Liming Acid Lakes in Sweden

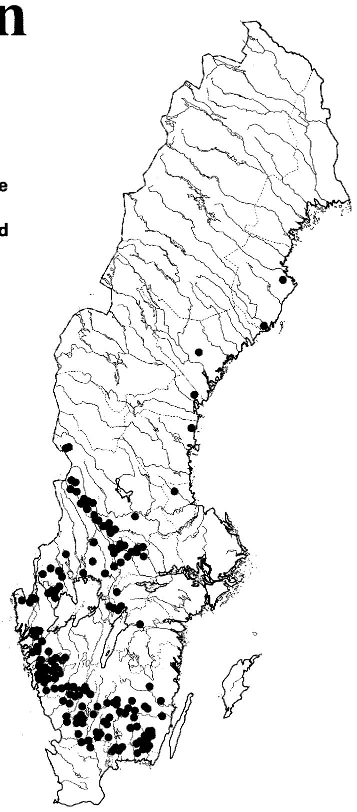


Figure 1. Liming activities are concentrated in the highly acidified regions in south and western Sweden.

Thousands of lakes and rivers in Scandinavia and North America located on low weathering bedrock or surrounded by lime-poor soils are suffering from the effects of acid rain.

In Sweden alone, water in one-fourth of the country (100 000 km^2) will have critical pH-values some time during the year. Twenty thousand lakes are affected in addition to countless kilometers of brooks and small rivers (see Figure 1).

The first biological symptom of acidification was noticed in the 1920s and 1930s. There was a decreased roe hatching for one of the most sensitive fish species, roach (*Leusiscus rutilus*) in some very poorly buffered lakes with pH-values below 6 during the summer. Today these lakes are the most acid in Sweden with a pH of 4–4.5 or even less in surface water during periods of snow-melt (1).

Decades of acid deposition graudally has impoverished the soil content of basic ions. As a consequence, groundwater pH also decreases, carrying certain soil salts and heavy metals into the surface waters. Thus, in the most affected area of Sweden both lake and ground water pH has decreased by 1–2 pH units and the concentrations of soil metals like aluminum and of atmospheric metals (*eg* cadmium) has increased about ten times the "normal" values.

Given the present trends, future atmospheric acidification will cause tremendous problems directly from the acidity and indirectly due to metal poisoning of soil and water.

COUNTER MEASURES

Sulfur emission restrictions have been in force for several years in Sweden. For the past two years only low sulfur oil (< 1 percent) is allowed to be burned in south to central Sweden. The extra costs for this amount to around $100 million. The aim is to have the 1985 emissions down to the level of the 1950s. After years of international research and political arguing a Convention on Long-Distance Transboundary Air Pollution was recently signed by the ECE members (see Ambio No. 6, 1979 p 281). More than half of Sweden's total acid load comes from abroad. Consequently, until no further international restrictions have taken place the rain will stay acidic.

In 1976 the Swedish Government initiated liming measures for restoring acidified lakes and rivers. The aim of the experimental activity is:

- to save waters of special value for fishery, nature conservancy or recreational uses
- to study the ecological effects
- to try different methods
- to estimate the costs.

The present budget is $2.5 million which corresponds to about one tenth of the actual need. The proposals for 1980 and 1981 are $5 million and $7.5 million respectively.

Now, anyone with an acidified or threatened lake or stream has the possibility to ask for economic support. In practice though, most of the money has been spent on waters of "common interst".

Before the experimental period started, around 200 small lakes had been limed. During 1977–79, 700 lakes and rivers have been limed, most of them with government support. So far, the watershed directly affected comprises an area of 6000 km^2 and the amount of lime spread amounts to 120 000 tons.

DOSES, REMEDIES AND COSTS

In Southern Sweden the present lime need, in order to compensate for acidification, is 50–75 kg $CaCO_3$ per hectare of watershed per year. This corresponds to an actual pH of 4.0–4.3 in precipitation and to a dry deposition rate of the same size.

The remedies involve various perscriptions, from fine-ground or crushed limestone, dolomite, lime slags and olivine to slaked or unslaked lime, leach or soda. The total costs for spreading one ton of fine-ground limestone is $50–70 (Figure 2). If a helicopter has to be used the cost is slightly higher (Figure 3). Normally, the dosage is calculated to last for five years.

WAYS OF APPLICATION

10–20 g/m^3 of lime (as $CaCO_3$) including neutralizing and buffering effects, are needed if applied directly into the water. This corresponds to 50–75 kg per hectare of watershed per year. If applied on land the doses have to be a hundred times greater (*ie* several tons per hectare) to give an acceptable leaching rate to the water.

Lime application directly into the water seems to give the most acceptable pH-values for the least costs. One single lime application may show neutralizing effects for 5–10 years. This method of treatment is suitable for lakes with a longer retention time. Waters with very short turnover times, however, have received "overdoses" of lime on their shores and in feeder streams.

The largest lake liming project to date is Lake Unden, which covers an area of 9500 hectares in southern Sweden. In this case all inflow streams received 8000 tons of lime. Though the lake itself has a retention time of 20–30 years, liming effects show up soon, even in the outflow water, because of the stratified conditions during high flows.

