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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. In the early 1980s severe deterioration of forest condition was observed in large areas of Europe. As a response to growing concern about the role of air pollution in this decline, the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was established in 1985 under the UN/ECE Convention on Long-range Transboundary Air Pollution. In 1986 the European Union (EU) adopted the Scheme on the Protection of Forests against Atmospheric Pollution. Since then ICP Forests and EU have been cooperating closely in the monitoring of effects of air pollution and other stress factors on forests. Today 38 countries participate in the monitoring programme and several others are in the process of joining it.

2. In order to meet the main objectives a systematic large-scale monitoring network (level I) and an intensive forest monitoring programme (level II) have been set up. The strength of the level I grid is its representativeness and the vast extent of its approximately 6,000 permanent plots, arranged in a 16 km x 16 km grid throughout Europe. Annual crown condition assessments are carried out at level I. In addition, soil and/or foliage surveys have been conducted on most of the plots. For intensive monitoring more than 860 level II plots have been selected in the most important forest ecosystems of the participating countries. On these plots a larger number of key factors are measured; the data collected can be used in case studies for the more common combinations of tree species and sites. Key factors are covered by both levels, so that an extrapolation of results is feasible.

3. The unique data set from both surveys is increasingly used by research organizations from outside the monitoring programme; it is expected that these external demands will further increase in the future. Cooperation has been launched with other monitoring programmes outside Europe such as the Acid Deposition Monitoring Network in East Asia (EANET). Following the new strategy of ICP Forests for the years 2001 – 2006, the need for further surveys is currently being discussed in order to also deliver relevant information on other recent policy issues like climate change, sustainable forest management and biodiversity in forests.

I. ELEMENT INPUT, LEACHING AND BUDGETS FOR FOREST SOILS

4. The main aim of the intensive monitoring programme is to contribute to a better understanding of the impact of air pollution and other factors that may influence forest ecosystems.
More specific objectives in this context are the assessment of:

(a) The fate of atmospheric pollutants in ecosystems in terms of accumulation, release and leaching;
(b) Critical loads and critical levels of atmospheric pollutants (SO_2, NO_x, NH_3, heavy metals) for forest ecosystems in relation to present loads;
(c) Responses of forest ecosystems to changes in air pollution by deriving trends in stress factors and ecosystem condition;
(d) Impacts of future scenarios of air pollution on the forest ecosystem condition.

5. The emphasis of this chapter is on water and element fluxes through the forest ecosystem. This topic is an important aspect of chemical nutrient cycles in forests, which in turn are related to damage effects. Furthermore, it is a prerequisite for the calculation of critical loads. Element budgets have already been calculated for intensive monitoring plots by several countries including Greece (FIMCI, 1998), Ireland (FIMCI, 1998; Boyle et al., 2000), Belgium (FIMCI, 1999, 2000), Germany (FIMCI, 1999; Sprangenberg, 1997; Wetzel, 1998; Block et al., 1999) and Slovakia (FIMCI, 2000). Furthermore, there have been several literature compilations of element budgets, focusing on the behaviour of nitrogen (e.g. Dise et al., 1998a,b; Gundersen et al., 1998a,b). A Europe-wide assessment of element budgets, using all available data on deposition, meteorology and soil solution chemistry at the intensive monitoring plots has, however, not yet been carried out. This chapter aims to fill this gap.

6. Evaluations were only conducted after intensive checks on data reliability, in view of differences in data assessment methods, and on data consistency as described in detail in EC-UN/ECE, 2001. Data up to 1998 have been used.

A. Methods used

7. On 309 level II plots, both bulk deposition in open field locations close to the forest stands and throughfall deposition below the forest canopy were measured. On some of those plots stemflow measurements were also carried out, specifically in beech stands, where stemflow can significantly contribute to total deposition. Total atmospheric inputs in forest stands were derived by adding throughfall and stemflow values corrected for element uptake or leaching from the leaves and needles. Elements measured included sulphate (SO_4), nitrate (NO_3) and ammonium (NH_4) (the last two being summarized as nitrogen (N)) as well as base cations, being the sum of calcium (Ca), magnesium (Mg) and potassium (K).

