

CHAPTER 4

RESTORATION OF ACIDIC LAKES

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4.1 Reversibility of Acidification

There are several illustrative examples of recovery of acidified lakes. A few of these examples will be presented as basis for conclusions of the reversibility of lake acidification.

The Sudbury location is notable for its massive exposure of sulfur deposition during the uncontrolled development of metal smelters there since the end of the last century. In 1972, a major source of sulfur emission was closed and another dispersed more effectively by construction of a 381 m stack. The emissions were thereby reduced by 70%. In a lake, called Baby Lake 1 km away, pH increased from 4.0 in 1972 to more than 5.6 in 1988. Alkalinity increased and the concentrations of toxic heavy metal decreased. In a larger sample of 37 lakes in the same area, pH levels increased in all of the acidic lakes and sulfate concentrations decreased in those with highest concentrations (Keller et al., 1986).

Although these lakes suffered excessive acid deposition for almost a century their chemical recovery has been rapid, but biological recovery is delayed and the recovered communities are likely to be unstable and uncertain.

Acidification of lakes in western Sweden developed progressively through the 1940s to reach a peak in the 1970s, where pH level was about 4.5 and sulfates concentrations significantly elevated. These changes were, as mentioned in Section 3.5, accompanied by reproductive failure in fish populations. To some extent, the changes reflected hydrological conditions and in 1977 this trend was reversed and pH increased by 0.3 to 0.4 pH units. This was associated with a

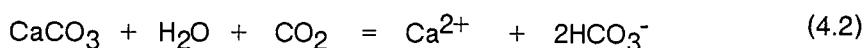
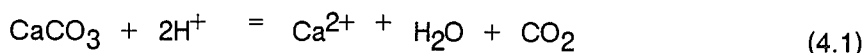
decrease of about 20% in the wet deposition of sulfate, but not of acidity in rain, which tended to increase, possibly due to the increase of nitrate in rain water (Forsberg et al., 1985). Recovery of water chemistry was rapid, but significant improvements in fish populations are still not recorded.

The experience gained with liming have generally given the same results as mentioned above for the Sudbury lakes and for the lakes in western Sweden. The water chemistry shows a rapid recovery, including a reduction in the concentrations of heavy metals and other trace elements, while the biological recovery is somehow slower due to hysteresis effects and slow recruitment particularly of fishes and birds. This implies that the recovery of the biological diversity is equally slow.

Technological methods used in the ecosystem or by imitation of the ecosystems (for instance the application of artificial wetlands) are often called ecotechnological methods or the application of ecological engineering; see Mitsch and Jørgensen (1989). The methods mentioned in this chapter are all ecotechnological methods, while the next chapter will deal with pollution abatement by application of environmental engineering and with environmental management by use of models. This chapter deals with in situ methods, while the regional abatement of acidification is a question of reduction of the acid gases at the source; see the overview of sources in Chapter 2.

4.2 Liming of Acidic Lakes

The acidity of lake water is determined by the concentrations of various weak acids including humic acid and hydrogen carbonate ions. The latter ions have only very small concentrations in water at low pH. Lime is widely applied to neutralize the acid ions and increase the hydrogen carbonate concentration of water. By application of lime the following processes occur:



Immediately after the addition of lime, pH will increase to about 8.0, but pH will afterwards be reduced to the level corresponding to the chemical reactions of the acids in the lake water and the added lime. It is desirable to achieve a pH of 6.5 - 7.0 and an alkalinity of 0.1-0.2 meq/l. It implies that about 10-25 mg of lime must be used per liter, dependent of course on the acidity of the lake water.

Other chemicals such as dolomite, calcium oxide, calcium hydroxide and sodium carbonate may also be applied, but they are usually more expensive to use. An important problem related to liming is the concentrations of heavy metals in the applied chemicals. The concentration of heavy metals in the Swedish lime corresponds to the background concentrations of heavy metals, when 10 mg lime is applied per liter in a 10 m deep lake. Typical concentrations of heavy metals in lime are: cadmium 0.2-2 ppm, nickel 10-45 ppm, mercury 0.03-0.12 ppm, chromium 6-25 ppm, copper 5-33 ppm, zinc 10-100 ppm and iron about 1%. Consequently, it is necessary to analyze heavy metals concentrations of the lime before a wide application of lake liming is initiated.

