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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. Since 1986, the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) and the European Union (EU) have been cooperating closely in monitoring the effects of air pollution and other stress factors on forests. The activities pursue the objectives of resolutions of the Ministerial Conference on the Protection of Forests in Europe (resolution S1 - Strasbourg, H1 - Helsinki, L2 - Lisbon). Today 39 countries are participating in the monitoring programme, which contributes to the implementation of clean air policies under the UNECE Convention on Long-range Transboundary Air Pollution, EU legislation, as well as national policies and legislation.



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2. The objectives of the monitoring programme are:

(a) To provide a periodic overview of 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) 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 spread over 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.

3. The objectives of the programme are met through a systematic large-scale monitoring network (level I) and an Intensive Forest Monitoring Programme (level II).

4. At level I approximately 6 000 permanent plots are systematically arranged in a 16 km x 16 km grid throughout Europe. At these sites crown condition is assessed annually. In addition, soil and/or foliage surveys were conducted on most of the plots. A new soil survey is under discussion.
For intensive monitoring, more than 860 level II plots have been selected in the most important forest ecosystems of the participating countries. A larger number of key factors are measured on these plots; the data collected can be used for case studies of the more common combinations of tree species and sites. Key factors measured at both levels form the basis for an extrapolation of results. The inclusion of further parameters and surveys is currently being considered.

## I. PRESENT DEPOSITION AND CRITICAL LOADS OF NITROGEN, ACIDITY AND HEAVY METALS FOR FOREST ECOSYSTEMS

5. For most European countries, critical load maps for nitrogen and acidity are available based on estimated data. The large number of level II plots, their comparatively wide distribution and the extensive database offer the possibility of validating and improving existing models and contributing to the development of new methods. A Europe-wide assessment of critical loads based on measured data of intensive monitoring plots in comparison with measured present loads has not yet been available and is presented for the first time in this report. As data collection, submission and validation are rather time-consuming, data up to 1999 were used. Evaluations were conducted after intensive checks on data reliability and consistency. Critical loads were calculated for approximately 230 intensive monitoring plots for which all relevant data on deposition, meteorology, forest growth and soil and soil solution chemistry were available. Results for nitrogen are reported as the sum of nitrate ($NO_3$) and ammonium ($NH_4$). Acidity is defined as the sum of sulphate ($SO_4$) and nitrogen.

## A. Definition of critical limits and loads

6. Atmospheric inputs affect different parts of the forest ecosystems simultaneously. Therefore, various related critical loads that take into account these different effects can be calculated. The lowest of these is the critical load relevant for the protection of the specific ecosystem. It has to be remembered that the critical loads presented refer to a steady state. An excess implies an increase in the concentration of nitrogen and acidity, ultimately reaching the critical limit. In practice the time before effects become visible can take several years or decades.

7. In this report critical loads for nitrogen which aim at no further net accumulation of nitrogen in the soil were calculated. The calculations are based on a nitrogen threshold in the soil solution of 0.28 $g.m^{-3}$ (0.02 $mol_c.m^{-3}$). For sites with higher values, increased leaching is to be expected. In addition, critical nitrogen loads which aim at ensuring that concentrations of nitrogen in the foliage of trees stay below a critical limit of 18 $g.kg^{-1}$ are included. Above this limit, effects on trees such as an increased vulnerability to drought stress, frost, pest and diseases can be expected. Another approach aims at determining the effects of nitrogen deposition on ground vegetation. Here, the limits are based on empirical data.

8. The critical loads for acidity take into account the impact on tree roots of free aluminium in the soil solution. They were calculated by aiming for ratios of toxic aluminium to base cations in the soil solution staying below a critical limit of 0.8 for pine and spruce and 1.6 for oak and beech. Other critical loads for acidity assume no further loss of exchangeable base cations in base-rich forest soils (loess, clay and peat soils) and no further loss of readily available aluminium in base-poor sandy forest soils.

9. Critical loads for heavy metals which ultimately lead to concentrations in soil solution that may affect soil organisms were calculated. For cadmium a concentration of 0.8 $mg.m^{-3}$ was used; for lead the limit was 8 $mg.m^{-3}$.

## B. Nitrogen

10. The average nitrogen deposition from 1995 to 1999 on all 234 plots is 19 $kg.ha^{-1}.yr^{-1}$. The lowest loads were found for pine, followed by spruce, reflecting their location in mostly low-deposition areas, such as Scandinavia (table 1). High nitrogen inputs above 22.4 $kg.ha^{-1}.yr^{-1}$ (1 600 $mol_c.ha^{-1}.yr^{-1}$) occur only on plots in Central Europe. Total nitrogen input is generally found to be much lower on plots in Northern and Southern Europe.

