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Impacts and problems related to acid deposition in Europe

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1 Acid deposition in Europe

The first international network with measurements of precipitation qualities in Europe started in Sweden in the early 1950s. It was discovered that the precipitation gradually became more acidic in southern Sweden, and Oden (1968) concluded that the most important source to the acidification was the combustion of coal, coke and oil.

During the first half of the 1970s the OECD project on long range transport of air pollutants were run, concluding that sulphur compounds could be transported over several hundred kilometres or more in the atmosphere (OECD, 1977). Effect studies also became operative at that time; the Norwegian research programme on Acid Precipitation – Effects on Forest and Fish presented their conclusions in 1980, based on studies over nine years and three hundred research reports (Overrein et al., 1980). The most far-reaching studies related to air pollution and its effects in Europe the past twenty years, have been carried out within the framework of the Economic Commission for Europe (ECE). Figure 1 gives an overview of the International Co-operative Programmes on Effects within the ECE framework.

Recognising the adverse effects of acid rain and air pollutants, large efforts have been made in Europe to reduce, or control, the emissions to air of sulphur dioxide, nitrogen oxides, volatile organic compounds, and more recently, of metals and persistent organic compounds. As a result of this work the emissions of the main acidifying compound, sulphur dioxide, has been reduced 55 per cent in Europe since 1980. The emissions of nitrogen oxides, also contributing to acidification of the ecosystems, remain very much the same today as in 1980 (Mylona et al., 1999). Figures 2 and 3 give the emissions of sulphur dioxide from some of the large emitting countries, and for Europe as a total for sulphur dioxide, nitrogen oxides and ammonia.

Science the first years gave impulse to agreements for emissions reductions, as expressed in the Protocols to Convention on Long-Range Transboundary Air Pollution, later years much efforts have been spent at providing the link between environment damage and emission reductions. Important in this context is the critical load concept; a quantitative estimate of an exposure to one or more pollutants, below which significant harmful effects on sensitive elements of the environment do not occur according to present knowledge (Figure 4).

2 Effects on water chemistry and aquatic life

During the 1960s when it was observed that precipitation gradually became more acidic in southern Scandinavia, a large decline in the trout population started in the region. When bedrock and land surrounding a lake contain sufficient bicarbonates to neutralise the acid input there is no notable changes in the lake biology. However, at low contents of bicarbonate and large amounts of acid precipitation, or during snow melting in the watershed, biological damage and even mass death among fish species may occur in rivers and lakes. This was the situation in the southern parts of Norway during the 1960s and 1970s. The sensitivity with respect to acidic water is, however, variable for different fish species and fish populations. Figure 5 shows the Storgama Lake in southern Norway.

In the absence of neutralising substances, and besides the direct acidifying effect, there will also be an increased solubility and washout of metals from soil, and elevated concentrations of metals in surface water. The most toxic metals are aluminium, cadmium, iron, manganese and mercury. High acidity in combination with aluminium lead to gill lesions and mortality. The hatching frequency of eggs can be decreased, as seen e.g. for Atlantic salmon and brown trout (Herrmann et al., 1993).

Acid precipitation usually contains high concentrations of sulphates, nitrates and ammonium, and these components are also deposited as dry deposition of particles and gases. Nitrogen compounds are nutrients for vegetation, which will be beneficial when there is a nitrogen deficit in soil. Too large depositions, however, lead to changes in soil and vegetation and to elevated concentrations of nitrate in lake surface water. High nitrogen deposition, sometimes with additional input from agricultural activities, may lead to eutrophication in sensitive areas. In this case some plant species will grow excessively while others die, and there could be algae blooms depleting oxygen, and thereby affecting fish and other life forms in the lake. Increasing nitrate concentrations in surface water is seen at many intensive research sites in Europe. Possible signs of developing nitrogen saturation i.e. changes in soil chemistry and seasonal patterns of nitrogen concentrations in soil solution, are seen at some sites in Sweden.

Besides fish, many invertebrates are sensitive to acid water and become extinct at different levels of acidity. One of the main tasks of the ICP Waters Programme is to compare the distribution of different invertebrate species from different regions, and to measure differences in a community over time.

Liming of lakes is an artificial way to reduce the acidity in the lake and liming may also possibly reduce the effect of aluminium on fish and other life forms. Liming is used e.g. in Norway and Sweden in order to improve the situation and to help restore fish populations.

Due to acid precipitation the concentration of sulphate in surface water is elevated. Trend analysis shows that sulphate concentrations in surface water now are decreasing at almost all monitoring sites in Europe as shown in Figure 6 (Working Group on Effects (undated), Stoddard et al., 1999). This is due to the reduced emissions of sulphur dioxide in Europe. In most cases the decrease of sulphate in surface water was larger in the 1990s than in the 1980s. In most Nordic countries surface water acidity increased during the 1980s, but decreased again in the 1990s. At many sites in western and southern Europe the acidity decreased even in the 1980s, but this trend was accelerated in the 1990s. In the

United Kingdom there has been no change during the 1990s. Lake acidity is often expressed by the alkalinity which is the lakes ability to neutralise acid input. Figure 7 presents changes in alkalinity in different regions in the 1980s and the 1990s, and Figure 8 the changes with time in the Storgama lake.
During the 1980s the nitrate concentrations in surface water increased, but the increase levelled out in the 1990s. Since nitrogen compounds are involved in biological processes, the concentrations in surface water may not correspond directly to input through dry and wet deposition.