The efficiency of the liming process is dependent on the contact time and the contact surface. The distribution method for the lime in relation to its specific surface may therefore be important for the efficiency.

Liming may be performed in the lake, in the tributaries or in the entire catchment area.

Several chemical changes have been observed by liming of lakes. Usually the nitrate concentration will decrease due to increased primary production and due, to a certain extent, to increased phosphorus concentration in the lake water. Lime contains minor amounts of phosphorus, which together with the mobilization of the phosphorus in the sediment, explain the increased concentration of total phosphorus. Hultberg and Anderson (1982) find, however, a decreased concentration of phosphorus in lake water after 7 years of liming, which may be explained by a more pronounced precipitation of phosphorus by aluminum at higher pH.

Aluminium is generally precipitated by higher pH mainly as hydroxide. Reductions from 500 µg/l to 100 µg/l have been observed a few months after the liming was initiated.

Due to precipitation of heavy metals, the bioaccumulations of these toxic trace metals are reduced significantly after liming. Bengtson et al., (1981) report a

decline of the cadmium concentration from 0.2 µg/l to less than 0.05 µg/l after liming in Swedish lakes. The concentration in the sediment increased correspondingly, due to the precipitation.

It was emphasized in Section 4.1 that the biological recovery process is somehow slower than the chemical recovery process. Observations from several Swedish lakes have shown that even after 3-5 years of liming the loss of carnivorous fish has still not been compensated. The biological diversity was, however, increased and less acid-resistant phytoplankton species have been introduced. The benthic fauna is usually also fully recovered after a few years of liming. It may be concluded that a transition state between the biology of an acidic lake and a neutral lake was achieved, but a complete recovery was still not obtained.

It is, however, important that the microbiological activity in lakes, which have been limed for several years, has returned to the level of neutral lakes. This implies that the turnover rate also has returned to a normal level. There is still very limited experience with the long-term effect of liming, but it is possible to conclude that a complete recovery should be expected, although the time needed to obtain this is longer than previously foreseen.

Experience indicates furthermore that it is necessary to lime the entire catchment area to obtain a significant effect, although the effect of land-based liming is much slower than the effect of lime added directly to the aquatic ecosystems. Only 1-2% of the land-deposit lime is washed out per year and it is reduced after 2-3 years, see Fig. 4.1. These effects are, however, important for the long-term results of the liming, but as Fig. 4.1 further illustrates only liming of the entire or almost entire catchment area guarantees success.

The cost of liming is approximately \$10-25 per ton of lime distributed. The cost is dependent on the price of the limestone, which does not, however, vary very much from place to place, and the methods of distribution. As much as 118,000 km² of Sweden (= 26% of the country) needs liming, because the alkalinity of lake water is 0.1 meq/l or less. This would cost more than \$20 mill. per year to carry out.

