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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

I. INTRODUCTION

1. It was in the early 1980s that a decline in crown condition of forest trees began to attract widespread interest. In response to growing concern that the reason for this decline could be air pollution, 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. Since then forest condition and development have been monitored under UN/ECE and the European Commission (EC). This year an internal review of ICP Forests has been completed. The important outcome of this

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process is reflected, inter alia, in revised objectives of the programme (see ICP Forests document on Strategy for the period 2001-2006) and proposed terms of reference (EB.AIR/WG.1/2000/4, annex). In order to pursue the main objectives of the programme, a large-scale monitoring network (level I) was originally set up which now comprises approximately 5700 permanent plots throughout Europe. Level II monitoring at more than 870 plots has been established to carry out in-depth studies. These plots are located in forests that represent the more important forest ecosystems and more widespread growing conditions in the respective country. Here a larger number of key factors are measured.The two monitoring levels overlap with respect to certain key parameters, so an up-scaling of results, i.e. providing detailed information for level I sites, will become feasible.

II. INFLUENCE OF ATMOSPHERIC DEPOSITION AND OTHER ENVIRONMENTAL STRESS FACTORS ON FOREST ECOSYSTEMS

2. The general aim of the intensive monitoring programme is to contribute to a better understanding of the impact of air pollution and other factors which may influence forest ecosystems. Evaluations were only conducted after intensive checks on data reliability, in view of differences in data assessment methods, and on data consistency. This included results from laboratory intercomparisons for the chemical analyses of the soil, foliage and atmospheric deposition. Procedures with respect to quality assurance (QA) and quality control (QC) focused on the chemical composition of four main measurements: bulk deposition, throughfall, stemflow and soil solution, as described in detail by De Vries et al [1]. As data validation and processing are rather complex, only data up to 1997 were used in the present evaluations.

A. Atmospheric deposition

3. Atmospheric deposition was measured at 317 level II plots below the forest canopy (throughfall). Other important information was derived from measuring bulk deposition at 443 open field locations close to the forest stands. In order to get information on the total deposition in forest stands the throughfall values have to be corrected by the effects of element uptake or leaching. This is done by comparing throughfall to the bulk deposition, whereas corrections for the canopy uptake are calculated using models.

1. Ranges of atmospheric inputs

4. As with the previous year, approximately 55% of investigated plots received a nitrogen (N) input above 14 kg/ha/year (i.e. above 1000 mol_c/ha/year). This is a deposition level at which the species diversity of the ground vegetation may be at risk. The proportion of forest area with these high inputs is likely to be lower on the European scale, as the plots with high N input are mostly concentrated in central Europe, the region with the highest density of intensive monitoring plots. The measured deposition levels may in some instances increase tree growth, as most forests are originally nitrogen-limited.

5. In regions that were monitored in 1996 and 1997, a slight decrease in sulphur (S) deposition has been observed, whereas the reverse was found for nitrogen deposition. As a

consequence, both bulk and total deposition of N appeared to be higher than S deposition at nearly all the plots in 1997. The average calculated total N deposition was approximately twice as large as the S deposition (see fig. I). This is unlike the results for 1996, where N inputs were mostly lower in plots in central Europe. In 1996 total N deposition was calculated to be approximately 50% larger than S deposition.

2. Geographic variation of atmospheric inputs

6. As in the previous year, deposition differed significantly in individual geographic regions. The atmospheric deposition of all ions increased from the northern boreal regions to western Europe. The deposition of sulphate (SO_4), nitrate (NO_3) and calcium (Ca) was significantly higher in the central/eastern part of Europe, but ammonium (NH_4) was slightly higher in western Europe. There was a highly significant positive correlation of atmospheric deposition of SO_4 and Ca with precipitation, indicating that these ions are largely deposited by rainwater.

3. Temporal trends in atmospheric inputs

7. The larger decrease in S deposition compared to N is a phenomenon that has generally been detected during the past decade (e.g.[2]). At the time when the problem of "acid rain" was brought up (the end of the 1970s), S deposition was generally higher than N deposition. These changes have been documented in a recent study [2] in which annual bulk and throughfall deposition fluxes at 53 plots were compared between the 1980s and the 1990s. Whereas the earlier deposition rates were taken from a literature compilation [3], the latter values are based on the results of the intensive monitoring programme. The external data were used, as the time series of level II available at the European data centres were still too short. The comparison was only carried out for stands with the same tree species located within a distance of 10 km, situated mainly in Germany, France and Finland. The results show a larger N/S ratio in the 1990s compared to the 1980s at nearly all the plots (see fig. II). An even larger increase in N/S ratio over this period might have been expected. The reason for the comparatively small increase is that even though ammonium deposition stayed relatively constant in this period, nitrate deposition decreased considerably, although less than sulphur deposition.

