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WORKING PAPER NO. 11

DIATOMS AND ACID LAKES: PROCEEDINGS OF A WORKSHOP

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INTRODUCTION

Diatom analysis of lake sediments has become one of the most important techniques used in the contemporary debate on lake acidification. In recent years the relationship between diatom assemblages and pH has been quantified allowing the pH history of individual lakes to be reconstructed. Much reliance is placed on these reconstructions yet we have little understanding of the causal mechanisms that underlie the impressive statistics. There has been little research on the ecology and physiology of diatom taxa in acid and acidifying waters and we have little information on the role of either planktonic or non-planktonic diatoms in acid lake ecosystems. This Workshop, hence, was not only devoted to the exchange of information on current research projects but also to a discussion of some of the ecological questions that require resolution to improve our understanding of the diatom:pH relationship.

ASSESSMENT OF CHANGES IN pH BY THE STUDY OF DIATOMS IN CORES AND OLD SAMPLES

by

Klaus Arzet and Herman van Dam

There are two methods of assessing long term environmental changes using diatoms. The most frequently used method uses fossil diatoms in lake sediments to estimate environmental conditions in the past. The second uses old samples, which are sometimes present in Natural History Museums, herbaria, and personal collections. We have found a large collection of old samples from acid-sensitive soft water lakes and ponds in The Netherlands and in the University of Amsterdam. For modern comparison new samples were taken at the same localities in the last few years.

This method can be used in shallow waters with poorly developed sediments where it is impossible to use the core method. The samples can be dated very accurately, which otherwise is only possible in lakes with varved sediments, and past changes in the environment (e.g. drought or fire) can be reliably related to changes in diatom assemblages.

When old algal samples are unavailable fragments of aquatic macrophytes, stored in herbaria, can be used. Plants like Lobelia dortmanna, Myriophyllum alterniflorum and even Juncus bulbosus often have very rich epiphytic diatom floras, which are preserved well in herbarium specimens.

Sediment cores, however, give a continuous record of the pH history of a lake. However some problems have to be borne in mind when interpreting such data, concerning the comparability of both type of samples. Sediment samples contain all planktonic and benthic diatoms living in the lake, the composition of benthic and epiphytic diatoms depends much on the location and substrate of sampling. In the following account we have tried to give a few examples of the comparability of both methods.

