International and National Abatement Strategies for Transboundary Air Pollution

A MISTRA research programme

The ASTA Programme 1999-2002

A research programme funded by MISTRA (Swedish Foundation for Strategic Environmental Research) together with National Board of Forestry, Elforsk Ltd., Swedish National Energy Administration and Ministry of the Environment.

Objectives of the ASTA Programme

The overall objective of the Programme is to produce scientific data for international measures to control transboundary air pollution in Europe and to develop national strategies and measures in various sectors that are affected by transboundary air pollution.

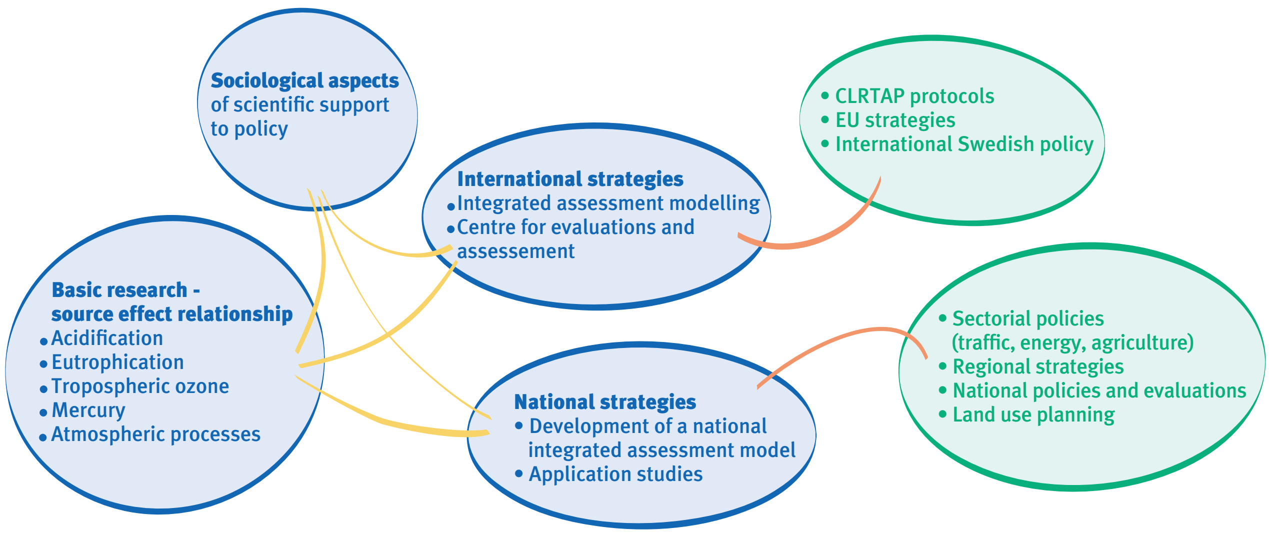
The ASTA Programme carries out research on acidification of soil and water, the effects of nitrogen input on forest ecosystems, the effects of ground-level ozone on vegetation and regional transport and concentrations of particulate air pollution. The effects of increased extraction of forest biofuels are also studied in conjunction with the effects of acidification of soil and water and the effects of nitrogen input.

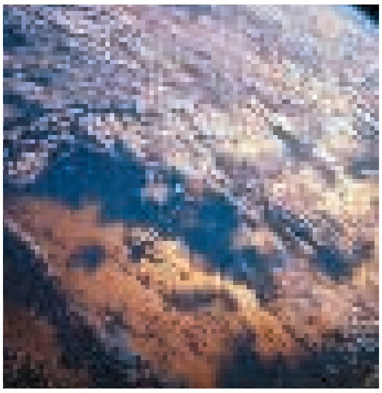
Other aims of the Programme:

- to strengthen and secure the future supply of Swedish expertise for the purposes of international negotiations on environmental agreements;
- to build a consensus on research findings through international networks;
- to provide information about and visualize the regional air pollution problem in order to increase policymakers' understanding of the issues; and
- to promote a better understanding of the interface between science and politics.

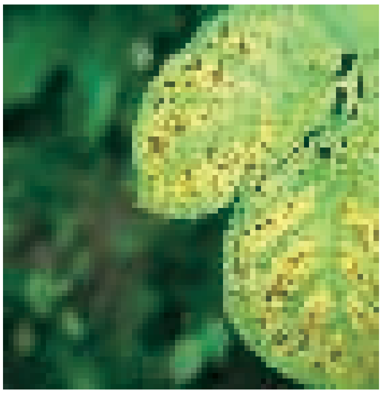
The Programme takes account of relevant international initiatives in the form of conventions, EC Directives and changes in strategies and approaches on the part of industry, public authorities and the general public.

Overall Programme Structure 1999 - 2002





The Centre's most important task is to critically assess and strengthen the scientific evidence with a view to future convention negotiations.
page 8



A new generation of critical levels is emerging which will take into account both the ozone flux to vegetation and differences in ozone exposure in Europe.
page 20

Acid deposition is at last falling to pre-industrial levels. At the same time we note that recovery takes time, and the time factor should be taken into account in connection with future decisions on necessary action.
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Does science have a role in international negotiations on the environment, or are they determined mainly by economic and political factors?
page 25

front cover: *As an effect of the crystal clear water of the acidified lake the White Water-lilies flower before reaching the water surface. The flying insects will not be able to propagate the flowers. This flowering bud of the White Water-lily (Nymphaea alba) is approximately one meter under the surface. The photo is taken in Lake Stora Hästevatten, an acidified reference lake next to Lake Gårdsjön in the south-west of Sweden.*
Photographer: *Fredrik Ehrenström*

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Programme activities in 2000

The ASTA Programme focused in 2000 on three key research areas divided into subprogrammes. The programmes coincide broadly with the general focus of the Programe as a whole.

The persons responsible for each subprogramme are mentioned in brackets.

Integrated analyses

- International Centre for Evaluation and Assessment (Peringe Grennfelt)
- National Strategies for Emission Control and Land Use (Olle Westling)
- Integrated Assessment Modelling (Harald Sverdrup)

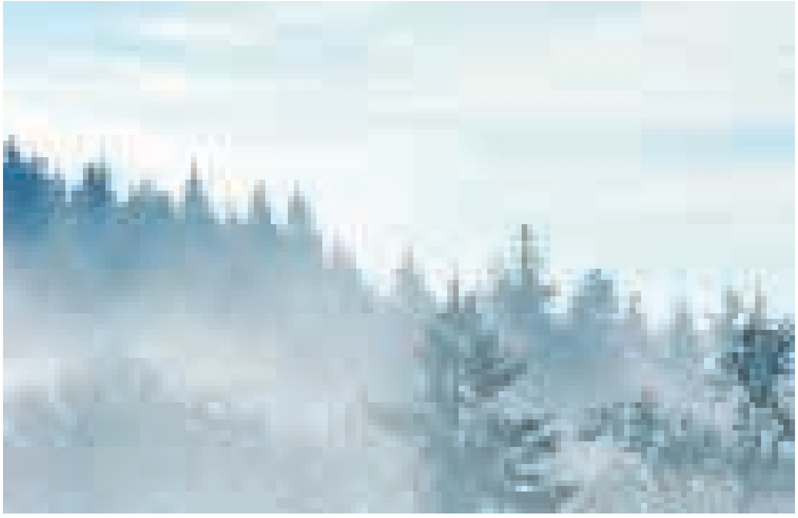
A social science perspective

- Scientific Processes behind Abatement Strategies (Göran Sundqvist)

Basic research on source-effect relationships

- Recovery from Acidification – Experiments and Modelling (Per Warfvinge)
- Nitrogen Induced Ecosystem Changes – Ecophysiological Changes and Vegetation Responses (Torgny Näsholm)
- Ground-Level Ozone – Effects on Vegetation (Håkan Pleijel)
- Particulate Air Pollution – Concentrations, Transport and Sources (Hans Christen Hansson)

Continued research on transboundary air pollutants



We have done research on acidification and transboundary air pollutants for more than 30 years. Won't the problems be solved soon?

I have heard comments like this increasingly often during the last few years. And there is certainly some justification for such questions. Now that sulphur deposition has been reduced by 60 per cent and more in a large part of western and central Europe since 1980, at the same time as observations increasingly indicate that environmental improvements have taken place in forests and lakes, it is quite natural for people to wonder whether the problem has not been solved and whether more research is really needed.

Furthermore, emissions continue to decrease. By the year 2010 the state of the environment will have improved even further. According to the analyses on which international undertakings to reduce emissions in Europe are based, the areas in Europe with deposition higher than the critical load for acidification will be far less than for the case in 1990.

Nonetheless, in Sweden and many other countries research continues to be done on transboundary air pollutants, albeit with much less intensity. What, then, is the justification for such research?

The main reason is that the problems will not be solved by 2010 and further measures are needed to achieve the declared objective, i.e. that critical loads will not be exceeded anywhere in Europe. This applies in particular to the impact of nitrogen deposition, but the impact of acid deposition and ground-level ozone will not have been eliminated either. However, the scientific evidence must be improved in order to justify further measures. As we approach the agreed limit values, the requirements as regards the quality of the data are likely to become more stringent. The risks associated with increasing uncertainty were recognized even before the Gothenburg Protocol under the Convention on Long-range Transboundary Air Pollution was signed. The fact that the impacts of transboundary air pollutants have diminished will also make it more difficult to justify further measures.

Another reason is that adverse impacts will continue to affect damaged ecosystems, but at present we know too little about the extent of these effects and whether or not further measures will be necessary in order to speed up recovery. Acidification has depleted the buffering capacity of many soils, and acidified soils will take a long time to recover. There is uncertainty as to how long this will take and to what extent some effects are irreversible.

The increased interest in the effects on health of submicron particles is a third important reason. Several new studies have shown that particles can be an important factor for impacts on health, especially the particles that are formed in the atmosphere by sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds (VOCs).

