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MONITORING OF FOREST CONDITIONS IN EUROPE

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

I. INTRODUCTION

1. The International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) has established a monitoring system to assess the changes in forest condition and its relation to air pollution. This forest condition assessment pursues three major objectives:

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(a) To gain further knowledge of the spatial and temporal variation in forest condition and of its relationships to stress factors, in particular air pollution. This is realized by means of an international large-scale systematic network. This is referred to as 'monitoring intensity level I';

(b) To investigate the relationships between air pollutants and other stress factors on forest ecosystems, and to study the development of important forest ecosystems in Europe. This is achieved through intensive monitoring at selected observation plots, which is referred to as 'monitoring intensity level II';

(c) To provide a deeper insight into the interactions between the various components of forest ecosystems by means of information available from in-depth studies on the influence of air pollution and other stress factors.

2. Different monitoring designs have been devised to suit these objectives:

(a) For the monitoring of forest condition and its changes on a large scale and over a long period of time, the so-called 'level I network' has been established. This level I network consists of approximately 5700 monitoring plots, which are systematically arranged in a 16 km × 16 km grid throughout Europe and on which three main assessments are conducted (see table 1);

(b) For the intensive monitoring programme, more than 860 level II plots have been established with the aim of recognizing key factors and processes on the ecosystem scale. Plots have been selected as typical for particular European regions. Here a bigger number of key factors are measured (see table 1).

3. The two monitoring levels overlap with respect to certain key parameters, so a scaling-up of results will become feasible. Thus, the total information provided by the monitoring system amounts to more than the sum of the results from the two individual levels, especially when integrated with other pan-European monitoring networks.

II. ATMOSPHERIC DEPOSITION AND ITS IMPACT ON SOIL SOLUTION CHEMISTRY (LEVEL II RESULTS)

4. The measuring of atmospheric input into forests is rather complex and expensive. In the integrated studies presented above concentrations of pollutants were therefore modelled for the big number of level I plots. However, a more precise approach is pursued by the Intensive Monitoring Programme (level II), where inputs are directly measured on the smaller number of level II plots. The Intensive Monitoring Programme (level II) in particular focuses on the deposition levels of SO_x, NO_x and NH_x as well as on other stress factors such as adverse meteorological conditions. Measurements of ozone (O_3) will be intensified due to the growing evidence of its impact on tree health. An overview of the most relevant relationships between the (ultimately)

available data in the Intensive Monitoring database is given in figure 1. This chapter focuses especially on the results obtained in the surveys on atmospheric deposition (320 plots) and soil solution chemistry (103 plots).

5. These analyses were conducted only after extensive quality controls, comprising checks on the reliability and comparability of the data as well as data quality assurance. As the data handling and validating is rather complex, only data from 1996 or earlier are integrated into the following evaluations.

A. Atmospheric deposition

1. Measuring atmospheric deposition

6. Atmospheric deposition on forests is measured below the forest canopy (throughfall). This method totals the contributions from wet and dry deposition but is in addition influenced by the uptake and leaching of elements from the leaves and needles. In stem flow measurements the rainwater which reaches the soil along the trunks of the sample trees is collected. Other important information is derived from measuring bulk deposition in an open field close to the forest stands. These measurements include wet and some dry deposition values but are not affected by canopy exchange. Nevertheless, open fields do not filter the air as forests do, so deposition values are lower.

7. To get information on the total deposition in forest stands, the throughfall and stem flow values have to be corrected for the effects of element uptake or leaching. This is done by a comparison of throughfall and stem flow to the bulk deposition, whereas corrections for the canopy uptake are calculated using models. When stem flow is not available, simple models are also used to get an indication.

2. Ranges and geographic variation in atmospheric inputs in view of critical loads

8. The total deposition of sulphur (S) and nitrate (N) covered a wide range. At approximately 90% of the plots deposition varied between 100 and 3000 mol_c /ha/year or 2 to 45 kg/ha/yr (see figure 2).

9. Approximately 45% of the plots received a nitrogen (N) input above 1000 mol_c/ha/year, or 14 kg/ha/yr (so 55% of the plots received less than 1000 mol_c/ha/yr; see figure 2). This is a deposition level at which the species diversity of the ground vegetation may be at risk. Critical loads beyond which tree health might be affected are higher and vary for different forest and site types from approximately 1000 to 3500 mol_c/ha/yr (approximately

14-50 kg/ha/yr). A comparison with present loads shows that those impacts still occur at several plots.

10. The total input of acidity (the input of S and N compounds corrected for base cations) ranged mostly between 200 and 4000 mol_c/ha/yr. Adverse impacts are likely above 1500-3000 mol_c/ha/yr, which occurs at about 15% of the plots. Depending on soil type and tree species, inputs above those loads are regarded as critical as they may cause nutrient depletion and increased aluminium concentrations in the soil.