An improvement in the invertebrate fauna can be seen in samples taken before and after 1990 at Norwegian and German measurement sites. There are indications of a similar trend at Swedish sites, and these results support the results showing recovery of acidified surface waters.

3 Effects on forests and soil

Air pollution is believed to be one among several factors with influence on forest condition. Figure 9 show an example of damaged and undamaged tree. Forest age is important for forest health, in addition droughts and attacks from fungi and insects may damage trees. The susceptibility to acidification is also dependent on tree species, soil type, -texture, and -depth and the thickness of the humus layer. Many scientists today consider air pollution a triggering, accompanying, or predisposing factor affecting the forest condition.

High concentrations in air of ozone and other photochemical oxidants adds to the stress by acid rain. Another harmful effect of acid rain is due to large deposition /of nitrogen compounds. -Although nitrogen compounds are nutrients for vegetation, very large depositions, e.g. as measured in central Europe, cause nutrient imbalances and make the forest more susceptible to natural stress factors.

The metals calcium, magnesium, sodium, and potassium (“base cations”) are of vital importance for the forest, and they occur naturally in variable amounts in soil in various complex chemical compounds, and in minerals. Acid deposition through rain and snow, or through particulate matter and gases will remove metals from the soil. The metals will be exchanged with hydrogen ions from deposited acid, and dissolved in soil water. As long as the acid deposition continues, but sufficient amounts of base cations still are available in the soil, this process will continue. When the reservoir of base cations is exhausted, the soil will become more acidic and toxic aluminium ions will be leached out. Toxic metals can be taken up by the vegetation root systems or led into brooks, rivers and eventually into lakes together with acids, causing changes and damage to aquatic fauna and flora.

In Europe the forests condition are surveyed through national programmes and through the ICP Forests Programme. The surveys conducted are on crown and foliar condition, on soil condition and soil chemistry, the tree growth, and the ground vegetation, as well as related to acid deposition and meteorological measurements.

Crown condition is assessed by defoliation and discolouration of trees. Annual changes in defoliation have been assessed since 1989 for seven major tree species and the results show continued deterioration in crown conditions. The degree of damage is different from one tree type to another. Defoliation in conifers is less pronounced than in broad-leaved trees.

Tree defoliation is most severe in central parts of Europe where the deposition of sulphur and nitrogen compounds are the highest. Statistical analysis carried out by Poland and Norway give strong evidence for a close relationship between crown condition and air pollution. Figure 10 show the percentage of trees damaged in 1996 together with the sulphur deposition (ECE Working Group on Effects, undated). Most other countries seem to consider air pollution to have a triggering effect on reduced forest condition. Clusters with considerable increase in defoliation can be seen in parts of central and Eastern Europe and at the Iberian peninsula. These cannot be fully explained by natural stress factors alone.

Results of soil condition surveys indicate a relation between acid deposition and top soil acidity. Acidified soils occur in central and northern Europe (Figure 11). A high acidity corresponds to a low pH value.

The surveys show that the carbon to nitrogen ratio in soils have decreased in the soil humus layer. This indicates that the large nitrogen depositions may disturb the organic matter and the nitrogen cycling in soil.

4 Effects on crops

In agriculture, sulphur and nitrogen pollutants are seldom considered a problem. Direct effects of sulphur dioxide only occur at high gas concentrations and acidic deposition is buffered through the liming activities commonly used in agriculture. This is also true for the nitrogen oxides. The direct injuries on crops from air pollution is related to ozone concentrations in air and not to acid deposition as such. But ozone in combination with other substances, gives strong oxidants which transform sulphur and nitrogen oxides in air to sulphuric and nitric acids; in this way ozone has an important role related to acid deposition problems.

Plants sensitive to ozone obtain spots on the leaves, can have reduced growth, reduced quality, and have a reduced crop yield. Ozone enters the stomata on leaf surfaces and reacts with cell walls and membrane components.

Trends in effects on crops are monitored in Europe through the ICP Crops; a series of thirteen plant species are studied. Some geographical differences are apparent and injuries at one or more monitoring site in Europe have been reported every year. Injuries are seen every year at some sites, e.g. in central and southern Europe. No trends with time are apparent.

5 Effects on materials

The ICP Materials Programme aims at a quantification of the environmental effects from the decreasing amounts of acidifying pollutants, as well as to identify other environmental changes that result in material damage. The programme has

39 research sites performing exposure experiments, e.g. with zinc and steel, in Europe.

