UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

EB.AIR/WG.1/2002/15
19 June 2002

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

EXECUTIVE BODY FOR THE CONVENTION ON
LONG-RANGE TRANSBOUNDARY AIR POLLUTION

Working Group on Effects
(Twenty-first session, Geneva, 28-30 August 2002)
Item 6 (d) of the provisional agenda

CAUSE-EFFECT RELATIONSHIPS OF FOREST ECOSYSTEMS

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

Introduction

1. The International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) and the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP Integrated Monitoring) have fairly closely related activities, and both also have close connections to other programmes within the Working Group on Effects. ICP Integrated Monitoring monitors the biological, chemical and physical state and processes in different ecosystem compartments. ICP Forests contributes to an increased understanding of forest ecosystems with the results from the pan-European Intensive Forest Monitoring Programme (level II monitoring) on air pollution, critical loads, pollution scenario impacts, carbon storage and indicators on forest ecosystem sustainability.

GE.02-31655

2. ICP Forests uses a plot or site approach, while ICP Integrated Monitoring mainly has a catchment (ecosystems) approach. Both programmes use bioindicators and monitor abiotic and biotic variables with the aim of establishing cause-effect relationships between environmental driving forces, in particular atmospheric deposition and forest ecosystem reactions. Hence, relations in a system comprising deposition - soil - vegetation are investigated. Both ICP Forests and ICP Integrated Monitoring determine hydrological balances and hydrochemical budgets for further development and validation of models. ICP Forests focuses on soil models, while ICP Integrated Monitoring also addresses problems related to surface waters and thus links these activities with ICP Waters.

3. The level II monitoring programme of ICP Forests has a considerable spatial coverage over Europe. It is directed towards the most widespread forest ecosystems and the plots are mainly located in ordinary, actively managed forests having an ongoing wood volume increment and also being subjected to harvesting and other forestry measures. Such activities create disturbance in the forest ecosystems as the canopy is opened and fixed nutrient elements and carbon are freed or removed in the harvesting process adding to the deposition impacts. Catchments covered by ICP Integrated Monitoring are fewer and less evenly distributed over the region. Ideally, there should be no ongoing management activities on the integrated monitoring sites. Hence, the sites comprise unmanaged mature and old forest stands with long continuity, often making up nature reserves with no ongoing wood volume increment, as well as stands that have not yet reached maturity.

4. The two programmes are complementary in particular in addressing problems related to natural and semi-natural forest sites. Coordinating their activities would provide for a more complete assessment of ongoing processes in, and of the condition of, forest ecosystems, thus allowing estimates of cause-effect relationships for the most important factors. Coordinated activities of ICP Forests and ICP Integrated Monitoring and their long-term databases might also facilitate the further development and testing of models, including dynamic models, as well as the adaption of relevant models for their application on ICP Forests sites to assess large-scale impacts of forestry measures.

I. MONITORING ACTIVITIES

5. Information on the surveys carried out at ICP Forests level II and by ICP Integrated Monitoring is presented in table 1. Surveys carried out in both programmes are: crown condition, foliar condition, species composition of the ground vegetation, soil chemistry, soil solution chemistry, atmospheric deposition, meteorology, phenology and litterfall. Surveys that are carried out at the ICP Forests level II only are: ozone injury and remote sensing. Soil biology, ground- and surface-water chemistry and bird inventories are assessed only by ICP Integrated Monitoring.

6. Table 2 gives an overview of the relevant key parameters which are available in the various surveys and studies in both programmes. Only those selected key parameters that give an adequate description of (i) the ecological and chemical condition of the ecosystem and (ii) the stresses on that ecosystem (De Vries, 2000) are included. The relevance of the various parameters (some of them mandatory, others optional) directly follows from the main objectives of ICP Forests level II monitoring and ICP Integrated Monitoring. As the responsibility for selecting the sample plots and

for choosing optional parameters lies with the National Focal Centres (NFCs), the intensity of the monitoring activities and the sets of parameters assessed are subject to national priorities.

II. MONITORING RESULTS

A. Relationships between crown condition of trees and environmental factors

1. Approach to the study

7. Defoliation and discoloration are being assessed extensively on the European scale (level I), on the level II plots and on the sites of ICP Integrated Monitoring. On the European scale they were used to identify spatial patterns and the temporal development of crown condition. The parameters can be seen as an integrative indicator of stress, reflecting adaptation mechanisms to shortages, e.g. in nutrient or water supply. However, they are not specific, which restricts the interpretation of possible cause-effect relations.

8. Valuable time series of crown condition assessments, data from the soil condition survey and the analysis of element contents of leaves and needles are now available from the large-scale monitoring plots. In the first integrative studies on the effects of environmental factors (climate, chemicals) carried out with multivariate statistics, effects of ozone, sulphur and nitrogen deposition as well as climate on crown condition could be detected (Klap et al., 2000; Seidling, 2001). The investigation of (time) trends in effects, stratified according to tree species and geographic region, yields more plausible results, confirming those from other regional studies with data comparable to the extensive level I monitoring.

9. Recent correlative studies carried out within the ICP Forests level II programme are aimed at relating crown condition, foliar chemistry, soil chemistry, soil solution chemistry and species composition of the ground vegetation to environmental factors, focusing, in particular, on relating the crown condition to atmospheric deposition (De Vries et al., 1998, 1999, 2000a, 2002). The statistical relationships have been derived using available knowledge on the various influencing factors. The studies were carried out using different statistical approaches, including ordination techniques and multiple regression models.

2. Correlative crown condition study at ICP Forests level II plots

10. An example of a correlative crown condition study was carried out at approximately 262 plots where throughfall data were available. It analysed the impact of different environmental factors on the defoliation of pine, spruce, oak and beech. Results showed that 30-50% of the variation in defoliation could be explained by the variation in stand age, soil type, precipitation, N and S deposition and foliar chemistry (table 3). Highly significant adverse relations were found between defoliation and stand age for all tree species except pine. The defoliation of spruce and oak appeared to be larger in poorly buffered sandy soils compared to well-buffered clayey soils.

11. The impacts of foliar contents on defoliation were generally small. An increase in precipitation and in N deposition sometimes caused increased defoliation, and sometimes the reverse was true. This conclusion is in line with results from other correlative studies on the impact

of acid deposition (Müller-Edzards et al., 1997; Klap et al., 2000; Hendriks et al., 2000). Possible explanations for this include:

(a) A negative effect of precipitation due to excessive wetness and a positive effect by a decrease in drought stress;
(b) A negative effect of N deposition in N-saturated systems and a positive effect of an increased N availability in nutrient-poor forests.

12. The results are considered as a first step of the level II evaluation. An in-depth interpretation was still hampered by a lack of information on stand history, pests and diseases and air quality at most of the plots and by the relatively small data set used. The same holds for studies at level I plots. When more data become available, the relationship may be improved by including (see e.g. Klap et al., 2000):

(a) The temporal correlations between the repeated observations on the same site (geographical data) and the spatial correlation between neighbouring sites;
(b) The prolonged or delayed effect of certain stress factors on forest condition. This holds specifically for climatic stress factors (such as an extreme drought or frost period), but it may also hold for a severe acute event of atmospheric pollution;
(c) The occurrence of interactions between predictor variables in the regression model. For instance, it might be necessary to include interaction terms between meteorological stress variables and soil variables and bio-geographic region;
(d) The use of threshold values with respect to the stress factors, such as critical concentration levels for ozone in the atmosphere or critical values for the nutrient contents in foliage. When values of stress factors are known (based on process-oriented research on causal dose-effect relationships) their influence can be neglected below an assumed critical limit. One may, however, also try to derive a critical level from available data.