B. The influence of atmospheric deposition on element pools in the soil

8. Information on the chemical soil composition, such as the nutrient pools of the major elements, gives insight into soil nutrient availability and acidity of the soil. This information can also be used to gain insight into the expected relative changes in these pools, considering the input of these elements from the atmosphere and their possible retention. The evaluation of element pools in the soil was related to 604 plots at which soil analyses were carried out up until 1997. An assessment of time periods needed to obtain significant trends and of relationships with environmental factors was related to the availability of deposition data and was conducted at approximately 200 plots. This evaluation was confined to nitrogen in the organic layer since this pool is most liable to change due to nitrogen deposition.

1. Modelled impacts of N deposition on N pools in the soil in a 10-year period

9. In order to estimate the time needed before a repeat soil survey provides information on significant changes, the change in N pool in the soil was investigated. The investigation of the nitrogen pools shows that the median N pool (50th percentile) in the organic layer is 396 kg/ha (see table 1). Assuming that the variation, in terms of standard deviation, of the element pools is 20%, it was possible to calculate the amount of additional N that was required in order to produce significant changes in the N pools in the soil. The median of these required changes was 81 kg/ha. In a next step these required changes were compared to the future atmospheric input of nitrogen, assuming that deposition remains constant for the next 10 years. The amount of these future inputs was at least 101 kg/ha per 10 years for 50% of the plots.

10. The comparison of required changes in the N pool in the organic layer and the accumulated N input in a 10-year period suggests that a significant change can be expected at more than 50% of plots. In reality, however, not all N will be retained in the organic layer since part is accumulating in the mineral soil and part is leached to groundwater. Using a simple model, allowing for these aspects, significant changes in N are estimated to be found in 25% of the plots, if the soil survey is repeated after 10 years.

11. The required time periods that are needed to assess significant trends in pools become proportionally greater with the pool size itself and generally decrease with an increase in atmospheric deposition. In-depth evaluations showed that, for exchangeable base metal pools, the percentage of plots for which changes can be expected is likely to be less, although it may take place at different plots.

2. Relationships between element pools and environmental factors

12. About 30-50% of the variation in element pools was explained by environmental factors. Precipitation and temperature explained the main part of the variation in element pools in the organic layer. Pools increased in more acid, wetter and colder situations. Soil type was the most important explanatory variable in the mineral layer, followed by precipitation and temperature. The pH only had a significant effect on the pool of exchangeable base cations.

C. Foliar chemical composition

13. The chemical composition of the foliage of forest trees is an important indicator for the functioning of trees, especially with respect to their nutrition. The concentration of elements (nutrients) in the foliage provides information on deficiency or excess, either in absolute values or relative to the concentration of other elements. An optimum range per species can thus be distinguished for all elements and ratios. The evaluation of the foliar composition was conducted for 674 plots of pine, spruce, oak and beech. An assessment of relationships of the foliar nutrient concentration with environmental factors took place at about 200 plots where deposition (throughfall) data were available.

1. Foliar nutrient concentrations and ratios

14. In approximately 30% of the stands, the nutrient status of the foliage can be judged to be low and/or unbalanced, taking all nutrients into account (see table 2). Beech had the highest percentage of stands with low concentrations and imbalance in potassium, calcium and magnesium. This was specifically true for Mg, which showed a deficiency in 32% of the beech trees. Taking all nutrients into account, a deficiency and imbalance for one or more of them occurred in 22-55% of the plots, the higher value relating to beech. This illustrates that in most cases only one nutrient was deficient or imbalanced compared to nitrogen.

2. The influence of atmospheric deposition and other stress factors

15. The impact of different environmental factors on foliar concentrations was analysed, using multiple regression analysis. There was a statistically significant relationship between stand age, soil type, altitude, precipitation temperature, soil chemistry and atmospheric deposition on foliar nutrient contents. However, the influence of these environmental factors differed considerably per nutrient and per tree species.

