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RECOVERY OF INVERTEBRATE FAUNA FROM ACIDIFICATION IN ICP WATER SITES IN EUROPE AND NORTH AMERICA

Report prepared by the Programme Centre of the International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes

Introduction

1. The International Cooperative Programme (ICP) Waters 15-year report (EB.AIR/WG.1/2003/6) documented widespread improvements in surface water chemistry in response to emissions control programmes and decreasing acidic deposition. The ultimate goal of emissions control programmes is biological recovery, e.g. the return of acid-sensitive species that have disappeared and the restoration of biological functions that have been impaired during the course of acidification.

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2. In 2000 ICP Waters conducted a trend analysis of its available biological data. The results, from Ireland, the United Kingdom, Scandinavia and Central Europe, included lowland as well as mountain areas. For the United Kingdom and most sites in Germany no statistically significant trends in acidification were found, although some positive signs of improvements in the invertebrate fauna were observed. A clear positive trend was found for the Norwegian sites and for most of the Swedish sites. For the most acidic sites in Central Europe, it was concluded that improvements in water quality had not yet reached a level where stable effects on biology could be detected. Biological recovery of such sites required considerable and stable improvements in water quality with respect to acidification.

3. This year's report presents an update of the results for trends in biology (invertebrate fauna) since 2000. The results confirm the results from 2000. The data suggest that continued improvement in the chemical status of acid-sensitive lakes and streams will lead to biological recovery in the future.

4. The report does not give a full literature review of other reports of biological recovery from acidification. The evaluation is restricted to countries from which there have been new data since 2000. The results are divided into long-term trends from sediment cores, trend analysis based on acidification indices and number of taxa, and multivariate statistical analyses in which biological community, water chemistry and time are evaluated together.

I. SEDIMENT CORES

5. For Austria, France, Italy and Spain, there is information on long-term trends from sediment cores. The core analysis has been performed through the European Union (EU) projects AL:PE, MOLAR and EMERGE. Core analyses from the moderately acidified site Schwarzsee ob Solden (AU03) in Austria show no trends in acidification over the past 200 years. Reconstruction of pH shows that the inferred pH for this period has been quite stable between 5.7 and 6.0. Although no clear trend in acidification was detected, most of the inferred pH values below 5.8 were estimated in the upper part of the core.

6. Core analyses of diatoms from Lake Aubé (FR01) in France (Pyrenees) show a very stable pH over the past centuries. The inferred pH at core bottom and core top were 6.0 and 5.9 respectively.

7. Core analyses of diatoms in Pione Superiore (IT03) in Italy show an inferred pH at the base of the core of 5.8-5.9 (300 years ago) and 5.6 at the top, which is very close to the present pH in the water. The change in the species composition registered over the 300-year period is probably

not caused by acidification, since pH has been more or less unchanged over the past 100 years. Moderate increases in acid deposition may have increased weathering rates and, in combination with increased temperature, this may cause increased production in the lake.

8. Core analyses from Lake Redo (ES01) in Spain (Pyrenees) show pH 6.8 at the base (before the industrial revolution) and pH 6.3 at the top of the core. The pH reduction has taken place mainly since 1940. In this period the concentrations of heavy metals also increased, indicating industrial pollution. However, the lake has not reached levels where damage to invertebrates is detected or expected.

II. OBSERVED TRENDS FROM MONITORING

9. For Finland, Ireland and the United Kingdom, there are no new data since the previous assessment. New results from the United Kingdom Acid Monitoring Network, however, show mounting evidence of a widespread biological response to declining water acidity in acidified lakes and streams. Both epilithic diatoms, aquatic macroinvertebrates, mosses and higher plants show positive trends at many sites.

10. Lakes in Killarney Park, Canada, are included in the biological monitoring of ICP Waters. These lakes have been seriously acidified especially from the smelters in Sudbury. Large-scale damage to both fish and invertebrates in this area in the 1970s has been described. The sulphur emission at Sudbury has been reduced by > 90% since peaking in the 1960s.

11. Biological recovery has been studied in lakes with various rates of chemical recovery and with various degrees of acid damage. The rate of biological recovery was less pronounced in low pH lakes (pH < 6) than in high pH lakes (pH > 6). Zooplankton showed recovery in lakes that chemically have recovered from pH < 6 to pH > 6 as well as in lakes that have not reached the pH > 6.