13. Evaluations of the soil chemistry, tree condition and nutritional state of the trees on level I plots in Germany indicate that, if high percentages of nutrients, especially magnesium, are bound in the organic layer, compared to the mineral soil, the forest condition is poor. This is probably due to the restriction of the rooting zone to the upper soil; under those conditions trees are more often subjected to drought and nutrient stress in dry periods, when water supply is short and the mineralization of elements from organic matter is hindered. However, conclusions are not simple to draw, and a multitude of interactions may occur, depending on the site quality, tree species, and stand and deposition history.

3. Correlative crown condition study at ICP Integrated Monitoring plots

14. ICP Integrated Monitoring has given only limited attention to the assessment of relationships between the crown condition of trees and environmental factors. De Zwart (1998) carried out an exploratory multivariate statistical gradient analysis of possible causes underlying forest damage at ICP Integrated Monitoring sites. The results suggested that coniferous defoliation, discoloration and lifespan of needles in the diverse phenomena of forest damage are explained for 18%, 42% and 55% respectively by the combined action of ozone and acidifying sulphur and nitrogen compounds in air.

15. From this and previous ordination exercises it was concluded that the applied statistical techniques are capable of revealing the underlying structure and possible cause-effect relationships in complex ecological data, provided that analysed gradients have an adequate range to be interpolated. Since the data obtained were unexpectedly poor in the span of environmental gradients, the results of the presented statistical ordination indicated only correlative cause-effect relationships with a limited validity. The poor span of gradients could be attributed to the relative scarcity of biological effect data and missing observations in both the chemical and biological data sets. It was concluded that impact assessment would be considerably improved by increased vegetation monitoring and reporting of relevant data within ICP Integrated Monitoring, as well as by inclusion of additional sites, such as those from ICP Forests.

B. Effects of environmental factors on ground vegetation

16. Relationships between species diversity of ground vegetation and environmental factors were evaluated at 366 level II plots. The results showed that 20% of the variation in the abundances of the various species occurring in the ground vegetation could be explained by the following factors: soil, climate and tree species (indirectly influencing the light regime). A small portion of the explained variance is due to throughfall deposition chemistry, but this result is based only on the spatial pattern of both vegetation and predictors. There may still be a strong effect of deposition on vegetation development in time, but such a study will become possible only when sufficient repetitive measurements are available. Results show, however, that soil acidification will negatively influence ground vegetation diversity in the forests. For various species, there is a significant relationship between occurrence probability and soil pH. The pH in the organic layer also explains most of the variation in species numbers. In this context it is planned to make full use of ICP Integrated Monitoring data (e.g. for validating predicted species composition based on relationships with environmental factors derived at level II plots).

C. Carbon sequestration in forest trees and forest soils

17. In recent years the increase of the carbon content in the atmosphere has gained more attention in forestry and environmental policies. Until recently, estimations of sequestration in soils, especially the vertical distribution, were rarely available on the European scale and were also very uncertain. The data set of ICP Forests is of particular interest as the increase of carbon content in the atmosphere can be mitigated by increased carbon sequestration in forest biomass and forest soils. First evaluations of level II data were carried out for stand biomass and for soils. Estimations of the sequestration in both tree biomass and soil showed reasonable agreement with literature estimates based on CO_2 exchange flux measurements at a few intensively monitored sites, being up-scaled to Europe. Using the data on C/N ratios and estimates of atmospheric N deposition at ICP Forests plots, the carbon sequestration in soils as compared to trees was estimated. The assumed relationship between carbon sequestration and nitrogen retention implies that low carbon sequestration is calculated in areas with low N deposition, such as the Northern countries, and high carbon sequestration in high nitrogen deposition areas, such as in Central Europe. The results of the ICP Forests study show that the ultimate contribution of the soil in sequestering carbon is likely to be small. However, on a smaller time scale, there may be a greater role for the soil in sequestering carbon due to an imbalance in carbon entering the soil by litterfall and fine root turnover, and leaving the soil by mineralization.

D. Impacts of atmospheric inputs of heavy metals on the metal concentrations in soil, soil solution and surface water

1. Ecotoxicological risks associated with elevated heavy metal concentrations

18. The ecotoxicological risks associated with elevated heavy metal concentrations in terrestrial ecosystems include:

(a) Reduced microbial biomass and/or species diversity of soil microorganisms and macrofungi, affecting microbial processes (see review by Bååth, 1989);

(b) Reduced abundance, diversity and biomass of soil fauna, especially invertebrates such as nematodes and earth worms (see review by Bengtsson and Tranvik, 1989);

(c) Reduced development and growth of roots and shoots (toxicity symptoms), decreased nutrient concentrations in foliar tissues (physiological symptoms) and decreased enzymatic activity (biochemical symptoms) of vascular plants including trees (see review by Balsberg-Påhlsson, 1989);

(d) Heavy metal accumulation followed by possible effects on essential organs of terrestrial fauna, such as birds, mammals, or cattle in agricultural soils. Those effects are important for cadmium (Cd), copper (Cu), mercury (Hg) and to a lesser extent lead (Pb), which can accumulate in the food chain (Jongbloed et al., 1994).

19. Concern about the atmospheric input of heavy metals (specifically Cd and Pb) to forest ecosystems is mainly related to the impact on soil organisms and the occurrence of bio-accumulation in the organic layer (Bringmark et al., 1998). With respect to Cu and Zn, the possible occurrence of deficiencies in view of forest growth is another relevant aspect, since they are essential metals. Another concern is related to the leaching of metals (specifically Cd and Hg) to surface water, having an adverse impact on aquatic organisms and causing bio-accumulation in fish, which then fails to meet food quality criteria. In forests, most adverse impacts are to be expected from Pb and Cd, while Hg is of primary concern in aquatic systems.

2. Metal inventories at ICP Forests level II plots

20. Up to now, studies within the context of the ICP Forests level II monitoring programme have been limited to a comparison of measured metal concentrations in forest soils to critical limits, focusing on the organic layer. Criteria used for the assessment of heavy metal concentrations in the organic layer are given in table 4. The upper values are based on a summary overview of critical metal contents in organic layers by Tyler (1992) related to the effects on soil microbiota and soil invertebrates. The lower values are derived from values reported by Andersson et al. (1991) for unpolluted sites in northernmost Sweden.

21. The measured contents of heavy metals in the organic layer varied mostly (in 90% of all cases) between 17-230 $mg.kg^{-1}$ for Pb, 0.1-2.3 $mg.kg^{-1}$ for Cd, 5-39 $mg.kg^{-1}$ for Cu and 15-284 $mg.kg^{-1}$ for Zn. A classification of the results in terms of background values and critical values (table 5) shows that Pb and Cu contents were elevated, compared to background levels, on more than 90% of the plots. For Cd and Zn, the numbers were lower: 59% and 83%, respectively.

