AIR POLLUTION AND CLIMATE SERIES

10

Acidification in 2010

An assessment of the situation at the end of next decade

Analyzing the threats to species and ecosystems that are likely to remain despite lowered emissions of acidifying air pollutants

By
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THE SWEDISH
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ON ACID RAIN

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Preface

The marked drop in the emissions of acidifying air pollutants that is expected to take place in Europe during the next decade does not mean that acidification will no longer be a threat to the environment. There is on the contrary every likelihood of the critical load for acid depositions being exceeded over great areas in 2010, and of acidification remaining a problem for decades thereafter.

It is by 2010 that the various programs for reducing emissions are supposed to have been carried out. Together with the Swedish Environmental Protection Agency, we therefore commissioned the Swedish Environmental Research Institute, IVL, to make this assessment of the situation as it is likely to be, under various assumptions, at that time and so uncover the latent threat to animal and plant species as well as areas of special interest from the point of view of conservation.

It is to be regarded as a pilot study only. A more penetrating analysis, with a more detailed description of the extent and the effects of acidification, desirable as it would have been, was however beyond our means at the time.

Looks of this kind into the future will be needed as a guide for decision makers in working out strategies for dealing with the problem of acidification. We therefore hope that further – and preferably deeper – studies will be made not only in Sweden but in other countries as well.

Nevertheless we hope that even the present one will give decision makers as well as the general public an idea of the problems that will remain after 2010 and so an appreciation of the need for further measures to control the emissions of acidifying air pollutants.

Göteborg, November 1999

Christer Ågren

Director, The Swedish NGO Secretariat on Acid Rain

Summary and conclusions

In 1990 depositions of acidic substances were exceeding the critical load over a great part of Sweden. Over the next ten years however the load will become considerably reduced as a result of measures already taken and others that are planned – according to a reference scenario in which depositions over various parts of Europe have been calculated under the assumption that the agreed measures actually will be undertaken. If in addition the aims of the EU's proposed strategies for dealing with acidification and the problem of ozone were put into practice, a marked further improvement could be expected by 2010, all as compared with the situation in 1990.

There will in any case be an improvement. But if one takes notice of the information presented by the international research institute IIASA, it is evident that acidification will not cease in Europe even if the most far-reaching proposals are carried out. While the problem will be greatest in some relatively densely populated areas on the continent and in Great Britain, acidification will continue even in some parts of Sweden. It will be worst in the southern and southwestern parts of the country that are already badly affected. There, according to IIASA's calculations, 5 to 10 per cent of the ecosystems will go on being acidified. Acidification is likely to remain a problem, too, at the southern end of the mountain region, where there are some parts both with high sensitivity and relatively heavy depositions of pollutants. Computer modelling also indicates a risk for continued acidification in the very far north, although there is some uncertainty as to whether there is a real risk there.

A great number of rare or endangered species that are sensitive to acidification are found just in those parts of Sweden where acidification is likely to remain a problem for some time. They occur in most groups of organisms and in environments both terrestrial (mainly mosses, lichens, and fungi) and aquatic (mainly invertebrates, but also some vertebrates and mosses). The threat to these is expected to be greatest in southwestern Sweden, for which region a deeper analysis of the areas that are likely to be most exposed would be of great value. The aim should be to identify those environments that are characterized by a combination of 1) heavy depositions, 2) high sensitivity, and 3) a great natural value in the form of species that are worth preserving, as well as of nature reserves, etc. Those suggested in this report include the Sandsjöbacka area, the Ätran valley and Högvadån stream in southwestern Sweden, and Fulufjället with its surroundings in the centre of the country. With acidification tending to become less widespread, attention should now be directed towards identifying future "hot spots."

Despite an overall reduction of the areas in which depositions are greater than the ecosystems can withstand, there are good reasons not to be too optimistic regarding an improvement of the situation as regards acidification. One outstanding reason is the long time that recovery is likely to take. Computer modelling indicates that although a 70-per-cent reduction of sulphur depositions should make for some improvement in the quality of the runoff water from most ecosys-

tems, base saturation will continue to drop over large areas where the soil is now acidified. Acid flushes, too, with sudden flows of water with greatly increased acidity, will continue to be a problem, especially for running-water organisms. The present computer models for assessing critical loads and the way they are being exceeded fail to cope with such dynamic effects.

There is also the difficulty that the models used for studying depositions and exceeding of the critical loads for pollutants have to work from maps with relatively large squares – now l50xl50 km, but later to be 50x50 km. Within such squares the depositions can vary considerably, and there may well be parts of them where they are much greater than the model indicates. A further reason for caution is that the models may underestimate the acidifying effects when the depositions of base cations fall, meaning that the level at which acid loads are critical will be still lower.

1. Background

Acidification has been judged one of Sweden's most serious environmental problem since as far back as the late sixties. Sweden is one of those countries in Europe where the geological conditions, and to some extent also the climate, result in an environment that is generally sensitive to acidification. Now however, through international cooperation within the Convention on Long Range Transboundary Air Pollution, and more recently within the European Union, the emissions of acidifying substances have begun to decline in Europe, and the trend is expected to continue and accelerate as a result both of the EU's acidification strategy and a new multi-pollutant protocol under the said Convention. A considerable reduction of emissions will thus be likely over the next ten years – leading in turn to less exceeding of the critical loads.

It was in view of all this that in the summer of 1998 the Swedish NGO Secretariat on Acid Rain and the Swedish Environmental Protection Agency commissioned the IVL to make a preliminary study of the extent to which critical loads would be exceeded in Sweden in future and of the biological consequences. The outcome is this report, giving an estimate of the coming exceeding of critical loads, and of which areas, ecosystems, and species can be judged to be endangered even after the year 2010. The data and sources of information that have been drawn on are listed in an appendix.

2. Aim of the study

Our assignment has been:

1. To use existing European data bases to compare previous depositions with those that would result from the application of two scenarios (REF and F1) for future depositions of acidifying substances (sulphur and nitrogen).

2. Proceeding from the situation in 1990 (Y90), and those resulting from REF and F1, to analyze future exceedings of critical loads for acidification in Sweden.

3. To determine, from the outcomes of 1 and 2, which species, ecosystems, and protected areas will be at greatest risk of damage from acidification in future, even if the depositions of acidifying substances should then be much lower.

Y90 has been used to describe the situation in 1990, except that for the calculations and comparisons the critical load has been estimated and defined in the same way as it is today (in other words, not as in 1990).

REF represents the reductions in emissions and depositions as they should be in 2010 if the measures already decided upon, nationally and internationally, are fully carried out.

F1 adds to REF the reductions of emissions and depositions that can be expected by 2010 if the EU strategies for attacking acidification and ozone pollution should be carried out to the extent proposed by the environmental directorate of the EU Commission in the autumn of 1998.

The conclusions are here based largely on the information in the report made by IIASA at the request of the EU Commission, which is also being used by the Commission itself as the base for the directive it is preparing for national ceilings on emissions of acidifying and ozone-forming air pollutants (Amann et al., 1998). Further information about the scenarios that have been studied can be found in Ågren (1998). The emission reductions that would be obtained in 2010, through application of the REF and F1 scenarios, both for the European Union with it's fifteen members and for the rest of Europe, are shown in Table 1.

Table 1. Reduction of the emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) from the levels of 1990, according to the REF and F1 scenarios, for the fifteen countries constituting the European Union and those of the rest of Europe.

	SO_2		NO_x		NH_3	
	REF	F1	REF	F1	REF	F1
EU 15	70%	77%	45%	53%	12%	22%
Rest of Europe	55%	55%	31%	31%	14%	14%

3. Exceeding of the critical loads

3.1. The IIASA figures

In it's report of October 1998, the IIASA presents the calculations it has made concerning the extent to which the critical loads would be exceeded after the measures have been completed in accordance with the F1 scenario (Amann et al., 1998). The proportion of unprotected ecosystems that would consequently remain within the EMEP's 150x150 km squares is shown in Figure 2. The highest figure for Sweden would be 8 per cent in a couple of squares. Under REF it would have been 12 per cent, and up to 30 per cent for some squares in the most exposed parts of Europe (mainly the border regions between Germany, the Netherlands, and Belgium). In a few cases more than 50 per cent of the ecosystems would remain unprotected against acidification even if the relatively far-reaching proposals of F1 were carried out. Another difference between Sweden and these parts of Europe is that whereas in Sweden it would largely be aquatic ecosystems that would suffer from excess of critical loads, on the continent it would mostly be terrestrial systems.

In Sweden aquatic ecosystems will be most likely to suffer from excessive depositions of acid. On the continent it will be terrestrial systems.

The exceeding of critical loads can also be expressed as the degree by which they will be exceeded in that 2 per cent of the ecosystem that is most sensitive in each of the EMEP squares (the 2 percentile). According to Amann et al. (1998), for the affected squares in Sweden the excess loading would be more than 100 eq per hectare a year even under the F1 scenario.[1] These two squares are shaded darker in Figure 2.

In the case of the other squares in Sweden where the critical loads would be exceeded, the exceeding would be less than 100 eq under the same scenario (according to IIASA). For the worst affected squares outside Sweden the excess load in the 2 per cent of the ecosystems that is most sensitive would amount to 1000 eq per hectare a year. But only in a few squares in Europe will such high excess loadings occur.