8. The leaching fluxes were calculated by multiplying the measured soil solution concentrations below the root zone with the water leaching fluxes at this depth. Water fluxes were calculated with hydrological models. These models calculated the water leaching from the soil profile, using data on the incoming precipitation and other meteorological information (net radiation, temperature, wind speed and relative humidity).

9. A comparison of inputs from the atmosphere and outputs leaching from the bottom of the root zone (element budgets) gave insight into the fate (accumulation or release) of sulphur, nitrogen, base cations and aluminium in the ecosystems.

B. Ranges and geographic variation of atmospheric inputs

10. Relatively high sulphate input of more than 12.8 kg SO_4-S $kg.ha^{-1}.yr^{-1}$ (= 800 $mol_c.ha^{-1}.yr^{-1}$) can be found on plots in all parts of Europe, except in central and northern Scandinavia. Many sites with high sulphate input are situated in central Europe. High nitrogen inputs of more than 22.2 $kg.ha^{-1}.yr^{-1}$ (= 1600 $mol_c.ha^{-1}.yr^{-1}$) occur mostly in central Europe. Total nitrogen input is generally much smaller in northern and southern Europe. In general, the atmospheric deposition of all ions increased from the northern boreal regions to western Europe. Base cation input was found to be relatively high (>800 $mol_c.ha^{-1}.yr^{-1}$) in southern Europe and Lithuania. Small inputs of base cations are found in Scandinavia.

C. Ranges and geographic variation in element leaching

11. The geographic variation of the soil leaching fluxes of N is large (specifically in Germany), indicating that both N deposition and soil characteristics influence N leaching. High N leaching fluxes of more than 14 $kg.ha^{-1}.yr^{-1}$ (= 1000 $mol_c.ha^{-1}.yr^{-1}$) occur in Belgium and central Germany, where the input of N (specifically of NH_4) is also high. Extensive N leaching is also known from the Netherlands. In northern Europe and in France N leaching fluxes are mostly below 2.8 $kg.ha^{-1}.yr^{-1}$ (= 200 $mol_c.ha^{-1}.yr^{-1}$). Very high leaching fluxes of SO_4 mainly occur in western and central Europe (Belgium and parts of Germany and the Czech Republic), reflecting the high deposition at those sites. The geographic variation of the Al leaching fluxes partly responds to S

and N leaching. Sites where the leaching flux of Al is high indicate the occurrence of an acid soil releasing Al in response to the high input (leaching) of SO_4 and possibly NO_3.

D. Comparison of deposition and leaching fluxes and resulting budgets

12. A comparison of median total deposition and median leaching fluxes (table 1) shows that median leaching fluxes are comparable to the deposition for sulphate, whereas leaching is generally much lower than deposition for nitrogen, indicating that nitrogen is strongly retained in the soil. Consequently, SO_4 is still the dominant source of actual soil acidification, whereas the acidifying effects of the higher nitrogen deposition are partly prevented due to its retention. In oak stands, sulphate leaching is significantly higher than the input, whereas the reverse is true for pine stands. The high leaching flux of base cations (BC) under oak stands is partly due to calcareous parent material from which weathering frees large amounts of base cations. The N leaching flux is the lowest under pine trees, which is partly caused by the low water fluxes. The median leaching flux of base cations is generally higher than for aluminium, indicating that the average Al/BC ratio in the soil solution is mostly below 1.0, which is considered as an average critical value above which impacts to roots may occur.

13. Budgets were calculated as the difference between input and output. A positive number thus implies that the soil gains elements, whereas a minus sign implies that the soil loses elements. The median budget for sulphur is close to zero in coniferous forests, whereas it is negative in deciduous forests (table 1). At approximately 50% of the plots SO_4 is retained. Nitrogen is retained in 85% of the sites (table 2) and accordingly the median nitrogen budget is positive for all tree species. The median base cation budget is close to zero for the coniferous tree species and negative for the deciduous species. The high values for base cation budgets for soil under deciduous forests are partly due to the occurrence of calcareous soils. Aluminium is released at all plots, but this result may be slightly biased since Al deposition is not taken into account.

14. The geographic variation of the budgets for sulphur and nitrogen shows that sites with the highest sulphur release are located in central Europe, where large reductions in sulphur deposition have taken place only recently. Most probably the current releases of sulphur compounds have partly been deposited in earlier times. Sites with a net release of nitrogen are found in Belgium and north-western Germany. This corresponds to areas having received a high N deposition over a long period of time.