22. The area of exceeded critical value for effects on soil organisms was negligible for Cd, but quite substantial for Cu (24%). There were also a few plots with Pb and Zn contents exceeding the critical value (table 5). For level I plots similar evaluations have been carried out, resulting in comparable results, only for copper was the critical limit used much higher (60 $mg.kg^{-1}$), resulting in only 3% of the plots exceeding the limit (Rademacher, 2001).

3. Metal budget studies at ICP Integrated Monitoring plots

23. Detailed studies of heavy metals have been carried out at ICP Integrated Monitoring sites for many years. These activities included studies, on a site-specific level, of both pools and fluxes of different heavy metals (e.g. Aastrup et al., 1995; Ukonmaanaho et al., 2001), and addressed also mercury processes (e.g. Munthe et al., 1998).

24. Information on heavy metal concentrations was provided from 29 sites, for 19 sites there are also available data on bulk deposition, for 22 sites moss chemistry, for 17 sites throughfall data, for 10 sites stem flow, soil, groundwater and runoff, for12 sites foliar and litter data, and for 22 sites soil data. So far, results for Cd, Pb, Cu, Zn and, partially, for Hg have been evaluated.

25. From 1996 to 1998 the ICP Integrated Monitoring sites reported mean annual concentrations of heavy metals in bulk deposition that were slightly lower than those for throughfall (table 6). Additional metals originate from dry deposited pollution and from inner circulation. In the soil water, the range of concentrations is higher, which implies both retention and loss. Ranges for runoff concentrations (site medians) showed much lower values, being the result of considerable retention in the soils (table 6). The large variation in metal exports from forested catchments certainly reflect differences between sites as a consequence of actual metal deposition or other factors.

26. The input/output balance for Finnish and Swedish ICP Integrated Monitoring catchments has been reported in scientific papers and national reports. There was considerable metal retention for Cd, Cu, Ni, Pb and Zn: 80 to 95% of the total input. At some sites retention is somewhat lower for Cd and Zn, but even for these more mobile metals the general picture is an ongoing accumulation in the system.

27. Soils have a large capacity for heavy metal storage due to adsorption to organic material. The present soil pools have resulted from a long deposition history. Reduced deposition and relocation between soil layers by leaching in recent years have not had a full impact yet. The contents are higher in humus layers as compared to the mineral soil layers, with the exception of Ni (table 7). Especially for Pb, a major component of long-range air pollution, there was a pronounced allocation to humus layers. The same is the case for Hg, although data are scarce. More detailed evaluations of the ICP Integrated Monitoring data sets are currently in progress.

E. Impacts of atmospheric inputs of nitrogen and sulphur on their leaching: element budgets

1. Nutrient and proton budget studies at ICP Forests level II plots

28. Input-output budget studies provide information on the possible accumulation or release of sulphur, nitrogen, base cations and aluminium in an ecosystem. More specifically, results on the input and output of those elements give insight into: (i) the actual rate of acidification due to release of base cations and aluminium; and (ii) the potential rate of acidification by immobilization of S and N. Results on the input and output of Al and base cations (BC) give information about the mechanisms buffering the acid input. The ratio of Al to BC release is believed to be a key aspect with respect to soil-mediated effects of acid inputs. These features can be used to derive critical deposition loads for forest soils (ecosystems), and the comparison of these loads with present loads will help assess air pollution stress on the chemical ecosystem condition.

29. Input-output budget studies were carried out at approximately 120 level II plots where reliable atmospheric deposition and soil solution chemistry data were available. Total deposition was calculated by adding measured throughfall and stemflow values below the forest canopy, while correcting for the effects of nitrogen uptake and base cation release by the forest canopy (leaves and needles), using data on bulk deposition in open field locations near the forest stands. Output fluxes were calculated by multiplying calculated water fluxes on a biweekly or monthly basis with measurements of element concentrations in soil solution. Details of the procedures are described in De Vries et al. (2001).

30. A comparison of median total deposition and median leaching fluxes (see table 8) shows that median leaching fluxes are comparable to the deposition for sulphate, whereas leaching is generally much lower than deposition for nitrogen indicating that N is strongly retained in the soil. This indicates that SO_4 is still the dominant source of actual soil acidification, while the acidifying effects of the higher nitrogen deposition are hindered 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 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 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, being considered as an average critical value above which impacts on roots may occur.

31. Sites with the highest S release are located in central Europe, where only recently a strong reduction in S deposition has taken place. Most probably the S compounds currently released have been partly deposited in earlier times. Sites with a net release of N are found in Belgium and north-western Germany. This corresponds to the area having received a high N deposition over a prolonged period of time. The surprisingly high N retention in south-eastern Germany may be due to the fact that budgets are mainly based on the year 1996, which may lead to unrepresentative results given the relatively low precipitation in this period.

2. Nutrient and proton budget studies at ICP Integrated Monitoring sites

32. The first results of ICP Integrated Monitoring on input-output and proton (hydrogen ion) budget calculations were presented in the Fourth Annual Synoptic Report (ICP Integrated Monitoring Programme Centre, 1995) and the updated results regarding the effects of N deposition were presented in Forsius et al. (1996). Data from selected programme sites were also included in the European study evaluating soil organic horizon C/N ratio as an indicator of nitrate leaching (Dise et al., 1998b). Starr (1999) has presented methods for the calculation of water balance components at ICP Integrated Monitoring sites. New results regarding the calculation of fluxes and trends of S and N compounds were presented in Forsius et al. (2001). Relationships exist between N deposition and N output flux, and C/N ratio of the forest floor and N output flux observed at the ICP Integrated Monitoring sites (figure 1).

33. A critical deposition threshold of about 9-10 kg $N.ha^{-1}.yr^{-1}$, indicated by several previous assessments, was confirmed by the input-output calculations with the programme data. The output flux of nitrogen was strongly correlated with key ecosystem variables like N deposition, N concentration in organic matter and current-year needles, and N flux in litterfall. The soil organic horizon C/N ratio seems to give a reasonable estimate of the annual export flux of N for European forested sites receiving throughfall deposition of N up to about 30 kg $N.ha^{-1}.yr^{-1}$ (Dise et al., 1998b; Forsius et al., 2001). The budget calculations showed a large difference between the sites regarding the relative importance of the various processes involved in the transfer of acidity, reflecting both the gradients in deposition inputs and the differences in site characteristics. The proton budget calculations showed a clear relationship between the net acidifying effect of nitrogen processes and the amount of N deposition. When the deposition increases N processes also become increasingly important as net sources of acidity.

F. Trends in deposition and surface water chemistry

34. Empirical evidence on trends in environmental effects is essential to assess the effectiveness of international emission reduction policies (Working Group on Effects, 1999). The Convention on Long-range Transboundary Air Pollution was signed in 1979, when emissions of sulphur were quite high and acidification of surface waters and damage to forests were of major concern. The ICP Integrated Monitoring sites are mainly catchments where the stream and lake water chemistry of a defined region can be monitored. Consequently, many ICP Integrated Monitoring publications/reports deal with changes in water quality, partly incorporating also the results of ICP Waters (Newell and Skjelkvåle, 1997; Stoddard et al., 1999). These results offer a chance to obtain an integrated picture of the relevant processes and spatial patterns on a large scale. Due to the long time data series available, the environmental benefits of the emission reductions achieved can be clearly documented (figure 2).