According to Amann et al. (1998), under the REF scenario 4.1 per cent of the Swedish ecosystem area would be subject to depositions in excess of the critical load. Under F1 it would be 3.5 per cent. These figures correspond to 1,600,000 and 1,360,000 hectares. In the Netherlands, which have the greatest excess of critical loads in Europe, the corresponding figures would be 61.9 per cent under REF and 23.7 per cent under F1 (equal to 198,000 and 76,000 hectares). The figure for most of the countries in southern Europe is nearer zero (<1 per cent).

3.2 Scenarios compared for excess loading

For Table 2, information from IIASA and RIVM/CCE concerning depositions and critical loads for the 150x150 km EMEP squares has been used to calculate on the one hand the absolute exceeding of critical

[1] eq stands for equivalents, which are a measure of the number of charges in ions. Each hydrogen ion for instance has one charge, and therefore makes one equivalent. A sulphate ion has two, and so makes two. 100 H^+ eq ha^{-1} yr^{-1} equals 1.6 kg sulphur ha^{-1} yr^{-1}.

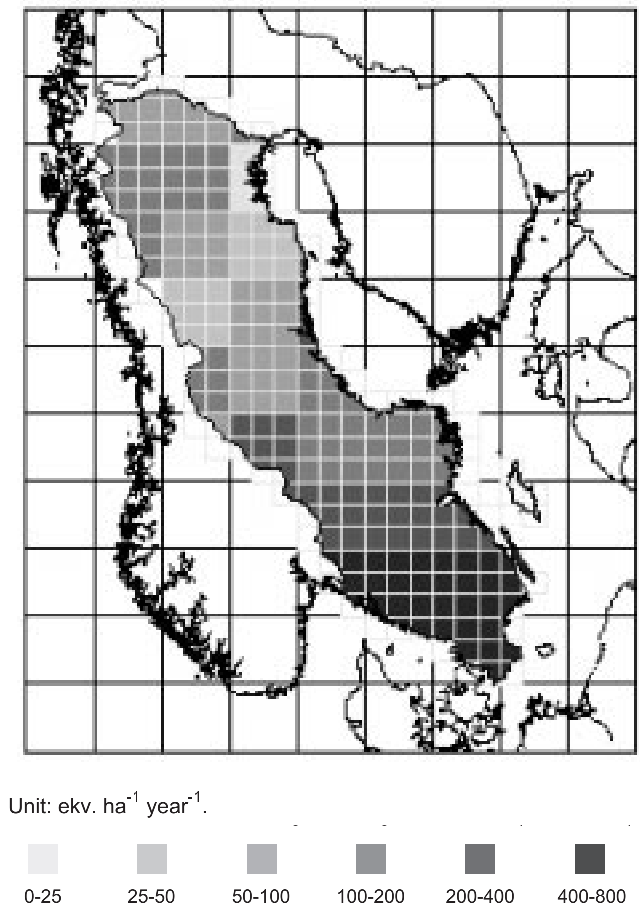
Table 2. Proportion of EMEP squares a) where nitrogen can be expected to contribute to acidification, and b) where the critical load for acidification will be exceeded for 2 and 5 percentiles (i.e. in the 2 and 5 per cent of the most sensitive ecosystems in each square). There are thirty-two squares covering Sweden.

	1990	REF	F1
Nitrogen acidifying	72%	41%	34%
Excess dep. 2%ile	100%	44%	34%
Excess dep. 5%ile	81%	12%	6%

loads and on the other the percentage of EMEP squares where nitrogen depositions contribute to acidification. In making the calculations the median sensitivity of the ecosystems in a certain square has been used to determine the lowest load of nitrogen that would contribute to acidification ($CL_{min\ (N)}$). All depositions of nitrogen above that level have been considered to be potentially acidifying (see also Fig. 4).

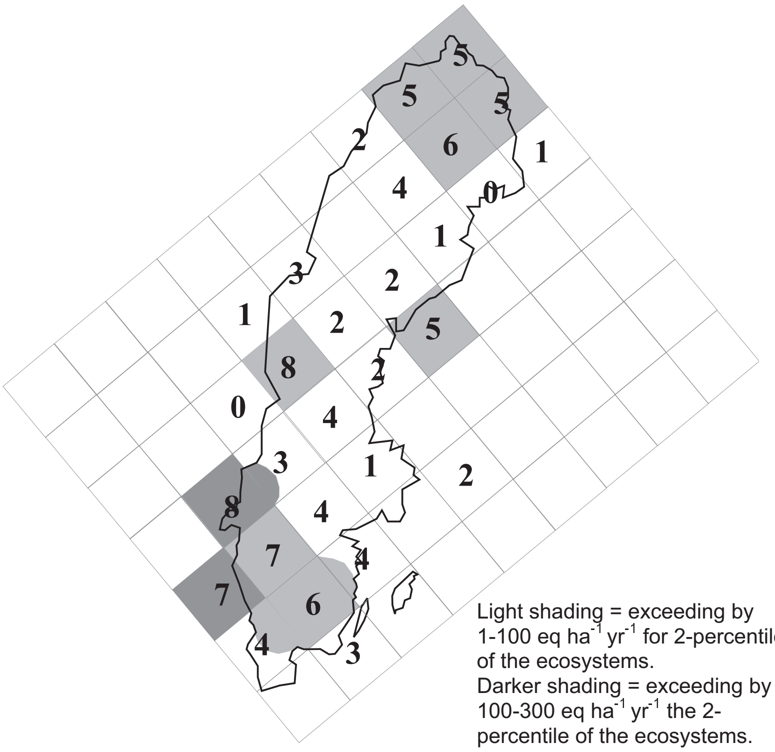
From Table 2 it appears that there will be a considerable improvement in the situation as concerns acidification both for REF and F1, although there is also a considerable difference between the effects of REF and F1.

Figure 1. The overstepping of critical loads (2 percentile) in 1990 (Y90).



It is important to remember, in regard to Figure 1, that using the 150x150 km EMEP squares gives a rather rough picture of the situation. In our discussion of the biological effects of continued acidification further on in this report we have mainly kept to the picture in Figure 2, but without strict observance of the squares' boundaries. We have also used the more detailed information about the distribution of depositions (Section 3.3) and the distribution of sensitivity over the whole country which is available for instance in the National Inventory for lakes and streams described in Section 5. We have however based further analyses on the squares in Figure 2, in which, according to IIASA, more than 5 per cent of the ecosystem area will still suffer above-critical loads even if the proposals of the F1 scenario are carried out. Some parts of the squares that will not, according to IIASA, be so highly overloaded, but adjoin those where 5 per cent of the ecosystem area will still be acidified, have also been taken into account. This applies for instance to some areas abutting on the southern uplands and the border country between Värmland and Dalsland.

Figure 2. Percentage of the ecosystems with excesses of critical load in the EMEP squares under the F1 scenario.



Light shading = exceeding by 1-100 eq ha^{-1} yr^{-1} for 2-percentile of the ecosystems.
Darker shading = exceeding by 100-300 eq ha^{-1} yr^{-1} the 2-percentile of the ecosystems.

3.3. Projected trend of depositions over various parts of Sweden

IVL (Gun Lövblad) has estimated the trend of the fallout from 1994 onwards, using the REF and F1 scenarios, but with a higher geographical resolution than IIASA has employed (i.e. with 50x50 km squares instead of 150x150 km). A similar picture emerges in both cases. To give an idea of the expected reduction, this is shown in Table 3 for the three pollutants in the various regions of the country.

Table 3. Estimated reduction, from 1994 to 2010, of the fallout of acidifying substances over the different regions of Sweden, according to REF and F1.

Region	SO_x		NO_x		NH_x	
	REF	F1	REF	F1	REF	F1
SW Sweden	60	62	20	49	8	22
Blekinge+Skåne	46	58	16	41	10	22
Kronoberg	46	63	18	45	10	23
Stockholm region	36	47	14	38	7	19
South Norrland	36	48	17	39	8	18
North Norrland	27	38	16	37	11	20

As appears from the table, the changes will be greatest for sulphur depositions, and considerably less for reduced nitrogen, with oxidized nitrogen coming somewhere inbetween. The reduction will be markedly greater in South Sweden than in the northern part of the country, especially as regards sulphur. The trend is therefore not only towards distinctly lower depositions of acidifying substances as a whole, but also towards a great increase in the relative role of nitrogen in the acidification process, despite some lessening of its absolute role. It is also quite clear from the table that reductions under the F1 scenario would be much greater than those under REF.

3.4. The geographical distribution of excess critical loads

Relative closeness to continental sources of emissions, combined with high rainfall, make the southwest the "classic" area for acidification.

Figure 2 reveals a pattern for the way the excess critical load for acidification will be spread over Sweden. In the first place there is a belt across the southwestern and southernmost part of the country where a relatively large excess can be expected even if all the proposed measures for reducing the fallout of acidifying substances should have been carried out by 2010. This is the "classic" acidification area for Sweden, where the problem is due partly to high sensitivity, but still more to heavy depositions. The reason for these is both the relative proximity to the emission sources further south in Europe and the area's high rainfall.