3. The shares of nitrogen and sulphur compounds and of base cations in the atmospheric input

11. Even though on average the measured throughfall was roughly the same for nitrogen (N) and sulphur (S), the average total N input turned out to be 50% higher than the S input after the calculated corrections for canopy uptake. This implies that nitrogen is a dominating factor in the acidic input in large parts of Europe. In northern and central Europe especially, ammonium, mostly from intensive husbandry, seems to be the dominating compound in the N inputs. The spatial distribution patterns of N and S deposition are quite different. Whereas bulk deposition and total deposition of nitrogen generally appeared to be higher than sulphur deposition at plots in western Europe (United Kingdom, Belgium, Netherlands, Luxembourg, France), the reverse was generally observed at plots in central Europe (Poland, Czech Republic, Austria, Hungary).

12. Base cation input mostly has positive effects on forest ecosystems, as it neutralizes acidic input and at the same time serves as nutrient for the trees. The geographic pattern of bulk deposition of calcium (Ca), being the most important neutralizing base cation, is comparable to that of S and N: low in northern Europe, high in central and southern Europe and intermediate in western Europe. In central and southern Europe the acidic input is thus largely neutralized by the input of base cations.

13. A significant relationship was further observed between the input of Ca and sulphate (SO_4) both in bulk and in total deposition. The correlation may partly be due to associated emissions of sulphur dioxide (SO_2) and Ca from smelters and refineries (see figure 3).

B. Soil solution chemistry

1. Monitoring soil solution chemistry

14. For the monitoring of soil solution chemistry, at the majority of the plots use was made of tension lysimeters, which extract water from different soil layers. Data for the soil solution chemistry in 1996 were stored for a

total of 103 plots concentrated in western and northern Europe. The evaluation focused on the chemistry of major ions in soil solution impacted by nitrate (N) and sulphur (S) deposition, either directly (SO_4, NO_3, NH_4) or indirectly through soil buffering reactions. The most important results are given below.

2. Ranges in element concentrations in view of critical levels

15. Concentrations of sulphate (SO_4), nitrate (NO_3), total nitrogen (N), aluminium (Al) and calcium (Ca) ranged mostly between 0 and 2 $mmol_c.m^{-3}$. Concentrations of ammonium (NH_4) were nearly always lower than 1 $mmol_c.m^{-3}$. The concentrations of NO_3 exceeded the official ground water quality criteria of 800 $mmol_c.m^{-3}$ at 18-26% of the plots, depending on the depth considered (table 2).

16. The ratio of the concentration of toxic Al versus the concentrations of the base cation nutrients Ca, Mg and K is an important parameter to evaluate the state of soil acidification. Generally, a ratio of > 1 is regarded as critical. This critical ratio was exceeded in approximately 10-15% of the plots, depending on the layer considered (see table 2).

3. Relationships between element concentrations in soil solution

17. The aluminium (Al) concentration in both topsoil and subsoil was strongly related to the concentration of SO_4 and NO_3 in acid soils (soils with a base saturation below 25% or a pH below 4.5), especially in the subsoil (see figure 4). This indicates that in those soils the acid input is mainly neutralized by the release of toxic aluminium. Above those base saturation and pH levels, the relationship between the concentration of Al versus SO_4 plus NO_3 was very weak, indicating that the acidity is neutralized by the release of nutrient base cations.

4. Simultaneous impact of atmospheric deposition, meteorological conditions and soil chemistry on the soil solution chemistry

18. Atmospheric deposition has a major influence on the concentrations of the most important ions in the soil solution. The influence of atmospheric deposition was even bigger than that of meteorological conditions and soil chemistry. In statistical terms, it could explain more of the variations in the concentration of these major ions. The deposition of NH_4 had a highly significant impact on all the considered compounds (except on SO_4), increasing the concentration of N compounds, base cations and Al and decreasing the pH. This can be explained by the acidifying impact of NH_4 deposition, caused by the conversion of NH_4 to NO_3 (nitrification) in the soil. The impact of the deposition of SO_4+NO_3 on base cations and Al was generally slightly lower. This result should, however, be interpreted with care, since there is a high

correlation between the deposition of NH_4, NO_3 and SO_4. The impact of total N deposition on the NO_3 concentration is shown in figure 5.

19. In general, NO_3 and NH_4 concentrations in the soil solution are low at an N deposition below 1000 mol_c/ha/year. Above this deposition level, concentrations generally increased with an increase in deposition level, but large variations did occur.

C. Special focus: Ozone effects and a prospects for their assessment

20. The effects of photochemical oxidants on vegetation were first observed more than four decades ago in the greater Los Angeles basin in the United States. Since then, many investigations have shown that ozone, the most prevalent and widespread of this group of pollutants, has to be regarded as very phytotoxic. It has been shown to cause injury to the foliage of agricultural and horticultural crops, and conifers and deciduous trees in the United States of America and Asia and, since the early 1980s, in Europe [5,6].

21. In nearly all regions of Europe ozone concentrations during the summer 'ozone episode' are high enough to possibly put sensitive plants at risk, although the risk decreases from southern to northern Europe. The value that is recognized as an accepted standard for the protection of forest trees from adverse ozone effects [5, 8] is frequently and repeatedly exceeded in many areas such as Austria or Switzerland and especially in the Mediterranean [7].