35. The first results of monthly integrated monitoring data on bulk and throughfall deposition as well as runoff water chemistry were presented in Vuorenmaa (1997). A recovery of freshwater quality is documented for many regions, corresponding to the reduced deposition of sulphur. An evaluation of the element budget data of 14 integrated monitoring sites for the period 1988-1996 revealed that, despite the continuing clear downward trend in S inputs, the response pattern in the water chemistry of the individual sites is different (Vuorenmaa et al., 2000). Especially in Central Europe, where S deposition load was the highest for a long period of time (e.g. Czech Republic), the retained amounts of S in the soil seem to regulate the sulphur dynamics with continuing high outputs of S with reduced inputs. Data from Southern

Europe, mainly Italy, from sites in the Southern Alps, confirm the overall trends (Mosello and Marchetto, 1995; Mosello et al., 1999). Extension of monitoring activities to other sites in Italy is planned (Ferretti, 2000). New calculations of the trends in N and S compounds, base cations and hydrogen ions have been made for integrated monitoring sites in Europe (Forsius et al., 2001). The site-specific trends were calculated for deposition and runoff water fluxes using monthly data and non-parametric methods. Statistically significant downward trends in SO_4 and H^+ deposition were observed at a majority of the ICP Integrated Monitoring sites.

36. Decreasing trends were more common for NH_4 than for NO_3. Sites with higher N deposition and lower C/N ratios clearly showed higher N output fluxes, and the results were consistent with previous observations from European forested ecosystems (Gundersen et al., 1998). Decreasing SO_4, NO_3, base cation and H^+ trends in output fluxes were observed at several sites in the Nordic countries and the Baltic States. The results partly confirm the effective implementation of emission reduction policy in Europe. However, clear responses were not observed at all integrated monitoring sites, showing that recovery at many sensitive sites can be slow and that the responses at individual sites may vary greatly.

37. ICP Integrated Monitoring data on water chemistry have also been used for a trend analysis carried out by ICP Waters and presented in its nine-year report (Lükewille et al., 1997) and in a recent article of Stoddard et al. (1999). These results showed that regional recovery in surface water buffering capacity was observed in all European regions studied, but in only one region (of five) in North America. The lack of recovery was attributed to strong declines in base cation concentrations exceeding the decreases in sulphate. However, S-absorbing soils in Central Europe, which had received very high amounts of S input in the past, were under-represented in the study (Alewell et al., 2000). These sites exhibit considerable lags of response to reduced S inputs or even increased sulphur output due to the dissolution of sulphur pools in the soil. This has been observed on a large scale in parts of Eastern Europe since 1990 where drastic reductions of S inputs in forests occur (Raben et al., 2000). Continued national and international research and monitoring efforts are thus needed to obtain scientific evidence of the recovery process to support future emission reduction policies.

G. Impacts of future scenarios of atmospheric deposition on the ecosystem condition, specifically the soil and surface water chemistry

1. Dynamic modelling approach

38. In a policy-oriented framework, dynamic models are needed to explore the temporal aspect of ecosystem protection and recovery. These models are flexible and can be adjusted for the assessment of alternative scenarios of policy importance. The critical load concept, used for defining environmental protection levels, does not reveal the time scales of recovery. At its seventeenth session (December 1999), the Executive Body for the Convention stressed the importance of the monitoring and dynamic modelling of recovery. A joint expert group on dynamic modelling has been established to assess, coordinate and further develop the modelling activities of

different ICPs, with due account given to relevant national activities and international research projects. On the basis of an agreed strategy the modelling activities are being developed at different spatial scales. Available data sets of ICP Forests and ICP Integrated Monitoring provide a valuable contribution to these activities, including the modelling of the possible effects of emission reductions on forest ecosystems.

2. Modelling studies at ICP Integrated Monitoring sites

39. Dynamic models have been developed and used for the emission/deposition scenario assessment at selected ICP Integrated Monitoring sites (e.g. Forsius et al., 1997, 1998a, 1998b; Posch et al., 1997; Jenkins, 2001). A study carried out with data sets from five sites, at Forellenbach, Gårdsjön, Birkenes, Afron Hafren and Hietajärvi , and calibrated with measured data from 1990-1994, indicated expected recovery of soils and waters from acid load (Forsius et al., 1998a). However, the authors pointed out that there were uncertainties regarding the implementation in the models of the nitrogen dynamics and the effects of possible N saturation (MAGIC, SAFE, SMART models), due to the gaps in knowledge still existing on this topic. Further uncertainties arise from the unknown relations between possible climatic change, in combination with a surplus of nitrogen on acidified soils.

40. The modelling studies carried out at ICP Integrated Monitoring sites have shown that the recovery of soil and water quality of the ecosystems is determined by both the significance and also the time of implementation of emission reductions (e.g. figure 3).

41. According to the models, the timing of emission reductions determines the state of recovery over a short time scale (up to 30 years). The quicker the target level of reductions is achieved, the more rapidly the surface water and soil status recover. For the long-term response (> 30 years), the scale of the emission reductions is more important than their timing. The model simulations also indicate that N emission controls are very important to enable the maximum recovery in response to S emission reductions. Increased nitrogen leaching has the potential to not only offset the recovery predicted in response to S emission reductions but also to cause substantial deterioration in pH status of freshwaters and worsen other N pollution problems in some areas of Europe.

42. The reduction in deposition of S and N compounds at the ICP Integrated Monitoring sites, needed for the implementation of the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, was estimated for the year 2010 using transfer matrices and official emissions data. Implementation of the new Protocol will further decrease the deposition of S and N at the assessed sites in parts of Western and North-western Europe, but in more Eastern parts the decreases will be smaller (Forsius et al., 2001). This has implications for the future response patterns at these sites.

3. Plans for the future

43. Further development of the dynamic models is still needed. As far as abiotic processes are concerned, the modelling of acidification is mostly successful. The additional implementation of non-linear biological processes with unknown interactions is in principle not yet solved. However, for risk assessment on a large scale simple empirical models may be sufficient to predict system

behaviour, within certain limits (Armbruster and Matzner, 2001). Modelling the upper soil layers and the uptake of water and nutrients requires the knowledge of rooting depths. In this respect, there are considerable gaps in information on the quantities and distribution of the rooting zone. However, there are also still uncertainties connected to the modelling of water flows, which can be studied in detail on intensive research plots like sites of ICP Integrated Monitoring (e.g. Hauhs et al., 1998).

44. Dynamic modelling for ICP Forests level II plots is planned for 2003. Ultimately, modelling will not be limited to soil and soil solution chemistry, but will also include the prediction of changes in forest growth and species composition of the ground vegetation in response to both atmospheric deposition and climate scenarios. Such models will include empirical relationships, to account for the multiple effects of stressors on forest ecosystems. An example is the study of the impact on ground vegetation in which an evaluation of data from ICP Forest plots with multivariate statistical methods would be used. In this way empirical response relations based on thousands of observations allow the transfer of information from in-depth studies to the larger scale (regionalization).