11. The average critical load aiming at no further nitrogen accumulation in the soil was near 8 $kg.ha^{-1}.yr^{-1}$. These critical loads were exceeded on 92% of the evaluated level-II plots (tables 1 and 2). Critical loads are lower for pine, which has a lower nitrogen uptake, than for the other tree species. High critical loads characterize ecosystems which are less sensitive to high nitrogen inputs. Such plots are mainly located in Southern Europe, where forest ecosystems, specifically broadleaf forests, have a higher nitrogen uptake. Results confirm that forests in Northern Europe are more sensitive to nitrogen inputs as the net uptake of nitrogen by trees is low in these regions.

12. Critical nitrogen loads related to effects on tree foliage were higher. Thus reactions of trees are expected at higher nitrogen inputs only. The average was near 14 $kg.ha^{-1}.yr^{-1}$ for pine and near

20 kg.ha$^{-1}$.yr$^{-1}$ for spruce. These loads were exceeded on 45% of the evaluated conifer plots, indicating an increased vulnerability to drought stress, frost, pests and disease.

13. Critical loads requiring no changes in the ground vegetation were exceeded on 58% of the plots. This shows that changes in plant diversity are very likely in European forests.

**Table 1.** Average total present nitrogen deposition load (PDL kg) and critical load (CL kg) in kg.ha$^{-1}$.yr$^{-1}$ and percentage of plots with excess deposition (CLex %). Critical loads are related to effects in the soil. Values in brackets are given in mol$_c$.ha$^{-1}$.yr$^{-1}$

| Species | Number of sites | PDL kg | CL kg | CLex (%) |
|---|---|---|---|---|
| Pine | 57 | 15 (1074) | 6 (419) | 96 |
| Spruce | 96 | 19 (1359) | 9 (618) | 86 |
| Oak | 28 | 21 (1476) | 9 (623) | 93 |
| Beech | 42 | 22 (1540) | 9 (659) | 98 |
| Other | 11 | 17 (1198) | 9 (670) | 91 |
| All | 234 | 19 (1329) | 8 (580) | 92 |

**Table 2.** Level-II plots with deposition above critical loads related to different compartments of the forest ecosystem

| Ecosystem compartment | Per cent of level-II plots with excess of | |
|---|---|---|
| | Critical nitrogen loads | Critical acidity loads |
| Soil | 92 | 64 |
| Tree | 45 | 33 |
| Ground vegetation | 58 | - |

## C. Acidity

14. The average acid load (nitrogen plus sulphate) on 226 plots is nearly 2 100 mol$_c$.ha$^{-1}$.yr$^{-1}$. As with nitrogen, the lowest loads were found for pine, followed by spruce (table 3). Relatively high acid inputs can be found everywhere in Europe, except in central and northern parts of Scandinavia, but most sites with the highest acid inputs (up to 3 000 mol$_c$.ha$^{-1}$.yr$^{-1}$) are situated in Central Europe.

15. Critical loads, which take into account the impact on tree roots through free aluminium in the soil solution, are clearly lower for pine and spruce. These species are more sensitive to aluminium than oak or beech. In general, the critical acid load increases from the northern boreal regions to Southern Europe, which shows that forest ecosystems in the South are less sensitive to acidic inputs. This is firstly due to higher neutralizing base cation inputs from the atmosphere and from soil weathering and secondly to a higher nitrogen uptake by the vegetation in the South. The critical loads are exceeded on 33% of the plots (tables 2 and 3).

16. Critical loads related to base cation and aluminium pools in the soil are lower. They are exceeded on 66% of the plots.

**Table 3.** Average total present acid deposition load (PDL mol) and critical load (CL mol) in $mol_c.ha^{-1}.yr^{-1}$ and excess deposition (CLex %). Critical loads are related to effects on tree roots

| Species | Number of sites | PDL mol | CL mol | CLex (%) |
|---|---|---|---|---|
| Pine | 55 | 1749 | 2906 | 40 |
| Spruce | 94 | 2146 | 2726 | 34 |
| Oak | 27 | 2272 | 4721 | 25 |
| Beech | 40 | 2346 | 4624 | 31 |
| Other | 10 | 2032 | 5282 | 18 |
| All | 226 | 2094 | 3469 | 33 |

D. Heavy metals

17. On average the present lead deposition is much higher than the critical load, whereas the excess is small for cadmium. The share of plots where critical loads were exceeded was 91% for lead and 29% for cadmium (table 4). These results are, however, based on very stringent criteria related to possible impacts on soil organisms.