E. Relationships between element inputs and element leaching

15. In accordance with results found by e.g. Dise et al. (1998a, b), the leaching of N is generally negligible below a throughfall input of 10 $kg.ha^{-1}.yr^{-1}$ (= 714 $mol.ha^{-1}.yr^{-1}$). At N throughfall inputs above 10 $kg.ha^{-1}.yr^{-1}$, leaching of N is generally high, although lower than the input, indicating N retention at most of the plots. In this range, there are only five sites where N leaching is higher than N input by throughfall.

16. At several sites, Al leaching fluxes are higher than the acid deposition, so the leaching of sulphate and nitrogen is higher than the input. This shows that the acid input is almost completely buffered by the release of Al and that, in addition, acidifying compounds, most probably S, are

released from the soil (fig. I). At all other sites the Al leaching flux is lower, indicating that part of the potential acid input is buffered by retention (in most cases N) and/or base cation release.

17. Results of multiple regression analyses show that variations in the leaching of sulphate, base cations and aluminium were strongly related to the atmospheric input of S, this being the major source of actual acidification. Nitrogen leaching was mainly related to the nitrogen deposition and the fraction of ammonium in the input (ammonium is more strongly retained than nitrate), whereas the soil C/N ratio did not have a significant impact. Variations in BC leaching were not only related to the BC input, but also to soil type, pH and base saturation. Base saturation was also significantly related to the Al leaching flux.

II. SPECIES COMPOSITION OF THE GROUND VEGETATION

18. After the United Nations Conference on Environment and Development in Rio de Janeiro (Brazil) in 1992, there was growing concern over the worldwide loss of biodiversity. Anthropogenic influences on forest biodiversity include impacts of forest management, deposition and disturbance of the water cycles. Deposition of nitrogen has led to changes in ground vegetation in a number of cases. The species composition of the ground vegetation is an indication of the floristic biodiversity of forest ecosystems and might be useful as an indicator of forest biodiversity.

19. Ground vegetation data are available for more than 400 level II plots. First evaluations focused on the number of species per sample plot. They are evaluated irrespective of the area sampled since the results of an in-depth evaluation showed no significant influence of sample area on species numbers. Evaluations only include higher plants, since not all countries include mosses and lichens in their ground vegetation assessments.

20. The results show high species numbers in Mediterranean areas. The lowest species numbers occur in central Europe. Nevertheless, there are also large differences in species numbers between the plots within countries. Many factors influence species numbers, including parent material, management system, stem density as well as atmospheric inputs.

21. The combination of ground vegetation data and environmental data sampled over a large part of Europe that are now available offers a unique opportunity to relate the species composition of the ground vegetation to these environmental factors. In this way, it will be possible to identify those environmental factors that most strongly determine the species diversity of the ground vegetation. If such factors are known, it may be possible to assess more precisely the threats to species diversity, which local governments might wish to anticipate. Results of such analyses are foreseen in next year’s report.

III. ATMOSPHERIC HEAVY METALS AND FOREST ECOSYSTEMS

22. From the many substances that are deposited onto forest ecosystems, heavy metals are of interest as they accumulate in the systems and may cause long-term problems (Larcher, 1994). In very low concentrations iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) are essential micronutrients for plants. Chromium (Cr), nickel (Ni), lead (Pb), cadmium (Cd) and mercury (Hg) do not occur in significant concentration in most forest ecosystems under pristine conditions. In

recent times heavy metals have been widely spread through emissions, pesticides, mining and foundry industries. The current evaluation is based on level I data.

A. Heavy metals in soil

23. In the course of time, various heavy metals have accumulated in the soil, ranging from a few kilos to several hundred kilos per hectare (Schultz, 1987; Friedland 1992; Schütze and Nagel, 1997). Heavy metal ions are mostly absorbed to the organic complex in the soil and/or to the clay minerals. Ion exchange processes at these cation exchange sites are mostly accelerated at low pH, resulting in higher mobility. Due to this phenomenon soil acidification processes can release heavy metals that accumulated in earlier times and thus threaten ground and surface waters.

