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TRACING BIOLOGICAL RECOVERY IN SURFACE WATERS BY USING MULTIVARIATE STATISTICS

Summary report */

I. INTRODUCTION

1. Recent research has shown that there was a significant recovery in water chemistry from 1989 to 1998, following the reduced emissions of sulphur in Northern Europe and North America (Stoddard et al, 1999; Skjelkvåle et al., 2000). This recovery has also been reflected in the macro-zoobenthos in some watersheds in southwestern Norway, as documented by the acidification indexes developed at the Laboratory of Freshwater Ecology and Inland Fisheries (LFI), Department of Zoology, University of Bergen (Raddum & Fjellheim, 1984; Raddum, 1999).

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*/ Tracing recovery from acidification – a multivariate approach (short version) Godtfred A. Halvorsen of LFI, Einar Heegaard of the Department of Botany, University of Bergen, and Gunnar G. Raddum of LFI.

2. The aim of our analysis is to see if this recovery can be traced as changes in the abundance of the benthic community during the same period. The method used is described in detail in Skjelkvåle et al. (2000). By using of the multivariate redundancy analysis (RDA) we try to find the proportion of the variation in the abundance data that can be equally well explained by changes in the water chemistry data available as by a linear time variable. A simple Spearman rank correlation test is then used to test which of the water chemistry variables are correlated with linear time. If both spring and autumn samples exist for each year, we have also tested how much seasonal changes in water chemistry affect the benthic community by replacing the linear time variable with a seasonal one.

3. Three watersheds with benthic samples from running water in Norway, six lakes in the United Kingdom, and seven lakes in Sweden, all from the International Cooperative Programme (ICP) Waters biological database, have been analysed.

II. RESULTS AND DISCUSSION

A. Norway

4. The watersheds Nausta (NO08), Gaular (NO09) and Vikedal (NO06) are situated from north to south in the western part of the country. They are all located in fjord systems at about the same distance from the outer coastline. The southernmost Vikedal River is the one most affected by acid rain, while the Nausta River lies in an area where acidification has been less pronounced.

1. The Nausta watershed

5. The biological data set in the Nausta watershed consists of kick samples from 20 localities in the main river and in some of its tributaries, expressed as relative abundances. The localities were sampled each spring and autumn. Water chemistry is sampled at two localities, one in the main river and one in the tributary Trodøla. The water chemistry variables included in the analyses were pH, calcium concentration (Ca), acid neutralizing capacity (ANC), the concentration of total organic carbon (TOC) and the concentration of labile aluminium (LAl). Both localities showed significant trends of recovery in water chemistry from 1989 to 1998 (Skjelkvåle et al., 2000).

6. Since we did not have water chemistry data from each benthic locality, two different strategies were followed. The first was to treat all benthic localities as subsamples from the whole river, and to include the pooled abundance data from the whole watershed in the analyses. Separate analyses were run with this data set and the chemical data sets from both the main river and the tributary. The other was to use the two water chemistry data sets as representatives for the development in water chemistry in the watershed, and analyse the biological data from each benthic sampling station with the water chemistry from both water sampling stations.

7. Two of the benthic localities, locality 11 in the main Nausta river and locality 7 in the tributary Trodøla, are the same as the water sampling stations, so these two localities will be considered first. Both localities gave significant ordinations with linear time included as the only environmental variable in the RDA, i.e. there was a linear time trend in the biological material. However, when the respective water chemistry data sets were included, only the tributary Trodøla

gave a significant result. The amount of variation in the abundance data explained by the water chemistry was 35.2%, and the proportion explained by both water chemistry and linear time was 6.3%. The seasonal trend in the material was larger, 12.3% of the variation in the abundance data could be explained by the seasonal variation in the water chemistry data. The correlation analysis showed that linear time was positively correlated with an increase in pH and ANC, and a decrease in LAl. This means that we have a linear trend in the benthic community in the tributary Trodøla that can be interpreted as a response to recovering water chemistry.

8. Twelve of the localities and the pooled abundance data from the whole watershed gave significant ordinations with linear time included as the only variable, i.e. a linear trend was apparent in the material. However, only one of the localities showed a signal of recovery when the water chemistry data from the main river were included in the analysis. This was the uppermost locality in the main river. When the water chemistry data from the tributary Trodøla were used, an additional 6 localities gave a signal of recovery. Also, the pooled data from the whole watershed gave a significant result with this data set. The amount of abundance variation explained ranged from 4.3% to 8.7%, and the localities were mainly in the tributaries. Only two localities from the upper and middle reaches of the main river gave an indication of recovery.

9. The amount of variation explained by the seasonal changes in the water chemistry varied from 1.7% to 17.2%, and was on average higher than the amount explained by linear time.

10. Trends in recovery can be identified in the benthic community in the Nausta watershed. This is mainly found in the upper reaches and in the tributaries of the river. This is also consistent with the results given by the acidity indexes. The indexes from the localities in the lower reaches of the main river indicate little or no acidification during the period from 1989 to 1998.