16. There was a significant relationship between foliar N and S deposition and the foliar N and S concentration for the coniferous species (see fig. III). The correlation between foliar N concentration and N throughfall was higher for pine than for spruce. For both pine and spruce, a large variation in N content was however observed even at low N inputs. This variation is most probably caused by local differences in N availability from the soil, which is partly influenced by the past land use. This result shows that a possible imbalance of nutrients compared to nitrogen is certainly influenced by atmospheric N input, at least for these tree species.

17. With the exception of Mg, no effect of base cations deposition on the foliar base cation concentraion could be demonstrated. In general the foliar concentration of base cations was however positively correlated to the concentration of the respective cation in the organic and/or mineral layer. This shows that the availability of cations in the soil has a larger influence on the foliar status of these nutrients than atmospheric deposition.

D. Relationships between crown condition and environmental factors

18. A correlative study has been conducted in order to analyse the impact of different environmental factors on the defoliation of pine, spruce, oak and beech. The impact was evaluated for 262 plots for which throughfall data were available. An in-depth interpretation will be improved when information on stand history, pests and diseases and air quality becomes available. Results showed that 20-50% of the variation in defoliation could be explained by the variation in stand age, soil type, precipitation, N and S deposition and foliar chemistry (see table 3). Compared to earlier studies on a European scale (e.g.[4; 5], see also chapter IV), the high percentage of variation that could be explained by different environmental factors is an important finding. These results have been achieved using measured data that were available on a relatively large number of plots rather than the modelled data which had to be relied upon in previous studies.

19. Explanation of the effects of individual environmental factors was as follows (see also table 3):

(a) As with previous studies, defoliation was found to increase with stand age for all tree species, except pine;

(b) The defoliation of spruce and oak appeared to be larger in sandy soils than in clay soils, most likely due to differences in water and nutrient availability;

(c) An increase in precipitation was correlated with an increased defoliation for pine, but for spruce the opposite effect was found, probably due to a decrease in drought stress;

(d) Higher nitrogen and sulphur deposition were correlated to a higher defoliation of spruce oak and beech with the exception of N for spruce, probably due to an increased N availability at N-poor sites.

III. CROWN CONDITION IN 1999 AND ITS DEVELOPMENT IN THE PAST

20. Crown condition is an important indicator for the development of forest condition. Whereas it has become one response variable among others at level II monitoring, it is the main parameter in level I monitoring. In multivariate statistics conducted with level I as well as with level II or external data, correlations between crown condition and environmental stress factors have been demonstrated (see chap. II, sec. D and chap. IV). Crown condition is assessed in 5% defoliation steps and grouped into five defoliation classes of uneven width. It reacts to many different stress factors. Defoliation values of one year thus contain limited information on the influence of single factors. The development of defoliation over time may however give evidence of continuously acting stressors such as air pollution, provided other factors like age are taken into account.

21. The results of the transnational survey are part of the survey conducted in 1999 on the 16 km x 16 km grid net of 30 participating countries. The evaluations given are based on the 5764 level I plots from all EU member States and 15 non-EU countries, which were assessed by the Programme Coordinating Centre of ICP Forests in Hamburg (Germany). In total 128 977 trees were assessed. National assessments on denser networks were also conducted.

1. Crown condition in 1999

22. In 1999 almost a quarter (22.6%) of all assessed trees throughout Europe were classified as moderately or severely damaged. In 1998 the respective figure was 23.1%. In 1999 almost 1% of the trees were dead, 41% were slightly defoliated, and over a third (36%) were classified as healthy. Crown condition in the EU countries was slightly better than in Europe as a whole. Of the four main tree species, European and sessile oak were by far the most severely defoliated.

2. Annual mortality rates

23. Annual mortality rates in the years from 1992 to 1999 ranged between 0.1% and 0.8% for the main tree species. Between 1% and 4% of the trees were annually removed from the plots. These values are in a range that can be considered as normal for managed European forests. Thus

on a large scale, die-back is not to be expected. For some species and regions, however, severe mortality was reported locally (e.g. European oak).

24. The defoliation of removed trees was on average comparable to the defoliation of the total sample of all monitored trees. This shows that forest management is unlikely to have an influence on mean defoliation figures. Trees classified as severely damaged showed a considerably higher mortality rate in the following seven years. Also the proportion of removed trees was increased. On the other hand, a large proportion of the severely damaged trees recovered: 38% of the Norway spruce, 43% of the deciduous oak species, 61% of the common beech and 62% of the Scots pine.