24. Various critical levels for heavy metal concentrations in the soil have been suggested aiming at different soil types and effects on different compartments of forest ecosystems. Damage to forest ecosystems can to a large extent be excluded below the specific values that have been chosen for the evaluation of level I soil data from the available literature (Atanassov et al., 1999; Bååth, 1989; Bengtsson and Tranvik, 1989; Coughtrey et al., 1979; Inman and Parker, 1978; Tyler, 1996; Tyler et al., 1996; Vanmechelen et al., 1997; Wilson,1997; summarized in table 3). Limits for toxic effects on soil microorganisms and trees may be higher, specifically in those soils rich in humus and clay.

25. Heavy metal pollution of soils is not critical in most of the observed level I plots. Exceedances at level I plots vary between 0 and 15% for different soil layers and elements. Lead concentrations in the humus layer are high at approximately 15% of the evaluated level I plots. The higher value in the humus layer compared to the mineral soil is due to the fact that the ions are mostly absorbed by organic compounds. Concentrations of cadmium and nickel exceed critical levels in 10 to 12% of plots.

B. Heavy metals in plants

26. Uptake of heavy metals by plants occurs together with nutrients through the roots or, as in the case of less mobile ions, directly through leaves and needles. Toxic effects are due to damage to enzymes or cellular metabolism. In addition, heavy metals can find their way into the plant cells and can thus damage the organism. Species-specific levels of an excess supply have been defined by the pan-European Expert Panel on Foliar Analysis (EC-UN/ECE, 1995, 1998; table 4) and are mostly below the critical levels that specify thresholds for the decrease of physiological parameters.

27. The measured values lie mostly within pollution limits regarded as being harmless and which show that the nutrient supply is also within safe limits, especially with regard to important micro-nutrients such as Cu and Zn. A differentiated examination of the various tree species (groups) does, however, in some cases show a surplus of nutrients and excessive toxic (threshold) values. Pine, especially the older needle years, showed the highest median value for lead (5 $mg.kg^{-1}$). Excess concentrations were detected in 13% of the spruce samples. Copper supply was very high in 45% of the beech samples and is regarded as critical in 8% of the samples.

C. Outlook

28. In future evaluations, still more emphasis will be laid on heavy metals in forest soils by comparing present and critical deposition levels, so-called critical loads. Critical loads will be calculated for situations in which (i) no further accumulation of heavy metals occurs or (ii) accumulation of heavy metals is below critical limits in the soil or soil solution. Both approaches require information on present metal concentrations as given in this chapter.

IV. CROWN CONDITION IN 2000 AND ITS DEVELOPMENT IN THE PAST

29. The 2000 transnational survey was carried out on a systematic 16 km x 16 km grid in all EU member States and in 15 non-EU countries. The evaluations are based on the assessments of crown condition on 6,040 level I plots comprising 135,839 sample trees. Some national assessments were performed on denser networks. On national and international levels, quality assurance measures are carried out to ensure data consistency over time. International intercalibration courses have been redesigned in order to investigate differences between national methods. The Programme Coordinating Centre of ICP Forests in Hamburg, Germany, is responsible for the evaluation of the results at the European level.

30. The main parameter used for the large-scale assessment of forest condition is defoliation, which describes crown condition by means of estimated needle or leaf loss in relation to a fully-leaved theoretical reference tree. Defoliation is assessed in 5% steps and grouped into five classes. Crown condition reacts to many different stress factors. Defoliation values of one year thus contain limited information on the influence of single factors.

A. Crown condition in 2000

31. Almost a quarter (22.8%) of all assessed trees were classified as moderately or severely damaged or dead in 2000. Crown condition in the EU countries was slightly better than in Europe as a whole. Of the plot's four most common tree species, European and sessile oak were still the most severely defoliated and also showed the highest proportion of dead trees.

B. Development of crown condition

32. The number of assessed plots and trees has changed over the years mainly because of the growing number of participating countries. Therefore, the development of crown condition is calculated on the basis of so-called common tree samples. These comprise only trees that have been assessed continuously over a number of years. Results show that the proportions of damaged and dead common sample trees increased continuously up to 1995. Since then the trend has stabilized at this comparatively high level. Also, the proportion of plots that show a significant decrease in mean plot defoliation compared to 1994 is the same as the proportion of plots with a significant improvement. A general, Europe-wide interpretation of this evolution is difficult. Instead, specific in-depth evaluations are being carried out in some areas taking into consideration all important stress factors.