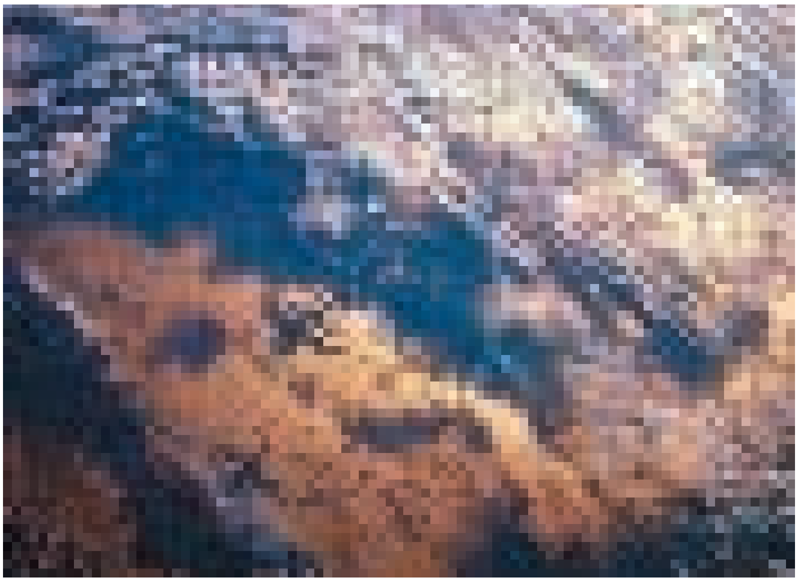
The purpose of the ASTA project is to meet the need to further improve the scientific evidence and to identify critical research areas in which the Programme can make a significant contribution to further measures. Apart from specific work in areas such as acidification and the impacts on ecosystems of nitrogen deposition and ground-level ozone, the Programme has concentrated on synthesizing and integrating knowledge and on a special research project on the interaction between scientists and policymakers.

Peringe Grennfelt

By Peringe Grennfelt

The Centre for Evaluation and Assessments

The Centre's most important task is to critically assess and strengthen the scientific evidence with a view to future convention negotiations.



A subprogramme within the ASTA Programme concentrates on the needs of evaluation, impact analyses and consensus-building.

The aim is to collect, critical assess, evaluate and strengthen the scientific evidence for the purposes of the new rounds of negotiations under the Convention on Long-Range Transboundary Air Pollution and the European Union that will probably start around 2004.

The main focus in 1999 and 2000 was on the following three activities:

- **Integration of dynamic aspects, especially recovery, into the critical load concept.** The way the term 'critical load' is used in international environmental cooperation today gives the impression that as long as critical loads are not exceeded the state of the environment is acceptable and no further measures are necessary. However, in this respect the methodology is misleading. For one thing it underestimates the areas in which critical loads are exceeded, and for another the recovery of acidified areas still depends on the amount of deposition even if it is below the critical load. These views were presented in a keynote speech at the conference on critical loads in Copenhagen in November 1999 and is now published in a scientific journal.
- **The organization of a workshop on the need of data in preparation for the reviews of the international conventions was another task addressed by the Centre.** This workshop was held in April 2000 and was attended by more than 100 participants, including representatives of all the bodies involved in the Convention on Long-Range Transboundary Air Pollution and the EU. The conference concluded that the evidence must be improved in practically all areas before the start of the next round of negotiations. This applies both to the purely scientific evidence in the form of knowledge of the processes that play an important role in the transport and effects of pollutants as well as to data in the form of emissions, concentrations and the state of the environment. Modelling data also need to be improved (TemaNord 2000:557).
- **Critical evaluation and harmonization of models in order to facilitate studies of recovery on an international scale.** This activity may be regarded as a sequel to the work of integrating dynamic aspects into the critical load concept. The main purpose of the project is to arrange workshops in close cooperation with the modelling activities within the framework of ASTA's acidification programme.

In the next phase a project will evaluate the extent to which the decrease in concentrations and deposition is as great as one would expect, given the measures that have been taken so far. Other initiatives that will be taken will cover effects of nitrogen deposition to forest ecosystems and new approaches in integrated assessment modelling.

Participants (see picture on page 11)

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Suggestions for further reading: *Workshop on future needs for regional air pollution strategies in Saltsjöbaden, April 10-12 2000, TemaNord 2000:557, Nordic Council of Ministers Publication Series.*

Grennfelt, P. et al. Critical loads - Is there a need for a new concept? Water, Air and Soil Pollution: Focus 1: 1-7, 2001

Both air pollutants and the forest itself cause acidification of forest soils. What is the interaction between them and how does this affect the quantity of forest biomass that can be extracted?

By Olle Westling

Extraction of biofuels and acidification trends – national strategies

The efforts to achieve the national environmental objectives relating to the degree of acidification, the nutrient status and the productive capacity of forest soils require decision guidance data and analytic tools that indicate the effectiveness of various measures. The measures that are usually referred to in this context are reductions of air polluting emissions in Europe or changes in land use.

The national ASTA subprogramme focuses mainly on the connection between the impact of air pollutants distributed over large land areas and land use, especially the use of forest land.

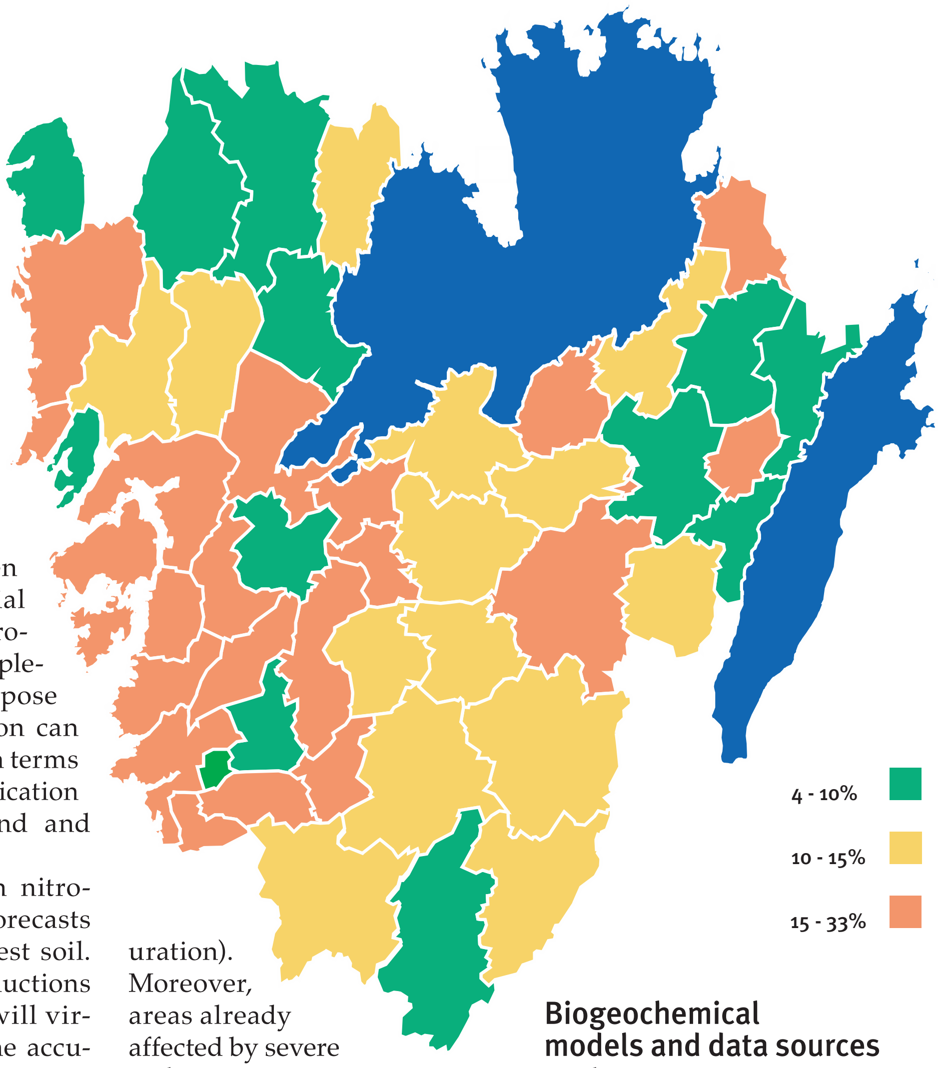
The purpose of the subprogramme is to develop models and tools for integrated analyses concentrating on impacts on ecosystems.

In order to design strategies for land use and emissions of air pollutants that are consistent with the environmental objectives, the subprogramme focuses mainly on three key issues:

- Will Sweden achieve sustainable improvement of the environment as a result of the planned emission reductions in Europe up to 2010?
- What national measures to reduce emissions are most cost-effective in order to achieve various environmental objectives, and can the objectives relating to land use and emissions of air pollutants be reconciled?
- How great is the potential for extracting forest biomass on a sustainable basis in areas affected by air pollution (growth, hydrology, nutrient supply, acidification, need of recovery)?

The national component of the ASTA Programme is a platform for integrated analysis that includes a number of aspects which the project stakeholders have considerable influence on. There are two priority aspects in the initial phase: nitrogen and acidifying processes.

above: *Extraction of forest fuels, a new method for compacting logging residue into bales, which is subsequently used as fuel. The methods used for extracting forest fuels are being improved in order to increase the competitiveness of biofuels.*



The nitrogen budget in forest soil

The supply of nitrogen in forest soil is a crucial production factor. Anthropogenic nitrogen supplements given for the purpose of increasing production can represent a risk factor in terms of eutrophication, acidification and leaching to ground and surface water.