3. Development of crown condition

25. A comparison of the years 1994 and 1999 shows significant changes in mean defoliation on almost half of the plots in Europe. The proportion of plots with deteriorating crown condition (23.4%) is slightly larger than the proportion of recuperating plots (21.4%). Compared to the period from 1992 to 1998 the difference between worsening (31.2%) and improving (15.4%) plots has decreased, indicating that in recent times the overall deterioration has slowed down.

26. In most of the ten climatic regions distinguished in Europe [1], there is no evident trend, but deteriorating plots are concentrated in some parts of the Mediterranean region. This region comprises large areas of Portugal, southern Spain and France, parts of Italy as well as parts of Croatia. Here the mean defoliation of all species has increased considerably during the past five years. In-depth evaluations show that crown condition of common beech, Scots pine and maritime pine has been deteriorating especially in this region. For example, the proportion of maritime pine that was classified as undamaged in the Mediterranean (lower) region has dropped from 65% to 38% during that period. The reasons for this are probably a number of dry years, insect attack and fungal infestation. Of the air polluting agents, ozone is suspected to have particularly damaging effects in this region [2]. Further information is expected as soon as the large-scale ozone monitoring data become available.

27. Recuperating plots are more abundant in the so-called Subatlantic region, which comprises Poland, western Slovakia, Czech Republic and eastern Germany. The recuperation has mainly been explained by favourable weather conditions in recent years. The possible influence of the strong decrease in sulphur inputs is difficult to separate from these natural impacts. Recuperation was most pronounced for Scots pine; in the Subatlantic region the proportion of pine trees that were classified as damaged has decreased from 46% to 26% during the past five years.

28. The development of mean defoliation in the six main European tree species reveals an overall deterioration. However, the trends have to be considered for individual tree species and, if the database is sufficient, even for single regions (see fig. IV). Scots pine is the only main tree species that shows a small but continuous improvement in mean defoliation during the past five years. It is the most frequent tree species on level I plots and is present in most of the climatic regions. However, the overall improvement of its crown condition has to be interpreted with caution as there are differences in the development in different regions; the crown condition in the Subatlantic region has improved but there is a worsening in the Mediterranean regions. In contrast,

the trend in Norway spruce is similar in most regions. Mean defoliation peaked during the mid-nineties and showed a new increase at the end of the decade. There has been a slight deterioration in the condition of common beech according to observations from plots of the European-wide monitoring system. It is mainly due to the deterioration in the southern parts of Europe, while in other parts of Europe defoliation has been fluctuating. For the first time since 1991 mean defoliation of European oak decreased in 1999. This improvement in crown condition has been observed in all regions in which the species occurs. Maritime pine and holm oak only occur in southern parts of Europe, where in some areas a further deterioration of the former has been observed and in the latter a deterioration in 1999 after a short recuperation during 1997 and 1998.

IV. ANALYSIS OF CAUSES OF DAMAGE USING MULTIVARIATE STATISTICS

29. One approach to analysing the factors that influence forest condition is to use multivariate statistics which simultaneously take into account the influence and the interactions of several stress factors. Throughout Europe 23 studies, partly using level I and level II data, have been analysed in this way in order to explain defoliation processes. It is necessary to bear in mind that almost all studies of the overview focus on certain regions and main tree species. For the evaluation of climate and air pollution effects, modelled or interpolated data were used in the 23 reviewed studies.

1. Age and biotic factors

30. In several studies a statistical influence of the following factors became obvious:

(a) Statistically, age was the variable most strongly correlated with crown condition [1, 2, 3, 7, 8, 9, 10, 12, 13, 15, 17, 19, 24, 26];

(b) Insects and fungi play an important role especially for the defoliation of oak species. They can be triggered by weather conditions, environmental factors or indigenously controlled population processes [9, 17];

(c) Flowering and fruiting of trees affect defoliation particularly in Scots pine and masting beech [7, 17].

2. Climatic factors

31. Almost all studies reveal damaging effects of drought on the main tree species. Scots pine as well as pedunculate oak and sessile oak also seem to be influenced by cold winters and late frosts. In addition, climatic gradients are of relevance to the interpretation of defoliation, especially if larger areas are considered [5, 7, 8, 11, 12, 13, 16, 17, 18, 24, 25, 26].

