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ACIDIFICATION OF SURFACE WATERS IN EUROPE: DOSE/RESPONSE OF AQUATIC FAUNA AND LONG-TERM TRENDS */

I. INTRODUCTION

1. The International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes (ICP Waters), established in 1985 as part of the effect-oriented activities under the Convention, operates within a monitoring hierarchy that is designed to evaluate the environmental effects of acid deposition on surface waters and predict future ecosystem changes occurring under different deposition scenarios. The Programme Centre and the programme database are located at the Norwegian Institute for Water Research (NIVA); close cooperation is maintained with the Zoological Institute, University of Bergen, Norway.

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*/ Summary report of the results achieved by the International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes, prepared with the assistance of Mr. G.R. Raddum, Zoological Institute, University of Bergen, Norway.

2. The programme is based on existing national activities in participating countries and their monitoring sites, and is implemented through cooperation between designated national laboratories and institutes. Monitoring practice varies from country to country with respect to time-series and type of studies. In Norway relevant series of biological monitoring data existed since 1981; Germany, Ireland and Sweden have also carried out biological monitoring for several years. Altogether, biological and chemical data which can be used for deriving dose/response relationships are available from 108 sites. In addition, invertebrate and fish data exist from 165 and 1095 sites in Norway which are not regularly monitored.

3. Invertebrates respond to different compounds in the water. In acidified areas it is the toxic effect of a low pH or a pH in combination with aluminium which is the main cause of species reduction (Raddum and Fjellheim, 1984; Engblom and Lingdell, 1984; Herrmann et al., 1993; and Larsen et al., in press). The toxic effect is reduced by increased concentration of Ca and humic content (Lien et al., 1996).

4. The effects of acidification on invertebrates are evaluated by the use of a model based on the presence/absence of species/taxa that are sensitive to or tolerant of acid water. The indicator species are grouped into four categories according to their tolerance. The model is developed for the fauna in Norway where few species are totally absent before the pH declines below 5.5. When the most sensitive species are present the locality is defined to be little or not acidified, score l. If these species are absent, but the locality contains species tolerating a pH as low as 5.0, the locality will be categorized as moderately acidified, score 0.5. An acidification score of 0.25 is used if all the sensitive species mentioned above are lacking, while species tolerating a pH as low as 4.7 are present. Lastly, if the locality contains only very tolerant species, which can sustain a pH below 4.7, the site is defined as strongly acidified, score 0. This is a step-by-step model which does not take into account sublethal effects.

5. Species can, however, be absent for reasons other than acid water. Therefore, especially the earlier stages of acidification can be difficult to detect by the indicator model described above. To handle this situation, multi-variate numerical techniques have been used to quantify the relationships between invertebrates and important compounds of the water quality. Furthermore, the predictive ability of invertebrates regarding pH is investigated and new indicator species are detected.

II. RESULTS

6. The degree and geographic extent of acidification damage to biology vary in different parts of Europe depending on the buffer capacity of the bedrock and deposition. In areas with highly oligotrophic water, low in calcium content, as in Norway, the fauna is characterized by a low number of both sensitive and tolerant species. The reason is that many species have not been able to adapt to this condition. The fauna in water with high ionic strength and rich in calcium is usually more diverse than in oligotrophic water. Species adapted to ion-rich water will normally have diminished their ability to tolerate a low pH.

7. This can be illustrated by comparing lakes with score 1 (low acidification) from Norway and Germany. In Norway the mean pH of localities where the most sensitive species were present was 5.8 while this pH was 6.8 in corresponding localities in Germany. Similarly, the mean acid neutralizing capacity (ANC) was 10 and 150 μeg/l. Consequently, in oligotrophic water with low Ca concentrations, range 0.3 - 2 mg/l, an ANC of 20 μeg/l is recommended to protect fish and invertebrates in regions with acid deposition. In water with higher ion content and Ca concentrations, range 3 - 6 mg/l or more, the critical limit of ANC should be raised. It is, however, not easy to determine this ANC limit, as there are many variations in the water chemistry data. The most sensitive fauna was, however, very seldom found in this type of water with a pH of 6. Therefore, the ANC limit was determined based on a correlation analysis between pH and ANC. The analysis shows that a pH of 6 corresponds to an ANC of 50 μeg/l. In acidified regions of central Europe a critical limit of ANC of 50 μeg/l is therefore proposed to protect the most sensitive organisms. This limit should also be set in other areas with calcium-rich watersheds, like in many of the monitoring sites in Sweden.

8. Acidification and reduction of species were the highest in areas which originally had a high diversity. The reason for this is that the fraction of sensitive species is higher in these communities than in less diverse communities. Strongly acidified localities in Sweden and central Europe are therefore relatively more damaged, in per cent of species lost, than for example acidified areas in Norway and Ireland.

9. The multi-variate numerical analysis was used to quantify the relationship between the species and the water chemistry components pH, calcium, ANC, total aluminium and conductivity. Detrendened canonical correspondence analysis (DCCA) showed a high correlation with pH and aluminium (axis 1), which consequently were the most important factors explaining variations in the fauna. Also, conductivity and ANC were significant variables for explaining fauna changes along axis 1. Along axis 2 calcium was the only significant factor to modify invertebrate communities.

10. The predictive abilities of invertebrates regarding pH were explored by means of weighted averaging (WA) regression and calibration and weighted averaging partial-least-squares regression (WA-PLS). It was shown that the predictive ability of invertebrates is good ($\mathrm{RMSEP}_{\mathrm{boot}}$ for WA = 0.309 pH units), which means that fauna analysis can predict the pH of a locality to ±0.3 pH units. Invertebrates therefore have the same predictive ability as diatoms. Indicator taxa for pH were found by Gaussian regression. Many species were found to increase in number as the pH decreased, while other increased as the pH increased. Also, many species were found to characterize either a low or a high pH. These analyses are important for verifying the tolerance of the indicator species used in the simple score method mentioned above. New indicator species have also been detected through this analysis.

11. To define long-term trends in invertebrate fauna, the acidification scores have been used for the watersheds that have enjoyed long and regular monitoring. For some of the river systems in Norway this dates back to 1981. The data show that the spring samples generally show the highest acidification, low score, due to the release of acids as the snow melts. In autumn the acidity was lower, as indicated by a higher score value. Due to the difference between the seasons, the trend analysis is performed separately

on spring and autumn data. A significant increase in the score value (reduced acidity) was recorded for the autumn in the period 1989-1994 in two of the monitored watersheds. For the spring a significant increase in the value was found for the period 1982-1988 in the watershed with the lowest acidic deposition. The observed increase in the score value is probably the result of reductions in acid deposition in Norway. So far the improvements are best seen in areas that had originally little acidification damage, while strongly acidified areas show smaller changes over time.

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