III. OUTLOOK

45. Both ICP Forests and ICP Integrated Monitoring, by successfully fulfilling their mandates, substantially contribute to the effect-oriented activities under the Working Group on Effects. Obviously, ICP Forests has sites with a larger spatial coverage than ICP Integrated Monitoring. It should be noted, however, that due to the different objectives of both programmes, the same spatial distributions of sites is not needed. ICP Integrated Monitoring also covers important gradients, mainly across Europe and its plots with varying conditions provide, inter alia, inputs for modified models. On the contrary, ICP Forests provides possibilities for calculations reflecting natural conditions on a wider scale. Further, ICP Forests includes managed forest while ICP Integrated Monitoring mainly focuses on natural unmanaged forest and related land. These differences also provide possibilities for evaluating the effects of silviculture.

46. Both programmes share the same limitation: the sites and/or catchments are often more typical of forest stands on drained soils. The selected sites do not cover the total range of soil types on natural and semi-natural landscapes. Often poorly drained and wet soils are avoided. These soils types, however, cover substantial areas and are crucial in catchments concerning water and nutrient turnover. One such type is peatland and other wetlands covering extensive areas, especially in Northern Europe, and with considerable influence on ecosystems on the landscape scale. In a catchment approach these sites obviously have to be included to some extent.

47. Indicator species adapted to key habitats on moist or wet soils in several cases give earlier signs of pollution impacts than more common and trivial vegetation species. In addition, poorly drained and wet soils could have great relevance for the monitoring of climate change effects.

48. Both programmes also will have to devote more attention to assessing the impact of gaseous components such as ozone, and to full-scale consideration of biotic stresses. ICP Forests is already developing its activities in these areas.

49. Continuing close cooperation would be beneficial to both programmes. Harmonizing monitoring methods should be further pursued, and the results regularly compared. Substantial attention should be devoted to the development of models for their future large-scale application on the programmes' sites. This, together with coordinated cooperation with other programmes and external monitoring networks, could provide new insight and understanding of possible ways and means for maintaining sustainable development and achieving further substantial recovery from air pollution impacts. Close cooperation in developing and applying suitable evaluation/interpretation/presentation strategies would be also beneficial for both programmes.

References

Aastrup, M., Iverfeldt, ÅÅ., Bringmark, L., Kvarnäs, H., Thunholm, B., Hultberg, H. ,1995. Monitoring of heavy metals in protected forest catchments. Water Air and Soil Pollution 85: 755-760.

Alewell, C., Manderscheid, B., Meesenburg, H. and Bittersohl, J. 2000., I*s acidification still an ecological threat*? Nature 407: 856-857.

Armbruster, M. and Matzner, E. 2001. Indikatoren des Stoffhaushalts von Waldökosystemen. Bayreuther Forum Ökologie 84: 189 - 204.

Andersson, A., Å. Nilsson and L. Håkanson, 1991. Metal concentrations of the morlayer as influenced by deposition and soil parent material. Swedish Environmental Protection Agency Report 3990.

Bååth, E. ,1989. Effects of heavy metals in soil on microbial processes and populations. A literature review. *Water Air and Soil Pollution* 47: 335-379.

Balsberg-Påhlsson, A.M., 1989. Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants. A literature review. *Water Air and Soil Pollution* 47: 287-319.

Bengtsson, G. & Tranvik, L., 1989. Critical metal concentrations for forest soil invertebrates. A review of the limitations. *Water Air and Soil Pollution* 47: 381-417.

Bringmark, L., Bringmark, E. & Samuelsson, B., 1998. Effects on mor layer respiration by small experimental additions of mercury and lead. *The Science of the Total Environment* 213: 115-119.

De Vries, W., Reinds, G.J., Deelstra, H.D., Klap, J. M. and Vel, E.M., 1998. *Intensive Monitoring of Forest Ecosystems in Europe.* Technical Report 1998. UNECE, EC, Forest Intensive Monitoring Coordinating Institute, 193 pp.

De Vries, W., Reinds, G.J., Deelstra, H.D., Klap, J. M. and Vel, E.M., 1999. *Intensive Monitoring of Forest Ecosystems in Europe.* Technical report 1999. UNECE, EC, Forest Intensive Monitoring Coordinating Institute, 173 pp.

De Vries, W., Reinds, G.J., Kerkvoorde, M., Hendriks, C.M.A., Leeters, E.E.J.M., Gros, C.P., Voogd, J.C.H. and Vel, E.M., 2000a. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report 2000. UNECE, EC, Forest Intensive Monitoring Coordinating Institute, 188 pp.

De Vries, W., 2000. Intensive Monitoring of Forest Ecosystems in Europe. *Evaluation of the programme in view of its objectives, studies to reach the objectives and priorities for the scientific evaluation of the data.* Heerenveen, the Netherlands, Forest Intensive Monitoring Coordinating Institute, A strategy document, 40 pp.

De Vries, W., G.J. Reinds, C. van der Salm, G.P.J. Draaijers, A. Bleeker, J.W. Erisman, J. Auee, P. Gundersen, H.L Kristensen, H. van Dobben, D. de Zwart, J. Derome, J.C.H. Voogd and E.M. Vel. *Intensive Monitoring of Forest Ecosystems in Europe*. Technical Report 2001. UNECE and EC, Geneva and Brussels, Forest Intensive Monitoring Coordinating Institute, 177 pp.

De Vries, W., G.J. Reinds, H. van Dobben, D. de Zwart, D. Aamlid, P Neville, M. Posch, J. Auee, J.C.H. Voogd and E.M. Vel. *Intensive Monitoring of Forest Ecosystems in Europe*. Technical Report 2002. UNECE and EC, Geneva and Brussels, Forest Intensive Monitoring Coordinating Institute, 177 pp.

De Zwart, D. 1998. *Multivariate gradient analysis applied to relate chemical and biological observations* In: Kleemola S., Forsius M. (eds), 7th Annual Report 1998. UNECE ICP Integrated Monitoring. The Finnish Environment 217: 15-29. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-0301-9.

Dise, N.B, Matzner, E. and Forsius M. 1998b. Evaluation of organic horizon C:N ratio as an indicator of nitrate leaching in conifer forests accross Europe. *Environmental Pollution* 102: 453-456.

Ferretti, M. (Ed.) 2000., *Integrated and Combined (I & C) Evaluation of Intensive Monitoring of Forest Ecosystems in Italy – Concepts, Methods and first results.* Annali Istituto Sperimentale per la Selvicoltura, Spec. Issue, Arezzo Anno 1999, Vol. 30.

Forsius, M., Kleemola, S. and Vuorenmaa, J., 1996. *Assessment of nitrogen processes at ICP IM sites.* In: Kleemola S., Forsius M. (eds), 5th Annual Report 1996. UNECE ICP Integrated Monitoring. The Finnish Environment 27: 25-38. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-0045-1.

Forsius, M., Alveteg, M., Bak, J., Guardans, R., Holmberg, M., Jenkins, A., Johansson, M., Kleemola, S., Rankinen, K., Renshaw, M., Sverdrup, H. and Syri, S., 1997. *Assessment of the Effects of the EU Acidification Strategy: Dynamic modelling on Integrated Monitoring sites.* Finnish Environment Institute, Helsinki. ISBN 952-11-0979-3. 40 pp.