The subproject on nitrogen is based on two forecasts about the status of forest soil. One is that emission reductions continuing after 2010 will virtually put an end to the accumulation of nitrogen in most of the productive forest land in Sweden. According to this forecast this will be the case for more than 90 per cent of the productive area.
According to the other forecast, the effects of clear felling will be the greatest single source of increased leaching of nitrogen from forest soil in the foreseeable future. The extent of leaching is a function of historical accumulation of nitrogen and runoff quantities.

The acidity and base cation budget in forest soil

Sustainable management of forest soil is only possible where the soil is not acidified by unnatural means through reduction of exchangeable base cation (i.e. a reduction in per cent base saturation).
Moreover, areas already affected by severe anthropogenic acidification need to recover.

The sites and regions where measures are necessary in the form of changes in land use (e.g. compensatory fertilization) are difficult to identify, given today's insufficient knowledge of this area.

One way of identifying these areas is to examine the runoff water from forest land. The acid-base status of the soil is reflected in the leaching of the chemical composition of the soil. Runoff water is therefore an important indicator of the acidification status. A complicating factor is the fact that the effects of acidification on surface water due to deposition differ from those of acidification due to the growth and harvesting of forest trees.

Biogeochemical models and data sources

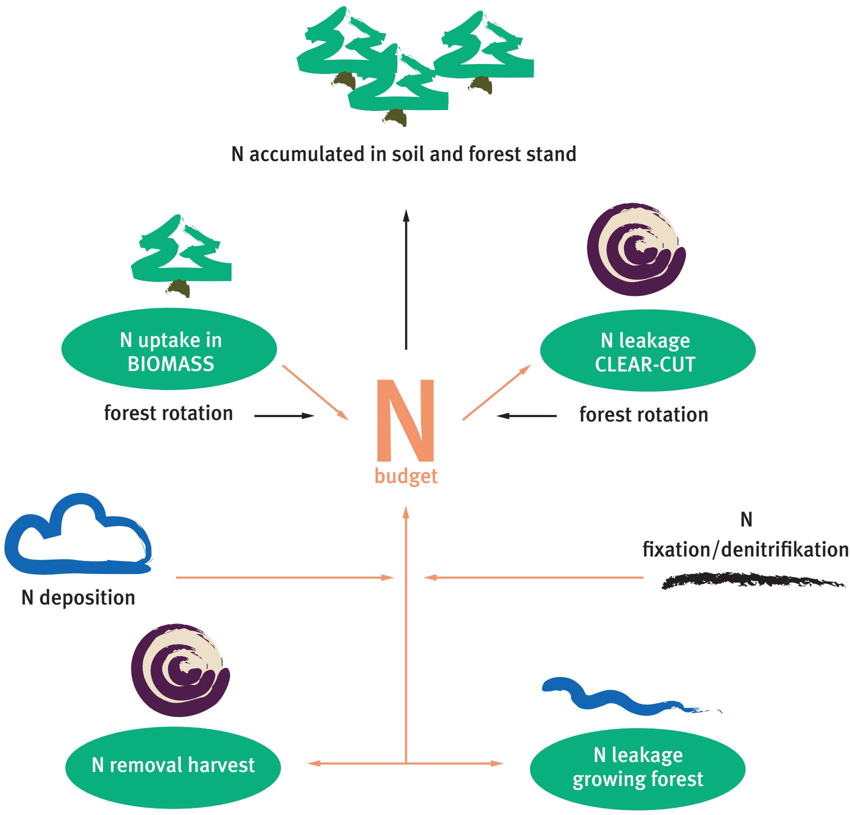
Mathematical models will be developed and adapted in order to find out more about regional developments and the need of measures to address acidification and accumulations of nitrogen.

These are basically biogeochemical models applied to geographical areas of varying size. The models will be tried out both on fixed grids (e.g. 5x5 km) and on entire catchment areas treated as single units. During the model development process measurement data from a few small, thoroughly investigated areas will be used for control purposes. Models will also be developed for use in large catchment areas.

The work of describing leaching from forest soil and cleared tracts along a deposition gradient has started in Västra Götaland county, where there

above: Nitrogen leaching from clearcuts in Västra Götaland county (per cent to the total leaching during a forest generation). The estimated percentage of nitrogen that has leached from cleared tracts in a municipality can in some cases account for more than 20 per cent of all nitrogen leaching. During a complete forest generation this amounts to an addition of 10-15 per cent to the normal leaching from the managed area.

below: *Nitrogen turnover in forest soil. An example of systems that are used to calculate changes in the nitrogen supply in forest soil. Nitrogen turnover is a complicated process and model descriptions for managed forest land include many components.*



are obvious interactions between air pollutants and land use. Increased leaching from clearcuts in areas with high nitrogen deposition increases the load on lakes and rivers and contributes to eutrophication.

Indicators for sustainable land use

The project also comprises development and adoption of indicators for the purpose of describing the status of forest soil in relation to environmental objectives and sustainable land use.

The following are examples of indicators that will be included:

- the C/N ratio in the humus layer,
- accumulation of nitrogen in forest soil,
- leaching of nitrogen from clearcut areas,
- limit values for harmful and acidification-related levels of pH, inorganic aluminium and acidic neutralizing capacity (ANC) in runoff water,
- limit values for soil chemistry properties that may cause abnormal leaching of inorganic aluminium.

Collaboration with other MISTRA programmes

The national subprogramme is being conducted in close collaboration with other research programmes and inventory projects.

The research programmes include Sustainable Forestry in Southern Sweden (SUFOR) and Remote Sensing for the Environment (RESE). Close cooperation will also take place with other inventory activities such as the National Forest Survey, national environmental monitoring programmes and inventories of critical loads.

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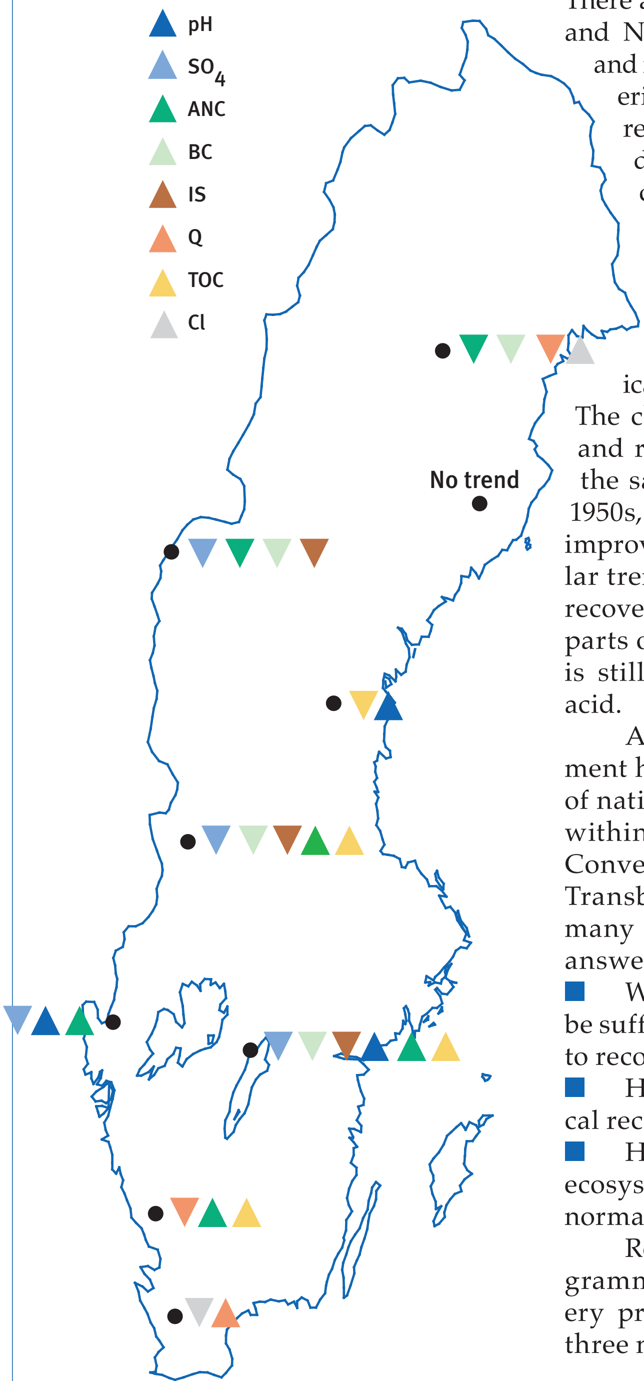
Suggestions for further reading: *Westling, O. Löfgren, S. & Akselsson C. Arealförluster från skogliga avrinningsområden i Västra Götaland (only in Swedish). 2001. National Board of Forestry, Jönköping, Report 2:2001.*

Löfgren, S. & Westling O. Förslag till modell för att beräkna kväveförlusterna från växande skog och hyggen i Sydsverige (only in Swedish). 2001. Technical report (in press).

By Per Warfvinge, Kevin Bishop, Mattias Alveteg and Filip Moldan

Many signs of recovery

Acid deposition is at last falling to pre-industrial levels. At the same time we note that recovery takes time, and the time factor should be taken into account in connection with future decisions on necessary action.



above: Significant trends in catchment measurements within the Swedish National Environmental Monitor Programme (significant at the p< 0.1 level, tested by Seasonal Kendall test).
The symbol direction ▲ indicate increasing concentration and direction ▼ indicate decreasing concentration.

There are many signs in Europe and North America that lakes and rivers are gradually recovering from acidification. The reason for this is that acid deposition has decreased constantly during the last 10-20 years. The improvements are visible, especially in very sensitive areas, where deposition greatly exceeded the critical load.

The chemistry in many lakes and rivers in Norway is now the same as in the 1940s and 1950s, and their biology is improving too. There is a similar trend in Sweden, although recovery is slower. In some parts of the country forest soil is still becoming increasingly acid.

Although the environment has improved as a result of national action coordinated within the framework of the Convention on Long-Range Transboundary Air Pollution, many questions remain to be answered:

- Will the adopted measures be sufficient for the ecosystems to recover?
- How quickly will chemical recovery take place?
- How long will it be before ecosystems will again function normally?