Another part of the country where quite considerable exceeding of the critical load may be expected is, according to the IIASA calculations, an area of the mountain region and the inland part of Norrland generally. The risk of it continuing to be so will be greatest for some parts at the southern end of the mountain chain, where sensitivity and depositions are both high. Although the rock formations are calcareous in some parts, in others they are very poor in lime. The precipitation is moreover here and there extremely heavy, and from the point of view of acidification, the situation is especially critical during the thaw.

The thinness of the soil layers makes further for high sensitivity. Yet another factor making it relatively high in these parts is the low net production in many of the ecosystems. This means that the $CL_{min (N)}$ is either very low or practically zero (see Fig. 4). The ecosystems are thus poor at eliminating nitrogen from the acidification process, and so have low levels for critical load. The low temperatures also cause slow weathering, which again makes for high sensitivity. As regards the northernmost parts of Norrland, where according to IIASA there will be a relatively large proportion of unprotected ecosystems, it is difficult to determine with any certainty whether the risk will actually be so great, or whether there is something awry with the computer modelling.

4. Greatest effects in aquatic or terrestrial environments?

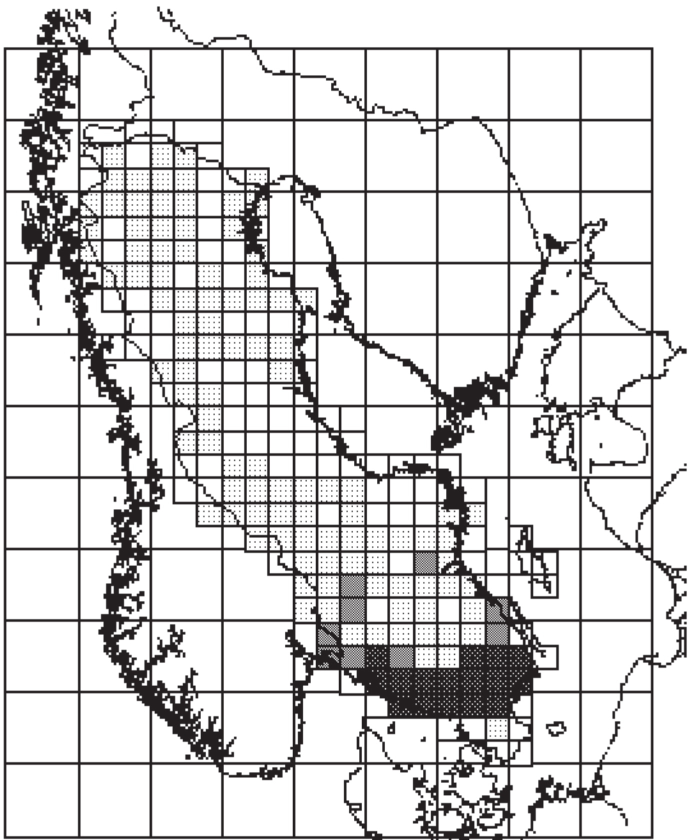
There is general consensus that aquatic ecosystems will be more at risk from acidification and its consequent biological effects than terrestrial systems during the next ten years when depositions have become considerably lower. This applies not only to southwestern Sweden but also to some of the central and northern parts of the country, where IIASA foresees a relatively large area of ecosystem remaining unprotected even if the measures of F1 are carried out. One outstanding reason for this is the occurrence of acid flushes which are liable to cause damage even in systems that are otherwise well buffered and subject at times to only small or moderate excesses of acid. Acid flushes are brief surges of heavily acidified floodwater, often with high concentrations of aluminium and other metals, caused by the snowmelt or by heavy rains following a period of drought.

Since it will be the aquatic ecosystems that are likely to draw the most attention in any further consideration of the acidification problem, we are presenting in Section 5 a more detailed account of the present state of knowledge concerning the way such systems will be affected by excess critical loads.

5. The National Inventory of lakes and streams

This, the latest of such inventories, provides excellent data on the situation up to 1995 as regards the acidification of lakes and streams (Wilander et al., 1998). Combined with data gathered in connection with the national forest survey, this inventory has enabled a calculation to be made of the critical loading in a large number (4763 all told) of lakes and streams. The calculations have been based on the so-called NILU squares measuring 50x50 km, needing 223 to cover the whole country. The geographical resolution is therefore much better than that obtained from the thirty-two EMEP squares. The liming of lakes has also been taken into account. In that case a correction has been made in order to try and determine the level of base cations as it was before liming started. The outcome can be seen in Figure 3.

Figure 3. Extent of the overstepping of critical loads on lakes and stream in Sweden (A. Wilander and Swedish Environmental Protection Agency, 1998).



At present the excess critical loads for acidification occur mostly in parts of southwestern Sweden, mainly because there the overall load of pollutant is still relatively high. There are excesses in practically all the squares of Götaland and westernmost Svealand, as well as in a not inconsiderable number in Norrland (mostly in the regions bordering on the mountain range). The critical loads are being exceeded in 58 per cent of the NILU squares, and very greatly in 11 per cent. In these cases the contribution of nitrogen to acidification has not been taken into account.

The critical loads were being exceeded in more than 10 per cent of the lakes in fifteen of the country's twenty-four local administrative districts. This was most apparent in South Sweden, with excesses in a large proportion (35-63 per cent) of the waters where samples were taken in the Kronoberg, Kalmar, Blekinge, Kristianstad, and Halland districts. In most of the NILU squares for these parts the excess was more than 30 meq m^{-2} yr^{-1}.

The critical load for acidification is found to have been exceeded in nearly half of the lakes with an area of more than one hectare.

From extrapolation of the results of the national inventory it would appear that the critical load is being exceeded in 20 per cent of the lakes in Sweden with a surface area of more than 4 hectares (which means about 10,000 lakes). To that number should of course be added numerous lakes and tarns of less than 4 hectares, probably as many again. In those lakes where samples were taken most of the excess loadings were found in the two smallest categories, from 4 to 10 hectares and 10 to 100, which meant a great majority of the sampled lakes and altogether nearly half of all the country's lakes with a surface area of more than 1 hectare.

Wilander et al. (1998) also made a parallel calculation according to a more complex model. Whereas their other calculation only considered the effects of sulphur, this one also takes in nitrogen. Here it was principally the same model as that used for Table 2 and is described in Figure 4. According to that the critical loads would be exceeded in altogether 42 per cent of the country's lakes. In 16 per cent of them both sulphur and nitrogen were involved. The depositions of nitrogen were so great in the districts of Blekinge, Halland, and Bohuslän that they will definitely have to be reduced if the excess of critical load is to be eliminated.

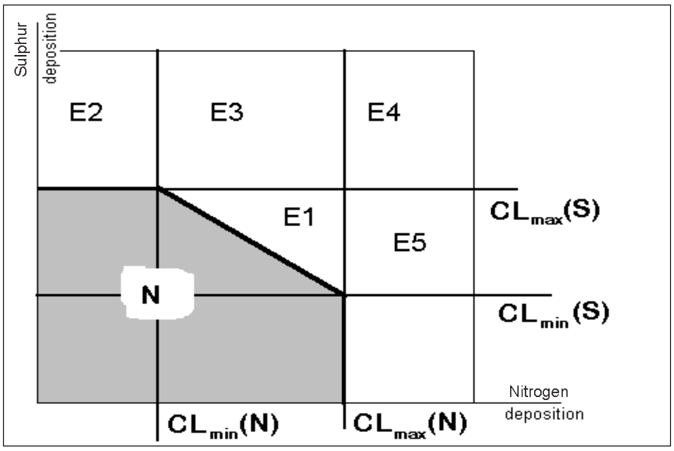
Nitrogen depositions are also causing an exceeding of the load in a number of lakes in the mountains. Because the normal uptake of nitrogen is very slow in this northern region of forests and bare mountains, only relatively small additions are needed to bring depositions over the critical level. The total of lakes where the critical level for acidification was exceeded was much greater with this model. There is however some uncertainty, since the circulation processes for nitrogen are to some extent poorly quantified. The findings can nevertheless well serve as an indication of the importance of nitrogen in the acidification process. Since the emissions of sulphur will be diminishing more rapidly in Europe than those of nitrogen during the next decade, the importance of nitrogen will only increase.

Given the reduction of depositions that is envisaged for 2010 in the REF and F1 scenarios, those of sulphur will fall still further than they are now doing, with the result that in many parts of Sweden they will drop below the critical levels. In South Sweden, however, the continuance of high depositions will mean that the critical loads will still be exceeded, as they also will in those parts of northern Sweden where the situation would in any case have remained critical. There however the $CL_{min(N)}$ is very low, largely because of the absence of effective nitrogen sinks in the unexploited forest regions of the foothills.

Principle for critical load

Sensitive lakes often have a very low $CL_{min(N)}$, which means that the shaded area in Figure 4 must also be relatively small. As regards the squares outside that area, changes for objects within E2 and E3 to the effect that the critical loading will not be exceeded can only come about as a result of reduced sulphur depositions. To produce the same effect for objects within E4, depositions both of sulphur and nitrogen will have to be reduced. For El it must be either N or S, although possibly in suitable combinations, which may also be the case for objects in E3 and E5 if they lie close to square E4.