**Table 4.** Average total present deposition load (PDL), critical load (CL) and excess deposition (CLex excess) of lead and cadmium (in g.ha-1.yr-1)

| Number of sites for all tree species | PDL ($g.ha^{-1}.yr^{-1}$) | | CL ($g.ha^{-1}.yr^{-1}$) | | CLex (%) | |
|---|---|---|---|---|---|---|
| | Lead | Cadmium | Lead | Cadmium | Lead | Cadmium |
| 242 | 26 | 0.38 | 3.8 | 0.33 | 91 | 29 |

E. Outlook

18. Apart from critical loads, present deposition thresholds were also calculated. They take into account the present plot-specific situation and - in contrast to critical loads - do not assume a steady state. Thus they are a more precise instrument to evaluate risks to the forests. Preliminary calculations indicate that present deposition thresholds are higher than critical loads for nitrogen, whereas the reverse is true for acidity. This aspect will be considered in greater detail in next year's executive report, when dynamic models will be applied to predict impacts of acid deposition scenarios on forest soils. The further development of critical loads needs continuation of the close cooperation with other bodies and programmes under the Convention.

## II. GROUND VEGETATION AND FOREST BIODIVERSITY

19. The species composition of the ground vegetation assessed at intensive monitoring plots is an indication of the plant diversity of forest ecosystems. Level II offers a unique opportunity to relate the species composition of the ground vegetation to environmental factors, including atmospheric deposition. This was done to identify, where possible, those environmental factors that most strongly determine the plant diversity of the ground vegetation, specifically in view of the hypothesis that the deposition of nitrogenous compounds is an important threat. If such factors are known, it may be possible to assess more precisely the threats to plant diversity so that local governments might respond proactively.

### A. Plant diversity at plot level

20. An evaluation of plant diversity, indicated by the Simpson index, was carried out with the available data from 674 plots. The value of this index is higher where there are more species. The results show that there are large differences between the plots throughout Europe.

21. Relationships between plant diversity and species numbers of the ground vegetation on the one hand and environmental factors on the other were evaluated for approximately 200 plots for which combined data sets were available, including soil and tree species information, climatic data, and atmospheric deposition (throughfall).

22. Part of the variation in the abundance of the various species occurring in the ground vegetation could be explained by tree species, actual soil situation and climate, mainly in terms of precipitation and temperature (table 5). "Rich" soils with high pH, high base saturation and high availability of base cations, as well as southern climates and oak forests, seem to determine high plant diversity. The impact of nitrogen deposition was lower but statistically significant. Deposition effects may partly be hidden because of the relationship between acid deposition and actual soil pH on the plot, which was an important variable explaining ground vegetation composition. In addition, the results are related only to the spatial distribution of species. Related studies show that temporal changes in ground vegetation composition can be influenced by atmospheric deposition. This suggests a stronger influence of deposition on ground vegetation than presented in these results. Future data collection will allow a more appropriate assessment of deposition impacts on vegetation changes.

**Table 5.** **E**xplained variance of the species abundances that could be ascribed to the four main groups of variables based on 194 plots

| Variable group | Explained variance |
|---|---|
| Actual soil situation | 7.6% |
| Temperature, precipitation | 5.6% |
| Tree species | 4.1% |
| Deposition | 3.3% |
| Total | 20.6% |

### B. Single species in relation to environmental factors

23. Relationships between the occurrence probability of individual species and environmental factors were investigated for 332 different species. This was done by relating the species occurrence to more than 10 000 possible combinations of measured level II data. The results show a predominant influence of soil chemistry, in particular pH, on the occurrence of single species and confirm the previous findings. Most species occur in alkaline conditions whereas for acid sites only a few specially adapted species will predominate. This is in line with current views which accept acidification as a factor that negatively affects biodiversity. Models are to be developed in the coming years based on the evaluations presented. They will allow simulations that predict changes in ground vegetation composition under changing environmental conditions.

## III. CROWN CONDITION IN 2001 AND PAST DEVELOPMENTS

24. The annual crown condition survey is the main tool of the programme to obtain a large-scale overview of the condition of forests in Europe. In 2001 the assessments were conducted in all EU member States and in 15 non-EU countries on the transnational 16 km x 16 km grid. Some 132 000 trees were assessed on nearly 6 000 plots during the summer months. Quality assurance measures were routinely applied in the countries and extensive plausibility and consistency checks were carried out by the Programme Coordinating Centre in Hamburg, Germany. Due to changes in the assessment methods, French and Italian data sets were excluded from the time series.