3. Air pollutants

32. A number of studies also showed a statistical influence of air pollutants, such as:

(a) Influence of sulphur compounds. Sulphur compounds show effects on the defoliation or discoloration of Norway spruce as the long living needles of this species are particularly susceptible to high sulphur concentrations and deposition. As sulphur dioxide concentrations have already been reduced in large parts of Europe, the damage through sulphur compounds was even higher in the past [1, 9, 13, 16, 17, 24];

(b) Ozone effects on different broadleaved tree species. Tree damage by ozone mostly occurs under Mediterranean climate conditions. However, in northern parts of Europe, where most of the evaluated studies were performed, ozone concentrations could significantly explain some of the observed defoliation [5, 9, 10, 11, 13, 14, 17, 18];

(c) Damaging and beneficial effects of nitrogen. The effects of nitrogen very much depend on the area of concern. There were positive effects on crown condition in those regions where nitrogen supply still seems to be a limiting factor for tree growth (e.g. in parts of the United Kingdom). In nitrogen-saturated stands (e.g. in the Netherlands) it may worsen defoliation [1, 12, 13].

4. Soil-mediated influences

33. In studies conducted mainly in central Europe, changes in physical and chemical soil properties that originate, at least in part, from atmospheric deposition have been identified. However, only a few significant statistical relationships have been detected:

(a) Acidification: low pH, low concentrations of calcium and/or manganese, low base saturation and high concentrations of aluminium coincide with high defoliation values in Scots pine and Norway spruce and partly also in beech [2, 3, 6, 7, 19];

(b) Drought: soil moisture deficit has been found have a negative influence on crown condition especially in Norway spruce and beech, but less so in Scots pine [2, 7, 15, 17, 25];

(c) Further relationships depend on special, mostly regional circumstances and can hardly be generalized.

V. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

34. During its 14 years of existence, the collective forest condition monitoring of ICP Forests in close cooperation with the EU has developed into one of the world's largest biomonitoring systems. On the European scale, the spatial and temporal variations in crown condition are assessed and additional data on soil and foliage from the same plots permit integrated studies with respect to certain environmental factor combinations. On the ecosystem scale, the intensive monitoring contributes to the understanding of processes under the impact of air pollution and other stressors.

35. From the latest monitoring results on crown condition, several conclusions can be drawn:

(a) Compared to last year’s evaluations the overall deterioration in crown condition has slowed down. Changes in defoliation vary between species and regions. In parts of the Mediterranean region, mean deterioration has shown the sharpest increase compared to other regions. This is mainly due to the continuing deterioration of marine pine and holm oak. In eastern/central Europe, mean defoliation has shown a considerable decrease. The improvement in this region has been most pronounced for Scots pine;

(b) In-depth evaluations of mortality rates show that die-back on a large scale has not occured during the monitoring period.

36. In most cases it is not possible to identify causes of observed deterioration of individual stands or trees. Statistical evaluations indicate that there is a complex system of environmental conditions and stress factors that may act sequentially, concurrently, synergistically or cumulatively on forest stands and thus lead to different types of ecological reactions by the trees. The main factors that are statistically relevant in explaining defoliation are tree age, plant-eating insects and fungi, climatic extremes, air pollutants like sulphur and nitrogen compounds and ozone, and acid or dehydrated soils.

37. The intensive investigations carried out on the site and stress factors which influence forest ecosystems, as well as on the biological and chemical ecosystem condition, reveal that:

(a) At 266 investigated level II plots, atmospheric nitrogen deposition is mostly higher than that of sulphur. Approximately 55% of the considered plots received nitrogen inputs at which adverse effects can be expected. However, these plots are not hemogeneously distributed over Europe;

(b) Defoliation of pine, spruce, oak and beech is significantly influenced by stand age, soil type, precipitation, nitrogen and sulphur deposition. A statistical analysis of 262 plots indicated that approximately 20-50% of the variation in defoliation could be explained by these environmental factors;

(c) The nutrient status of the foliage can be judged as low and/or unbalanced in approximately 30% of 674 investigated plots. Both nitrogen and sulphur deposition lead to increased concentrations of these elements in the needles of Scots pine and Norway spruce. In contrast, site type had a more significant influence on foliage chemistry of calcium, magnesium and potassium;

(d) Element pools in soils are influenced by soil type, tree species, altitude, precipitation, temperature and pH. Modelling calculations suggest that, if nitrogen inputs remain unchanged, significant changes in nitrogen pools are to be expected at approximately 25% of the 200 investigated plots in a ten-year period.