Figure 4. Principle for critical load according to the FAB model. The squares mark the boundaries between different alternatives for preventing the exceeding of the critical load.



N = the area where the combination of depositions will not cause the critical load to be exceeded in lakes and runoff areas.
CL_{min} = the level at which the substance will be fully assimilated in the runoff area and no acidification of the lakes will take place.
CL_{max} = the level that the runoff area plus lakes can withstand provided there is no effect from the other substance.

6. Biological effects when critical loads are exceeded

The biological changes in an ecosystem can be weighed variously. Important from an ethical point of view is the threat to rare species or such as are red-listed (that is to say, more or less endangered). The question is then whether acid depositions would be threatening the survival of certain species in the long term: within a defined region, in Sweden generally, or in the worst instance over a still wider area. Only exceptionally however are the rarer species vital to the functioning of an ecosystem. From the functional aspect, which means essentially the ability of the system to go on producing, what is usually more important is whether ordinary species disappear or move in as a result of acidification. Here however we shall, in accordance with our assignment, concentrate on species that are unusual in some way or other, on areas that are already protected or would be worth protecting.

6.1. Threatened species in various groups of organisms

Table 4 accounts for species that are red-listed and judged by the Swedish Threatened Species Unit (ArtDatabanken) at the Swedish University of Agricultural Sciences to be permanently under threat from air pollution according to Bernes (1994). There acidification was accounted as a separate factor for surface waters. For forest and farmland on the other hand air pollution in general was given as the cause of change. In other words, no differentiation was made between the effects of acidification and, say, eutrophication from depositions of nitrogen, which are known to have an effect on certain ecosystems and groups of organisms. Thus in Table 4 acidification is the sole factor only for surface waters. Otherwise it is air pollution. Although it would be possible to extract from the ArtDatabanken statistics those species in other environments than freshwater that are more specifically in danger from acidification, this would require additional work.

Red-listed species are divided into four categories, in which 0=vanished, 1=acutely threatened, 2=vulnerable, 3=rare, 4=needs watching.

Table 4. Species that have vanished, are endangered, red-listed on account of air pollution (on forest and farm land) and of acidification (freshwater). The figures indicate: vanished/endangered/red-listed. From Bernes (1994).

	forest	farm land	aquatic ecosystems
vascular plants	0/0/0	0/1/1	0/1/1
mosses	6/14/25	3/6/14	1/3/12
lichens	6/30/38	0/6/9	0/0/0
fungi	0/20/45	0/10/16	0/0/0
vertebrates	1/1/1	1/2/4	0/1/12
invertebrates	1/11/23	0/2/4	0/15/41

It should be noted that in the table vascular plants are poorly represented (and the effects probably underestimated), and that fungi and lichen are of no significance in aquatic environments, since they occur very little there. Bernes (1994) does on the other hand report on the effects on species in wetlands and in mountainous regions, although in those places only a few species are endangered by air pollution. In wetlands there are 3 under threat and 7 red-listed (all invertebrates in the latter). In mountain parts one is threatened and 3 are red-listed.

6.1.1. Vascular plants

While the available information in regard to the effects of eutrophication on terrestrial species of vascular plants is relatively large, it is more difficult to distinguish with any certainty the species that are under threat from acidification (according to M. Aronsson, ArtDatabanken).

As concerns Sweden, there is important information regarding the effects of acidification on vascular plants in Skåne, in the far south of the country. Several valuable studies made at the University of Lund have revealed the sensitivity of various species to acidification, as well as changes in the flora of the local deciduous woodlands for the same reason (Falkengren-Grerup l992; Falkengren-Grerup et al., 1995). Among the species that were found to require soil with a relatively high pH value were some that are red-listed: hairy brome (*Bromus ramosus*), threat Category 3; lesser hairy brome (*Bromus benekinii*), Category 4; wood barley (*Hordelymus europaeus*), also Category 4. Another very rare species in the Lund University list, which is also endangered, was enchanter's nightshade (*Circaea lutetiana*). That the lesser hairy brome is relatively sensitive to acidification is confirmed in surveys of a number of plants (Sverdrup & Warfvinge, 1993; Anderson & Brunet, 1993), where sensitivity is expressed as that of root growth to the quotient of base cations to aluminium.

Studies at Lund University have revealed changes in the flora of the local deciduous woodlands as a result of acidification.

It is important to note that the extensive studies of the state of acidification in the deciduous woodlands of Skåne show that the changes in the pH values resulting from acidification have been greater wherever the original pH value was higher (except possibly where there were limestone soils with a very high original pH) (Falkengren-Grerup, 1992). This means that continued acidification must be judged to be a distinct threat to the above-named grasses as well as to other species. Skåne is the part of Sweden that is thought likely to be having the greatest depositions of acidifying substances after 2010 even if the F1 plan is carried out – this despite the fact that the percentage reduction of depositions is expected to be greatest in this part of the country.

The most comprehensive studies of the effects of air pollution on vascular plants in any European country have been made in the Netherlands, followed by some in Britain and Germany. In a summary of the effects of acidification and nitrogen depositions on species diversity in natural and semi-natural vegetation in Europe (to a large extent focused on vascular plants, and especially in the Netherlands and Britain), Bobbink et al. (1998) come to the conclusion that species diversity is most likely to be affected in the following types of ecosystem:

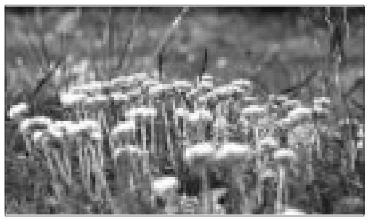
1. Lakes and streams with low buffering capacity.

2. Deciduous and coniferous woods not growing on calcareous soil.

3. Some types of grassland (meadow and pasture) on soils that are poor in calcium carbonate, and heathlands.

According to Bobbink et al. (1998), ecosystems with a fairly good supply of calcium carbonate in the soil, as well as various types of wetland (bogs, marshy land by open water, lowland wet heaths), can in general be expected to be less sensitive to acidification. Depositions of nitrogen can however, by causing eutrophication and consequently affecting competition among species, also have an effect on these kinds of ecosystem. As regards alpine systems the authors account the situation difficult to determine, in respect both of acidification and eutrophication.

The species said by Bobbink et al. (1998) to be endangered by acidification are often rare and already red-listed in many countries on the continent. Many are found on meadow and grazing land, but especially on heathland, of which in Sweden there is most in the southwestern parts of the country, where the ecosystems are likely to remain exposed to acidification even if the F1 plan for reducing emissions should be carried out.



Mountain everlasting (*Antennaria dioica*) is one of a group that may become red-listed. Another, arnica, has already shown a marked decline.

Here, though, it is not a matter of species that are red-listed in Sweden, but such as are considered likely to diminish rapidly as a result of various factors, including the use of fertilizers and changes in land use. Examples are arnica (*Arnica montana*), mountain everlasting (*Antennaria dioica*), and marsh gentian (*Gentiana pneumonanthe*). Although these species are not red-listed, they are subject to discussion in conservation circles, and some may yet become red-listed. Arnica, which is mainly found in the acidified southern parts of Sweden, has already shown marked decline. In the Netherlands, where it has been closely studied, its sensitivity to acidification is well established (see Fennema, 1992, for example). Marsh gentian has also greatly declined. In Sweden it is only found in the southwest, and moreover it supports the caterpillars of the butterfly Alcon blue (*Maculinea alcon*), which is itself red-listed. Mountain everlasting is more widespread in Sweden than either of the other two species.

Studies in the Netherlands indicate that the main cause of decline of many of the species in heathland ecosystems, including those just named, is acidification (Houdijk et al., 1993). Researchers in the Netherlands in particular have noted marked changes, characterized by the displacement of heather (*Calluna vulgaris*) and cross-leaved heath (*Erica tetralix*) by grasses such as wavy hair-grass (*Deschampsia flexuosa*) and purple moorgrass (*Molinia caerulea*) (Aerts & Berendse, 1998). Alteration of the competitive situation due to heavy additions of nitrogen from the atmosphere – in other words, eutrophication – is accounted the primary cause of these changes. It seems however that a decline due to acidification starts before the grasses begin to drive out the heath species (Houdijk et al., 1993).

The general impression one gets from the literature is that, for effects on vascular plants, the eutrophication caused by nitrogen depositions is of much greater importance than acidification. Strong support for this view comes from an extensive statistical survey of the changes in the vascular flora of Skåne (Tyler & Olsson, 1997). Since nitrogen depositions are unlikely to diminish to anything like the same extent as the total deposition of acidifying pollutants, where vascular plants are concerned attention will have to be directed mainly to the effects of eutrophication. But that is a matter that lies outside the scope of this study.

The freshwater environments that have become acidified in the Netherlands differ in the main from the acidified lakes in Sweden, since in the Netherlands they are often small lakes in dune and heath surroundings. The vascular species that are a cause of worry on the continent, such as shoreweed (*Littorella uniflora*), water lobelia (*Lo-*

belia dortmanna), and quillwort (*Isoëtes* spp.), will probably suffer from acidification in Sweden too. Whereas in Sweden these species are relatively common, they are very rare in other parts of Europe, and are therefore attracting greater attention for the sake of species conservation. An aquatic plant that is rare in Sweden and has been denoted sensitive to acidification is pillwort (*Pilularia globulifera*) (Fiskesjö & Ingelög, 1985).