33. The development of the proportion of moderately and severely damaged and dead trees differs between climatic regions (defined by Walter et al., 1975). Improving trends during recent years were recognized in the Mountainous North, in the Boreal and in the Subatlantic regions. A sharp increase in the proportion of trees in defoliation classes 2 - 4 was observed in the Continental region. This deterioration was recorded for almost all of the more important tree species within that region. The share of damaged and dead Austrian pine and Hungarian oak trees roughly doubled during the past year. The observed decline was mainly explained by a series of weather extremes resulting in floods followed by warm and dry conditions. On the evaluated plots of the Atlantic South region, mostly located in Spain, an alarming increase in the number of trees in defoliation classes 2 - 4 occurred. All of the most common species on the plots, including maritime pine, European oak and eucalyptus, show an increase in defoliation. The sharpest increase, however, was recorded for chestnut, Monterey pine and birch. Local experts blame forest fires and the high number of trees removed in the course of construction measures and forest management practices.

34. Individual time trends for the six main tree species are characterized by an overall deterioration, even though there are fluctuations between the years (fig. II).

35. The positive trend for Scots pine that started in 1994 has reversed since 1998. This is mainly due to a slight worsening in pine in the Continental, Mountainous South and Atlantic North climatic regions. Mean defoliation of Norway spruce has fluctuated at a high level in recent years. Mean defoliation of common beech trees has remained roughly constant since 1999. Also, the average crown condition of European and sessile oak has changed little. However, a considerable improvement in the Atlantic North climatic region compensated for a serious deterioration in the Mountainous South. The continuous worsening of mean defoliation of maritime pine since 1993 was in the past year mainly based on results from the Atlantic South region. Crown condition of holm oak and Aleppo pine deteriorated until 1995 and has fluctuated since then.

V. REACTIONS OF FOREST ECOSYSTEMS TO OBSERVED STRESS FACTORS

36. Stress factors interact not only with each other, but their influence depends also on a large variety of environmental preconditions and on the forest ecosystem condition itself. Multivariate statistics are a tool that partly copies and theoretically reconstructs simplified nets of interacting factors. Thus they make it possible to determine the importance of single influences and stress factors.

37. Two such studies were recently carried out under the pan-European monitoring programme. They are based on level I data in combination with external data on soil (Vanmechelen et al., 1997), meteorology and deposition (Van Leeuwen et al., 1999).

38. In order to come to a more holistic view of the functioning of forest ecosystems and to learn more about causes of forest damage and effects of stress factors, in-depth level II results were compiled and interpreted in combination with publications available from monitoring sites of the International Cooperative Programme on Integrated Monitoring (ICP IM). Results of the compilation related to rooting systems are also given in this chapter.

A. Multiple influences on soil chemistry

39. The results of a multiple regression analysis show that soil chemistry is influenced by meteorological parameters, tree species and soil type (see table 5). The effect of the meteorological parameters may be related to the strongly varying capacity of different tree species to filter acidic compounds from the air (e.g. high for dense conifers), and to the different chemical characteristics of their litter. The impact of total acid deposition on soil chemistry could be seen in large areas of west, central and eastern Europe, whereas impacts of nitrogen deposition were statistically most relevant in central and western Europe. In general, the influence of atmospheric deposition on soil chemistry was even greater than that of the soil properties themselves, e.g. soil type.

B. Multiple influences on tree crown condition

40. In two pilot areas, multiple influences on ten-year average defoliation values were evaluated. Pilot area 1 comprises Flanders (Belgium), the Netherlands and north-western Germany, thus containing regions with high nitrogen deposition. High concentrations of acidic deposition were found in parts of the mountainous pilot area 2, embracing northern Czech Republic, south-western Poland and southern Saxony (Germany).