12. In the Czech Republic, the first signs of zooplankton recovery have been observed in some Bohemian Forest lakes. The species Ceriodaphnia quadrangula was reported from Lake Cerné (Schwarzer See) at the end of the 19th century. In 1935–1936 this species together with the species Cyclops abyssorum were the main component of zooplankton both in the open water and along the rocky shores. Between 1947 and 1969 C. quadrangula was still present in the lake. During the 1980-1992 period the species was not recorded, indicating loss due to acidification. In 1994 the species again appeared in the littoral zone and in 1997 in the open water (fig. I). At present it occurs regularly along the rocky shores.

13. C. quadrangula has also been reported since 1871 in other Bohemian lakes. However, for the following 100 years little information exists about the zooplankton. During the monitoring programme in the years 1997, 1998 and 1999 no individuals of the species were noted, but in October 2002 the species was reported from the littoral zone, while in 2003 it occurred both in the littoral zone and in open water. C. quadrangula is rather tolerant to acid stress.

14. The beginning of zooplankton recovery in Lake Plešné (Plöckensteiner) seems to be manifested by the increase in the numbers of pelagic rotifers during 1990–1999.

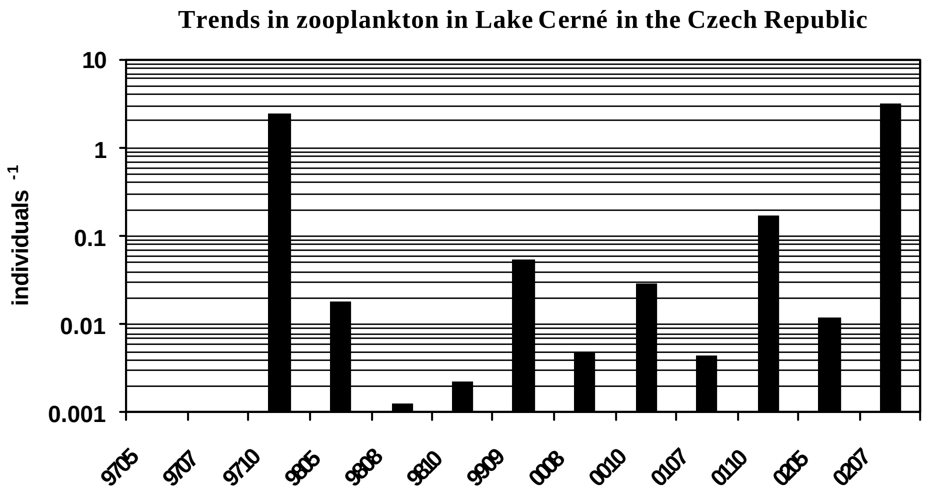

Figure I. Abundance of Ceriodaphnia quadrangula in open water (average column densities) of Lake Cerné in the Czech Republic. In the years 1980–1996 no Ceriodaphnia were found, while the species occurred again in autumn 1997. Time of sampling in the form YYMM.

15. The German monitoring programme on invertebrate fauna consists of 27 separate sites. All data are submitted to ICP Waters. The data are evaluated with a modified acidification index (Säuerezustandsklasse), which is well developed for biological monitoring in Germany.

16. There have been some signs of recovery of sensitive species in several of the German sites, but no stable or significant trends yet. The highest potential for significant improvements seems to be in the east of the country. The general lack of clear trends in aquatic biota so far is in line with the water chemistry results. In general, the chemical improvements have not reached a level at which biological response is expected. In some sites the pH change has even been negative, while in other sites it is highly variable over time. Such situations are not expected to benefit biological communities.

17. The Latvian ICP Waters sites have high conductivity, pH and Ca concentrations. In addition they also contain too much dissolved organic material for acid-sensitive organisms like stoneflies, which are virtually absent in the waters. The high organic content is also indicated by the high density of oligochaets. Typical for eutrophic waters is also the high abundance of snails and mussels, which leads to large numbers of leeches in the Latvian sites. The waters are not acid-sensitive, have not been significantly influenced by acid rain and their fauna is typical of well-buffered water quality.

18. The ICP Waters sites in southern and western Norway, Farsund, Vikedal (NO06), Gaular (NO07) and Nausta (NO08), show a general increase in the invertebrate acidification index over time. An example of the relationship between the development of the acidification index and the main chemical parameters from 1982 to 2002 is shown for Vikedal in figure II. The improvements in sulphate and pH started in the early 1990s. This was accompanied by an increase in the index. Both Vikedal and Farsund have a very similar index development, indicating similar changes over large areas of south-western Norway.