25. The crown condition was assessed in terms of defoliation. This parameter describes the lack of foliage for each sample tree. Defoliation depends on many stress factors and is, therefore, a valuable measure to describe the overall forest condition.

### A. Crown condition in 2001 and trends

26. Almost a quarter (22.4%) of all trees assessed in 2001 were classified as moderately or severely defoliated or dead. Crown conditions in the EU member States were slightly better than in Europe as a whole. Of the plots’ four most frequent tree species, European and sessile oak were still the most severely defoliated and also showed the highest proportion of dead trees (figure I).

27. The temporal development of defoliation was analysed for a sample of all continuously monitored trees. With the exception of the holm oak, mean defoliation of all main tree species increased in 2001 (figure II). The share of damaged and dead trees (defoliation classes 2-4) of all species was highest in 1995 (25.8%) and decreased in the following two years. Since then a steady but slow increase in damage has been recorded.

28. The mid-term development of defoliation varies not only between tree species, but also between regions. Plot-wise mapping shows that the number of plots with a significant increase is slightly larger than the number of plots with a decrease in mean defoliation.

29. Regions with prevailing improvements of crown condition are southern Poland and south-western France. Deterioration took place mainly in eastern Bulgaria and southern Italy. Local experts explain the observed deterioration in Southern Europe mainly by unfavourable weather conditions. For Bulgaria, extensive forest fires were also reported and the damaged areas in

southern Italy are among the regions with the highest ozone concentrations in Europe during the observation period. In addition, beech and chestnut plots suffered from severe insect and fungal attacks. The improvement in southern Poland is ascribed to a reduction in air pollution and favourable weather conditions, especially in the period from 1994 to 1999.

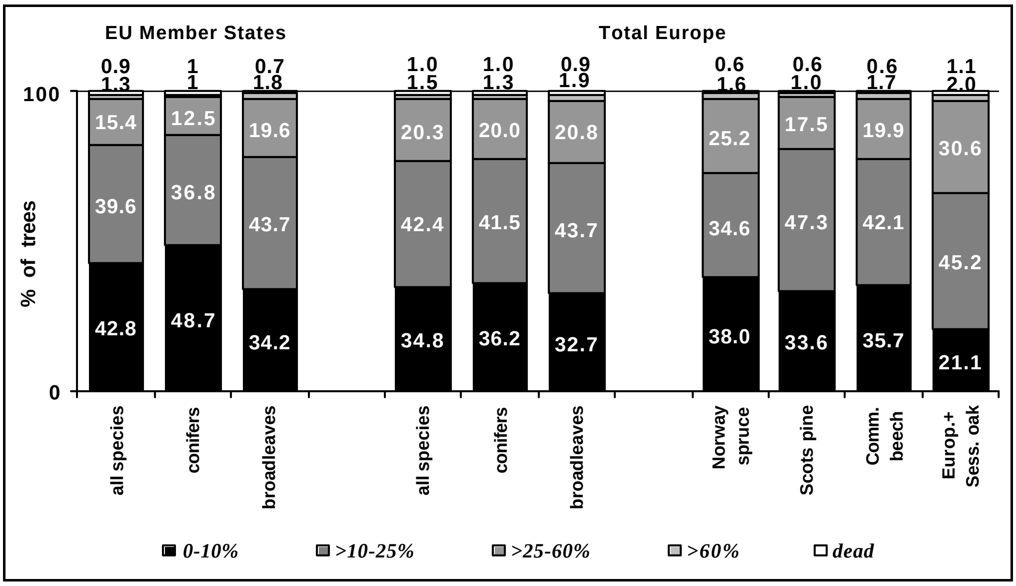


**Figure I.** Trees in different defoliation classes for main tree species (-groups). Total Europe and the European Union, 2001