Research in the ASTA Programme focuses on the recovery process. We are applying three methods:

- experimental recovery in the Gårdsjön Roof Project,
- analysis of environmental data and,
- mathematical modelling of recovery in various scales.

The Gårdsjön Roof Project – a glimpse of the future

Acidification in the Gårdsjön area, where a number of trials are in progress, has been studied for over three decades. Ten years ago a roof was built over a catchment area of 6,300 square metres to make it possible to study what happens when acid rain is artificially replaced by pre-industrial precipitation. Since the exclusion of normal precipitation from the area started there has been a small addition in the acid input as a side-effect of the impact of the roof on nutrient fluxes between trees and the soil.

When all acidifying sulphur deposition was eliminated the levels of sulphates and toxic aluminium in the runoff water decreased dramatically. The pH remained at a very low level for many years, but then gradually rose as the buffer capacity improved. However, the runoff water is still – after 10 years of irrigation with clean water – very toxic to aquatic organisms. It will probably take more than 50 years for the chemistry of the ecosystem to return to its natural state. The roof

experiment shows how important sub-critical load deposition is for rapid recovery.

In 2001 the sulphur deposition outside the roof is expected to be so low as to be equivalent to the acidification caused by the roof itself. It may then be time to take away the roof and once again let natural precipitation fall on the soil. In that case the experiment will continue without the roof and we will be able to use the accelerated recovery of the soil thanks to the experiment to study the next phase of the recovery process.

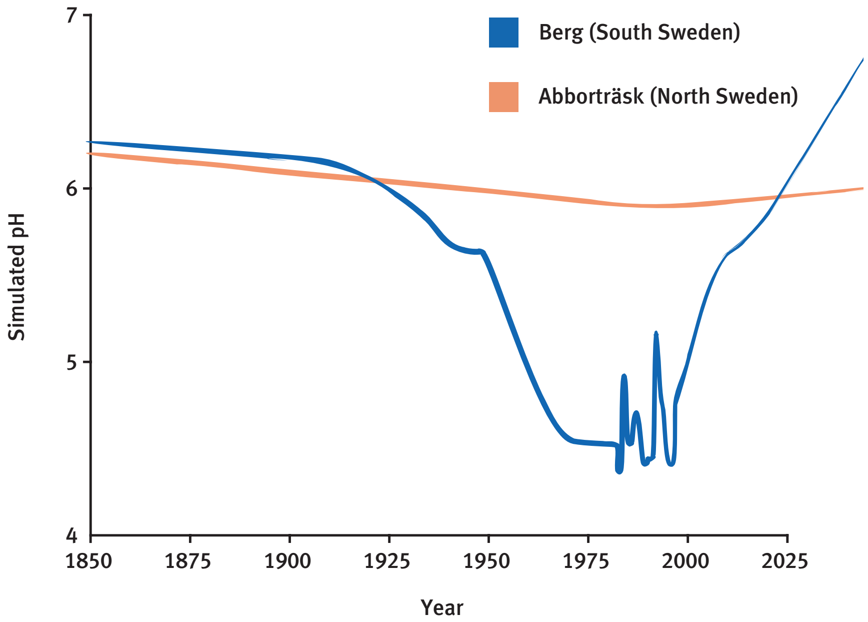
The importance of the time factor in the recovery process

The effects of reduced emissions of acidifying substances have been studied in field trials during the last few decades. Monitoring the results of previous measures provides information that can be used to refine instruments for the future. It has been established that recovery is a relatively slow process and that there is a considerable delay before the results of emission reductions become noticeable.

The concept of critical loads has also been used as a common starting-point with respect to acidification in connection with negotiations on air pollution control in Europe. In October 2000 ASTA arranged an expert conference within the framework of the air pollution convention to evaluate the possibility of taking dynamic aspects such as recovery processes into account as a complement to the mathematical models that are used to calculate critical loads. The time has now come to promote the use of dynamic mathematical models in order to develop tools for the measures that need to be taken. Naturally, the objective is

above: *The dominant "algae blanket" of thread-shaped blue-green algae species covers the plants of Bulbous Rush (Juncus bulbosus). The photo is taken in the acidified Lake Stora Hästevatten in the south-west of Sweden.*
Photographer: *Fredrik Ehrenström*

below: *Simulation of lake pH for lakes in northern Sweden and in south-western Sweden, an area severely affected by acidification.*



to make sure that the measures produce results within a reasonable period. The experts all agreed that more study is needed of the time factor.

Mathematical modelling of acidification data

Mathematical models are used in ASTA's acidification programme for various kinds of data and various issues. The main focus has been on the following three levels:

- modelling of data from Gårdsjön for the purpose of testing, evaluating and further developing existing models,
- regional assessments of changes in the chemistry of Swedish forest soils,
- future scenarios for individual sites, both lakes and watercourses and forest ecosystems.

The data from Gårdsjön are used to evaluate the performance of the models from several points of view. Measurements have been carried out in this area for a long time, the reference area has been used for 30 years and the roof for almost 12 years. Apart from the long-term nature of these observations, the wide range of the available measurement data obtained from repeated soil examinations and sulphur turnover studies is invaluable for developing mathematical models.

At the regional level our database now includes complete datasets on 273 forest ecosystems for use in our modelling calculations. The SAFE (Simulating Acidification of Forested Ecosystems) model has been expanded to make it possible to take into account the fact that sulphur can be adsorbed onto soil particles. We have also improved our methods for calculating the chemistry of aluminium, which is a key substance in this context.

Regional calculations show that the decreases in deposition in many cases are sufficient to reverse acidification of forest soils. However, a crucial issue is land use, which may be an obstacle to recovery.

Our preliminary assessment is that the forest soils in the south of Sweden will recover, although very slowly. The difference between individual stands will be considerable depending on the geological conditions and the intensity of land use. Our calculations confirm the impression that in the north of Sweden acidification is very moderate.

Model studies have been performed on two catchment areas, Lake Abborrträsk in northernmost Sweden and the Pipbäcken stream in south-western Sweden, which is severely affected by acidification. Using the MAGIC (Model of Acidification of Groundwater in Catchments) model we have calculated that acidification in the most northerly regions has in many cases been very moderate. According to our model, the pH seems only to have fallen from 6.1 to 5.9 since the pre-industrial era. This is consistent with palaeolimnological studies in the region. The picture is completely different in areas where acid deposition has caused severe acidification.

Environmental data help us to monitor progress

Evaluation of acidification measurements in lakes and rivers provides essential data for assessing the reliability of the models and for predicting future acidification trends. Within the framework of this project, researchers at the Swedish University of Agricultural Science (SLU) performed statistical analyses of changes in the chemistry of the runoff in the areas included in the Swedish National Environmental Monitoring Programme.

The areas that are monitored give a good picture of changes in the environment. The measurements show that in eight of the nine areas there is a significant decrease in sulphur fluxes. The ninth area is situated in the north of Sweden where, as already mentioned, acidification has been very moderate. Moreover, in seven areas pH levels are rising, and this in turn leads to lower aluminium levels. As might be expected, the levels of calcium and magnesium in water are also declining. This slows recovery up and may well also hamper biological recovery.

Cooperation outside the ASTA Programme

We devote a great deal of energy to participating in various structures for international cooperation on dynamic modelling. ASTA researchers take part in the EU-funded programme RECOVER 2010 (Predicting Recovery in Acidified Fresh Waters by the Year 2010 and beyond). This includes regional model calculations in Switzerland and Germany and participation in various Nordic cooperation projects.

At ASTA we have, in cooperation with the coordination centre in the Netherlands, developed a method of describing recovery times for all conceivable deposition scenarios. The objective is to identify emission scenarios which ensure the fastest possible recovery for as many ecosystems as possible.

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Suggestions for further reading: *Krám, P., H. Laudon, K. Bishop, L. Rapp and J. Hruška (in press). Magic Modeling of Long-Term Lake Water and Soil Chemistry at Abborrträsket, Northern Sweden, Water Air and Soil Pollution.*

Fölster, J. and A. Wilander (in review) Recovery in Swedish forest streams. Environmental Pollution

*By Ursula Falkengren-Grerup,
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The impact of nitrogen deposition on forest flora

The occurrence of grass, rather than blueberries and lingonberries, on the ground between spruces is one visible effect of increased nitrogen input in forest soils. The effect persists for a long time after fertilization ceases.

This subprogramme studies the mechanisms of the changes in vegetation as a result of nitrogen deposition. By using various methods, we try to describe how the deposition of the last few decades has affected the availability of nitrogen and how the flora is affected. Another aim is to try to predict future changes in vegetation in the event of both increased and decreased nitrogen deposition. Several different approaches have been tried to achieve this objective.

■ **above left:** *Nitrogen treated forest area.*
■ **above right:** *Reference forest area, not treated with nitrogen.*

Acidity and nitrogen in deciduous forests in southern Sweden

In areas exposed to varying amounts of nitrogen deposition during long periods we study changes in vegetation and the potential capacity of the soil for nitrogen mineralization, i.e. the capacity to convert organic to inorganic nitrogen which can be absorbed by the plants. We also estimate the effect of nitrogen deposition on the ground vegetation by using a new indicator system for plants. The results of these studies indicate that the field layer vegetation in deciduous forests in southern Sweden clearly reacts to the amounts of nitrogen deposition to which the ecosystem is exposed, provided that soil pH remains within the species' tolerance levels.

Nitrogen deposition is normally accumulated in the soil, with the exception of forest sites with a very high nitrogen load, where nitrate leakage occurs. As a result of this accumulation the variation in nitrogen deposition over different parts of Sweden is reflected in the levels in deciduous forest soils of (potentially) available ammonium and nitrate. There are great differences even in neighbouring areas; for example, the levels of available nitrogen are higher in the Skåne/Halland region than the Småland/Öland region. This tendency continues northwards towards the province of Uppland, where nitrogen deposition is approximately half as great as in the areas in southern Sweden even though the climate is relatively similar.