Forsius, M., Alveteg, M., Jenkins, A., Johansson, M., Kleemola, S., Lükewille, A., Posch, M., Sverdrup, H. and Walse, C., 1998a. MAGIC, SAFE and SMART model applications at Integrated Monitoring Sites: Effects of emission reduction scenarios. *Water, Air and Soil Pollution* 105: 21-30.

Forsius, M., Guardans, R., Jenkins, A., Lundin, L. and Nielsen, K.E. (eds), 1998b. *Integrated Monitoring: Environmental assessment through model and empirical analysis - Final results from an EU/LIFE-project.* The Finnish Environment 218. Finnish Environment Institute, Helsinki. ISBN 952-11-0302-7. 172 pp.

Forsius, M., Kleemola, S., Vuorenmaa, J., and Syri, S. 2001. Fluxes and trends of nitrogen and sulpur compounds at Integrated Monitoring Sites in Europe. *Water Air and Soil Pollution* 130: 1641-1648.

Gundersen, P., Callesen, I. and de Vries, W., 1998. Nitrate leaching in forest ecosystems is controlled by forest floor C/N ratio. Environmental Pollution 102: 403-407.

Hauhs, M., Lange, H., Callenberg, R., Hoch, R., Moldan, F., Rodhe, A., Seibert, J. and Bishop, K. 1998. *Modelling the Hydrology of the Covered Catchment. Experimental Reversal of Acid Rain Effects - The Gårdsjön Roof Project*, p. 383-395.

Hendriks, C.M.A., Olsthoorn, A.F.M., Klap, J.M., Goedhart, P.W, Oude Voshaar, J.H., Bleeker, A., de Vries, F., van der Salm, C., Voogd, J.C.H., de Vries, W. and Wijdeven, S.M.J., 2000. *Relationships between crown condition and its determining factors in the Netherlands for the period 1984-1994.* Wageningen, the Netherlands, Alterra Green World research, Report 161, 69 pp.

ICP IM Programme Centre, 1995. *Assessment of nitrogen processes on ICP IM sites*. In: 4th Annual Synoptic Report 1995, UNECE ICP Integrated Monitoring. Finnish Environment Agency, Helsinki, Finland, pp. 19-61.

Jenkins, A., 2001. *Progress report on dynamic modelling of surface water and soil*. In: Kleemola S., Forsius M. (eds), 10th Annual Report 2001. UNECE ICP Integrated Monitoring. The Finnish Environment 498:40-42. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-0931-9.

Jongbloed, R.H., Peijnenburg, J., Mensink, B.J.W.G., Traas, Th.P. & R. Luttik, R., 1994. *A model for environmental risk assessment and standard setting based on biomagnification. Top predators in terrestrial ecosystems*. Report 719101012, National Institute of Public Health and the Environment (RIVM), Bilthoven, Netherlands, 85 pp.

Klap, J.M., Oude Voshaar, J., De Vries, W. and Erisman, J.W., 2000. *Effects of environmental stress and crown condition in Europe. IV Statistical analyses of relationships.* Water, Air and Soil Pollution, 119: 387-420.

Lükewille, A., Jeffries, D., Johannessen, M., Raddum, G., Stoddard, J. and Traaen, T., 1997. *The nine year report: Acidification of surface water in Europe and North America. Long-term developments (1980s and 1990s).* Convention on Long-Range Transboundary Air Pollution, International cooperative programme on assessment and monitoring of acidification of rivers and lakes. Programme Centre NIVA Oslo. Norwegian Institute for Water Research, Oslo, Norway. NIVA Report 3637-97.

Mosello, R. and Marchetto, A., 1995. Chemistry *of atmospheric wet deposition in Italy: results from a five-year study.* Ambio 25: 21-25.

Mosello, R., Marchetto, A., Boggero, A., Brizzio, M.C., Tartari, G.A. and Rogora, M., 1999. *Pluriannual evolution of the hydrochemistry of two Alpine Lakes (Lake Paione Inferiore and Lake Paione Superiore, Ossola Valey) in relation to atmospheric loads*. J. Limnol. 58: 42-48.

Müller Edzards, C., De Vries, W. and Erisman, J.W. (Eds.), 1997. *Ten Years of Monitoring Forest Condition in Europe - Studies on Temporal Development, Spatial Distribution and Impacts of Natural and Anthropogenic Stress Factors.* Technical Background Report. EC-UNECE 1997. Geneva, Brussels, 386 pp.

Newell, A.D. and B.L. Skjelkvåle. 1997. *Acidification trends in surface waters in the international program on acidification of rivers and lakes.* Water, Air and Soil Pollut. 93: 27-57.

Posch, M., Johansson, M. and Forsius, M., 1997. *Critical loads and dynamic models*. In: Kleemola, S., Forsius M. (eds.), 6th Annual Report 1997. UNECE ICP Integrated Monitoring. The Finnish Environment 116:13-23. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-0587-9.

Raben, G., Andreae, H. and Meyer-Heisig, M., 2000. *Long-term Acid Load and Its Consequences in Forest Ecosystems of Saxony (Germany)*. Water, Air and Soil Poll. 122: 93-103.

Rademacher P. 2001. *Atmospheric Heavy Metals and Forest Ecosystems*. UNECE. Geneva.

Seidling, W. 2001. *Integrative Studies on Forest Ecosystem Conditions.* Multivariate Evaluations on Tree Crown Condition for two Areas with distinct Deposition Gradients. UNECE & European Commission & Flemish Community. Geneva, Brussels, Ghent.

Starr, M., 1999. *WATBAL: A model for estimating monthly water balance components, including soil water fluxes.* In: Kleemola S., Forsius M. (eds), 8th Annual Report 1999. UNECE ICP Integrated Monitoring. The Finnish Environment 325: 31-35. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-0521-6.

Stoddard, J.L., Jeffries, D.S., Lükewille, A., Clair, T.A., Dillon, P.J., Driscoll C.T., Forsius, M., Johannessen, M., Kahl, J.S., Kellogg, J.H., Kemp, A., Mannio, J., Monteith, D.T., Murdoch, P.S., Patrick, S. Rebsdorf, A., Skjelkvåle, B.L, Stainton, M.P., Traaen, T., van Dam, H., Webster, K.E., Wieting, J. and Wilander, A., 1999. Regional trends in aquatic recovery from acidification in North America and Europe. *Nature* 401: 575- 578.

Tyler, G., 1992. *Critical concentrations of heavy metals in the mor horizon of Swedish forests.* Swedish Environmental Protection Agency. Report 4078.

Ukonmaanaho L., Starr, M., Mannio, J., and Ruoho-Airola, T., 2001. *Heavy metal budgets for two headwater forested catchments in background areas of Finland*. Environmental Pollution 114: 63-75

Vuorenmaa, J., Kleemola, S. and Forsius, M. 2000., *Trend assessement of deposition, runoff water fluxes and water chemistry at European ICP Integrated Monitoring sites*. Verh. Internat. Verein. Limnol. 27: 384-390.