11. Both water chemistry data sets from the watershed showed significant trends in recovery from 1989 to 1998 (Skjelkvåle, 2000). The tributary Trodøla has, however, been affected more by acidification than the main river. The pH increased from about 5.4 to 5.6 between 1989 and 1998, while in the main river it increased from about 5.6 to 6.0 in the same period. This is just above what is regarded as the limit for sensitive organisms in the main river, while the level in the tributary is still below what is regarded as necessary for the establishment of surviving populations of sensitive organisms. The water chemistry data set from the tributary Trodøla gives more indications of recovery in our analyses than does the data set from the main river. This means that the patterns of change in the Trodøla data set are better correlated with the changes in the abundance data than the data set from the main river.

12. That the seasonal variable explains on average more of the species abundance variation than the linear time variable, indicates that the watershed is vulnerable to acidic episodes like snowmelt in spring and sea-salt episodes during the winter. This was also stated in a baseline report before the start of the monitoring of the river in the mid-1980s (Lien et al., 1988).

2. <u>The Gaular watershed</u>

13. The data set from this watershed consists of 17 benthic localities and one water sampling station. The procedure for the analyses was the same as for the Nausta watershed.

14. The pooled data from the watershed gave a significant ordination with linear time, as did 8 of the 17 localities, i.e. they showed linear trends in the abundance data. However, only one gave a significant result when the water chemistry was included. This was a tributary to the main branch of the river. The amount of variation explained by linear changes in the water chemistry was 3.7%, while the seasonal changes explained 10.7%. The benthic locality with the water sampling station did not show any signal of recovery. Linear time was correlated with an increase in pH and ANC, and a decrease in LAl. The pH increased from about 5.3 to about 5.8 in this watershed during the ten-year period. Both this increase and an increase in ANC were shown to be significant in Skjelkvåle et al. (2000). The lack of signals of recovery in our analysis from the Gaular watershed is consistent with the acidification indexes, which classify large parts of the watershed as moderately acidified.

3. The Vikedal watershed

15. This watershed is the southernmost of the Norwegian watersheds analysed here, and the one that has been affected most by acidification. The anadromous stretch of the river was limed in the mid-1980s. This analysis includes 10 localities in the unlimed part of the watershed. One water chemistry station is situated above the limed stretch, but there are no benthic data from that locality.

16. The pooled data set from all of the unlimed localities and three of the benthic localities gave significant ordinations with only linear time included in the analyses. Only one of the localities, however, showed a sign of recovery when the water chemistry variables were added. The amount of variation explained was 6%. The acidity indexes from the unlimed parts of this watershed are also low, the mean values for all the localities indicating that the unlimed part is still moderately acidified. The seasonal change in the water chemistry variables explained only 2.5% of the variation in the abundance data. Also, two more localities gave significant ordinations when the seasonal variable was analysed, with the seasonal change explaining 2.3% and 2.9% of the variation.

17. This watershed is different from the two more northerly ones. In Vikedal the acidity indexes shows that the autumn is the most acidic, with lower values than in the spring. This is opposite to the Gaular and the Nausta watersheds, where we find the lowest values in spring. The Vikedal watershed lies at lower altitudes, and in an area of Norway with rather small amounts of snow in the winter. Consequently, the snowmelt in spring is less important than in the two other watersheds, which reach much higher altitudes and also have more winter snow. Rainstorms during the autumn appear to be more important for the acidification in Vikedal, than in Nausta and Gaular.

B. United Kingdom

18. The biological data from the United Kingdom consist of kick samples from the littoral zone of six lakes, expressed as relative abundances. The samples are taken in the spring. Each lake has corresponding water chemistry samples. The water chemistry variables included in the analyses were pH, Ca, ANC, and the concentration of dissolved organic carbon (DOC). The

following lakes were analysed: Loch Coire nan Arr (UK01) in north-western Scotland, Lochnagar (UK04) in the eastern Grampian mountains of Scotland, Round Loch of Glenhead (UK07) in the Galloway region, south-western Scotland, Scoat Tarn (UK10) in the Lake District, north-western England, Llyn Llagi (UK15) in Northern Wales, and Blue Lough (UK21) in the south-east of Northern Ireland. The localities are described in Evans et al. (2000).

19. Four of the lakes (UK01, UK04, UK10, and UK21) showed linear trends in the abundance data, when the RDAs were run with linear time as the only environmental variable. None of the localities produced significant ordinations when the water chemistry data were included. No sign that could be interpreted as a recovery from acidification was discovered in the benthic communities. The ordination from Lochnagar (UK04) with the water chemistry data included was close to being significant ($p = 0.055$). However, according to Evans et al. (2000) the process going on in this locality is a continuing acidification rather than a recovery from acidification.