19. The mean acidification index for the Swedish sites has been estimated for the period 1985-1989, 1990-1995, 1997, 1998, 1999 and 2000 (fig. III). The index for Härsvatn (SE12) has been 0 through the whole period. In Lake Brunsjön (SE08) and Fiolen (SE09) the index has been 0.5 and 1 respectively since 1997, while in Fräcksjön (SE11) and Stensjön (SE06) a stable index 1 has occurred since 1995. The situation in Storasjön (SE10) has varied with an index between 0 and 0.5, while in Lake Tväringen (SE05) the index has been stable at 1 during the whole period.

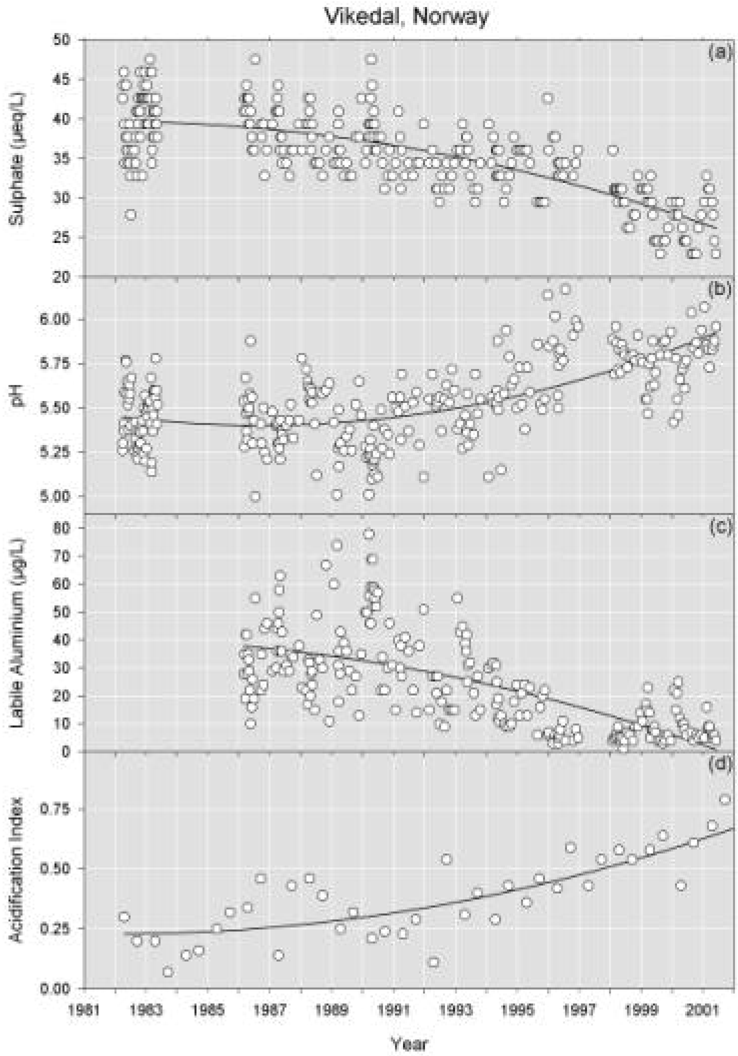

Figure II. Development of water chemical parameters and the acidification index in Vikedal

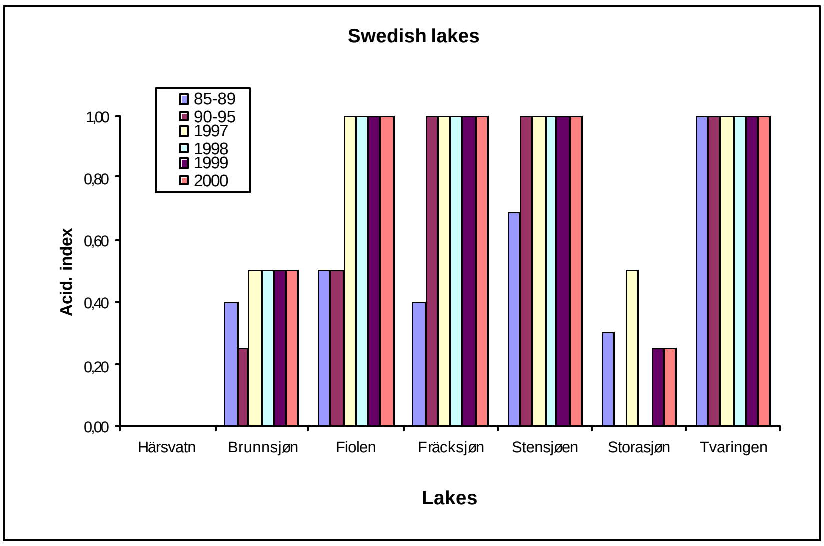

Figure III. Acidification indexes for Swedish lakes during the period 1985 – 2000