22. Whereas the direct effects of high ozone concentrations on trees have been explained by many studies during the past 30 years, the influences of indirect effects associated with chronic ozone exposure are rather unpredictable. For example, early senescence and premature leaf drop of deciduous trees have been frequently observed. This may be associated with a disturbance in carbon supply, since it is known that ozone blocks the transfer of carbohydrates from leaves to roots. Thus, trees can have reduced energy reserves for the 'spring flush'. If, in addition, they are infested with insects, energy reserves are further reduced, leading to a spiral of decreasing vitality. Examples of such forest degradation are known from the San Bernardino Mountains in California or the Sierra in the vicinity of Mexico City, where trees predisposed by ozone are massively invaded and destroyed by bark beetle infestations.

23. Frost, drought, high light intensities and nutrient levels are other external stress factors that predispose trees to chronic ozone exposure. The effects of ozone seem to be increased when there are mineral deficiencies in the soil due to acidification. High nitrogen deposition may exacerbate problems already being caused by ozone pollution, as indicated, for example, in recent studies on ponderosa pine in California [3]. Similar phenomena may

be occurring in other polluted Mediterranean areas on a regional scale. For Mediterranean climates, information on dry deposition is therefore more important than information on wet deposition, but at European level insufficient data sets are available. These necessary inputs could be given in the future by the Intensive Monitoring Programme of ICP Forests. In addition there is a need to develop methods for the harmonized assessment of ozone concentrations, exceedance of critical levels and its effects on the forest ecosystem.

24. Moreover, it is very important to observe European forest species for the occurrence of ozone stress indicated by visible injury (natural bio-indicators). Since ozone injury can be rather conspicuous, and symptoms are often camouflaged by other stress factors like drought, precise symptom identification on natural vegetation needs professional expertise. This can be done by routine standard inspection of selected sites within Europe. On this basis, maps of confirmed ozone injury to trees could be produced. In addition, at such sites, it would be useful to look at links between 'ozone dose' and its effects. Here, knowledge on ozone concentrations and climatic factors is a prerequisite to predict possible economic losses.

25. At sites where ozone concentrations are lower and visible injury on natural vegetation rare, a second way of assessing the impact of ozone on forests might be the widespread use of ozone-susceptible species such as black cherry as indicators. Some studies have already been undertaken on poplar [2].

26. Of all the pollutants discussed so far which are present in remote forested areas, ozone probably has the highest degree of phytotoxicity based on concentration and duration of exposure. It is, therefore, reasonable to assume that ozone is a major contributary factor in the decline observed in forests today, especially in the south of Europe.

III. CROWN CONDITION AND INTEGRATED EVALUATIONS (LEVEL I RESULTS)

A. Development of crown condition

27. Regarding the development of the main tree species in Europe since 1989, an overall deteriorating trend on the assessed level I plots has become obvious. Nevertheless, the trends are different for the individual species (see figure 6).

28. Crown condition of Norway spruce has fluctuated since 1989. The state of Scots pine has improved during the past years. Particularly in regions of Germany and Poland it has recuperated since 1992. This development has been explained by favourable weather conditions and reduced atmospheric inputs.

29. In contrast to these main coniferous species, the state of the assessed European oak, maritime pine and to a certain extent common beech is alarming. They have all suffered a severe decline in crown condition during the past years; the condition of beech and European oak stabilized in 1998 for the first time in years.

30. It is quite normal for time trends of crown condition to vary to some extent between years, because defoliation is influenced by a multitude of changing natural and anthropogenic stress factors. An overall deteriorating trend does therefore not prove the existence of specific stress factors.

31. Yet, natural stress factors are thought to be in long-term equilibrium with the forests, which would result in continuous waves of changing crown condition. But as the means of the Europe-wide assessed trees instead indicate a long-term decline, it can be assumed that there are in addition stress factors, for example air pollution or climatic change, which affect tree vitality continuously and over large areas.

B. Special focus on the decline of European and Sessile oak

32. In 1998 European oak was the most severely damaged main tree species in Europe by far(see figure 6). Yet, the latest development of European oak crown condition shows quite different trends in individual regions (see figure 7). In the Sub-Atlantic region, which comprises more than half of all the continuously monitored trees and which mainly covers eastern France, Germany, Poland, Austria and western Slovakia, the share of oak trees which were considered to be damaged was clearly higher than, for instance, in the Atlantic (south) during almost the whole observation period.

33. In 1998 in the Sub-Atlantic region there was again a sharp increase in the share of damaged oak trees. However, in the Atlantic (south) and Mountainous (south) regions (not depicted), crown condition deterioration is slowing and reversing, showing a clear improvement in 1998. These regions cover western and southern France, northern Spain and Italy.

34. This crown condition is largely due to regional or even wider gradations of defoliating insects and does not generally lead to the further decline and death of trees. This may eventually occur by additional interference of some of the other above-mentioned factors. Decline seems to be most frequent on European oak but it has been observed on Sessile oak as well.

35. The symptoms of the widespread oak damage are thinning and progressive dieback of crowns, including yellowing and decreased size of leaves and remaining foliage being arranged in tufts at the end of bare shoots. Trunks may show bark necrosis and slime flux, mainly due to borer attacks.