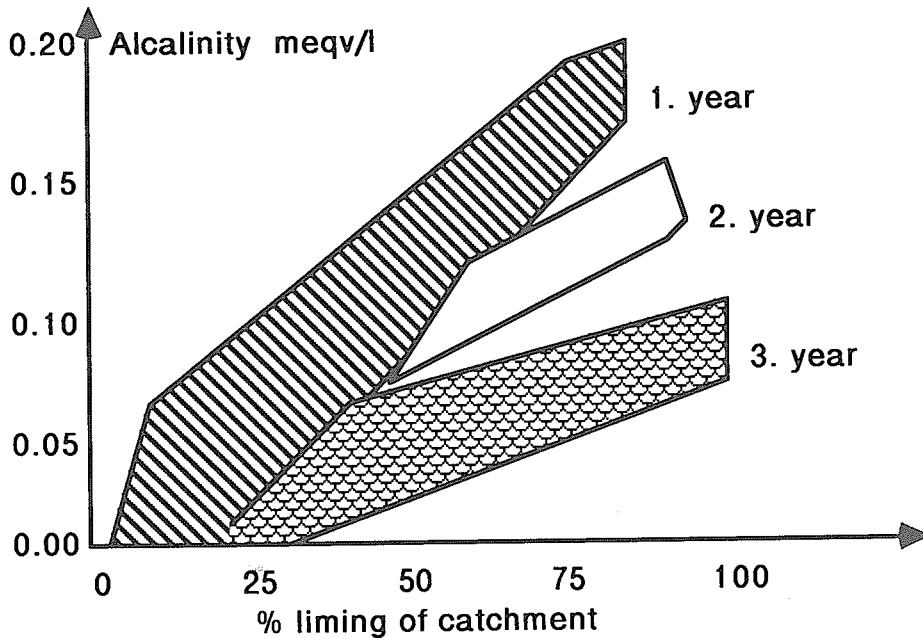


Fig 4.1 The increase in alkalinity from liming of the catchment area. The effect for the first, second and third year are shown. It is plotted versus the percentage of the catchment area limed.

4.3 The Application of other Ecotechnological Methods

Liming is the most applied ecotechnological method for reduction and neutralization of acidification. Other in situ methods may, however, be applied to obtain a higher efficiency on biological recovery. They could therefore work hand in hand with liming to obtain a faster and more complete recovery within a shorter period of time. A slower recovery due to hysteresis is known for many ecological cases, for instance eutrophication. Hysteresis is also known in context with acidification. The high hydrogen ion concentration is maintained due to production and adaptation by the species present in the acidified ecosystem. Therefore it may be important to introduce other species in addition to liming to assure the long term stability of liming. However, the application of this strategy requires that the forcing functions, i.e., the pH of the rain water, are changed. The ecosystem will otherwise

return to the acidic conditions again including species composition. The forcing functions will determine the long-term conditions of the ecosystem - only by changing the forcing functions, shall we be able to recover the ecosystem, but the time needed for recovery can be changed by use of ecological engineering methods. The conclusion is therefore that we have to play on the entire spectrum of methods to obtain the best and fastest result. Liming assures a higher pH but only for a certain period (dependent mainly on the retention time of the water in the lake) if the inputs of hydrogen ions are not changed. Correspondingly, the adjustment of pH by use of liming, does change the pH, but to bring the ecosystem back to normal the application of other means is required to assure that the entire biological community is adjusted to the normal pH again.

Rohde (1981) has introduced the concept of a biological buffering system. The idea is to introduce acid-tolerant and acid-resistant algae species to increase the primary production in acidic lakes. The primary production will again raise the pH due to the photosynthesis. The method has not however been very successful up to now, as it is difficult to obtain a higher level of photosynthesis, when hydrogen carbonate ions are missing in the lake water; see Jansson et al. (1981).

The introduction of acid-tolerant fish species is another method to accelerate the biological recovery. *Salmo gairdneri*, the North American trout, has been proposed and applied as an acid-tolerant species with some success, particularly where liming was used simultaneously, Erikson et al., (1980 and 1987). This approach has enabled some lakes to provide satisfactory fishery due to increased fertility of the introduced fish species at the dominant pH-value of the lake water.

The application of land-use / management strategies have been explored to counter acidification, particularly that associated with growth of coniferous trees. Conifers have been replaced with broadleaf species, forest cutback, burning and ploughing regimes (Ormerod et al., 1988 and Welsh et al., 1987). The results have been an increase in pH, particularly in cases where the low pH has been caused by natural processes. If the low pH has been mainly caused by acid rain, the method has hardly any effect, at least not on a long term basis.

Hydrological management has also been used to counter acidification,

where a source of less-acidic groundwater is available or increased lake retention may enhance sediment generation of alkalinity, which is the case for calcium-rich sediment.

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