Vuorenmaa, J., 1997. *Trend assessment of bulk and throughfall deposition and runoff water chemistry at ICP IM sites*. In: Kleemola S., Forsius M. (eds), 6th Annual Report 1997. UNECE ICP Integrated Monitoring. The Finnish Environment 116:24-42. Finnish Environment Institute, Helsinki, Finland. ISBN 952-11-0587-9.

Working Group on Effects, 1999. *Trends in impacts of long-range transboundary air pollution.* Compiled by the International Cooperative programmes of the UNECE Working Group on Effects. Centre for Ecology and Hydrology, United Kingdom. ISBN 1 870 393 52X. 81 p.

Note: These references are reproduced in the form in which they were received by the secretariat.

Table 1. Surveys carried out at ICP Forests (level II) and ICP Integrated Monitoring forest plots and all plots (F/All)

Surveys conducted	ICP Forests Level II			ICP Integrated Monitoring		
	Periodicy	Intensity	Plots	Periodicy	Intensity	F/All
Atmospheric deposition: (bulk deposition, throughfall, stemflow)	Weekly – monthly	Part of the plots	496	Weekly – monthly	Part of the sites (bulk deposition all sites)	43/51
Ambient air quality	Daily-weekly	Part of the plots	79	Daily-weekly	Part of the sites	36/42
Ozone injury	Yearly	Part of the plots	79			
Meteorological condition	Daily	Part of the plots	201	Daily	Part of the sites	35/42
Crown condition	Yearly	All plots	862	Yearly	Part of the sites	31
Foliar chemistry	Every 2 years	All plots	855	Yearly	Part of the sites	32
Litterfall (chemistry)[1]	Yearly	Part of the plots	350	Yearly	Part of the sites	15
Tree growth	Every 5 years	All plots	858	-	-	
Inventory of plants/ Ground vegetation	Every 1 - 5 years	Part of the plots	634	Every 1- 5 years[2]	Part of the sites	25
Metal chemistry of mosses	-	-		Every 5 years	Part of the sites	22
Soil chemistry	Every 10 years	All plots	862	Every 5 years	All sites	36/38
Soil water chemistry	Weekly – monthly	Part of the plots	250	Weekly-monthly	Part of the sites	41/51
Groundwater and lake water chemistry	-	-		2-6 monthly	Part of the sites	18/20
Runoff water chemistry	-	-		Daily-monthly	Part of the sites	27/32
Inventory of birds	-	-		Every 3 - 5 years	Part of the sites	6
Phenology	Yearly	Part of the plots	44	-	-	
Microbial decomposition	-	-		Yearly	Part of the sites	15
Hydrobiology of streams and lakes	-	-		6 monthly	Part of the sites	6
Remote sensing	5 or 10 yearly	Part of the plots	385	-	-	

[1] At some plots only litterfall excluding the chemical composition of falling leaves and needles.
[2] Includes a separate survey on trunk epiphytes and aerial green algae.

Table 2. Key parameters describing the 'ecological and chemical' conditions of forests and aquatic systems and the environmental stress on those systems assessed at ICP Forests and ICP Integrated Monitoring plots

Type of parameter		Key parameters ICP Forests level II	Key parameters ICP Integrated Monitoring
Site factors	Stand characteristics Site characteristics	Tree species, tree age, climatic region, altitude, soil type	Plot scale information on vegetation type, dominant tree species and soil type; Catchment/site scale information on altitude, vegetation type, soil type
Stress factors	Biotic stress	Easily assessable damage types	Easily assessable damage types on trees
	Air pollution	SO_4, NO_3, NH_4, Ca, Mg, K, pH in bulk deposition and throughfall (sometimes stemflow)	SO_4, NO_3, NH_4, Ca, Mg, K, pH in bulk deposition and throughfall (sometimes stemflow)
	Ambient air quality	Passive sampling of O_3, SO_2, NO_2, NO_3+HNO_3, NH_3 +NH_4	Measurement of gases and aerosols: O_3, SO_2, NO_2, NO_3+HNO_3, NH_3 +NH_4
	Meteorology	Precipitation, temperature, wind speed and direction, global radiation, air humidity	Precipitation, temperature, wind speed and direction, global radiation, air humidity
Biological condition	Crown condition	Defoliation, discoloration	Defoliation, discoloration
	Increment	Diameter at breast height, tree height	
	Ground vegetation	Species composition and coverage	Species composition, coverage of species on permanent vegetation plots
	Soil biology		Weight loss due to decomposition, phosphatase activity of soil[1)], soil respiration[1)], N-mineralization[1)]
	Ozone injury	Damage of foliage due to excessive ozone exposure	
Chemical condition	Foliar composition		
	- major nutrients	N, P, S, Ca, Mg, K, N/P, N/Mg, N/K	N, P, S, Ca, Mg, K, C
	- minor nutrients	Fe, Mn, Cu, Zn	Fe, Mn, Cu, Zn
	- toxic elements	Al, Pb, Cd	Al, Pb, Cd
	Soil composition		
	- carbon	C	C
	- nutrients	N, P, Ca, Mg, K, C/N, N/P	N, P, exchangeable Ca, Mg, K
	- acidity	pH, base saturation[2)]	pH, base saturation
	- toxic elements	Pb, Cd, Cu, Zn	Pb, Cd, Cu, Zn
	Soil solution chemistry	SO_4, NO_3, NH_4, Ca, Mg, K, Al, Fe, Mn, pH, DOC	SO_4, NO_3, NH_4, Ca, Mg, K, Al, Fe, Mn, pH, DOC
	Surface water chemistry		SO_4, NO_3, NH_4, Ca, Mg, K, Al, Fe, Mn, pH, DOC

1) This parameter can be calculated from the mandatory meteorological parameters.
2) These parameters are rarely available or not at all.

Table 3. Overview of the predictor variables explaining defoliation of the four most represented tree species of the level II plots with the number of plots (n) and the percentage accounted for ($R^2_{adj.}$)

Variable	Scots pine	Norway spruce	Pedunculate oak	Common beech
Soil type		*		
Age (yr)	+	++	+	++
Precipitation ($mm.yr^{-1}$)	+	--		
Temperature (^0C)			-	--
N deposition ($mol_c.ha^{-1}.yr^{-1}$)		-	++	+
S deposition ($mol_c.ha^{-1}.yr^{-1}$)		++		
Foliar N content ($g.kg^{-1}$)	+			
Foliar Ca content ($g.kg^{-1}$)		--	++	
N	59	95	33	35
$R^2_{adj.}$	21	35	44	48

* for soil type implies that this variable was significantly related to defoliation.
++ highly significant and positively correlated with response variable.
+ significant and positively correlated with response variable.
-- highly significant and negatively correlated with response variable.
- significant and negatively correlated with response variable.