DIFFICULTIES

Obtaining yearly leaching of a certain amount of bicarbonate or an acceptable yearly pH-medium value is *not* the problem. The problem is to keep an acceptable value at high flow (*ie* during snow-melt). At this time the lake waters become highly stratified with the cold acid melting-water on top. As a result it doesn't mix with the water below which is of better quality.

The running waters carrying this melting-water represent an even greater problem. To neutralize the acidified melting-water, either large overdosing is needed when applied to water or on land or every year lime has to be applied on the snow pack.

Moreover, the acidification is not just a pH-problem but is also coupled to the anthropogenic pollution of metals deposited from the atmosphere and the increased leaching of metals from acidified soils.

The toxicity of most metals is higher in neutral than in acid water. Thus, when liming an acid lake the organisms suffer a transition period before the metals have precipitated. Aluminium leached from the soil is highly aggressive to fish gills in the pH range 4.5–6 and liming has even killed salmon and trout when the aim was to save the fish.

ECOLOGICAL EFFECTS

Within a number of projects, careful studies of the effects on most trophic levels were carried out. Figure 4 (a and b) shows the liming effects on planktonic crustaceans in two small, fishless lakes which were limed in the spring of 1978. The pH increased from 4.0–5.2 to around 6.5. Before liming, zooplankton density was quite small but increased considerably afterwards. Recolonization by indigenous species usually takes a rather long time. Two years after liming, the plankton community is still dominated by the same species. In another lake limed in 1975, the acid-sensitive *Daphnia cristata* did not re-appear until the autumn of 1979. The Recolonization of phytoplankton however, goes faster, and 1–2 years after liming most lakes have the normal diversity of species (2).

Figure 2. Workers spread lime with a pressure hose. Photo: Svante Göthblad.

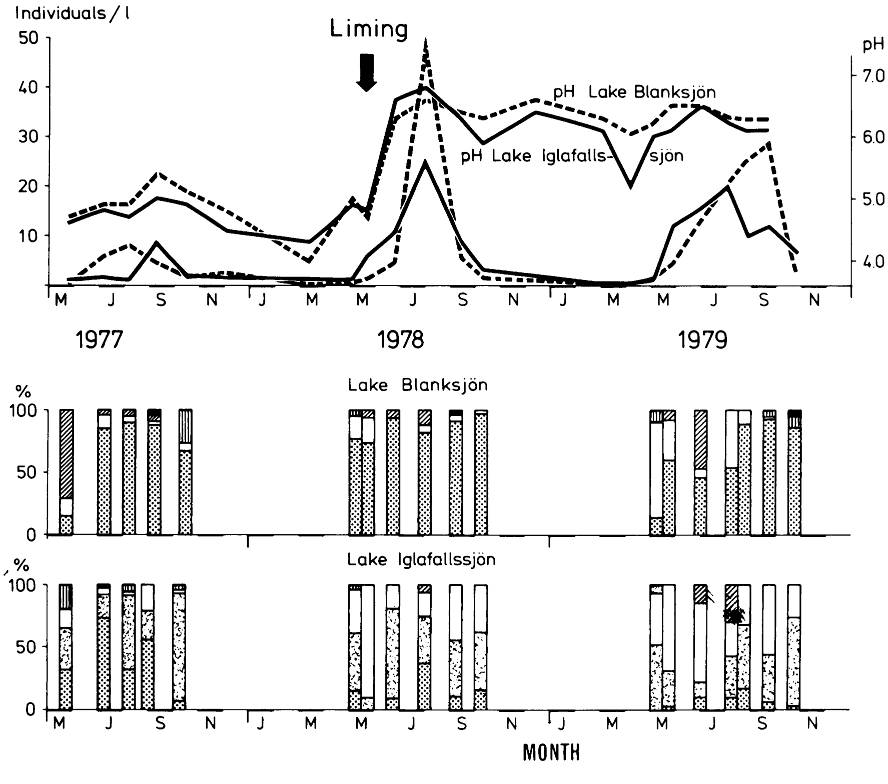
The effects on bottom organisms are not easily interpreted but comparisons with old data indicate that the pre-acid community is reached in time *if* immigration from neighboring waters is possible (3).

FISH

Many of the salmon rivers on the West Coast are suffering from acidification. In one of them, the Högvadsån River, salmon (*Salmo salan*) recruitment has been studied with the same measures since 1954.

Figure 3. Liming is sometimes done by helicopter. Photo: Leif Öster/Forest Service of Sweden.

Figure 4a. pH in surface waters of two lakes and the density of planktonic crustaceans before and after liming. The top two lines represent pH and the bottom two lines represent individuals.
4b. Distribution of different species of crustaceans.



The entire river system of 476 km², has been limed since 1978. In the last years before liming, two-summer old fish were either entirely missing or very scarce. At that time the water pH was 4.5–5.5 during high flow with an aluminium concentration of 0.2–0.4 mg/l.

After liming, the pH level stabilized above 6 and the number of one-summer-old fish is now about the same as before acidification. Furthermore, two-summer-old fish are found again (see Figures 5 and 6).