III. TRENDS DETECTED BY THE USE OF MULTIVARIATE STATISTICS

20. Multivariate statistical analyses have been carried out on data from Norway and Sweden. In Norway multivariate statistical trend analyses were performed on data from the rivers Nausta (NO08), Gaular (NO07) and Vikedal (NO06). Partial redundancy analysis (RDA) was used to find the amount of variation in the biological data that can be explained by linear trends in water chemistry, and a Spearman rank correlation test was used to explore the connections between the different water chemistry variables and linear time. The results for Nausta with 20 different sites spread on tributaries and in the main river are shown to illustrate these analyses (table 1). All the sites in the tributaries and most of the localities in the main river showed a significant result that can be explained by linear trends in the water chemistry for the 13-year period.

21. The correlation tests show a strong and significant correlation between time and increases in pH and acid neutralizing capacity (ANC), and between time and a decrease in the concentration of labile aluminium. These trends are recognized as recovery in the water chemistry of both the River Nausta and the tributary Trodøla.

22. The results from the tributary Trodøla (table 2) also show significant trends for all localities in the tributaries. The correlation tests between time and water chemistry from the Trodøla again indicate that the linear trends in the benthic community can be interpreted as a response to a chemical recovery in the waters.

Table 1. Spearman rank correlation matrix between the environmental variables from the main river in the Nausta watershed from 1989 to 2001 used in the RDAs. (Two tailed tests. ** significant at the 0.01 level. * significant at the 0.05 level.)

	Ca	**ANC**	**TOC**	**LAl**	**Time**
pH	0.427*	0.793**	0.465*	-0.723**	0.778**
Ca		0.450*	0.085	-0.248	0.320
ANC			0.569**	-0.700**	0.614**
TOC				-0.290	0.059
LAl					-0.703**

Table 2. Spearman rank correlation matrix between the environmental variables from the tributary Trodøla in the Nausta watershed from 1989 to 2001 used in the RDAs. (Two tailed tests. ** significant at the 0.01 level. * significant at the 0.05 level.)

	Ca	**ANC**	**TOC**	**LAl**	**Time**
pH	0.631**	0.947**	0.415*	-0.925**	0.843**
Ca		0.697**	-0.001	-0.522**	0.643**
ANC			0.473*	-0.848**	0.784**
TOC				-0.337	0.258
LAl					-0.841**

23. The Nausta, Gaula and Vikedal show changes in their total benthic communities which can be explained as responses to recovery in chemistry, i.e. less acidified chemistry. This is consistent with the results based on the acidity indices, which have also been increasing in all three watersheds. The amount of variation explained by these linear changes in water chemistry increased at almost all localities when the most recent 3-4 years of monitoring data were included.

24. Multivariate statistics applied to Swedish sites show trends in biological recovery in the sublittoral community in Fräcksjön (SE11) and Härsvatten (SE12) during the period from 1990 to 2002. The trends can be interpreted as a result of recovery in the water chemistry. Lake Brunnsjön (SE08) and Lake Stensjön (SE06) also show significant linear trends in the sublittoral community. However, these changes are linked to a decrease in the calcium content and cannot solely be explained as responses to reductions in acidity. Processes connected to climate change may be the cause of these changes, although increases in ANC in both lakes indicate that chemical recovery also plays a part in their biological changes.

25. The profundal / sublittoral community of Lake Storasjön also shows a significant linear trend. Again a decrease in the calcium content appears to be the strongest explanatory variable, but an increase in ANC also plays a role in the analyses of this lake. For all of the five lakes the total organic carbon (TOC) also increases. This may be caused both by a recovery in water chemistry and by climate change.

26. The profundal communities of the lakes do not show any signs of biological recovery. The confounding effect of oxygen depletion in the deep waters of the lakes is probably one important factor explaining the lack of trends.