36. Various investigations have supplied evidence that defoliation by leaf-eating insects plays a predominant role in the outbreaks of oak decline. Defoliation in two or more consecutive years rather than one single defoliation event is thought to be an important factor causing the decline [4,8]. The damage by the gypsy moth (*Lymantria dispar*) occurs rather late in spring. Therefore, it is thought to have a bigger impact than the defoliation in earlier spring by the oak roller moth (*Tortrix viridana*) and winter moth (*Operophtera brumata*). The impact of the defoliators can be aggravated if the replacing shoots which are formed in early summer are attacked by mildew [15,16].

37. Generally, drought is considered to be another major factor for the outbreak of damage to oak during the past several decades. This has been explicitly stated for many European countries [3,17,14,22,10,11,18]. For European oak in particular, close correlations were found between soil water relations and tree health. Especially on hydromorphic sites increased oak damage has been observed [13,1,12,14]. At those sites the rooting in the subsoil is impaired, leading to more severe drought stress in dry periods of the growing season [13,19,20].

38. Severe winter frost is regarded as another causal factor of oak decline in Europe and may have had a synchronizing effect on the occurrence of decline in the eighties [2,7,10,14].

39. In most locations borers (*Agrilus spp.*), whose larvae are able to girdle the stem, were found to be one of the earliest and most important secondary organisms [5,6,7,8].

40. In recent years fungi of the genus Phytophtora, which cause root rot, have been isolated from oak stands in central and eastern Europe [9] but it is doubtful whether they are of major importance in the context of oak decline [6]. Other fungi involved are *Armillaria spp.*, among which species with low pathogenicity (*A. gallica*) as late invaders of declining oaks seem to be more frequent than pathogenic species (*A. ostoyae, A. mellea*).

41. Air pollutants, the continuing nitrogen input in particular, are regarded as a risk to the stability of the ecosystem. Studies on the effects of ozone in the context of the oak decline have begun only recently.

42. Only under very extreme conditions can the decline of oak stands be attributed to one of the above-described factors alone. In most cases they are acting sequentially, concurrently, synergistically or cumulatively, which makes it rather difficult to explain the decline process for specific stands or even trees. Therefore, it is obvious that further intensive research is

needed to clear up the complex causes of oak decline in Europe. This should also include the research on Holm and Cork oak, as these species are also showing a decline.

C. Integrated studies

43. To find out about the factors that are influencing crown condition, integrated studies evaluate and combine data from different surveys that have been carried out on identical plots. Whereas national and regional studies are already available (e.g.[1-5]), such analyses on transnational level have begun only recently. This section presents the first results of two integrated studies.

1. Analysing impacts on crown condition in pilot areas

44. Within the ongoing investigations of the first integrated study different statistical methods are applied to defoliation, soil and foliar data of the level I grid. To cover regions with homogeneous conditions, two transnational pilot areas have been selected. Area 1 contains the lowlands of Flanders, the Netherlands and the north-western part of Germany. Area 2 is composed of the hilly to mountainous regions of southern Saxony (Germany), northern Czech Republic and the south-western part of Silesia (Poland). Both regions were bounded in a way that plots on calcareous parent materials were excluded so that soil parameters represent acidic and very acidic soils.

45. First results:

(a) Mean defoliation differs significantly between individual countries. This is partly due to different standards used. Those differences could nevertheless be minimized by mathematical means;

(b) After correcting the country effects, age effects became obvious, showing that the crowns of older trees are more defoliated than those of younger ones (see figure 8);

(c) Defoliation values of pine are significantly correlated to the defoliation of previous years. This correlation decreases from highly significant in the consecutive year, to non-significant after two to four years. These results demonstrate some kind of temporal waves of high and low defoliation;

(d) Defoliation values of Scots pine within area 1 increase significantly with decreasing basic exchangeable cations and cation exchange capacity of the upper mineral soil layer. This implies that increasing soil acidity leads to poor crown condition;

(e) Within area 2, defoliation of Scots pine increases with altitude and decreases with the weight of the organic layer.

2. Modelling the impacts of air pollution and weather conditions

46. In an exploratory phase of the second study, observed defoliation data at level I plots in Europe were correlated with site-specific model estimates of temperature and water stress and of air pollution (concentration and deposition levels of sulphur and nitrogen compounds and ozone). The major aim was to gain insight in the influence of air pollution in comparison to natural meteorological stress factors for different combinations of stand and site characteristics. The study was limited to the most common and widespread tree species including Scots pine, Norway spruce, oak species as well as common beech. The selected species account for more than two thirds of all trees.

47. The sharp changes in defoliation data at country borders, which are due to different standards, were included in the statistical analyses through a so-called country effect.

48. Apart from country and age, drought stress, in terms of relative transpiration, and various air pollution variables were significant predictors for the variation in crown condition. Those factors explained 37-55% of the variation in crown condition of the four major tree species. The modelled impact of drought stress on Scots pine is illustrated in figure 9.

49. The modelled impact of ozone exposure on beech, in terms of AOT60,[1] is illustrated in figure 10. It shows a clear impact of ozone exposure on the defoliation of beech. Similar relationships were found for the other broadleaved species.

50. First results:

(a) Drought stress modelled through relative transpiration coincides with increasing defoliation for Scots pine;

(b) It seems that defoliation of broadleaved tree species is affected by high ozone concentrations.