2. Outlook

38. The programme has finalized its internal review this year and agreed on a strategy for the future programme scheme valid until 2006. The pan-European monitoring system of ICP Forests offers a unique source of information on the condition of forest ecosystems. The data gathered in this programme and their evaluation are of interest for policy-making processes not only for environmental protection but also for other forest policy issues, such as sustainable forest management, biodiversity in forests or the effects of climate change on forest ecosystems. Thus the monitoring system provides a cost-effective multifunctional monitoring approach. Therefore, the further implementation of level II monitoring and further integrated evaluation of level I and level II data, partly in combination with external data, are of high priority in the programme. Further

areas of increasing importance will be the data quality management within the programme and the cooperation with other organizations working on related fields.

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Note: The references have been reproduced as received by the secretariat.

Table 1:
The ranges in nitrogen pools and the required changes in those pools to assess significant trends for the organic layer of intensive monitoring plots

Range	N pool ($kg.ha^{-1}$)	Required changes ($kg.ha^{-1}$)	Calculated 10-year N deposition ($kg.ha^{-1}$)
5%	66	14	8
50%	396	81	101
95%	2731	793	290

Table 2:
Percentage of plots with low nutrient availability and/or an unbalanced nutrient status compared to nitrogen (n = number of investigated plots)

Tree	P	K	Ca	Mg	All nutrients
Pine (n=245)	10	13	5	4	27
Spruce (n= 200)	7	10	2	4	22
Oak (n= 126)	26	5	7	8	38
Beech (n =103)	23	14	11	32	55
All trees (n= 645)	14	11	5	9	32

Table 3:
Overview of predictor variables explaining defoliation of 4 tree species of the intensive monitoring plots with the number of plots (N) and the percentage accounted for (R^2adj.)

Variable	Pine	Spruce	Oak	Beech
Age (year)	*	*	*	*
Soil type		*	*	
Precipitation ($mm.year^{-1}$)	*	*		*
N deposition ($mol_c.ha^{-1}.year^{-1}$)		*	*	*
S deposition ($mol_c.ha^{-1}.year^{-1}$)	*	*	*	
Foliar content ($g.kg^{-1}$)	*	*	*	
N	59	95	33	35
$R^2_{adj.}$	21	35	44	48

* significant correlation

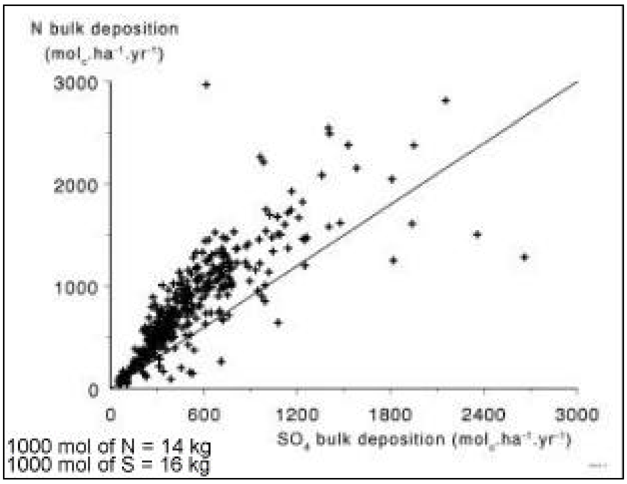

Figure I:
Relationships between the annual fluxes of N and S in bulk deposition at 401 plots, 1997. The solid line represents the 1:1 line

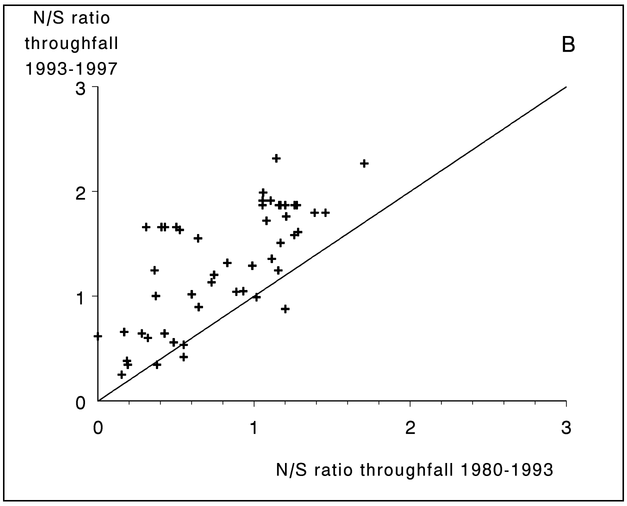

Figure II:
Comparison of the N/S ratio in throughfall deposition measured at 53 corresponding locations in the 80s and 90s. The maximum distance between compared plots was 10 km. The solid line represents the 1:1 line