Plants absorb nitrogen in inorganic form as ammonium and nitrate, and nitrogen mineralization is therefore an important soil process. Mineralization depends on pH, and it declines the lower the pH level is. pH levels in the southernmost part of Sweden are very low due to extensive soil acidification. In spite of this, where pH levels are under 4.5, the nitrogen mineralization is about twice as great in the Skåne/Halland region as in the Småland/Öland region (fig. 1A). These soils also have a higher nitrification potential (fig. 1B). The higher availability of nitrate may be very significant for the development of vegetation, since many species thrive if the nitrogen they absorb includes nitrate.

Nearly all the deciduous forests in southern Sweden grow on minerogenic soils, while coniferous forests usually grow on humous, podsolized soils. Variations in pH are therefore greater in deciduous forests and in less acid soils where extensive acidi-

the connection between the size of the nitrogen dose and the response of the vegetation. Another important aim of our work is to find indicators that will enable us to study impacts in the affected areas and to study how the vegetation recovers if the nitrogen load diminishes. We have carried out in-depth studies during the year of the recovery of vegetation following a decrease in the nitrogen load. Some of the most important results of these studies are summarized below.

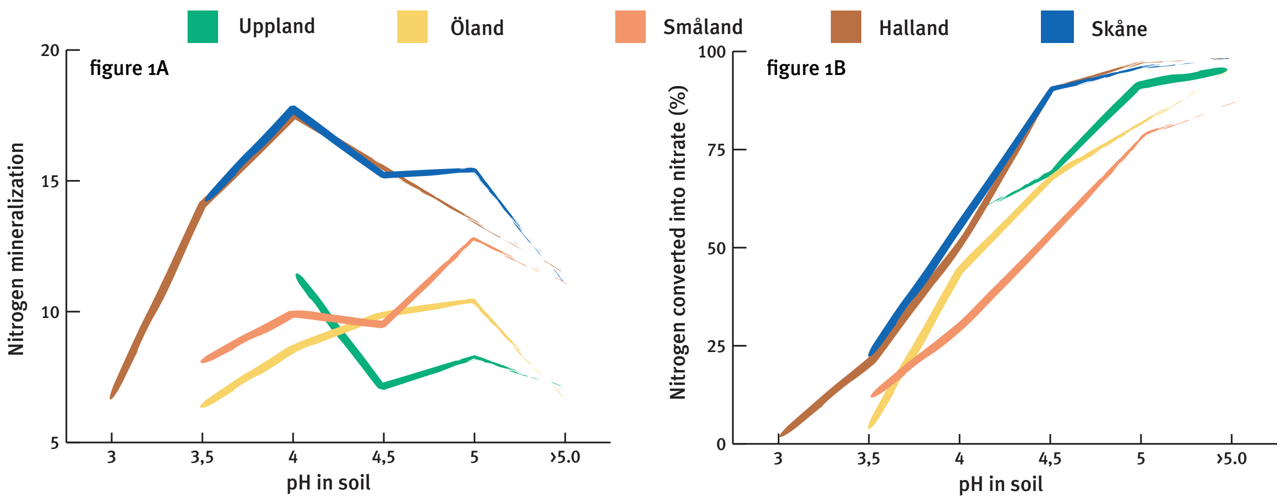
fication has occurred alongside nitrogen accumulation. A species that can hold its own in soils where plenty of nitrogen is available may thrive if it is not eliminated by high levels of hydrogen and aluminium ions due to acidification. It is therefore very important to pay attention both to the acidity of the soil and its nitrogen status.

Field trials in unaffected areas

In areas that have not been very much affected by nitrogen deposition we study how the vegetation reacts to increased nitrogen input. We study the mechanisms that lead to changes in the composition of the forest flora due to increased nitrogen availability. We also try to describe

Recovery of vegetation affected by nitrogen

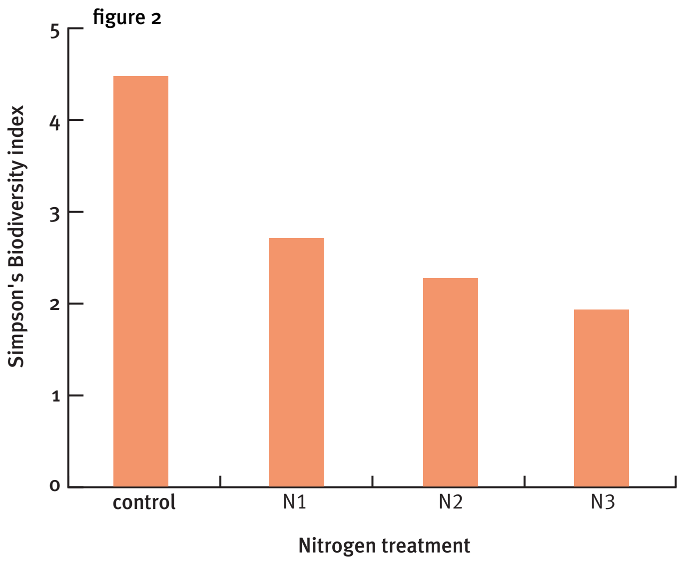
An important issue as regards the impact of nitrogen deposition on vegetation is whether the effects are reversible, and in that case how long it takes for an area affected by nitrogen deposition to resume its original character. Previous studies of forest ecosystems fertilized

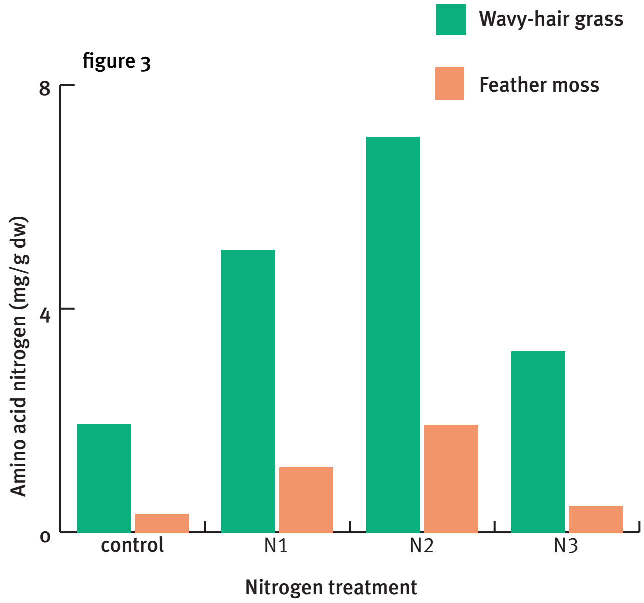


above: **1A)** *potential net mineralization of inorganic nitrogen and* **1B)** *percentage of the nitrogen converted into nitrate in deciduous forests in five regions in southern Sweden. Nitrogen mineralization and pH (0.2 M KCl) measured in the soil layer 5 cm under the forest litter.*

below left: **figure 2** *Effects of various nitrogen doses on biological diversity. Control = no fertilization; N1 = plots fertilized with approx. 30 kg of nitrogen per ha per year for 28 years, N2 = plots fertilized with approx. 60 kg of nitrogen per ha per year for 28 years, N3 = plots fertilized with approx. 90 kg of nitrogen per ha per year for 19 years; fertilization discontinued 9 years before start of the study.*

below right: **figure 3** *Effects of various nitrogen doses on the amino acid content of wavy-hair grass (Deschampsia flexuosa) and feather moss (Pleurozium schreberi). Same fertilization as in previos diagram.*





with nitrogen showed that the levels of inorganic nitrogen in the soil and the leakage of nitrogen to ground and surface water decrease rapidly and that the composition of mineral nutrients in trees changes when the nitrogen load decreases.

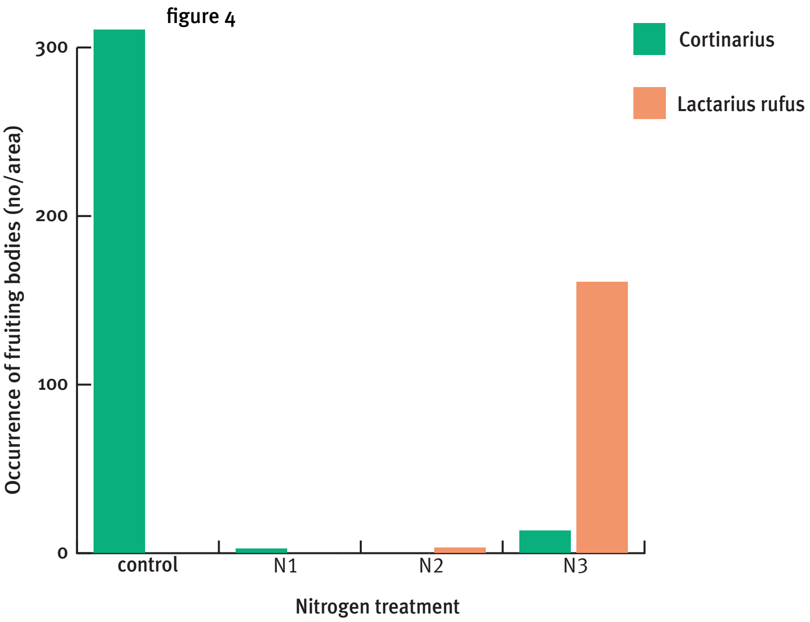
This might lead one to believe that forest ecosystems recover quite quickly once the nitrogen load decreases. We have studied the composition of species and the nitrogen status of plants in two trials in areas that were previously fertilized with nitrogen and where fertilization was discontinued or reduced.