51. Outlook: The results of the exploratory study were still limited due to:

(a) The changes in defoliation at country borders, due to methodological differences;

(b) The limited reliability of the site-specific estimates of the various stress factors;

(c) Simplifications in the statistical model;

(d) The lack of data on other relevant stress factors.

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[1] Accumulated number of hours of ozone concentrations above 60 ppb during the vegetation period.

To further improve the results and to overcome the above limitations, an in-depth study is being carried out.

IV. CONCLUSIONS

52. During its 13 years of existence, the collective monitoring of forest condition of UN/ECE and EU has developed into one of the world's largest biomonitoring systems. On the European scale, the spatial and temporal variation 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.

53. From the monitoring results obtained up until now, several conclusions can be drawn:

(a) A steady increase in defoliation of the main tree species has been occurring since 1988;

(b) The increase in defoliation was the sharpest in Maritime pine, Holm oak and European oak, with European oak at present showing by far the highest defoliation;

(c) Scots pine and Holm oak have only recently recuperated from their decline of previous years;

(d) Forest soil condition in Europe gives reason for concern, as soil acidification is widespread;

(e) Extremely acidified soils are almost exclusively located in central Europe, which is at the same time the region with the highest air pollution and the highest defoliation of trees.

54. The observed defoliation is attributed largely to natural stressors, such as pathogens and weather conditions. However, continuously increasing defoliation seems to indicate that deteriorating forest condition is difficult to explain by natural stressors alone. There is a spatial coincidence in the areas of highest deposition and defoliation in Europe. Even though it is difficult to disentangle the causes for crown condition development on a large scale, integrated studies show that, apart from tree age and altitude of plots, drought, ozone exposure and to some extent soil chemistry do influence the crown condition.

55. To examine in greater detail the factors that are influencing the forest ecosystems deposition measurements are carried out. They show that:

(a) Acidity inputs on approximately 15% of the plots, located in central and western Europe, exceed the threshold beyond which negative impacts on forest ecosystems are expected;

(b) On average the total input of nitrogen (N) is approximately twice that of sulphur (S). In general, sulphur dominates in central and eastern Europe, whereas nitrogen dominates in western Europe.

56. These atmospheric inputs have a direct impact on the forest ecosystems. Results show that:

(a) The variation in concentrations of major important chemicals could largely be explained by differences in atmospheric deposition and to a lesser extent by variations in meteorological conditions and soil chemistry;

(b) Due to the acidifying inputs of sulphur and nitrogen toxic aluminium might be released. In the current monitoring, the levels of aluminium that are considered acceptable for tree health were exceeded in approximately 10-15% of the plots.

57. Faced with the complex processes that characterize forest ecosystems, further implementation of the level II monitoring and further evaluation of the resulting data are top priorities, including calculations of critical loads of depositions. Also a priority is the continuation of the monitoring of crown soil and foliar condition on level I in order to track the development of forest condition on a large scale. Integrated evaluations of level I data need to be continued to assess the effects of air pollution and other stressors on forests on a large scale. Moreover, initial considerations within the programme show how the processes revealed at the ecosystem scale (level II) can be extrapolated to the large scale by means of level I data.

58. As ozone concentrations exceed critical levels in many cases and as its negative effects on trees have been clearly shown especially in southern Europe, the evaluation of ozone impacts should be intensified.

59. The results of 13 years of monitoring forest condition have contributed to the implementation of clean air policies by European countries under the Convention on Long-range Transboundary Air Pollution. One aim for the future is to compare and share results with similar programmes and offer research possibilities to other organizations. The broad evaluation of exchanged data will ensure the best possible appraisal and provide a wide-ranging group of policy makers with useful and needed information.

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Chapter III C:

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<u>Note</u>: References, tables and figures have been reproduced as received.

Table 1. Surveys carried out on level I and level II

Surveys conducted	Level I	Level II	
Crown condition	annually	annually	all plots
Foliar condition	once up until now	every 2 years	all plots
Soil chemistry	once up until now	every 10 years	all plots
Soil solution chemistry	-	continuously	> 10% of the plots
Tree growth	-	every 5 years	all plots
Ground vegetation	-	every 5 years	> 10% of the plots
Atmospheric deposition	-	continuously	> 10% of the plots
Meteorological condition	-	continuously	> 10% of the plots
Phenology	-	in discussion	
Remote sensing	-	in discussion	

Table 2. Percentage of observations of NO_3 concentrations and of Al/(Ca+Mg+K) ratios in the mineral topsoil and subsoil between different class limits

NO_3			Al/(Ca+Mg+K)		
concentration class ($mmol_c.m^{-3}$)	%topsoil (n=84)	%subsoil (n=89)	ratio class ($mmol_c.m^{-3}$)	%topsoil (n=83)	%subsoil (n=112)
< 100	51	56	< 0.5	67	63
100 - 800	23	26	0.5 - 1.0	22	20
> 800	26	18	> 1.0[1)]	11	17

1) For the Al/Ca ratio, the percentage of observations exceeding a critical value of 1.0 equalled 45% in the topsoil and 46% in the subsoil.