Table 4. Criteria used for the judgement of heavy metal concentrations in the organic layer

Class/criteria	Heavy metal concentration ($mg\ kg^{-1}$)			
	Pb	Cd	Cu	Zn
Low (background)	<15	<0.35	<5	<35
Elevated	15-150	0.35-3.5	5-20	35-300
High (above a toxicity level)	>150	>3.5	>20	>300

Source: Tyler, 1992 and Andersson et al., 1991

Table 5. Distribution (% of observations) over the classes ‘low’, ‘elevated and ‘high’ of the heavy metal contents in the organic layer of stands within the ICP Forests level II monitoring programme

Class /criteria[1)]	Distribution (% of observations)			
	Pb (N=91)	Cd (N=69)	Cu (N=89)	Zn (N=86)
Low (background)	4.4	37.7	3.4	17.4
Elevated	83.5	59.4	69.7	77.9
High (above a toxicity level)	8.8	0.0	23.6	4.7

Table 6. Heavy metal concentrations (mg/l) in bulk deposition, throughfall, soil water and stream water of the catchment ecosystems in 10-19 sites over Europe

Compartment	Cd	Cu	Pb	Zn	Ni
Bulk deposition	0.01-0.8	0.8-4.4	0.5-9.5	1-50	-
Throughfall	0.07-0.7	0.9-7	2-10	6-68	0.6-8
Soil water	0.07-1.3	0.24-5.4	0.26-27	11-138	6-12
Stream water	0.015-0.36	0.13-1.4	0.05-2	0.4-14	0.13-5

Table 7. Heavy metal contents (µg/g) in the humus layer and in the mineral soil in the 30-40 cm layer of ICP Integrated Monitoring sites

	Cd	Cu	Ni	Pb	Zn
Humus layer	0.3-1	5-23	0.6-8	13-160	23-100
Mineral soil	0.01-1	0.7-21	2-24	4-46	3-85

Table 8. Median total atmospheric deposition input, element leaching fluxes and budgets of sulphate, nitrogen and total base cations (Ca+Mg+K) as well as aluminium leaching (in $mol_c.ha^{-1}.yr^{-1}$)

Tree species	Number of sites	SO_4			N			BC			Al
		deposition	leaching	budget	deposition	leaching	budget	deposition	leaching	budget	leaching
Pine	29	517	197	216	714	7	703	491	156	253	138
Spruce	51	685	590	16	1198	112	1040	469	331	94	774
Oak	15	637	1025	-256	962	212	686	519	2184	-911	30
Beech	20	634	604	-22	1340	135	984	489	717	30	326
Other	6	509	590	28	826	54	772	751	1149	-862	31
All	121	592	509	21	995	60	871	482	377	86	294

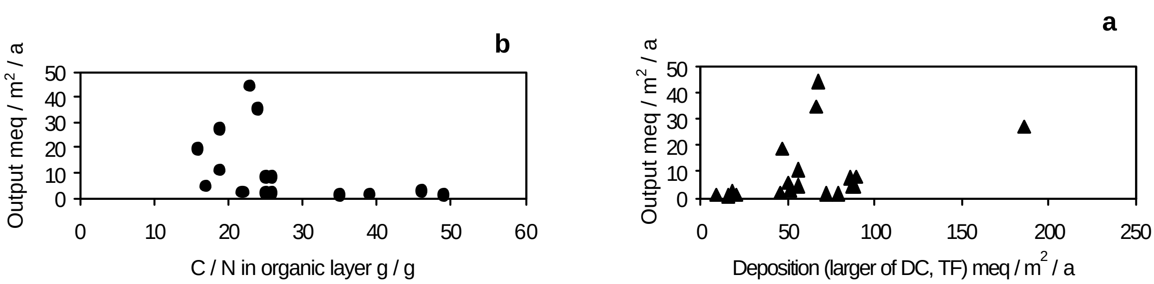

Figure 1. Relationship between N deposition and N output flux (a), and C/N ratio of the forest floor and N output flux (b) at the ICP Integrated Monitoring sites (Forsius et al., 2001)

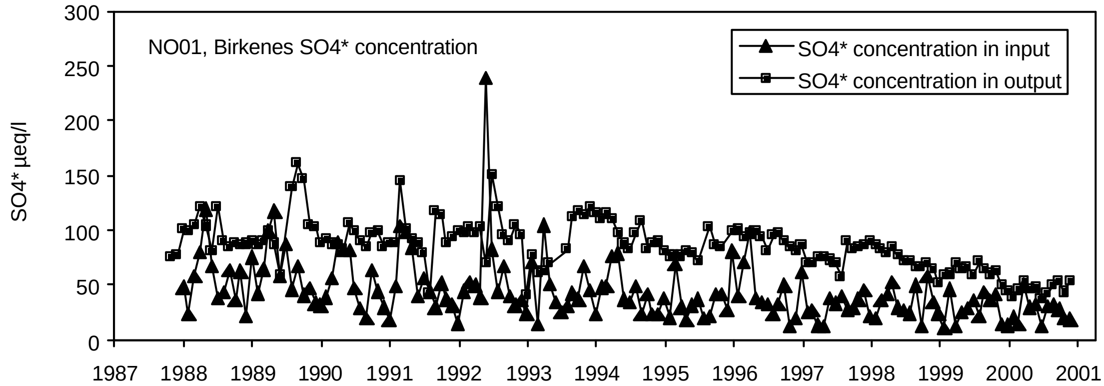

Figure 2. Changes in sulphate concentrations in deposition and stream water in 1988-2000 at the ICP Integrated Monitoring site Birkenes, southern Norway

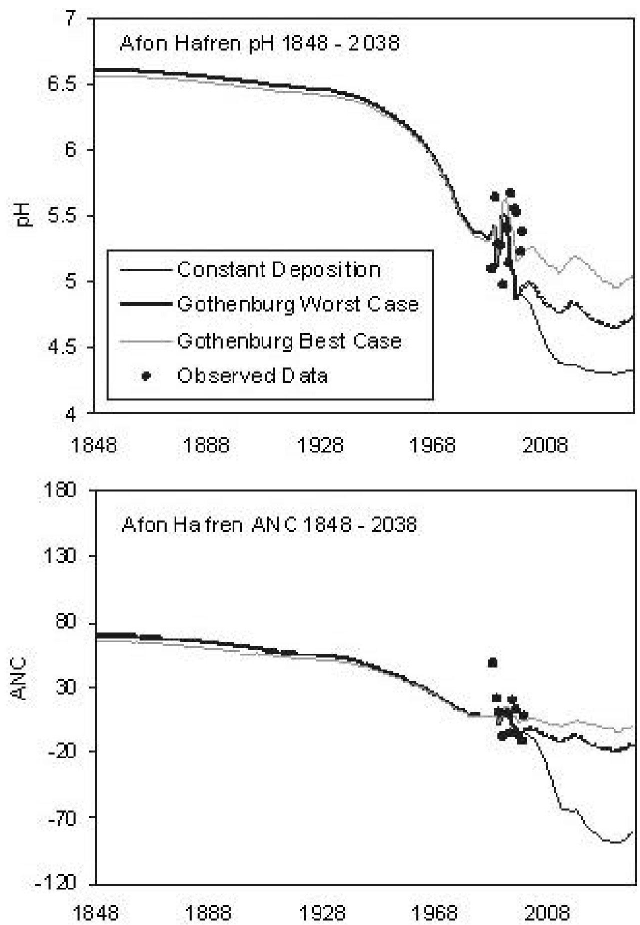

Figure 3. Simulated stream water pH and acid neutralizing capacity (ANC) (µeq/l) calculated with the MAGIC model at ICP Integrated Monitoring site Afon Hafren (GB02) with constant deposition and reductions proposed under the 1999 Gothenburg Protocol (Jenkins 2001)