6.1.2. Mosses

There are mosses that are sensitive to acidification in the *Ulota* genera. One species that is red-listed is *Ulota coarctata*, which grows on deciduous trees in the neighbourhood of streams or in ravines and on cliffs with ambient air of a high humidity. It favours trees with a smooth bark, mainly aspen but also grey alder, hazel, and willow. The localities are mostly in the southwestern part of the country (Halland and the western half of Västergötland) with its wet climate. Air pollution is estimated to be the great threat to those mosses falling into Category 4 of endangered species.

A moss that is extremely rare in Sweden, where it only occurs in the southwestern corner of the country, is *Hookeria lucens*. This beautiful example is found at the sources of streams and along becks with as yet clean, unacidified water in the wetter parts of the area where the critical loads for acidification are unfortunately likely to be exceeded for some time to come. *Hookeria lucens* does not occur in places with lime-rich water, needing instead lime-poor water with a relatively high pH value, which means that the chances of its being hit by acidification are rather great. It is red-listed and placed in Category 2.

Occurring in places where the critical load for acidification is likely to be exceeded for some time to come, the rare *Hookeria lucens* is especially endangered.

Another species that is sensitive to air pollution, and is moreover rare and red-listed, is *Neckera pumila*, which is only found in the wetter parts of southwestern Sweden. It falls into Category 4 of endangered species (Hallingbäck, 1989). Although it is still found in many places, such as the southern part of Halland, it has not only declined but changed its habitat, now growing on trees with a naturally richer bark (ash) and on younger beech trees than it did formerly (Hallingbäck, pers. comm.).

The scientific literature gives examples of experiments with artificially controlled exposure of mosses to acid rain. Rochefort & Vitt (1988) found that while the species *Tomenthypnum nitens* was stimulated by it, the species *Scorpidium scorpioides* remained unaffected. Both species occur in nutrient-rich fen. Rochefort & Vitt wonder if acid rain may not lead to changes in the competitive situation in that environment, on account of the varying sensitivity of the different species. It does not appear from their study however that the moss flora of rich fens would be likely to suffer from acidification, but rather that the flora in such fens generally shows good resistance to it.

6.1.3 Lichens

It is now generally accepted that many lichens are extremely sensitive to acidification. Proof is seen in the impoverishment of the lichen flora as a result of increased concentrations of sulphur dioxide in the air around cities and large point sources (Hawksworth & Rose, 1970). Several studies have also shown how lichens have re-established themselves in Britain after concentrations have gone down (Gilbert, 1992). There has been found to be a lapse of 5-10 years, the time it takes for lichens to re-colonize after the quality of the air has become such that they can survive. There is now data in Sweden, too, showing that moderately sensitive species are re-establishing themselves around population centres in southwestern Sweden (Naturcentrum AB and

IVL, unpublished data). Thus in both countries a clear connection can be seen between reduced pollution and biological recovery. From the Swedish studies it also appears that nitrogen oxides have become the leading toxic substances affecting lichens.

A decline of several species of lichen has also been noticed out in the countryside, far from any towns or point sources of pollutants. There is good reason to believe that depositions of acidifying substances have been largely responsible for the decline of lungwort lichens (*Lobaria* spp.) as well as a number of others needing a similar environment in the form of a wet climate and ecological continuity. Among them are many red-listed species of so-called oceanic lichens (occurring primarily in wet regions with a mild winter climate). They include lichens of the *Sticta* and *Pannaria* genera. One species of the latter that has declined markedly is the *Pannaria rubiginosa*, growing on the western side of the country. The lungwort lichens seem to have disappeared in many localities without any apparent cause in the way of changes in land-use practice (Hallingbäck, 1986). Experiments have shown these large-leaved species to be highly sensitive to acidifying substances, although it is sometimes difficult to distinguish between the effects of acidification and of nitrogen, and the toxic effects from gaseous and other atmospheric pollutants. The general evidence is however that the regional pollutant load has been largely responsible for the decline – which has been even greater in other European countries.

The lungwort lichens are typical oceanic species which are indigenous in wet environments on the western side of Europe, but also in the wetter parts of mountain regions. In Sweden the lungworts and other oceanic species are mostly found in the wettest parts of the southwestern region, just where the depositions of acidifying pollutants are likely to remain large. Typical examples of such species are *Lobaria virens* and *Lobaria amplissima*, although they are outnumbered by *Lobaria pulmonaria*, which is thought to be very sensitive indeed to air pollution – assumed to have caused a notable retreat of this last in Skåne (Hallingbäck & Olson, 1987). The species *Lobaria scrobiculata* also grows in the mountainous parts of Sweden, but there it has not declined to the same extent as it has in the southwest. A similar decline of this species has been noted in some parts of Canada (Tomas Hallingbäck, pers. comm.).

Loberia amplissima is one of those lichens that are mostly found in the wettest parts of southwestern Sweden, where acidic depositions are likely to remain excessive.

6.1.4. Fungi

It is well known that additions of nitrogen cause changes in the fungi flora (as evidenced in the form of the spore capsule). Tests with fertilizer are among the ways in which this has been proved (Rühling & Tyler, 1991). Nitrogen is moreover considered to have been the cause of important changes in the composition of the fungi flora in the Netherlands. While the picture is less clear as regards the specific effects of acidification, it is nevertheless known that different species and groups of fungi have different ranges of tolerance to acidity. Mushrooms (*Agaricus*), ink caps (*Coprinus*), and species of the genera *Inocybe* avoid the most acidified soils. Germund Tyler, who has participated in some extensive studies of the fungi flora in South Sweden, puts forward *Cortinarius*, subgenera *Phlegmacium,* as an example of a group that has been forced aside, most probably by acidification. The lack of localities with soil of a sufficiently high pH value or degree of base saturation is thought to be the reason for this group being so poorly represented in the deciduous woodlands of southern Sweden (Falkengren-Grerup, 1992).

6.1.5. Algae

While most of the macroalgae grow in the sea, some are also found in freshwater. Living in lakes of the kind that relatively easily becomes acidified, several species of charophytes (*Characeae*), of the *Nitella* genera, are judged to be endangered by acidification. Two species that are suspected of being sensitive hardly occur however in Sweden (Blindow in Aronsson et al., 1995). The species *Nitella gracilis*, which is considered endangered and has been placed in Category 3 in Sweden, is also being watched for decline in Britain on account of acidification (Tickle et al., 1995).

A species of cyano bacteria, *Nostoc zetterstedtii*, which is rare and clearly sensitive, will in all probability be red-listed. It has been seen in two cases to have been adversely affected by acidification, but also by extensive liming, causing it to vanish (Bengtsson, 1998).

6.1.6. Vertebrates

A fish species in acute danger is the spring-spawning cisco, the only remaining healthy stock of which seems to be in a lake that is being limed.

Sensitive species of fish will continue to be affected even after 2010 in the poorly buffered water of the lakes in South Sweden. The most endangered species are roach and in some cases others such as cyprinids, minnow, brown trout, and some southerly populations of Arctic charr, as well as vendace in some waters (Degerman & Lingdell 1994; Appelberg & Aldén, 1992; Appelberg et al., 1995). Especial mention should be made of the spring-spawning cisco in Lake Fegen. This species is in acute danger, since the whole region, which is already badly affected by acidification, lies in a part of the country where the critical loads are still likely to be exceeded after 2010. The spring-spawning cisco (*Coregomus trybomi*) is usually regarded as a separate species, distinguished from the ordinary vendace (*Coregomus albula)*. Only found in a few lakes in Sweden and Finland, it is thought to be facing extinction. It seems that the only remaining healthy stock in Sweden is in Lake Fegen, which is already somewhat acidified and is being limed. The species is red-listed, and placed in Category 1 (acutely endangered).

Other species of fish that occur in areas where the critical loads are still being exceeded are stone loach (*Barbatula barbatula*), spined loach (*Cobitis taenia*), and gudgeon (*Gobio gobio*). They are usually found in the parts of small streams with clear, clean water flowing gently over sandy or gravely bottoms, in places where there is probably little risk of acidification. Little is known however of their sensitivity and the degree of risk.

The streams along the west coast of Sweden are exceptional in that they are the spawning grounds for salmon (and sea trout in the smaller streams). The sources of most of these streams, and especially the smaller ones, lie for the most part in areas already affected by acidification and likely to remain so. Both of the species mentioned, but especially salmon, are extremely sensitive to aluminium when leaving the parr stage and later as smolt (for safety the pH value needs to be more than 6.4, and the concentration of unsteady organic aluminium below 20 μg/l). Consequently the fish stocks can be harmed in stretches of stream, which may be unaffected by acidification during most of the year, as a result of sudden flushes with water containing aluminium (cf Andersson et al., 1984; Degerman et al., 1986; Alenäs et al., 1995). Some stretches near the mouths of the streams are also the habitat of an enormous number of species of invertebrate.

Salmon stocks in normally unacidified streams can be harmed by sudden flushes carrying aluminium to which the young fish are extremely sensitive.