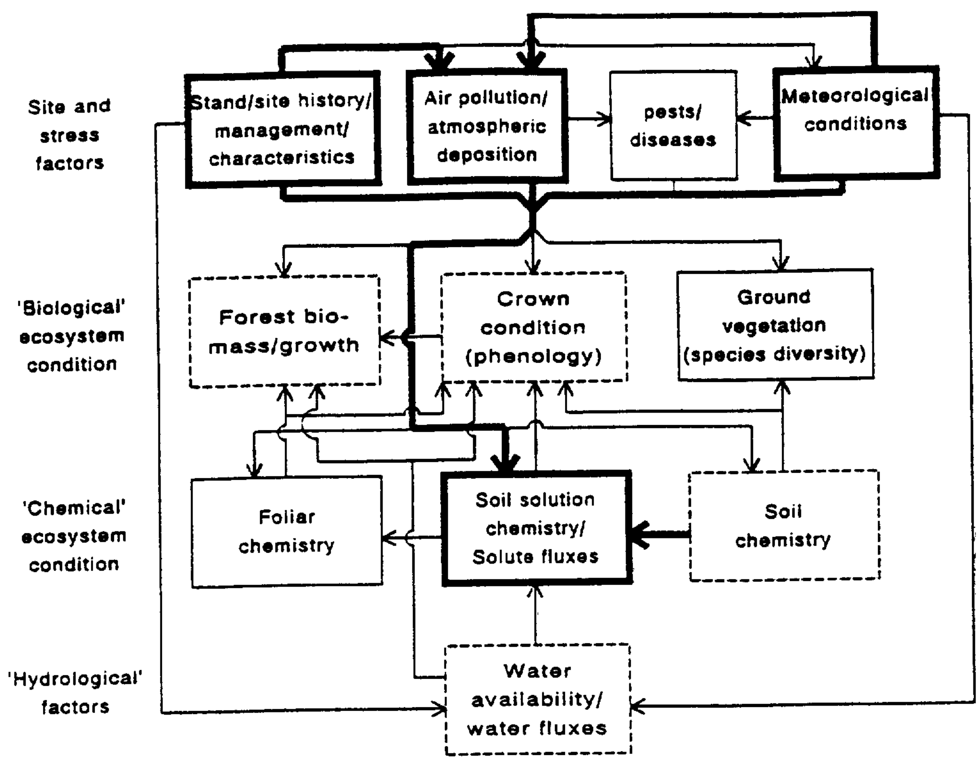

Figure 1. Flow diagram illustrating the relationships between site and stress factors and the forest ecosystems condition. Boxes and arrows in bold are specially investigated in this year's report

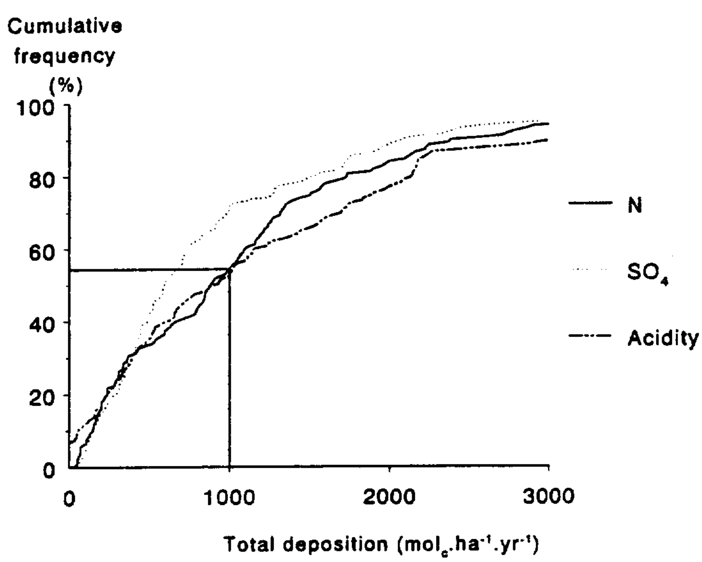

Figure 2. Cumulative frequency distributions of the total deposition of S and N acidity at 144 intensive monitoring plots

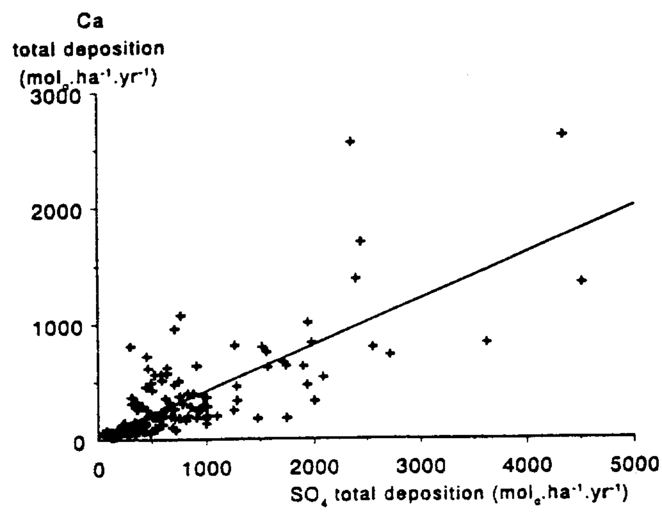

Figure 3. Relationships between the annual fluxes of Ca and SO_4 in total deposition (144 plots)