Steel and zinc are affected by dry deposition of sulphur dioxide as well as by acid precipitation. Dry deposition experiments carried out show that the sulphur dioxide concentration and the time of wetness (e.g. due to dew fall) are important, but that other factors probably also contribute to the corrosion. For materials exposed to precipitation, the amount of deposited acid is important. The corrosion due to dry deposition is larger than that for acidic wet deposition at most research sites. When comparing time periods at the end of the 1980s with results from the middle of the 1990s, there is a decrease in the material loss both for (unalloyed carbon) steel and for zinc. Dry depositions account for the largest decrease (67 per cent) in this period.

The trend in sulphur dioxide concentrations is the largest single factor contributing to the corrosion reduction, but it also appears that other factors leading to corrosion likewise have decreased influence from 1987. This cannot be directly related to a specific pollutant but reflects the multi-pollutant character of the process of material degradation.

6 Conclusions on trends

The emission of sulphur dioxide from Europe as a total has been reduced more than 50 per cent the last twenty years. In contrast to this, only a slight reduction of nitrogen oxides emission can be seen during this period.

In correspondence to the reduced sulphuric acid input, lake and river sulphate concentrations decreased in all regions with the exception of Great Britain, the decrease was generally larger in the 1990s than in the 1980s. Regions in Europe with declining sulphate concentrations also had an increase in alkalinity (i.e. decrease in acidity). A reduction of lake and river nitrate concentrations was rare, and very small when detected.

There are many stress factors affecting forest health, and air pollution is believed to be a predisposing or a triggering factor

The latest reports indicate that forest damage still is a serious problem in Europe; there is a wide scale deterioration, defoliation is severe in central Europe, forest soils are acidic, and a wide scale recovery in Europe is not evident although the acid depositions have been reduced.

The decreasing trend in the concentrations of acidifying air pollutant has resulted in a decreasing corrosion rate of exposed materials. The decreased sulphur dioxide concentrations are believed to be the largest single contributing factor to this decrease. The decreased corrosion rate is larger than expected from the reductions in sulphur dioxide and acidity in precipitation, and this reflects the multi-pollutant character of corrosion.

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8 References

Oden, S (1968) Nederbördens och luftens försurning, dess orsaker, förlopp och verkan i ulike miljöer. Stockholm, Statens naturvetenskapliga forskingsråd (Ekologikommiteen, Bull. no. 1).

OECD (1977) The OECD Programme on Long Range Transport of Air Pollutants. Measurements and Findings. Paris.

Overrein, L.N., Seip, H.M., Tollan, A. (1980) Acid precipitation - effects on forest and fish. Final report of the SNSF-project 1972 - 1980. SNSF-project, Oslo 1980 (Research Report FR 19/80).

ECE (1997) Air pollution studies 13. Effects of the long-range transboundary air pollution. New York, United Nations (ECE/EB.AIR/51).

ECE (1999) Air pollution studies 14. Effects of the long-range transboundary air pollution. New York, United Nations (ECE/EB.AIR/62).

Herrmann, J., Degerman, E., Gerhardt, A., Johansson C., Lingdell P.-E., Muniz, I. (1993) Acid stress effects on stream biology. *Ambio*, **22**, 298–306.

Lükewille, A., Jeffries, D, Johannesen,M., Raddum, G., Stoddard, J., Traaen, T. (1997) The nine year report: Acidification of surface water in Europe and North America - long-term developments (1980s and 1990s). Oslo, Norwegian Institute for Water Research.

Stoddard, J.L., Jeffries, D.S., Lükewille, A., Clair, T.A., Dillon, P.J., Driscoll, C.T., Forsius, M., Johannesen, 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., Wilander, A. (1999) Regional trends in aquatic recovery from acidification in North America and Europe. *Nature*, **40**, 575–578.

Mylona, S., Støren, E. and Grini, A. (1999) EMEP Emission Data. Status Report 1999. Oslo, Norwegian Meteorological Institute (EMEP/MSC-W Report 1/99).

Working Groups on Effects (undated) Trends in Impacts of Long-range Transboundary Air Pollution. Huntingdon, Institute of Terrestrial Ecology.

Appendix A

Figures

Figure 1. International Co-operative Programmes of the ECE Working Group on Effects.

Figure 2: Emissions of sulphur dioxide from large European emitting countries 1980 - 1993.

Figure 3: Total European emissions of sulphur dioxide, nitrogen oxides, and ammonia, 1980 - 1997.

Figure 4: Critical loads

Figure 5: Lake Storgama in southern Norway.

Figure 6: Trends in sulphate concentrations in lake surface water.

Figure 7: Trends in alkalinity in lake surface water.

Figure 8: Lake Storgama. Trends in sulphate in precipitation and in surface water sulphate concentrations and in alkalinity.

Figure 9: Damaged and undamaged trees.

Figure 10: Percentage of trees damaged in 1996 in Europe and sulphate deposition.

Figure 11: Measured and interpolated pH values for the mineral top soil of all monitoring plots (Europe).