Figure 5. pH and alkalinity in the Högvadsån River.

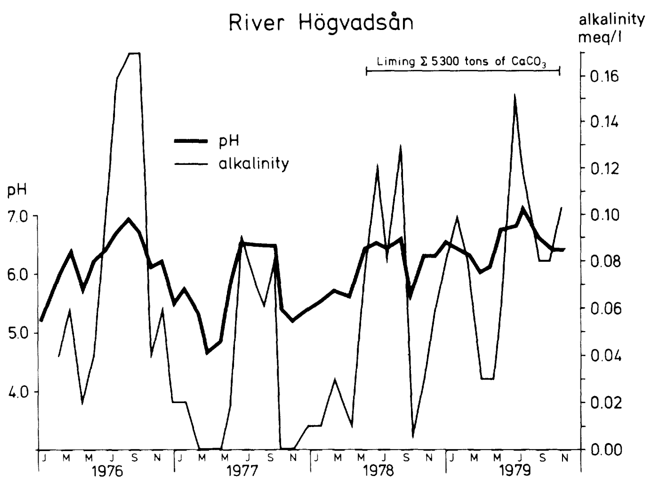
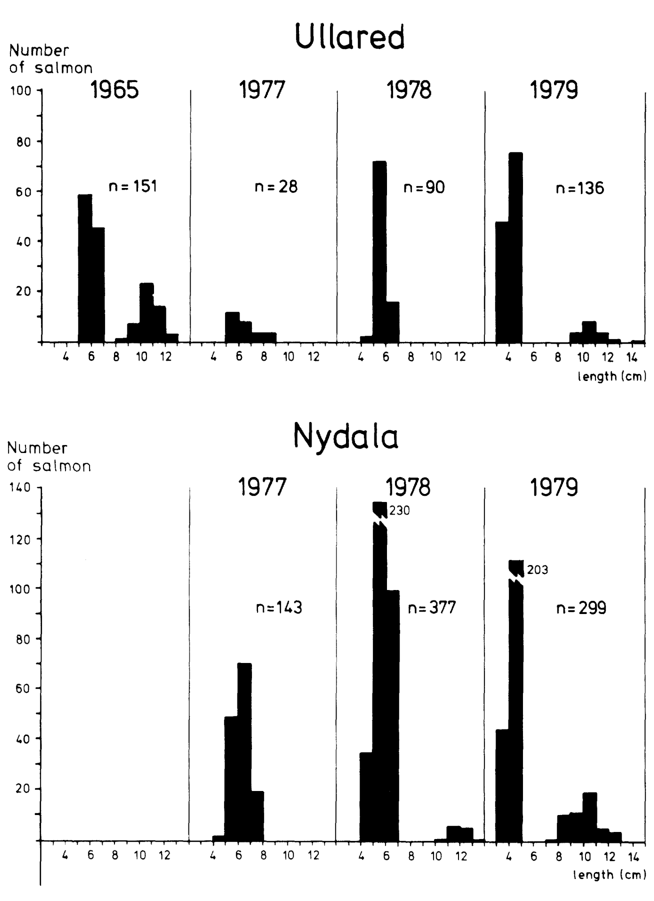


Figure 6. Catch of salmon in the Högvadsån River from 1965—1979.



The perch, *Perca fluviatilis,* is one of the most pH-tolerant species. Yet, in spite of this, its reproduction is inhibited in the most acidified waters. Liming may drastically change this picture. In lake Västra Skälsjön the total catch before liming was 10 perch (0.3 per net) with a size of 28–40 cm and no young fish were caught at all. After lime treatment, reproduction started and the same test now resulted in 1039 perch (28.9 per net) with a size range of 8–15 cm (Figure 7).

In many Swedish lakes, the acid sensitivie arctic char (*Salvelinus alpinus* L) has been wiped out. The age classes of arctic char in the moderately acidified Lake Östra Skälsjön, with a pH of 5.0–6.0, was dominated by older fish and some age classes were totally missing. In 1975 the inflow water was limed to an acceptable level and four years later the catch was dominated by fish born in 1976. However, the acid snow-melt of 1977 again disturbed the recruitment.

CONCLUSION

Liming is a possible method of keeping poorly buffered or acidified waters alive. However, the best way to improve the water quality is to decrease sulfur emissions and the acid load.

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References and Notes

1. B Almer, W Dickson, C Ekström and E Hörnström, *Sulfur in the Environment Part II,* J O Nriagu ed (1978) pp. 271-286.
2. Hörnström, *Kalkningseffekter på fytoplankton* (Fiskeristyrelsen, Göteborg, 1979) in Swedish.
3. P Mossberg, *Kalkningseffekter på bottenfauna* (Fiskeristyrelsen, Göteborg, 1979) in Swedish.
4. This Synopses is an English summary of the Swedish report *Kalkning av sjoar och vattendrag,* (Fiskeristyrelsen, Statens Naturvårdsverk, 1979).

Figure 7. Catch of perch (*Perca fluviatilis*) before and after liming in Lake Västra Skälsjön.