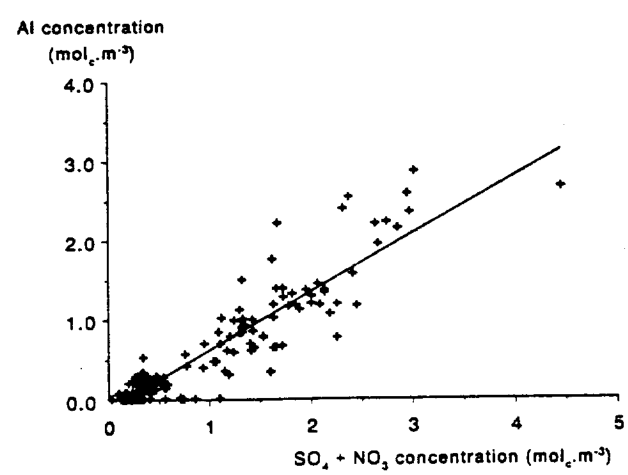

Figure 4. Relationship between the concentration of Al and the SO_4+NO^3 concentration in the subsoil (159 measurements) of intensive monitoring plots with pH < 4.5

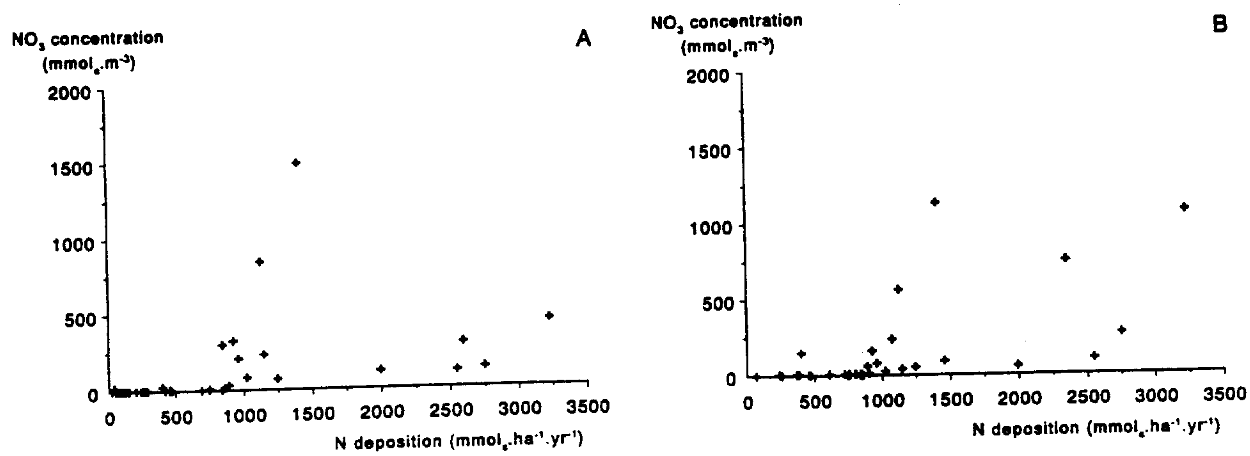

Figure 5. Relationships between the N and the NO_3 concentration in the topsoil (A) and subsoil (B) at those 50 intensive monitoring plots where soil solution and deposition measurements were available