41. In regression models, soil factors, e.g. cation exchange capacity, base saturation and total amount of nitrogen and carbon, explain part of the defoliation (see table 6). Climatic factors, such as heat index and late frost index, water availability as deducted from soil type, insects and fungi, were found to be of minor relevance in these areas. Altitude shows highly significant relationship with defoliation in the mountainous region of pilot area 2, suggesting climatic and/or ozone stress (Liu and Payer, 1996; Maier-Maercker and Koch, 1996; Baumgarten et al., 2000; Ewald et al., 2000). Modelled nitrogen or acidic deposition did not show a relationship with mean defoliation values. In time-trend models, however, defoliation of Norway spruce deteriorated with increasing deposition of nitrogen compounds as well as total acidity. All coniferous species show country-specific effects. These may include methodological and real differences and are in line with Klap et al., (2000). Also age was an important predictor for all species, which corroborates almost all investigations done so far on transnational, national or even regional levels (Seidling, 2000).

C. Effects on rooting systems

42. Large-scale inventories of soil condition confirm that the acidification of soils below the rooting zone is widespread in central Europe (Vanmechelen et al., 1997; national level, e.g. Wolff and Riek, 1997). Under these conditions, accumulated organic matter and nutrients in the topsoil are observed. In depth studies by ecosystem manipulation, case studies and monitoring results reveal that changes in the environment, caused by acidifying and/or eutrophying inputs to forest soils, also alter the rooting pattern towards rather flat rooting systems (Sverdrup and Warfvinge, 1993; Flückiger, 1999; Matzner and Murach, 1995). In addition, the vitality of fine roots and mycorrhiza colonization may be reduced. This implies that the often reported enhanced tree growth (e.g. Spiecker et al., 1996) is not necessarily connected to enhanced below-ground growth of roots. In contrast, a reversed pattern can often be seen, with increasing shoot/root ratios of trees. This will lead to instabilities of trees and forests and make them more susceptible to nutrient and water stress. Evaluations of the soil, tree and nutritional state of level I plots in Germany indicate

that, if high percentages of nutrients, especially magnesium, are bound in the organic layer, as compared to the mineral soil, the forest condition is poor (indicators: leaf/needle discolouration, leaf/needle losses, Riek and Wolff, 1999). It is concluded that the changed rooting systems predispose trees to drought and nutrient stress as nutrient mineralization is hindered in dry periods.

43. In recent years there has been considerable progress in estimating stand biomass and growth trends. On the other hand, the calculation of complete carbon budgets also requires information on (i) carbon storage and turnover in roots; (ii) the role of litter; and (iii) the vertical distribution of carbon in forest soils. Root measurements are expensive and are only carried out on a few level II plots as additional assessments. Litterfall is also surveyed on a few level II plots and ICP IM sites. These activities will gain importance in the future. Increased cooperation between different monitoring and research programmes is being planned to address these problems effectively.

VI. CONCLUSIONS AND OUTLOOK

44. With approximately 6,000 level I plots arranged on a systematic 16 km x 16 km grid and with 860 level II plots for intensive monitoring, the programme of ICP Forests and EU offers a unique source of information on the condition of forests in Europe. Its results are based on data collected by more than 30 European countries since 1986 using harmonized methods. The results are not only of great importance for clean air policies and strategies, but also for a number of other areas of forest and environmental policies.

45. The main result of the evaluations carried out to date is the clear indication that the physical and ecological conditions of forest ecosystems in Europe over the past decades have been influenced mainly by the deposition of atmospheric pollutants and by changing climatic conditions with a series of warm and dry periods, as well as heavy storms in recent years.

46. Recent evaluations of the large-scale data set revealed that nearly one quarter of all trees assessed were classified as damaged. A continuous deterioration took place from 1986 to 1995. In the past few years the proportion of damaged trees has stabilized at that high level. It should be noted, however, that there is a fluctuation in results for various regions and tree species. Several multivariate statistical evaluations of crown condition data have already been carried out and further in-depth evaluations are planned for the coming years. These will take into account additional variables and information such as phenological observations, chemical analyses of the foliage, growth trends, results of the litterfall assessments and ground vegetation composition.

47. The close relationship between atmospheric deposition and soil condition has been demonstrated in a number of earlier ICP Forests studies and confirmed by this report. This year’s special investigation points to the fact that heavy metals have accumulated in forest ecosystems during years of higher deposition rates. These elements can be released from the soil by the current acidification inputs. For up to 15% of the level I plots the concentrations of heavy metals in soil exceed critical levels and therefore present a potential risk for soil fauna and flora. However, results of tree foliage analysis mostly point to a low risk. Some results achieved for pine (for Pb) and beech (for Cu) require further investigations.

