). Following standardized methods developed within ICP Forests, visible O_3 injury was assessed at level II sites. Data from 18 sites in Italy, Spain and Switzerland were available for in-depth analyses. They were collected on 389 subplots. Correlation analyses were only carried out with data from 2004 as the assessment method was changed after 2003. On the average, 28 different species per plot were assessed, of which two species (7%) were symptomatic. The remaining species did not show visible O_3 injury. There was a positive but non-significant trend between the average proportion of symptomatic species per subplot and the average seasonal O_3 concentration for 2004. The transformation of O_3 concentration into the AOT40 exposure indices resulted in a stronger but still not significant trend between symptom development and O_3 exposures (figure 5).

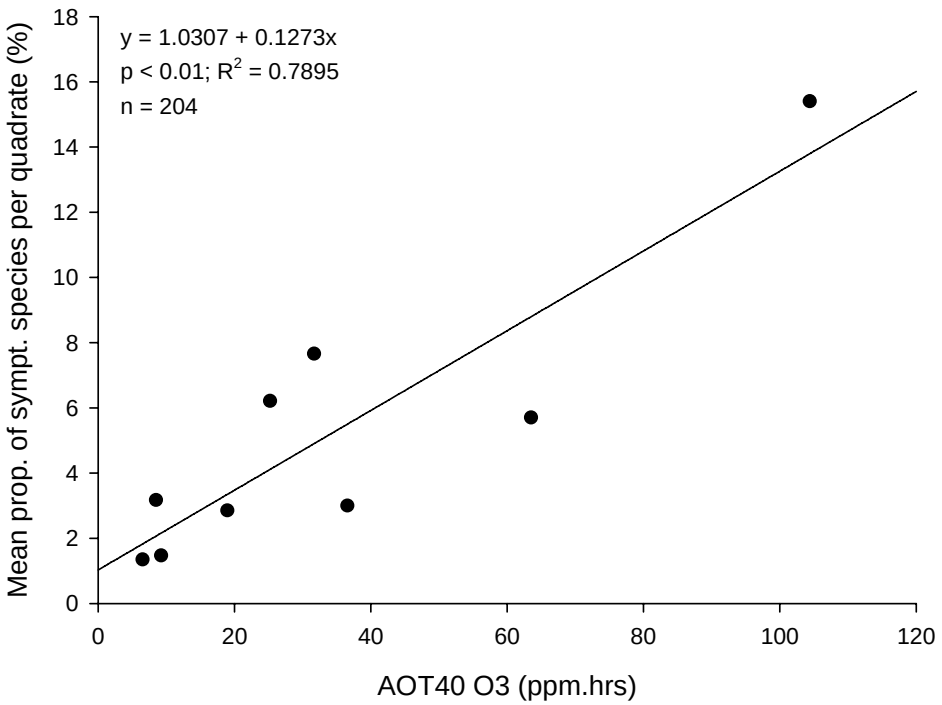

Figure 5. Correlation between mean proportion (%) of total number of symptomatic and non-symptomatic species vs. average seasonal AOT40 exposures (ppm h) per site in 2004.

15. Within a pilot study, O_3 flux was modelled for five level II sites with sufficient monitoring data. The study included substantial data quality and completeness checks to ensure the required data basis. For four plots, risk assessment based on measured O_3 concentrations revealed results comparable to those derived from the modelled stomatal conductance of O_3. For one of the plots stomatal conductance (O_3 flux) was very low, even though itsO_3 concentrations were the highest compared to the other plots. This discrepancy was due to a high vapour pressure deficit modelled for the respective plot. The results show that flux modelling allowed for a more

precise O_3 risk assessment. However, the extensive data requirements were still a severe constraint for this approach.

V. CROWN CONDITION

16. The influence of air pollution on forests in Europe has to be evaluated together with the general health status of forests and additional stress factors, because forests are complex ecosystems and different stressors interact. The forest health is monitored over large areas by a survey of tree crown defoliation. Trees that are fully foliated are classified as undamaged in the defoliation survey. Defoliation percentage denotes the proportion of needle or leave loss in comparison to a fully foliated reference tree.

17. The crown condition survey in 2007 comprised 4,834 plots in 27 countries, with 104,399 trees assessed. Of these, 21.8% had a needle or leaf loss of more than 25% and were thus classified as damaged or dead. In 2006, the respective share was 21.9%. European and sessile oak had the highest share of damaged and dead trees, 35.2% in 2007, of the most frequent tree species.

18. The long-term development of defoliation was calculated from the monitoring results of those countries which have been submitting data since 1990 every year without interruption (figure 6). In the period of observation, holm oak showed the severest increase in defoliation, with 10.3% mean defoliation in 2000 and 22.2% in 2007. A similar increase in defoliation, namely from 11.1% to 20.4%, was experienced by maritime pine. Defoliation of these Mediterranean species was largely attributed to several summer drought events in recent years. In the same period, defoliation of beech increased from 17.9% to 20.9%. In contrast, crown condition of Scots pine continued its recuperation. After having reached a peak in defoliation with 27.9% in 1994, defoliation decreased to 20.2% in 2007. Being less sensitive to drought, Scots pine showed no rise in defoliation even after the dry summer of the year 2003. As did European and sessile oak, Norway spruce its decrease in defoliation since its heights in 2004, which constituted a response to the drought of 2003.