The warty newt (*Triturus cristatus*), which is in Category 4 of endangered species, will suffer as a result of acidification because some of the becks where it occurs will be affected, lying as they do in places where there will continue to be an excess of acid depositions. This also applies to some bird species – black- and red-throated divers (*Gavia arctica, G. stellata*) and ospreys (*Pandion haliaetus*), all of which have special requirements and fall into Category 4. These species are mainly affected by changes in their food supply, and possibly by increased concentrations of metal (methyl mercury) in it. Normally however they inhabit and find their food in wider expanses of water, which are usually less liable to acidification. Even otters (*Lutra lutra*), which are also a demanding species, can occur in places that will be strongly affected by acidification even after 2010.

6.1.7. Invertebrates

In freshwater ecosystems many species of snails, mussels, crustaceans, and mayfly are sensitive to acidification. There are also others in the caddisfly and stonefly groups. Snails and mussels occur mostly in lakes, as do many species of mayfly and caddisfly. Most of the stonefly species grow up in running water. Some sensitive species of mayfly and caddisfly are also attached to running water, and in some parts of Sweden, mostly the south, have suffered severely from acidification. Only extensive liming is saving many populations of sensitive species (cf Degerman et al., 1995; Bergquist et al., l992; Lingdell & Engblom, 1995; Medin et al., 1993).

Examples of species where populations have vanished or are endangered are to be found chiefly among the most sensitive kinds, which can be affected in lakes and streams that are only moderately or occasionally acidified. These include the mayfly species *Ephemera vulgata* and *E. danica*, the gammarid *Gammarus lacustris*, and the small crustaceans *Lepidurus arcticus*, *Polyartemia forcipata*, and *Branchinecta paludosa*, which although generally rare in mountain waters are nevertheless common in small tarns where there are no fish.

Mayflies are among those evertebrates that can be affected even in lakes and streams that are only moderately or occasionally acidified.

Snails as a group are extremely sensitive to acidification. There is a relatively large number of rare species with fairly definite requirements as to their environment – usually water with plenty of nutrients and/or lime. Acidification, either now or later, will be no great threat to those species of snail that are strongly attached to very lime-rich environments (Lingdell & Engblom, 1990; Ökland, 1990; Degerman et al., 1994 and 1995). Because of their acidified habitats, commoner species, such as *Radix peregra* and *Ancylus fluviatilis*, are under more immediate threat.

Although it is uncertain how great the threat is to small mussels of the *Sphaeridae* family, a number of their species that are red-listed are found in the badly acidified southern parts of the country where the critical loads will continue to be exceeded. Little is known, however, about their habitats and numbers. The freshwater pearl mussel (*Margaritifera margaritifera*), which lives in running water, is in acute danger in some places. Many populations have already been knocked out in the streams of the acidified areas of South Sweden (cf Henrikson, 1996). The species, which is red-listed, has been assigned to Category *2* of those endangered.

The red-listed beetle *Stenelmis canaliculata*, which lives in running water and on the edges of some lakes, is an indicator of clean, unacidified water. It is not only threatened by acidification but also by oxygen depletion brought about by discharges of depleting substances from farming and other human activities.

Many of the streams of northern Sweden's inland up as far as the mountains are the home of a rich and varied fauna, particularly of insect nymphs of the species groups mayfly (*Ephemeroptera*), caddisfly (*Trichoptera*), and stonefly (*Plecoptera*). Many of these, such as the mayfly species *Brachycercus harisella* and *Heptagenia orbiticola*, the caddisflies *Hydropsyche saxonica*, *Molanna submarginalis*, and *Ecchisopteryx dalecarlia* are rare, as are the stoneflies *Capnia pygmaea* and *Nemoura arctica*. They often have special requirements in regard to pH, and are all highly sensitive to acidification. Since however they mostly occur in areas affected to varying extents by lime, they suffer little (cf Ahlström et al., 1995).

The situation in northern Sweden is peculiar in that the snow cover accumulates for a long time, while the runoff from the thaw is confined to a relatively short period. The result can be acid flushes even in streams with a relatively high alkalinity in summer (Bjärnborg, 1983; Ahlström et al., 1995). As in the case of salmon in west-coast streams, it is immaterial that the critical load is not exceeded as a long-term average, if there are short periods with acid water containing aluminium which harms or kills the fish. Studies, especially if carried out in the foothill zone, indicate that this is the main problem today. It is unclear however whether it will remain so, since that cannot be determined by a simple calculation of the critical load. It is likely on the other hand to have some significance when the pollutant load is near-critical and acidification has definitely resulted in extensive damage to sensitive organisms.

The group of invertebrates that is deemed most affected by air pollution and acidification in forest environments is that of terrestrial snails (Gärdenfors, 1987; Bernes, 1994). The extent to which the soil's supply of calcium has been depleted seems to have much to do with the snails' ability or not to survive. There is proof of a very sharp decline of the snail population in some parts of South Sweden. There are several among the red-listed species occurring in parts that are most affected by acidification. One is the species *Spermodea lamellata*, which lives in the woods of beech and other deciduous trees in those parts of South Sweden where the precipitation is particularly high (von Proschwitz, 1998). The threat to terrestrial snails will accelerate wherever the leaching out of base cations goes on.

6.2. Sensitive areas with high conservation value

Within those EMEP squares where the critical-load threshold for acidification will still have been crossed in 2010 are considerable numbers of protected areas in the form of nature reserves, conservation areas, and national parks. There are also numerous other areas that have been classified as of national interest for conservation and recreation. The present study has been confined to that half of all such areas (totalling about 35,000 sq. kilometres) where parts of the flora and fauna were judged to be at risk from acidification. Only about 10 per cent of this total area was estimated to be highly or medially sensitive to acidification, and a further 60 per cent to be doubtful. The conclusion for the remaining 25 to 30 per cent has been that in spite of everything it would have a generally low sensitivity. Moreover, about 50 per cent of all possible study objects was immediately withdrawn from placing in any category, either because of the high status of the limestone substratum (and so mostly with little sensitivity to acidification), or because they were only of geological interest.

The study has been confined to half of the area of interest for conservation where some of the flora or fauna were judged to be at risk from acidification.

Being of necessity wide sweeps, the surveys used for this study (Naturvårdsverket 1991,1992) often lack the detailed information that would have been desirable. Here follow the guidelines by which the sensitivity of any object to acidification has been judged.

Objects where much surface water was involved have often been classified as highly sensitive so long as it was not absolutely clear from the survey that it was a matter of environments with a moderate nutrient content or others with richer soil due to the influence of limestone. This has also applied to objects where a still greater part of the area was covered by water. Forested areas have been classified according to the available information, although there may be smaller areas with richer soils (and so less sensitive to acidification) within any larger area of study. The area as a whole may be more sensitive, and possibly in parts even highly so. Provided there was no limestone substratum, areas of virgin forest were judged to be highly sensitive to acidification. The relatively large areas of bog of various kinds were reckoned to be only moderately sensitive, since much of the vegetation in such places may be considered to be well adapted to the acid environment that is so characteristic of bogs. Some islands of fen within a larger bog structure, where there can only be a little or moderate effect of limestone, may on the other hand be very sensitive to acidification.

The following are examples of areas of importance from the point of view of conservation that are so situated in regions where acidification will still prevail after 2010 that their most sensitive ecosystems will be likely to suffer. Areas with differing types of nature and other characteristics have been selected within these regions: southern, central, and northernmost Sweden. Damage from acidification has been found to be especially great in South Sweden, where there are heavy depositions, but also in some of the central parts of the country. While the available estimates indicate a risk for the most sensitive ecosystems in northern Sweden, there is not the same certainty there.

Southern Region

1. The Ätran and Högvadsån valleys

A valuable section of the country which takes in the transition from a coastal plain to hilly parts inland, with glaciofluvial deposits along the sides of the valleys. Ravines cut by streams, as well as meadows and woodland pastures, provide biotopes abundant in species, while on higher ground there are conifer forests of almost virgin type. The Ätran with its Högvadsån tributary constitutes a national treasure on account of a unique species of salmon. These are in fact the most productive of all the rivers along the west coast, attracting fishermen from all over Sweden as well as from abroad. The two streams are also a home for the freshwater pearl mussel (*Margaritifera margaritifera*). Because of the damming of the main stream, the Högvadsån is now the principal reproduction area for the salmon. But it is acidified and has to be limed, and another serious threat to the salmon has come from a parasite, *Gyrodaetylus salaris*.

2. Sandsjöbacka

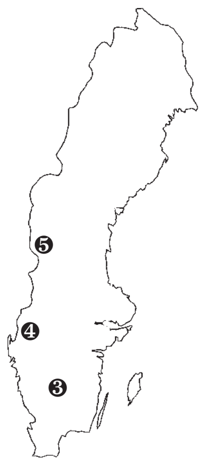
Area consisting for the most part of a plateau split by fault valleys typical for the west-coast region. An outstanding feature is the Sandsjö drumlin, the largest in southwest Sweden. There are wash deposits higher up in the valleys, and marine sediment in the more lower-lying parts (now largely under the plough). Largish areas of moorland on ground moraine, sparse pinewoods on bare rock, a great number of small lakes, and various kinds of wetland in the depressions, as well as partially luxuriant deciduous woods (some with sessile oaks, *Quercus petrea*), make up a highly varied and partly open landscape. Its very variety has resulted in an abundant fauna and flora, including several species that are of interest precisely for their location. Closeness to centres of population, combined to some extent with ease of entry, has made this an area of national interest for outdoor recreation. Some of the lakes, like others in adjoining areas, are

Locations of the Ätran valley (1) and Sandsjöbacka (2) areas. Most lakes and streams are acidified, and some largely so, in this exposed part of the country.

however among the most acidified in the whole of Sweden, with pH values down to about 4.