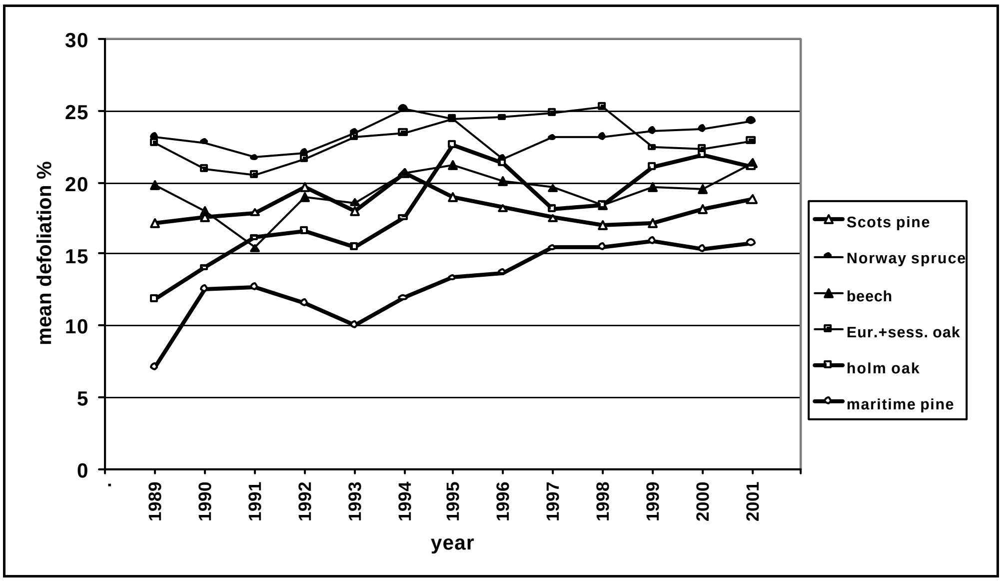


**Figure II.** Development of mean defoliation for Europe's main tree species, calculated for continuously monitored trees. Sample sizes vary between 1 215 trees for European and sessile oak and 3 012 for spruce

## B. Influences on crown condition

30. In-depth evaluations for Scots pine and beech were carried out for those level-I plots for which data on at least three pine or beech trees were continuously reported from 1994 to 1999. The evaluation period ended in 1999, as later deposition data were not available.

31. Defoliation field estimates throughout Europe are strongly influenced by stand age (older trees are usually more defoliated) and by the country in which the level-I plot is located (assessment methods sometimes vary between countries).

32. The levels of defoliation presented were therefore evaluated as differences between field estimates and modelled plot values which take into account the “stand age” and “country” variables and hence compensate for their influence. The development of defoliation was calculated as the plot-wise linear gradient of a regression through all annual mean plot values of the years 1994 to 1999. Age and country influences were negligible for time trend evaluations.

33. The geostatistical method kriging was used to interpolate levels and trends of defoliation, based on the available level-I plots. Interpolated values were calculated only for grid points with more than four plots available in a radius of 100 km. Multivariate models were used to explain defoliation by different environmental influences. A coincidence of high defoliation with certain stress factors can be interpreted as a damaging effect.

### 1. Scots pine

34. In Estonia, southern Poland and north-eastern Spain, there are regions with relatively high mean defoliation. However, crown condition has improved in these regions. Also, in central Norway a decrease in the rather high mean defoliation has been observed, whereas in southern Norway the relatively good crown condition has deteriorated.

### 2. Common beech

35. Southern Germany shows a relatively high mean defoliation of beech, which worsened towards the end of the observation period. Romania is characterized by high fluctuations in beech crown condition. The high defoliation in central Romania decreased until 1999, whereas the relatively low defoliation in the mid-east and mid-west of the country clearly increased. Other European regions with deteriorating crown condition for beech trees are north-western Germany and the region along the border between Slovenia and Croatia. Improvements were registered for Slovakia and regions in Germany.

### 3. Multiple influences on crown condition

36. Model results show that high precipitation is related to relatively healthy tree crowns (table 6). In addition, pine plots show a possible interaction of site characteristics and precipitation: on plots with low and medium water availability there is a positive correlation between precipitation and crown condition. It seems that on these plots an increased water supply improves forest condition, whereas the reverse is true for sites with more than enough water available in the soil. With respect to biotic damage factors, insects (and on beech plots also fungi) are related to high or

increasing defoliation. Sulphur deposition was also correlated in all four models with high or increasing defoliation. This supports research results on the damaging effects of sulphur inputs. The correlations between nitrogen inputs and forest condition are not significant and reveal ambiguous conditions. This might confirm current knowledge, as nitrogen inputs on the one hand eutrophy forest ecosystems but on the other may have acidifying effects. Interaction terms of deposition and soil pH in the model (not depicted) show that the effects of deposition in general depend on the acidity status of the soil. A linear trend could explain parts of the temporal variation of defoliation for pine as well as for beech. This shows that there are linear trends which are independent from the other explanatory variables of the model. As already shown on the maps, however, there is no uniform Europe-wide trend, but varying conditions on different plots.