C. Sweden

20. The biological data from the seven Swedish lakes are kick samples from the littoral zone, and quantitative samples from the sublittoral and/or the profundal zone. The following lakes were analysed: Tväringen (SE05) and Stensjön (SE06), inland in mid-Sweden, Fräcksjön (SE14) and Härsvatten (SE12) close to the south-western coast, Fiolen (SE09) and Storasjö (SE10) inland in southern Sweden, and Brunnsjön (SE08) on the south-eastern coast. The littoral samples were taken in the spring during the first half of the period, but changed to the autumn from 1995 onwards. The quantitative samples analysed from the sublittoral and the profundal zones were all taken in the autumn. All samples had corresponding water samples. The water chemistry variables included in the analyses were pH, Ca, ANC, and TOC. The littoral abundance data were analysed as relative abundances, while the sublittoral and profundal samples were analysed as numbers of individuals per m^2.

21. No littoral samples gave any significant result when the change in sampling strategy was corrected.

22. Five lakes had sublittoral samples (SE06, SE08, SE09, SE11 and SE12). Of these three lakes gave the RDAs significant results when only time was run as the environmental variable. Only two lakes, Fiolen (SE09) and Härsvatten (SE12), showed significant results when the water chemistry was analysed.

23. The variation in the water chemistry in Fiolen explained 54.1% of the variation in the abundance data, and 17.5% of this variation could equally well be explained by linear time. Correlation tests between linear time and the water chemistry variables showed that linear time was correlated with an increase in pH and a decrease in the calcium concentration, i.e. features associated with a recovery from acidification. The pH increased from about 6.3 to about 6.5 in Fiolen during the ten-year period. Although the acidification has been slight, signs of recovery can be traced in the benthic community.

24. Härsvatten is the most acid of the Swedish ICP Waters lakes. The pH increased from about 4.3 to about 4.7 in the period. Analyses in Skjelkvåle et al. (2000) showed that there had been

significant decreases in the hydrogen ion concentrations, in sulphate and in the sum of base cations. In our analysis the changes in water chemistry explained 73.8% of the variation in the sublittoral abundance data, and 34.4% of this variation could be attributed to a change in linear time. Linear time was correlated with an increase in pH, and a decrease in Ca and TOC. This shows signs of recovery in the sublittoral zone of the lake, although the lake is still very acid. It also shows that the multivariate method is capable of tracing recovery in parts of the pH scale where methods based on acidity indexes would probably have indicated no change.

25. All seven lakes had profundal samples. Only one lake (Fiolen, SE 09) showed a linear trend in the profundal abundance data, but did not give a significant result when the water chemistry was included.

III. CONCLUSIONS

26. The multivariate method found evidence of recovery from acidification in some localities in all of the three Norwegian watersheds, and also in two of the seven lakes analysed in Sweden. There was no sign of recovery in the benthic community in the ICP Waters lakes in the United Kingdom.

27. The results from Norway are in good accordance with the results based on the acidity indexes. The northernmost Nausta watershed shows more signs of recovery than the other two watersheds analysed here. This watershed is also the least acidified of the Norwegian ICP Waters sites.

28. The results from the Swedish sites show that the multivariate method can trace signs of recovery in the benthic community in lakes that are recovering chemically, but still are in a very acidic state. Also, the results from Fiolen show that a recovery can be traced when the acidification has been slight, and when the recovery has occurred over a pH gradient where the lake would be classified as not acidified. In cases like this, methods based on indexes would probably have indicated no change at all.

29. The method only indicates where a recovery in the benthic community has occurred. It does not say anything about how far the site is from its natural, unaffected state. However, it may provide an indication of the relative strength of the recovery. It gives a measure of how much of the total change in the abundance data can be attributed to linear changes in water chemistry. As such, the method may also identify acidification processes equally well as recovery from acidification.

30. The Norwegian data set shows that the method can give a relative measure of how much seasonal changes in the water chemistry affect the benthic community, and by this identify a possible recovery process. The results from the Nausta and the Gaular watersheds show that seasonal changes in water chemistry related to snowmelt in spring and/or sea-salt episodes in winter may confound the identification of a recovery process. In the Vikedal watershed, however, the seasonal changes appear to be of less importance, and the rainfall during the autumn seems to be the most important factor in inhibiting a biological recovery.

31. The multivariate method appears to be conservative in the context of indicating recovery. The number of localities which show linear trends when the linear time variable is included in the analyses as the only variable, is higher than when the water chemistry variables are included as well. This means that the method can be used in cases like the Norwegian monitoring sites, where we do not have water chemistry samples from each benthic locality, but have to rely on one or a few sampling sites to represent each watershed. The method does apparently not overestimate signs of recovery.

32. We regard the multivariate method to be complementary to methods based on acidity indexes. It may corroborate a sign of recovery indicated by the indexes and, most important, it may also discover signs of recovery where the indexes have no resolution.

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