19. Previous studies (e.g. Lorenz et al. 2003) have shown that variation in defoliation is mainly explained by tree age, weather extremes and biotic factors. Air pollution was found to correlate partly with defoliation. The crown condition survey was deemed a valuable early warning system for many stress factors for forest health.

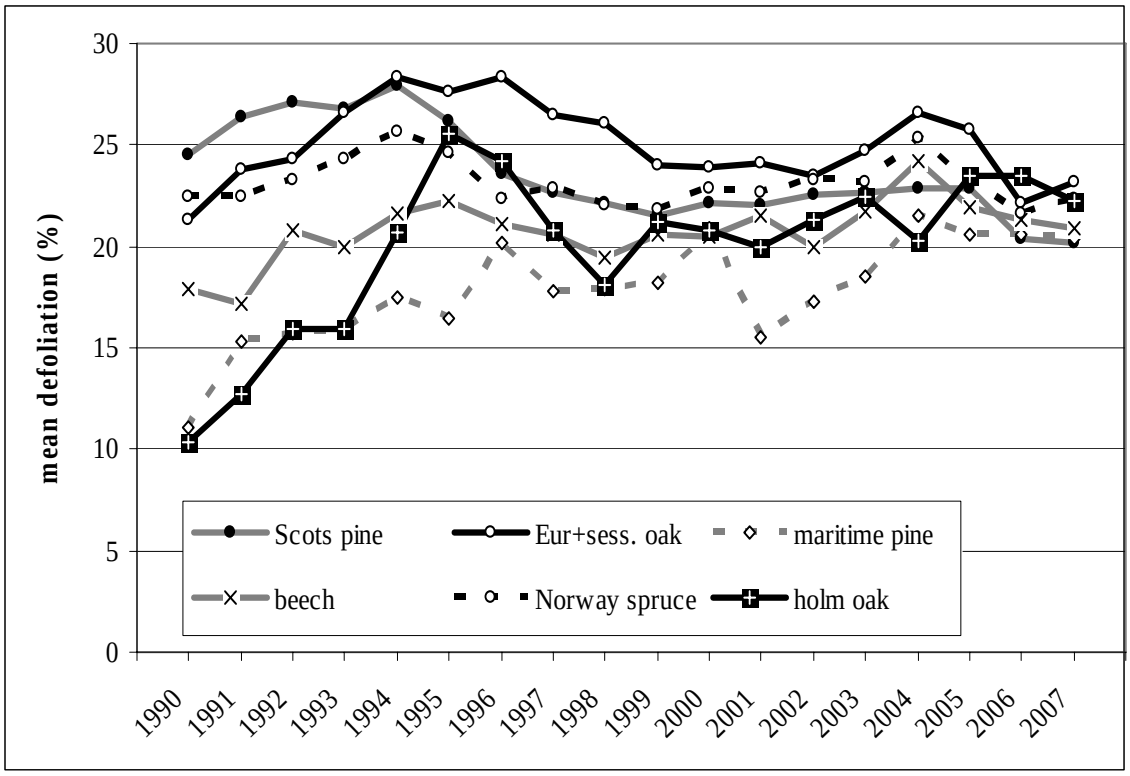

Figure 6. Percentage of damaged trees of all tree species and mean defoliation for the most frequent tree species (data include countries with continuous data submission).

VI. CONCLUSIONS

20. Since 1986, forest condition has been monitored jointly by ICP Forests and the European Commission. Today, the programme is one of the largest forest monitoring networks in the world. The system combines an inventory approach with intensive monitoring. It provides reliable and representative data on forest ecosystem health and vitality and helps to detect the responses of forest ecosystems to the changing environment.

21. The intensive monitoring provides data for atmospheric deposition and for more complex studies on ecosystem responses. Bulk and throughfall deposition of sulphate was above nitrate and ammonium inputs in the period 2000–2005. Sulphate showed a more pronounced decrease compared to the N compounds; on 20% of the plots sulphate inputs decreased, whereas N inputs remained unchanged on around 90% of the plots.

22. Effects of N deposition on forest ecosystems remain in the specific focus of the monitoring activities. The exceedance of critical loads for nutrient N was linked to increased defoliation of beech trees. In a pilot study, N inputs and inappropriate tree species selection were

identified as the main causes for nutrient imbalances that were predicted to remain until the end of the modelling period in 2050.

23. O_3 risk assessment has been further developed by ICP Forests. It now provides information on O_3 concentrations measured by passive sampling in remote areas. In the years 2000 to 2005, the highest O_3 levels in forest areas of Europe were measured during 2003, a season with one of the hottest summers on record in Europe. Modelled AOT 40 values revealed that the critical limits defined within the Convention work were widely and frequently exceeded in all years. The intensive monitoring plots provide a basis for application of O_3 flux modelling, which allows for more accurate assessment of the O_3 risk. However, intensification of data collection is needed to ensure a sufficiently large number of adequately equipped plots.

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[1] The references have been reproduced as received by the secretariat.