**Table 6.** Relations between temporal and spatial variation of defoliation of Scots pine and common beech and various explaining variables as results of multivariate regression analyses. The $R^2$ value indicates the percentage of variance explained by the model

| Defoliation | | $R^2$ | No. of plots | Variables | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Precipit. index | Site*precipit.[a] interaction | Insect | Fungi | Deposition[b] | | | Linear trend | Age | Country |
| | | | | | | | | S | $NH_x$ | $NO_y$ | | | |
| Spatial variation | Pine | 60.9 | 1313 | - | * | ++ | | ++ | + | - | | ** | ** |
| | Beech | 41.1 | 399 | -- | | + | ++ | + | - | + | | ** | ** |
| Temporal variation | Pine | 44.5 | 1313 | - | * | + | | ++ | + | - | * | | |
| | Beech | 39.3 | 399 | - | | + | + | + | - | + | * | | |

Notes:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| - | negative correlation | -- | significant negative correlation | + | positive correlation | ++ | significant positive correlation | * | correlation | ** | significant correlation |

[a] Source: Global Precipitation Climatology Centre (www.dwd.de/research/gpcc).
[b] Source: EMEP 150 km x 150 km grid (www.emep.int).

## IV. CONCLUSIONS

37. Approximately a third of Europe is covered by forests. These extensive ecosystems are partly affected by the deposition of atmospheric pollutants. These inputs act within a complex of other anthropogenic and natural stress factors.

38. The monitoring programme of EU and ICP Forests joins experts from 39 countries. It operates nearly 7 000 plots throughout Europe and maintains effective communication with policy makers and the public. It has become an essential source of information on clean air policy and impacts of atmospheric pollution, and its relation to sustainable forest management, biodiversity and climate change.

39. Time trends of its large-scale data on forest condition again show an overall deterioration in crown condition over the past five years, although the level of damage is lower than the peak in the mid-1990s. More than 20% of all trees assessed in 2001 were classified as damaged. For the first time correlations between deposition and deteriorating crown condition were clearly shown in large-scale evaluations based on 1 300 plots of pine trees and nearly 400 beech plots. Furthermore,

insect and fungi attacks and unfavourable weather conditions have had an impact on forest condition.

40. Under the Intensive Monitoring Programme, total deposition was calculated for more than 200 plots. Inputs of nitrogen from 1995 to 1999 mostly range between 3.5 and 39 kg per hectare per year, with an average value of 19 kg. Average sulphur inputs are around 12.5 kg and range mostly between 3 and 29 kg. The effects of these depositions depend on the sensitivity of the ecosystems. Critical loads for nitrogen and acidity, which express the highest quantity of inputs tolerable for specific plots were calculated. Results show that the forests in Scandinavia are particularly sensitive. Critical loads for nitrogen and acidity were exceeded by present depositions on many plots. These results, calculated according to the Manual on Methodologies and Criteria for Mapping Critical Levels/Loads using the measurement data from intensive monitoring plots, may provide an additional important tool for verifying models applied and maps produced by other ICPs, in particular by ICP Modelling and Mapping.

41. The United Nations Conference on Environment and Development convened in Rio de Janeiro in 1992 expressed serious concern about the worldwide loss of biodiversity and considered atmospheric deposition as one of the factors that might be responsible for it. The ground vegetation data of the monitoring programme in relation to the measured environmental influences now show that the present acidity status of the soil is clearly related to the species occurrence. Impacts of nitrogen deposition were found for some species. Additional important environmental influences were precipitation, temperature and the tree species growing on the plots. The programme has recognized the importance of the biodiversity issues and its newly established working group is now responsible for intensified assessments and evaluations that might in the future make it possible to quantify environmental impacts on floristic biodiversity in forests.

42. In its 16 years of existence the forest monitoring programme of ICP Forests and EU has been an effective promoter, supporter and creator of awareness in the scientific, political and public areas. Its growing data sets and its infrastructure have become increasingly interesting for other organizations and projects. At the same time the widened scope of activities requires competent partners. In particular in the Nordic countries the programme’s monitoring data are linked to the national forest inventories. Also, their use for monitoring of Natura 2000 habitat types is under discussion. The work of ICP Forests and EU takes into account international processes like the Convention on Biological Diversity and the Framework Convention on Climate Change and benefits, for example, from cooperation with the Ministerial Conference on the Protection of Forests in Europe and with deposition monitoring networks in other parts of the world.