In one of these trials we compared the vegetation in three types of plots: plots that had never been treated with nitrogen, plots that had continuously been fertilized with nitrogen, and plots that were previously exposed to nitrogen fertilization. The results show that nitrogen fertilization completely changed the composition of the species in the area. The species that had previously dominated the field and bottom layers were forced out and replaced by species which previously only occurred rarely or not at all. The result was an ecosystem with significantly lower biological diversity (fig. 2). The transformation from a forest in which the field layer consisted mainly of blueberry and lingonberry sprigs and the bottom layer mainly of feather moss and stair-step moss into a forest in which these layers are dominated by narrow-leaved grasses, including wavy-hair grass, and various brachytheciaceae, is practically complete. The results also show that the areas where nitrogen fertilization was discontinued (about a decade ago) have not recovered. The original berries had not reestablished themselves in the plots despite the fall in nitrogen input.

In another trial we compared plots fertilized with nitrogen more than 50 years ago with plots that had never been fertilized. Despite the length of time that had passed and the fact that the fertilized plots were small, we found obvious signs of nitrogen effects, particularly in the composition of species in the bottom layer. Even 50 years after nitrogen fertilization was discontinued we found nitrogen-loving mosses in the areas that had previously been fertilized with nitrogen. There were also differences between the myc-

Suggestions for further reading: *Diekmann M. and Falkengren-Grerup U. A New Species Index for Forest Vascular Plants: Development of Functional Indices Based on Mineralisation Rates of Various Forms of Soil Nitrogen. 1998. J. Ecol. 86, 269-283.*

below: **figure 4** *Effects of various nitrogen doses on fungi in forest. Occurrence of fruiting bodies of Cortinarius spp. and Lactarius rufus. Same fertilization as in previous diagram.*



orrhizal fungi in the different plots. There were fewer fruiting bodies of Rusulla, a genus that is known to include many species that react negatively to increased nitrogen availability.

Mechanisms underlying changes in vegetation

The levels of free amino acids in plants were very much higher in the plots fertilized with nitrogen, which indicates that the nitrogen status of these plants was substantially affected (fig. 3). In plots where nitrogen fertilization had been discontinued, the nitrogen status of the plants was close to the control levels. Nitrogen fertilization also significantly affected the production of sporophores in mycorrhizal fungi. For example, in fertilized plots the occurence of *Cortinarius spp.* substantially decreased, while plots with discontinued nitrogen fertilization were dominated by *Lactarius rufus* (fig.4).

Long-term effects of nitrogen input

The results of the above trials indicate 1) that nitrogen has a radical effect on the ground vegetation in coniferous forests, 2) that this effect is long-term. How does the vegetation that is affected by nitrogen deposition recover when the deposition ceases? Our results are based on experiments carried out on rather small plots. As a result, the species that disappeared from the fertilized plots grow nearby, which makes it possible for them to spread to the previously fertilized areas. Nitrogen deposition affects large areas, and the species that disappear may therefore find it difficult to recolonize the affected areas when the deposition decreases. The changes in the composition of species that occur in the wake of nitrogen deposition therefore probably persist for a long time.

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Diekmann, M. and Falkengren-Grerup, U. Prediction of Species Response to Atmospheric Nitrogen Deposition. (Revised manuscript).

U. Bertills and T. Näsholm (eds.). Effects of Nitrogen Deposition on Forest Ecosystem. Swedish Environmental Protection Agency Report 5067

*By Per Erik Karlsson
and Håkan Pleijel*

Effects of ground-level ozone on forests and crops

A new generation of critical levels is emerging which will take into account both the ozone flux to vegetation and the differences in ozone exposure in Europe.

■ ***above:*** *Potato leaves exposed to ozone.*

There are many indications that the improvements agreed under the Gothenburg Protocol in 1999 will not be sufficient to achieve the critical level objective, which is defined as follows: "concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur, according to present knowledge".

This knowledge has already increased thanks to continued ozone research. Studies of the effects of ozone on plants in various places have shown that there are geographical differences that were not previously recognized. This means that the methods of calculation used to establish critical levels need to be revised. As regards ozone research, the focus of the ASTA Programme is therefore on applying a new approach to the evaluation of existing experimental data. One aim is to estimate the effects in quantitative and economic terms of ozone in agricultural and forest ecosystems in Sweden and Europe.

Critical levels for ozone – a new generation is emerging

Prior to the negotiation of the Gothenburg Protocol a new exposure index was introduced called AOT40 (Accumulated Exposure Over the Threshold 40 ppb Ozone). This is a measure of the accumulated exceedance of the ambient air ozone concentration 40 ppb.

The critical level is selected in order to protect the most sensitive receptor (plant species) under the most sensitive conditions imaginable. Critical levels based on AOT40 have been determined for agricultural crops, natural vegetation and forest trees. In order to go a step further and make quantitative and economic estimates of the effects of ozone on vegetation it will be necessary, however, to elaborate new critical levels. These levels are generally referred to as Level II, and the object is to adjust the new critical level to the variation in ozone sensitivity among species in different geographical areas.

Ozone molecules only have an effect when they are absorbed inside leaves or needles – a process called Stomata conductance. The ozone concentration in the air, together with Stomata conductance, is the most important factor determining ozone uptake. It has therefore been recognized that AOT40, a measure of the ozone level in the air, is not sufficient to explain the effects of ozone on plants. The ozone flux to the inside of plants must also be taken into account. A flux-based dose concept was widely accepted at an UN-ECE conference in April 1999 in Gerzensee, Switzerland, and it was declared that all effect-related ozone research should be based on fluxes within a year or two. One declared objective of the project is therefore to express the existing experimental data in terms of ozone uptake.

Ozone uptake and effects on forests

The impact of ozone on the growth of young trees was previ-

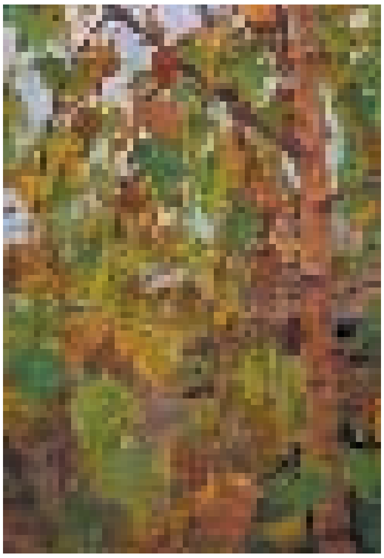
below: *A birch that has been exposed during daytime to ozone levels of about 60 ppb above ambient levels. Note that the leaf veins are pale and there are brownish areas between them. With normal ageing the leaf veins are green and the areas between them yellow.*

ously tested in multi-year experiments in open-top chambers at Östad, 40 km northeast of Gothenburg. In several experiments young Norway spruces were exposed to ozone in combination with drought stress and nutrient deficiency in the form of phosphorus deficiency during four-year periods. Young birches were exposed to ozone in a two-year experiment. The growth of the trees was monitored by continuous harvesting of biomass, including roots.

A simulation model has been developed within the ASTA programme for the purpose of calculating ozone uptake in spruce needles, and work is in progress on further development of this model to include birches. The effects of ozone on growth in spruces can now be expressed both in AOT40 and in terms of ozone uptake (CUO_3, Cumulated Uptake of Ozone).

Since no interaction was found between ozone and the combined treatments, the results of the various experiments involving spruce were evaluated together. The negative impact on the growth of Norway spruce shows a clear correlation with AOT40 (fig. A). The same strong correlation exists where the impact on growth is related to cumulated ozone uptake (fig. B).

Studies of ozone effects have also been performed on birch. The growth reduction in response to an ozone dose based on AOT40 is greater in birch than in spruce. The symptoms of ozone exposure are also more visible in birch than in spruce. Birch leaves also have much higher stomata conductance than spruce needles. Therefore, when we can establish the relationship between ozone uptake and the impact on growth also for birch, we will probably find a correlation similar to that for spruce.



Our results show for the first time a statistically significant correlation between growth of young Norway spruces and ozone levels (AOT40) and cumulated ozone uptake, respectively. The results are representative for young spruces aged 0-10 years. According to our results for 10-year-old spruces, the effect of ozone exposure at the present critical level (10 ppm h/year) is a cumulated growth reduction of about 8 percent (fig. A). In southern Sweden the present ozone levels are about the same as the critical level.

Ozone impact on potatoes

In 2000 the research on the effects of ozone on agricultural crops concentrated on two aspects: evaluation of ozone uptake and ozone effects on potatoes, based on data from the EU programme CHIP, and estimates of ozone exposure by means of various exposure indices.

The exposure of potatoes to ozone causes visible leaf damage. The CHIP Programme examined the effects of ozone damage on potato crops. Our analysis of the CHIP Programme data shows that:

- current ozone levels in Europe can reduce potato yields,
- the effects are smaller than those on wheat,
- the effects are best explained in terms of ozone uptake (COU_3), and
- potatoes grown in the Nordic countries are more sensitive to ozone than those in central Europe.

More than 3,000 measurements of leaf conductance from five places carried out during a two-year period (in Sweden, Finland, Belgium, Germany and the United Kingdom) were used to calibrate the model for the effects of external factors on conductance. The results will be published in a theme issue of the European Journal of Agronomy.