3. Store Mosse national park, with Kävsjön

Store Mosse comprises the largest raised bog anywhere in the country as well as the largest wetland complex outside Lapland. The landscape mostly takes the form of flat, treeless bogland. The vegetation is typical for southwestern Sweden, with such species as cross-leaved heath (*Erica tetralix*) and bog asphodel (*Narthecium ossifragum*), but with intrusions of more northerly species such as dwarf birch (*Betula nana*). Within the area are also wooded fens and swamps, and out on the bog are several long ridges of windblown sand. Crossing it here and there are also broad strips of fen with more abundant flora. The most interesting plants are to be found in the Björnekulla fen, among them being marsh helleborine (*Epipactis palustris*), Irish marsh orchid (*Dactylorhiza traunsteineri*), and hair sedge (*Carex capillaris*). The lake, Kävsjön, is famed for its abundance of bird species. The whooper swan (*Cygnus cygnus*), greylag goose (*Anser anser*), jack snipe (*Lymnocryptes minimus*), marsh harrier (*Circus aeruginosus*), and several species of duck all breed here. The lake and its surroundings constitute a very important resting place for migrant birds (listed in the Ramsar Convention), and the bog is believed to have Sweden's largest population of common crane (*Grus grus*). Its location on the western side of the south-Swedish highlands means it is exposed to heavy acidic pollution and is likely to remain so.



Spread along the west-coastal region, up to the eastern side of the border mountains, are Store Mosse (3) and Tresticklan (4) national parks, and the Fulufjället (5) plateau. All are affected by acidification.

4. Tresticklan

This national park includes one of the largest areas of practically virgin coniferous forest in South Sweden. Here is a fault-valley landscape with numerous lakes and bogs, with pine forest growing on bare rock as the main feature. The pinetrees are mostly 120 to 150 years old, with a few scattered stands aged about 200 years. The area is of great importance on account of the species associated with old growth, virgin-like forest, making it of especial value for research. The whole surrounding region, with its large lakes and streams, has been hard hit by acidification, which will still remain a threat after 2010.

Central Sweden

5. Fulufjället

Fulufjället is a plateau formation typical of the Dalecarlia mountains, with sides sloping steeply down to forested areas at the bottom. The area is marked for a national park. The Njupeskär in the Njupe River, on the north side of the plateau, is Sweden's highest waterfall. There are also a number of formations of geomorphological interest. On the plateau are some tarns, too, that deserve attention for hydrological reasons. Being one of the few mountain parts of the country that are as yet unaffected by reindeer grazing, its bare mountain area can show some unique types of vegetation, with some well-developed lichen heaths and grassy heathlands with junipers growing on them. Tall Norway spruce grows in the ravines of the becks, with stands in several places of almost virgin growth. In a long stretch of bog at the base of the plateau are some well-developed patches of flark vegetation. Among the abundant bird species are common scoters (*Melanitta nigra*), greater scaups (*Aythya marila*), and red-necked phalaropes (*Phalaropus lobatus*). Together with the adjoining Drevfjäll, the area is of importance for outdoor recreation, criss-crossed by numerous ski and hiker trails. Arctic charr in the lakes assures its attraction for fishermen.

A number of small lakes on the Fulufjället plateau became acidified at an early stage, and parts of the area must be among the most sensitive to acidification in the whole country. So far the fish have been saved by extensive liming, but acidification will nevertheless continue to be a threat to the area's remarkable natural assets.

6. Långfjället and Rogen

Whereas the Långfjäll area consists of two large massifs, Rogen is a level plateau with a number of lake systems and some low-rise mountains.

Both areas can show an enormous variety of specific geomorphological formations. The forests are also highly varied, ranging from very dry mountain-birch types to semi-virgin pine forest. In wetter parts, with richer soils, there are also some spruce forests of tall-herb type. In the Rogen area generally, pines mark the tree-line, while the central parts contain sparse growths of pine, with many standing dead trees, which are typical for the location. The trees in the latter places are extensively hung with various species of lichen, including the rare *Letharia vulpina*. On Långfjället there are also several rare species of oceanic lichens.

The massifs of the southern part of this area are the habitat of some rare animal species, which are now endangered. Among them are the wolverine (*Gulo gulo*) and the golden eagle (*Aquila chrysaetos*). Otters (*Lutra lutra*) occur all along the streams. The innumerable small lakes circling Rogen contain a great variety of fish species, with brown trout (*Salmo trutta*), Arctic charr (*Salvelinus alpinus*), grayling (*Thymallus thymallus*), powan (*Coregonus lavaretus* coll.), perch (*Perca fluviatilus*), pike (*Esox lucius*), burbot (*Lota lota*), and minnow (*Phoxinus phoxinus*) occurring in various combinations. Ducks and waders are also plentiful in this highly variegated landscape with its numerous lakes and wetlands. The aim is to make it a national park too.

Also in the mountain region, and close to the Norwegian border but much farther north and 600 kilometres apart, are the Långfjället (6) and Råvvejauri-Tarrekaise (7) areas, with a great variety of vegetation and wildlife.

Northern Sweden

7. Råvvejaure-Tarrekaise and the Pärlälven

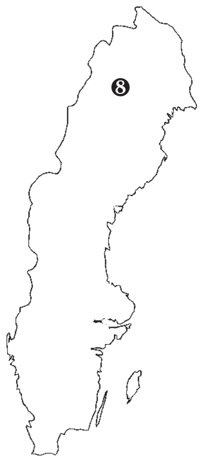
A richly variegated landscape with such a plethora of lakes and streams as to make water the predominant geomorphological factor. The slopes of the Tarrekaise massif are characterized by rock falls and deep ravines cut by the mountain streams. Along the courses of the streams are canyons, parts with giant potholes, flyggberg, and boulder ridges. At Kvikkjokk is one of Sweden's most extensive deltas of recent formation.

The big predators, brown bear (*Ursus arctos*), wolverine (*Gulo gulo*), and lynx (*Lynx lynx*), are found here in relatively large numbers, and in some parts there are Arctic foxes (*Alopex lagopus*) and otters (*Lutra lutra*). The abundant bird life includes some rare and threatened species such as the golden eagle (*Aquila chrysaetos*), white-tailed eagle (*Haliaeetus albicilla*), gyr falcon (*Falco rusticolus*), and eagle owl (*Bubo bubo*) which breed here regularly. Other local breeders include whooper swans (*Cygnus cygnus*), bean geese (*Anser fabalis*), smews (*Mergus abellus*), great snipes (*Gallinago media*), and little buntings (*Emberiza pusilla*). The southeastern end of the Purkijauri lake is an important stopover for birds breeding further north. The red-listed freshwater pearl mussel (*Margaritifera margaritifera*), a species sensitive to acidification, is still relatively abundant in the Pärlälven.

There are locations of interest for their more abundant vegetation in the form of mountain slopes with more favourable climate, deltas, and areas affected by limestone. Among the rare plant species are the ferns *Athyrium crenatum* and forked spleenwort (*Asplenium septentrionale)*, mountain saxifrage (*Saxifraga cotyledon*), Arctic rhododendron (*Rhododendron lapponicum*), the sedge *Carex parallela*, and the ranuncule *Ranunculus hyperboreus*. Here and there in the valleys are some unusually large areas with tall-herb vegetation, and the whole area is of interest as a meeting place for easterly and westerly species. The Pärlälven reserve, with untouched mountain forest, shows a great variety in the way of tree species, types of forest, successions, and the effects of fire. The undammed part of the Pärlälven, with good stocks of grayling (*Thymallus thymallus*) and brown trout (*Salmo trutta*), draws numbers of fishermen. The very amount of variation in these parts makes it difficult however to estimate the exact extent of the threat from acidification.

8. Sjaunja

This area, which is one of those listed for a national park, is also covered by the Ramsar convention for the protection of the most valuable wetlands. At its eastern end is Sweden's largest wetland complex, while the western part comprises low mountain slopes. The wetland area consists of a largely open landscape with numerous lakes and channels. While birchwoods predominate, there are also parts with pine of virgin growth. The trees in the pine forests vary greatly in age, but with a high proportion of older trees, some being as much as 500 years old. Such a large area, largely undisturbed, and with great natural variations, is inevitably of great scientific interest. More than 150 bird species have been noted here, and 100 of them have been breeding. Among the rare species are the white-tailed eagle (*Haliaeetus albicilla*), golden eagle (*Aquila chrysaetos*), gyr falcon (*Falco rusticolus*), and whooper swan (*Cygnus cygnus*). Among the twenty-five species of mammal that occur in this vast area are brown bear (*Ursus arctos*) wolverine (*Gulo gulo*), lynx (*Lynx lynx*), and otter (*Lutra lutra*).