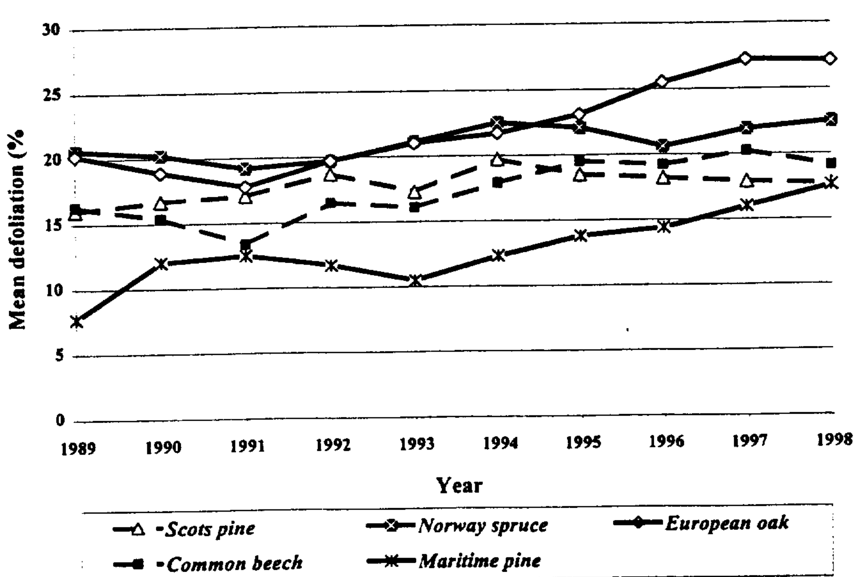

Figure 6. Development of mean defoliation for Europe's main tree species

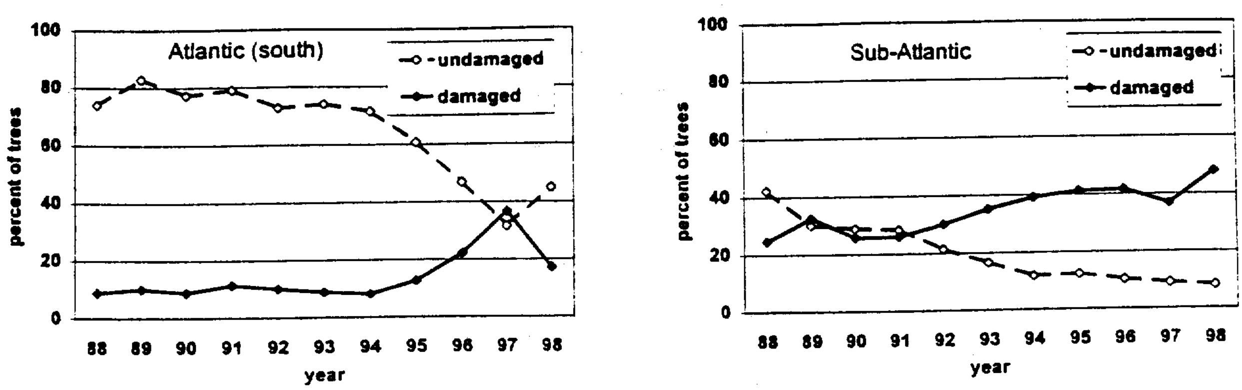

Figure 7. Development of the shares of damaged (> 25% defoliation) and undamaged (0-10% defoliation) European oak trees in different European regions

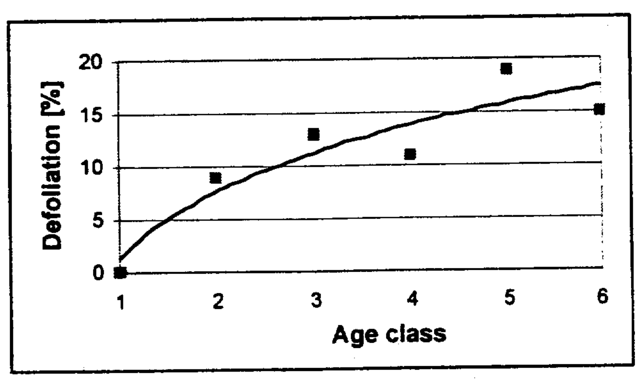

Figure 8. Age trend of *Pinus sylvestris* in pilot area I for 1997; 50th percentiles of defoliation are plotted against age class. Country effects were mathematically minimized beforehand for this particular year; each age class is 20 years

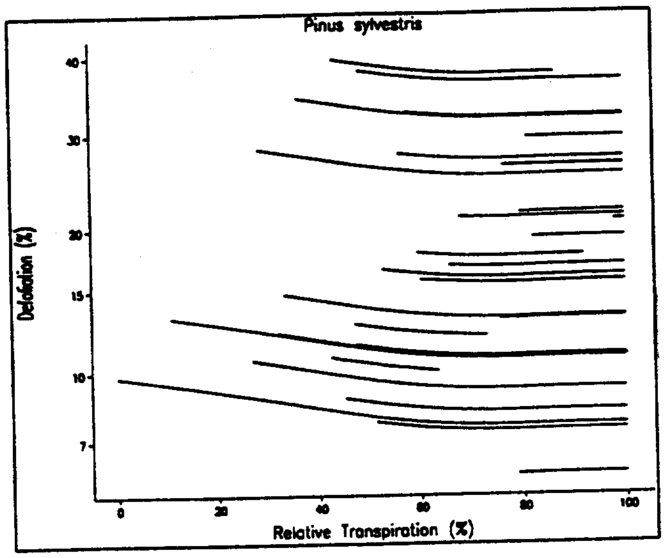

Figure 9. Relation between modelled relative transpiration (drought) and the defoliation of Scots pine (*Pinus sylvestris*); each line represents a different country

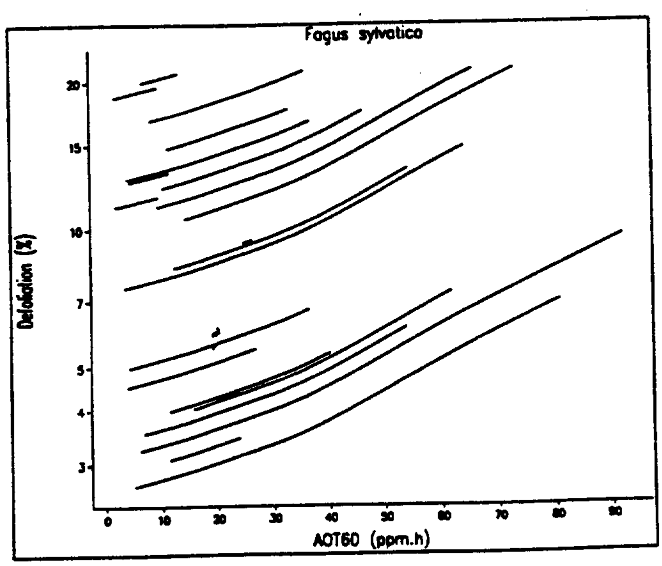

Figure 10. Relation between modelled ozone exposure and the defoliation of Common beech (*Fagus sylvatica*); each line represents a different country