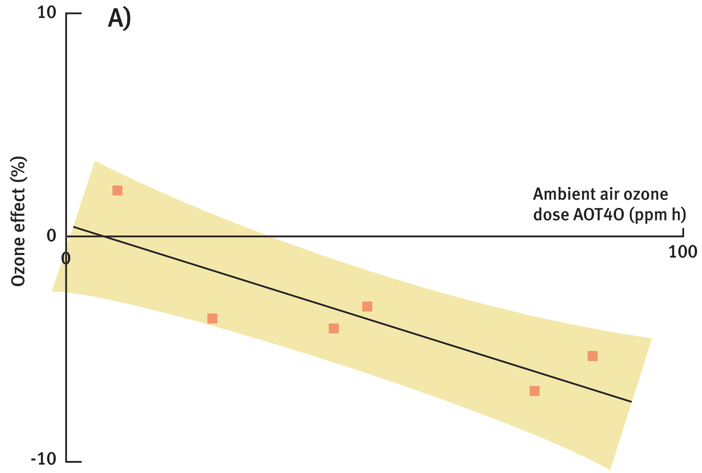
Ozone exposure based on levels and uptake

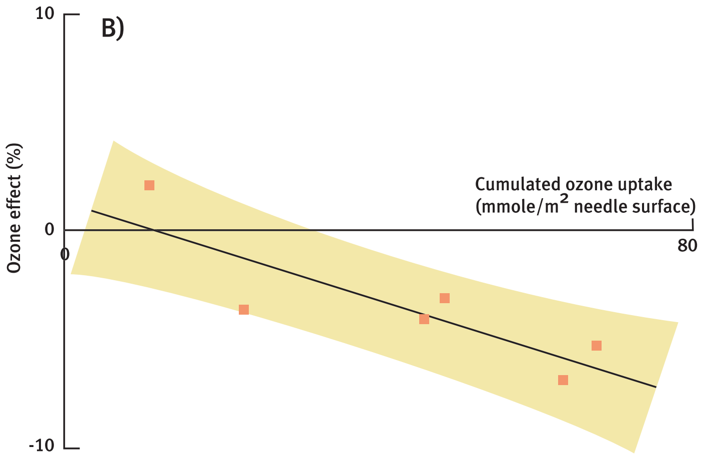
Within the ASTA programme we have also carried out direct comparisons between ambient air ozone levels, as AOT40, and ozone uptake. Eight years' measurements of ozone and climatic factors were used to calculate ozone levels and ozone uptake. They showed clearly that the ozone level (AOT40) depends on altitude. This is due to strong ozone concentration gradients over the crop field, with increasing concentrations higher up from the ground.

The correlation between AOT40 and ozone uptake turned out to be rather weak. For example, AOT40 was much higher in 1994 than 1995. The difference in ozone uptake during those years was moderate, however, since the conditions for high leaf conductance and consequently high ozone uptake were more favourable in 1995 and neutralized the effect of the ozone air concentrations.

In 2001 research will continue on the conductance model for wheat, and will include estimates of the differences in ozone uptake between field chambers and the field and estimates of crop losses in wheat and potatoes due to ozone.

diagrams below: *Effects of ozone on young trees. Total biomass in young spruces (four-seven years) in relation to A) AOT40 in daylight and B) cumulated ozone uptake. The spruces were exposed for four years in field chambers in combination with drought stress or in combination with nutrient deficiency in the form of phosphorus deficiency. The statistically significant correlation between growth and AOT40 and Cumulated ozone uptake, respectively, within the 95 percent confidence interval is indicated in yellow.*





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Suggestions for further reading: *Pleijel, H (ed). 1999. Ground-Level Ozone - A Threat to Vegetation. Swedish Environmental Protection Agency Report 4970.*

By Hans Christen Hansson, Erik Swietlicki, Adam Kristensson and Peter Tunved

The origin and transmission of particles

The discovery that particles may have an impact on health has boosted studies of the origin and composition of particles. The first assessments have now been completed.

The aim of this ASTA subprogramme is to increase the basic knowledge and quantify the importance of long-range transported particle fractions. The results of the subprogramme should be implemented in the structure of the EMEP programme on emissions, improving the parameterization of particle formation, transport and deposition.

In 2000 the subprogramme concentrated on building up a new measuring station at Vavihill on the Söderåsen ridge in the southern province of Skåne and continued with its continuous sampling at the Aspvreten measuring station south of Stockholm. Aerosol particle distribution measurements at Vavihill started in January 2001. Progress was also made on the database that is to be used for the project, and available data are now being collected. Some preliminary analyses of the data have already been made.

Measuring stations and chemical analyses

The Aspvreten and Vavihill stations are both background stations located in places where measurements have been made for many years within the framework of the national air monitoring programme. Aspvreten is situated in a forest about 80 km south of Stockholm. At present, continual measurements are made of PM2.5 and PM10 particles with the Tapered Element Oscillating Microbalance (TEOM) method and of aerosol size distribution with respect to particles under 0.5 μm with the Differential Mean Particle Size (DMPS) method. Chemical analyses are made, mainly of the organic carbon and black carbon content of aerosols. Some meteorological measurements are also made, as well as ozone measurements.

above: *The measuring station at Aspvreten.*

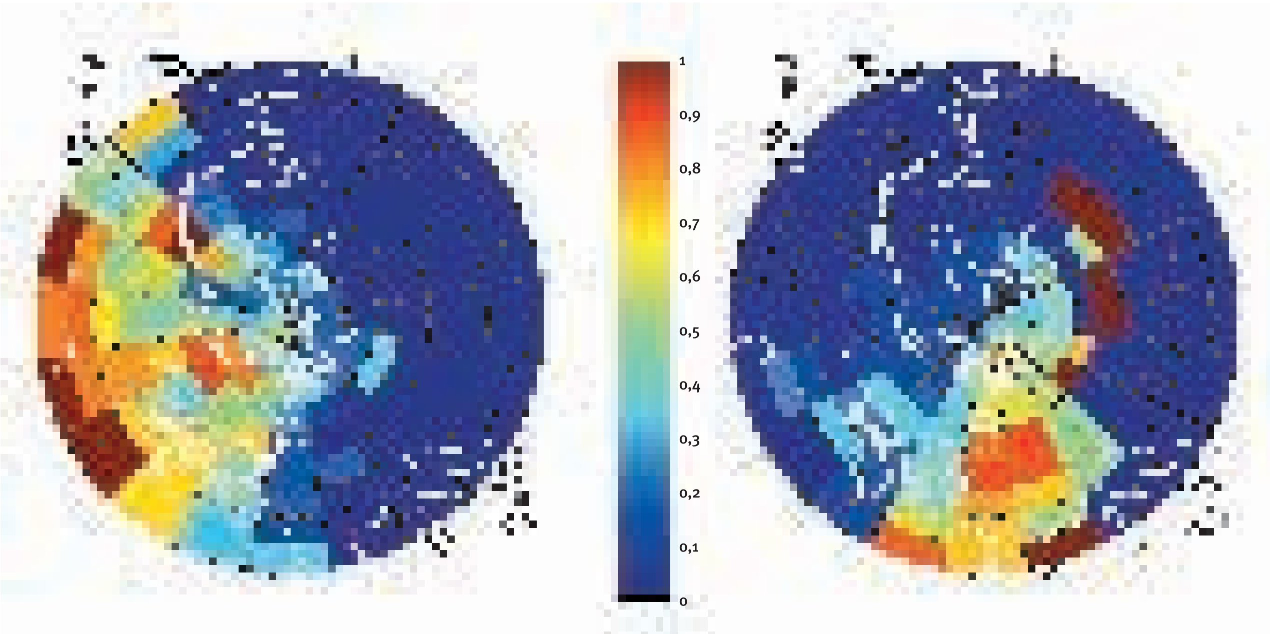
The new Vavihill measuring station is situated at the top of the Söderåsen ridge 60 km north of Malmö. The main task last year was to build up a functioning station. The station will include several aerosol measuring instruments. The newly installed laboratory container is equipped with a DMPS instrument for continuous measurement (every 10 minutes) of aerosol particles with a diameter of less than 0.9 μm. Two particle size separators have also been built. Following calibration these will form the basis of a new DMPS instrument dedicated to automatic long-term measurements. PM2.5/10 are already continuously measured at Vavihill, and continuous aerosol measurements similar to those in Aspvreten will also be carried out.

24-hour filter samples were taken at Vavihill measuring station during the spring of 2000 and these will be used for source-receptor modelling. The samples are divided into fine and coarse fractions of aerosols, i.e. particles of less than 2 μm and particles between 2 and 10 μm. The elemental content has been quantified using PIXE techniques. The results will be used to determine the contribution of various sources to PM2.5 particles.

In addition, a measurement campaign is planned for the hygroscopic properties of the particles. Measurements will be carried out simultaneously at both Aspvreten and Vavihill using the Hydroscopic Tandem Differential Mobility Analyser (HTDMA). The measurements will start in March 2001 and continue for two to four weeks. The results will provide important information on changes in hygroscopic properties during transport between various stations. The content of organic ions in aerosols may possibly be studied at a later stage. In that case these measurements will also be made in the form of campaigns.

Buildup of the database

All measurement data will be collected in a common database which, apart from parti-



cle data, will also include some meteorological data. Thanks to our collaboration with related projects it will be possible to include data from three measuring stations in Finland. These stations will contribute aerosol particle size distribution, among other things. There is a possibility that data from other countries will be included in the database too. This means that there will be a large geographical area to work on, which is important in studies of inputs from various sources. The database will act as an important tool for the evaluation of various processes that affect Nordic aerosols.

Survey of the origin of particles

Work has started on a preliminary analysis and structuring of the physical measurements. The following aerosol characteristics have been established by analysing trajectories and measurements with DMPS at Aspvreten. Polar and Arctic air masses contain the highest concentrations of small particles, while the highest concentrations of larger particles occur where the air originates from the continent. By examining the origin of the air it is possible to obtain information indicating the probability of an aerosol fulfilling a certain criterion after having passed a specific area.

Related projects

A report is being prepared in cooperation with the Swedish Environmental Protection Agency and the Swedish Meteorological and Hydrological Institute on a national survey of the occurrence of particles on the basis of PM2.5/10 measurements. This will represent a significant component of the Agency's reporting to the Ministry of the Environment on the need of new limit values for particles.

The model for particles transported over long distances – the EMEP model – is being developed in cooperation with the Norwegian Meteorological Institute and Helsinki University.

The project is funded by the Nordic Council of Ministers. Work is proceeding according to plan, and the results so far indicate that long-range transports account for a substantial proportion of the particle levels in ambient air. Local sources only dominate in environments with very heavy traffic or in connection with altitude inversion.