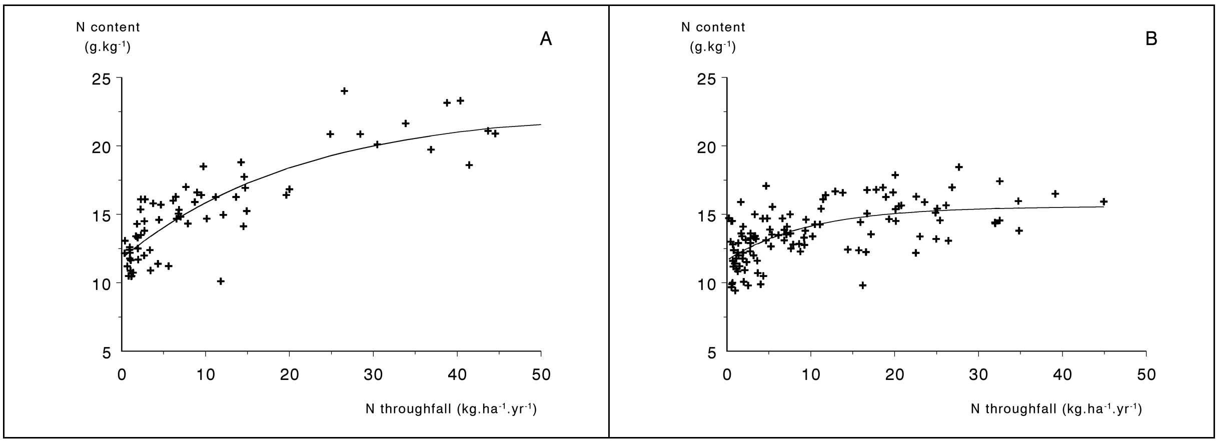

Figure III:
Relationships between N concentration in pine needles (A) and spruce needles (B) and N in throughfall

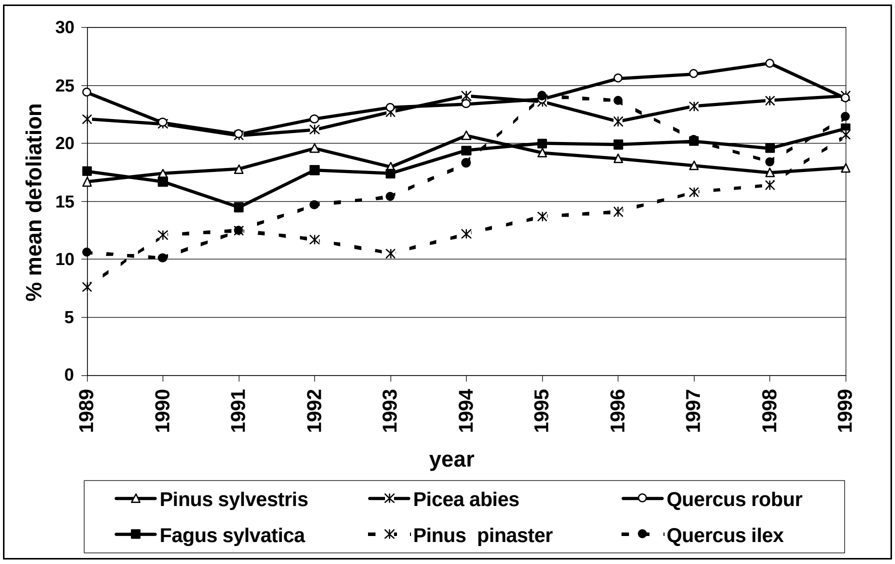

Figure IV:
Development of mean defoliation for the main European tree species
(Defoliation development was calculated only for trees which were continuously monitored from 1989 to 1999. The standard error for Scots pine, Norway spruce, holm oak and common beech was in all years below 0.4 %; for the other two species it was in all years below 0.6 %. Due to changes in the assessment methods French data were excluded from the time series.)