48. Many forest ecosystems release into the soil water sulphate, accumulated in previous episodes of higher sulphur deposition. At present, however, at most of the evaluated level II plots, inputs of nitrogen are higher than inputs of sulphur. The median total nitrogen deposition amounts to 16 kg per hectare per year. These plots are mainly located in central and western Europe. Although these inputs are high and may lead to changes in ground vegetation composition, only 10% of the plots show nitrogen leaching into the soil water. The resulting accumulation of nitrogen in the soil will have to be carefully monitored by the ICP Forests and EU programme. Due to the low leaching of nitrate, the sulphate leaching presents the main contribution to the actual soil acidification.

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Table 1:
Median total atmospheric deposition input (depo.), element leaching fluxes (leach.) and element budget of sulphate, nitrogen and total base cations (Ca+Mg+K), and aluminium leaching (in $mol_c.ha^{-1}.yr^{-1}$)

Tree species	Number of sites	SO_4			N			BC			Al
		depo.	leach.	budget	depo.	leach.	budget	depo.	leach.	budget	leach.
Pine	29	517	197	216	704	7	688	491	156	253	138
Spruce	51	685	590	16	1197	112	1021	448	331	94	774
Oak	15	637	1025	-256	683	212	457	519	2184	-911	30
Beech	20	634	604	-22	1327	135	943	489	717	30	326
Other	6	509	590	28	805	54	743	722	1149	-868	31
All	121	592	509	21	860	60	713	482	377	56	294

Table 2:
Percentage of plots with release or retention of sulphate, nitrogen, base cations (Ca+Mg+K) and aluminium

Behaviour	Percentage of plots			
	S	N	BC	Al
Release	56	15	55	100
Retention	44	85	45	0

Table 3:
Critical levels and their exceedances for major heavy metals at level I plots
hu: humus layer; min: mineral soil. (Further explanations in the text)

		Cr	Ni	Zn	Cu	Pb	Cd
Critical level ($mg.kg^{-1}$)		100	50	200	60	100	1.5
hu	number samples	1206	1153	1840	1608	1658	1513
	exceedances	**3%**	**<1%**	**3%**	**3%**	**15%**	**10%**
min	number samples	1302	1302	242	2087	1998	1632
	exceedances	**3%**	**10%**	**2%**	**2%**	**3%**	**12%**

Table 4:
Excess levels (EC-UN/ECE, 1995 and 1998) and critical levels (Balsberg Påhlsson, 1989; Sauerbeck, 1982) and their exceedances for major heavy metals in current-year needles and leaves of spruce and beech at level I plots
spr: spruce; be: beech. (Further explanations in the text)

		Zn	Mn	Fe	Cu	Pb
Excess level ($mg.kg^{-1}$)		60	2000	200	7	4
spr	N samples	974	974	926	360	206
	exceedances	**3%**	**6%**	**<1%**	**5%**	**13%**
Excess level ($mg.kg^{-1}$)		50	2500	200	10	10
be	N samples	160	160	160	141	133
	exceedances	**6%**	**6%**	**18%**	**45%**	**7%**
Critical level plant tissue ($mg.kg^{-1}$)		200			20	20
exceedances spruce		**<1%**			**<1%**	**<1%**
exceedances beech		**<1%**			**8%**	**2%**

Table 5**:**
Correlations between soil parameters and influencing environmental factors

			chemistry of organic soil layer				
			C/N ratio	pH ($CaCl_2$)	base saturation	Mg content	K content
Influencing factors		soil type	✻	✻	✻	✻	✻
		tree species	✻	✻	✻	✻	✻
		meteorology	✻	✻	✻	✻	✻
	deposition	NHx	✻	✻	✻		
		NOx		✻	✻		
		SOx		✻			
		total nitrogen					
		total acidity				✻	✻
% explained variance			49.4	57.2	30.6	41.5	30.4
number of level I plots			3673	3441	794	3311	3175

✻ significant correlation.