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above: *Transport of particles to Sweden. The colormap shows the probability for two specific conditions at Aspvreten: Left, air arriving at Aspvreten with high concentration of small particles and right air arriving with high concentration of large particles. It shows the possibility that a predefined condition is fullfilled, for example high concentration of small particles.*

By Rolf Lidskog
and Göran Sundqvist

The role of science in environmental policy

Does science have a role in international negotiations on the environment, or are they determined mainly by economic and political factors?

The Convention on Long-Range Transboundary Air Pollution (CLRTAP) is one of the earliest environmental conventions. The work done within the framework of this convention is regarded as one of the best examples of cooperation between researchers and policymakers for the purpose of ensuring effective control of an international environmental problem. Joint measuring and research programmes have been set up within the framework of the Convention in which researchers from different countries collaborate, as well as working groups in which researchers and policymakers can meet and discuss the need of both scientific data and political decisions.

ASTA's social science subprogramme focuses on the connection between research results and decisions on measures, and on how these measures are implemented. It deals with questions such as: How is scientific knowledge produced? How important are research results for decisions on measures? What do scientific experts do to communicate their results? What arrangements are there for cooperation between researchers and policymakers? How are conflicts between scientific fact and political recognition and legitimacy reconciled?

CLRTAP and the EU's air pollution control programme are studied within the ASTA Programme. Comparisons are also made between CLRTAP and other relevant conventions, in particular the Framework Convention on Climate Change.

International regimes

Social science research relating to international environmental policy often takes the regime concept as its starting-point. A regime consists of principles, norms, rules and decision-making procedures on which the parties focus their expectations and on which broad agreement can be reached. International regimes offer a forum for cooperation between independent states whose purpose is to ensure that these states do not act purely on the basis of national interests when it comes to transnational issues.

Regimes are weak institutions to the extent that they are only based on a normative system between nation-states. Consequently they do not have the option of imposing sanctions as in a nation-state. Regime research often addresses the question of how regimes can achieve their objectives effectively despite this limitation.

The role of science

The importance of scientific knowledge is under debate in connection with studies of regimes. Some researchers play down the role of science and regard regimes as negotiating forums for nation-states which are primarily interested in looking after their national interests. Other researchers assign a crucial role to science. They claim that access to a common knowledge base is crucial to the building of effective regimes.

The role of science in the

formulation, development and implementation of environmental regimes is thus controversial. The crux of the debate is whether scientific knowledge is the most important factor for the development of regimes, or whether it only has a marginal role in the negotiation process, which is driven by the political interests of nation-states.

A sociological approach

Nowadays the emphasis in the sociology of science is on the interaction and interdependence between science and politics. In accordance with this approach science is not regarded as an external factor that in some cases can influence the development of a regime. Nor can scientific knowledge, represented by epistemic communities, shape regimes without taking political factors into account. For a regime to be effective, a mutual relationship must be established between scientific knowledge and political reality. For this reason it is important to study how parties to a regime perceive and assess scientific knowledge, not least with regard to what extent it is seen as authoritative and useful.

The importance of science as a social and political force must be explained and cannot be taken for granted.

The social science strand of the ASTA Programme analyses the role of science in international air pollution control efforts. The significant role of science in this regime may be illustrated by the following recapitulation of its history.

Critical loads – a useful concept

The concept of critical loads was introduced at the end of the 1980s. Since 1994, when the second sulphur protocol was adopted, the concept has acted as a guideline in connection with the formulation of measures within the CLRTAP framework and recently also for the EU's air pollution control activities.

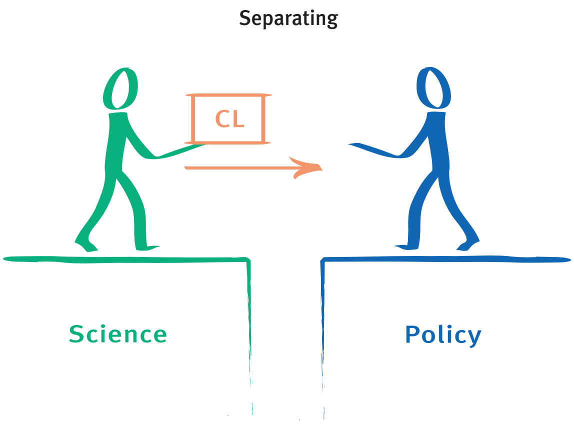
Action can only be based on the concept of critical loads where there is detailed knowledge about the sensitivity of ecosystems (lakes, soils and crops). Differentiated maps of Europe have been produced and modelling is based on the measured sensitivity of ecosystems in order to establish the most cost-effective emission reductions. The regime as a whole is related to this measuring and modelling system.

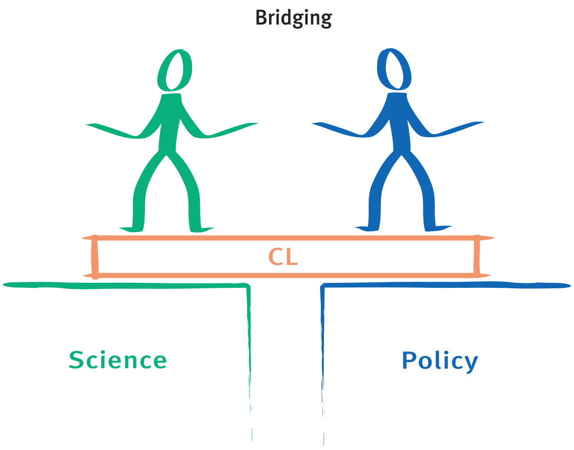
From pointing the finger at 'bad guys' and 'dirt-bags' CLRTAP has now moved on to identifying sensitive areas in various regions. This has made it possible to design more sophisticated measures and the relations between the parties are more relaxed. Policy analysts have characterized critical loads as a revolution in pro-environment efforts, which have made it possible for the first time to design measures on the basis of scientific environmental criteria rather than arbitrary percentage reductions determined with reference to political considerations.

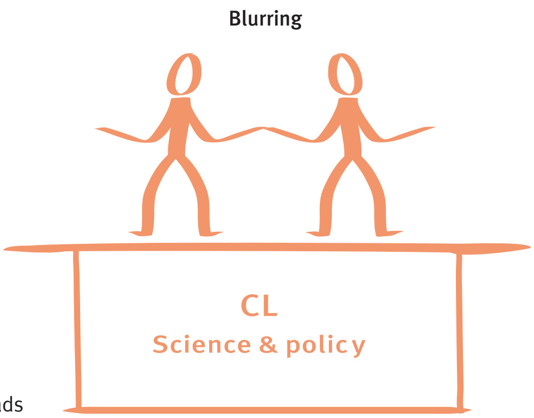
On closer inspection, however, the scientific basis for these action strategies is not uncontroversial. Critical loads are a 'threshold concept', but how are these thresholds established? It is no easy task to decide what is an acceptable degradation of an ecosystem. Critical loads are based on a simplification of natural processes. Individual ecosystems are selected as indicators, specific effects on these ecosystems are studied and threshold levels are determined. Despite these simplifications and uncertainties the concept is popular among many researchers who claim that it leads to a better understanding of soil acidification, eutrophication and effects on vegetation.

Others emphasize the political importance of the concept. In their view, its main advantage is that it makes it possible to formulate equitable and cost-effective action strategies.

There are, therefore, many different views on how the concept of critical loads can be used in air pollution control activities. One important kind of use-







CL - Critical Loads

fulness is that the concept has had an integrating function in these activities in the sense that it has been adopted by both politicians and researchers and has thus facilitated communication between these two groups.

How do science and politics collaborate?

Within the framework of this subprogramme we have studied how the concept of critical loads is used. There are obvious differences, and we have distinguished three different approaches to the relationship between science and politics within the CLRTAP framework.

Separating: one group regards critical loads as a way of recommending science-based action. There should be a clear borderline between science and policy, and policy should be based on science. Action that is based on science can be successful.

Bridging: another group considers that the most important function of critical loads is to create bridges between researchers and policymakers. Critical loads can be used and understood by both groups. Even if the two groups understand the concept somewhat differently, the important thing is that it creates interest and motivation with respect to air pollution control and facilitates communication between these two worlds.

Blurring: a third group claims that

the concept not only makes communication between researchers and policymakers possible, but that it even results in their agreeing on the cause of the problems, on relevant action and on how it should be taken. In the most enthusiastic descriptions researchers and policymakers are integrated so well that the differences between them are almost eliminated.

One conclusion that we can draw from our study is that critical loads are a robust concept that has proved to be sufficiently flexible to be meaningful both to researchers, politicians and the general public. It shapes both science and policies and creates both knowledge and values. The question is, however, to what extent it can continue to do so or whether it will be replaced by other concepts around which science and politics can cooperate.

Interaction in European cooperation

Within the framework of European air pollution control efforts, which are based on intimate cooperation between research and public policy, there is scope for political manoeuvring under the guise of credible science. Measures based on critical loads place stringent demands on science when it comes to meeting the expectations generated by this concept. There is sometimes considerable uncertainty about the sensitivity of ecosystems and thus about what the most cost-effective measures are. The chosen action strategies are basically the result of political choices and should be understood and analysed as such.

It is therefore not acceptable to assume that a science-based environmental regime makes political choices unnecessary. On the contrary, a science-based regime is the result of a social system that comprises both political negotiations and scientific practice.

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The programme is being implemented by the Section of Science and Technology Studies, Göteborg University.

Suggestions for further reading: *Haas, P. M. (ed.), Knowledge, Power, and International Policy Coordination. 1992. Columbia, SC: University of South Carolina Press. Young, O. R. (ed.),*

The Effectiveness of International Environmental Regimes: Causal Connections and Behavioral Mechanisms. 1999. Cambridge, Mass.: The MIT Press.

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