On about the same latitude as Råvvejauri (nearly 67°N) but at the lower end of the foothills, is the largely undisturbed Sjauna (8) area with great natural variations.

On the mountain slopes at the western end are a great number of interesting geomorphological formations. At places with a southern exposure and more easily weathered lime-rich bedrock, the vegetation can be exuberant.

On account of this great complexity, the overall sensitivity to acidification is difficult to assess. There are parts however that are definitely sensitive.

7. Concluding discourse

There can be no doubt that the reductions of the emissions of acidifying substances that are now proposed in Europe will also mean a distinct lessening of the extent to which the critical loads for acidification will be exceeded in this part of the world, compared with the situation in 1990. That has to some extent already happened.

The measures that have already been decided upon (the REF scenario) will alone bring about a great improvement, and a further reduction of emissions under the F1 scenario should lessen the excess of critical load for acidification still more in Sweden.

Even if the proposals of F1 are carried out, however, that will not mean an end to acidification. Whereas in Sweden a marked improvement can be expected, in other parts of Europe acidification will still be a great problem. But even in Sweden, and especially in the southernmost corner of the country, and to some extent also in the inland parts of the north, acidification will continue to be a considerable environmental problem even after 2010. The calculations made by IIASA show that 1,600,000 hectares would, under the REF scenario, still be subject to excess loads for acidification, and 1,360,000 under the assumptions of F1 (Amann et al., l998).

The remaining areas with excess loads are calculated to lie mainly in southwestern Sweden and at the southern end of the foothills of the northern mountain range. The situation will however be markedly better than it is today (Wilander et al., 1998), especially as regards the degree of excess loading. With present computer models the excess will often appear so marginal that the uncertainty of the results will have to be taken into account before arriving at any conclusion. The results point moreover to surface waters as being likely to be the most sensitive elements in the landscape. Many of the EMEP squares are likely to include one or more areas with lakes and/or running water where the loads will be exceeding the critical, but these may be too small to appear from mapping at the 5 or 2 percentile level. This only emphasizes the need to increase the resolution both in the critical-load maps and in the deposition data, especially for cases where sensitive objects are to be evaluated.

Making the more detailed calculations that will be necessary would place great demands on the basic data, for one thing because of the variations in the landscape both as regards depositions and the types of soil and vegetation. In one case concerning South Sweden it appeared that the need to lower the acidifying load would be 25 per cent greater if regard were taken to the way depositions varied in the landscape (for whole forests, or forest edges only, etc.), compared with what it would have been without this better resolution (Lövblad et al., l995, Lövblad, 1997).

In practice the situation will be quite different from that calculated from the critical load, since many of the waters that are here in question have been limed for long periods. There is also a further complication in the dynamic aspects of the change. Despite the fact that depositions are reckoned to fall below the expected critical load, and often by a wide margin, the effects of acidification will stay on for a long time. There are studies indicating that this lagging effect could delay recovery for several decades (Skeffington & Brown, 1992; Beijer et al., 1995; Moldan et al., l998; Moldan et al., l999; Sverdrup et al., 1998). In a few specific cases it has been estimated that the delay could be as much as 50 to 100 years (Skeffington & Brown, 1992; IVL, Andersson, unpublished). When dynamic models such as the MAGIC have been used, it has proved possible to adequately describe the changes in connection with experimental recovery for a decade or so (Moldan et al.,1998), so that predictions based on such computer modelling can be assumed to represent the possible development.

The delay will be an important factor for the chemistry and biology of unlimed waters during the recovery period. It is difficult to determine with any exactitude when the increasing pH and alkalinity, together with reduced concentrations of toxic aluminium, will permit organisms of varying sensitivity to start reproducing again, or allow new, robust populations to establish themselves. Here come questions of direct importance for the structure of the ecosystem. Key species are especially important; fish, for instance, influence both species composition and production at lower levels in the food chain. In some cases processes dependent upon chance can also have a strong influence on recolonization and so on the species structure in aquatic ecosystems during different stages of recovery.

8. Proposals for more penetrating studies

The present study has uncovered a number of questions that will need answering if the future situation in regard to acidification in Sweden is to be assessed more accurately. Here are some proposals for matters that might be penetrated more deeply:

- A calculation according to F1 and REF would give increased understanding of the future state of acidification if made in connection with the national inventory of lakes and streams, i.e. on the 50x50 km scale.
- Some of the research and surveys should focus on those ecosystems that are deemed to be at greatest risk on account of the effects of acidification that will remain in spite of all improvements. It would be a matter of identifying "hot spots" for acidification, where high depositions coincide with high sensitivity and a valuable environment, and of directing research and surveillance towards them. This would be especially desirable for the most acidification-sensitive parts of southwestern Sweden.
- The belief that surface waters will be the most endangered as a result of continued acidification deserves probing. The soils of southernmost Sweden are now badly affected by acidification, and this applies to soils that were previously shielded by limestone. In fact in Skåne the net change in the pH has been greatest in soils where it had previously been relatively high (Falkengren-Grerup, 1992). The lakes and groundwater of those parts are however still relatively well buffered by limestone lower down in the soil. The question is how well the loss of buffering capacity, and the great net changes in the environment for plants and animals which have taken place during the last few decades, will be caught up in our present computer models for calculating critical loads.
- There are a number of factors indicating that the present methods of determining and mapping the critical loads for acidification tend to underestimate the sensitivity of ecosystems. One might mention the dynamic effects of recovery from acidification, as well as the problems of acid flushes and reduced depositions of base cations. There should therefore be reason to further develop the methodology for determining and mapping critical loads.
- By working through the ArtDatabanken's data for red-listed species specifically in respect of acidification and eutrophication, important information could be gained for the future consequences of acidification for rare and endangered species.

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Appendix.

Data and other sources of information

The International Institute for Applied Systems Analysis, IIASA, in Laxenburg, Austria (Markus Amann, Wolfgang Schöpp), has made available data concerning the depositions of sulphur and oxidized and reduced nitrogen as they would appear under the Y90, REF, and F1 scenarios. Data, information and advice concerning the overstepping of critical loads has been received from RIVM/CCE, Bilthoven, Netherlands, through Max Posch. The calculations in this report have been based on the principles presented by Posch et al. (l995, 1997).

Several individuals have contributed valuable points of view on the state of acidification in Sweden, mentioning which ecosystems and species are judged to be most sensitive and therefore in some way endangered in future even when depositions of acidifying substances are lower. Lars Rapp and Anders Wilander of the University of Agricultural Sciences have provided important information on the overstepping of critical loads. The latter has also placed a map at our disposition. Tomas Hallingbäck and Mora Aronsson, both of the Swedish Threatened Species Unit (ArtDatabanken), as well as Svante Hultengren of Naturcentrum AB, and Kill Persson of the Halland district administration have contributed important views on the effects of acidification on rare and red-listed organisms.

Reports of the Swedish Environmental Protection Agency (Naturvårdsverket 1991, 1992) have provided the information necessary for determining which areas of natural interest are in places where excess critical loads for acidification will still be likely after 2010.

Even if all the planned measures aimed at cutting down the emissions of acidifying air pollutants during the next ten years should in fact be carried out, acidification is likely to remain a threat to many plant and animal species as well as whole ecosystems.

In this study the outlook has been examined in the light of various assumptions as to the possible trend of emissions. It appears from it that the problems of continued acidification may have been considerably underestimated.

The Swedish NGO Secretariat on Acid Rain

The essential aim of the Swedish NGO Secretariat on Acid Rain is to promote awareness of the problems associated with air pollution, and thus, in part as a result of public pressure, to bring about the required reduction of the emissions of air pollutants. The eventual aim is to have those emissions brought down to levels – the so-called critical loads – that the environment can tolerate without suffering damage.

In furtherance of these aims, the secretariat operates as follows, by

❑ Keeping under observation political trends and scientific developments.
❑ Acting as an information centre, primarily for European environmentalist organizations, but also for the media, authorities, and researchers.
❑ Publishing a magazine, Acid News, which is issued four to five times a year and is distributed free of charge.
❑ Producing and distributing information material.
❑ Supporting environmentalist bodies in other countries by various means, both financial and other, in their work towards common ends.
❑ Acting as coordinator of the international activities, including lobbying, of European environmentalist organizations, as for instance in connection with the meetings of the bodies responsible for international conventions, such as the Convention on Long Range Transboundary Air Pollution.
❑ Acting as an observer at the proceedings involving international agreements for reducing the emissions of greenhouse gases.

The work of the secretariat is largely directed on the one hand towards eastern Europe, especially Poland, the Baltic States, Russia, and the Czech Republic, and on the other towards the European Union and its member countries. By emitting large amounts of sulphur and nitrogen compounds, all these countries add significantly to acid depositions over Sweden.

As regards the eastern European countries, activity mostly takes the form of supporting and cooperating with the local environmentalist movements. Since 1988, for instance, financial support has been given towards maintaining information centres on energy, transport, and air pollution. All are run by local environmentalist organizations.

To date, four European conferences on strategy for environmental NGOs have been arranged by the secretariat, where common objectives and cooperative projects were developed. An important outcome has also been the agreement on the demands, based on scientific data concerning critical loads.