Table 6:
Overview of significant relationships between medium-term mean defoliation and predictor variables

		medium-term mean defoliation			
		Scots pine pilot area 1	Scots pine pilot area 2	N. spruce pilot area 2	Eur.+ses. oak. pilot area 1
Influencing factors	soil factors (5 factors per model)		✻	✻	✻
	climatic factors (3 factors per model)				✻
	water availability				
	insects	✻			
	fungi				
	altitude			✻	
	N deposition				
	acidic deposition				
	age	✻	✻	✻	✻
	'country'	✻	✻	✻	
% explained variance		59	73	61	75
number of level I plots		33	26	66	14

✻ significant correlation. excluded due to small sample size or lacking data.

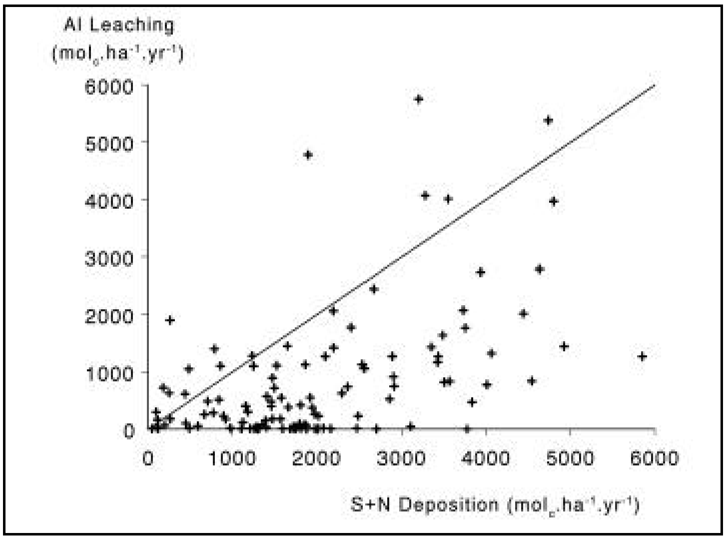

Figure I:
Relationship between Al leaching fluxes and the total deposition flux of S and N at the 121 monitoring sites

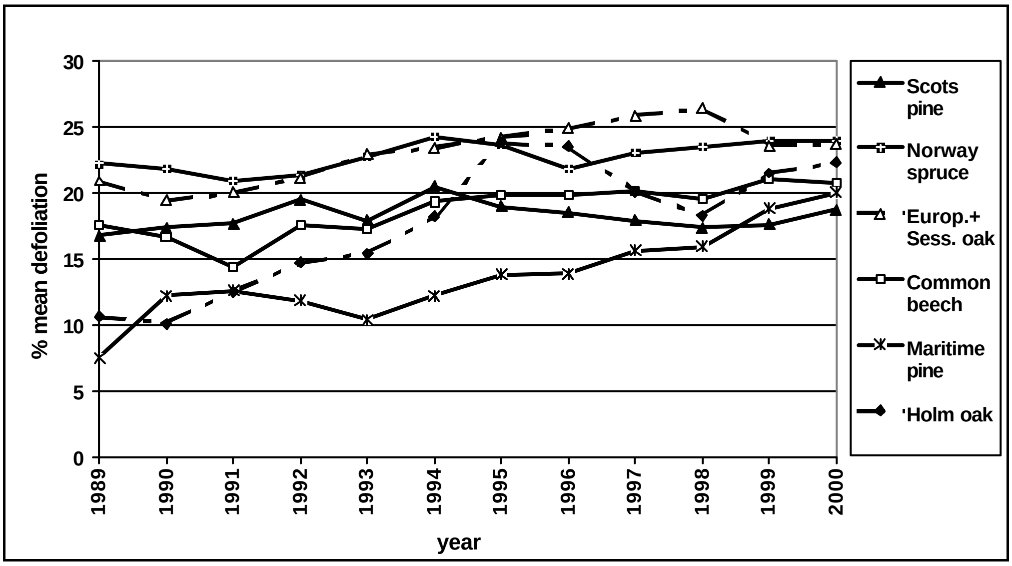

Figure II:
Mean defoliation for the main European tree species. (Defoliation development was calculated only for trees which were continuously monitored from 1989 to 2000. The standard deviation was in all cases below 0.6%. Due to changes in the assessment methods, French data were excluded from the time series.)