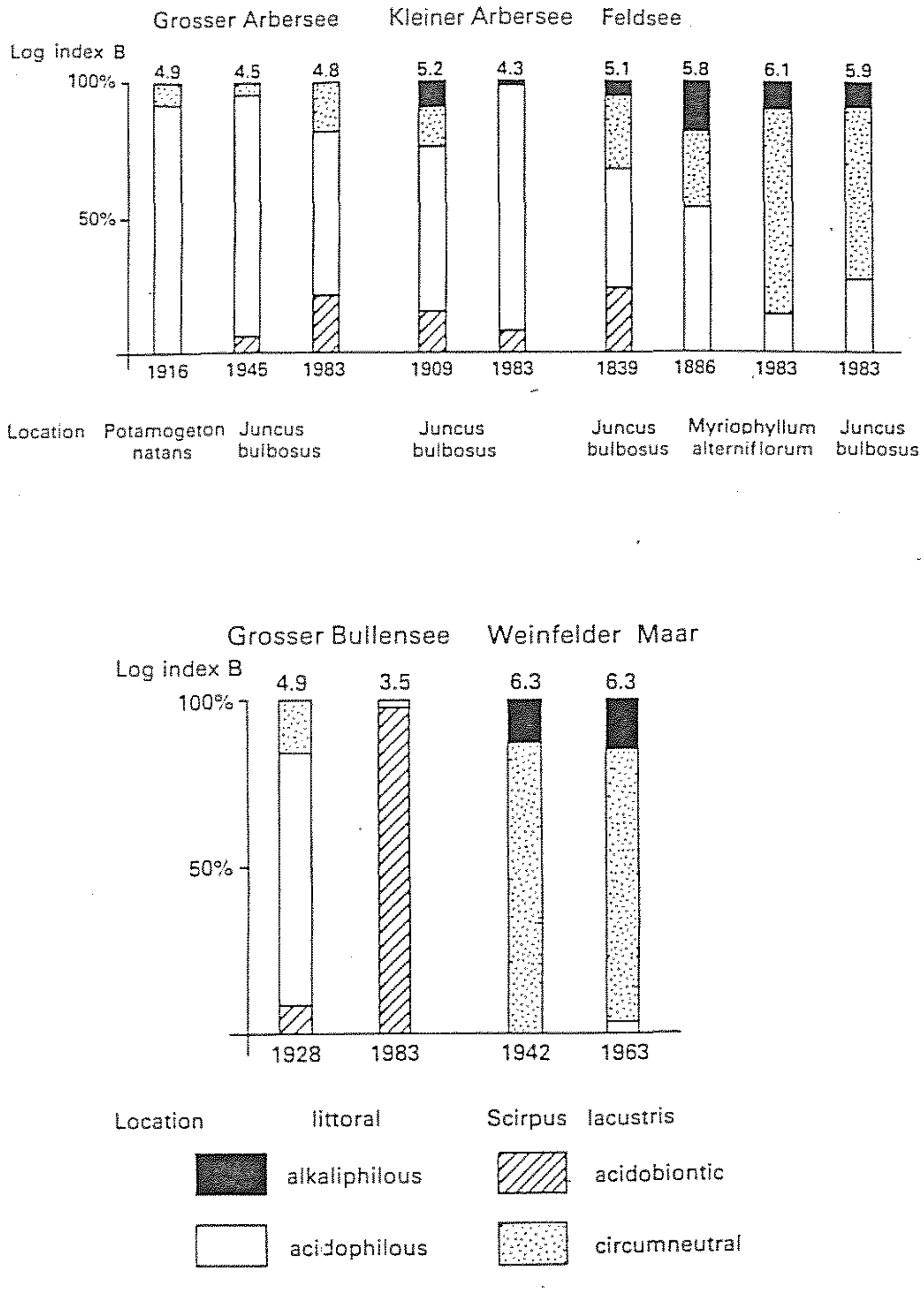

Fig. 1 pH spectra for epiphytic diatoms on old and modern aquatic macrophytes.

Althogether we have compared samples of five lakes in different regions of the F.R.G. (Fig. 1). In Kleiner Abersee (Bavarian Forest) the diatom distribution in the sediment core reveals a continuous decline in lake pH from 5.6 to 4.7 in the last 30 years according to Index B. Epiphytic diatoms on Juncus bulbosus collected in 1909 and 1983 indicate a similar shift to lower pH conditions, although diatom inferred pH on the basis of Index B tend to give lower pH-values than for the core samples (1909: 5.2, 1983: 4.3). An increase of acidobiontic species and a decrease of circumneutral and alkaliphilous species is observed in both types of material. Sediment samples of Grosser Arbersee (Bavarian Forest) reflect a similar pH-history. Samples collected on Potamogeton natans and Juncus bulbosus in this lake do not show much of a change in comparison to recently collected samples, even though there has been a slight increase in acidobiontic species. Possible sources of error are associated with the different sampling sites and different plant material used. Old samples collected in Grosser Bullensee (North Germany) in 1928 confirm the sediment data of this lake. Both methods suggest a decline in pH from 4.5 to 3.6 since the beginning of this century partly related to the draining of a nearby bog around that time. Sediment and old samples of two other lakes (Black Forest and Eifel) indicate a constant pH during this century, and this is supported also by historical and recent pH measurements (Fig. 1). Both methods prove to be sensitive to lake pH even though there are some disagreementsconcerning log Index B due to the different sampling methods.

The allocation of the species into the pH classification system developed by Hustedt was done by comparing colorimetric pH readings and the occurrence of planktonic and epiphytic diatoms. The pH reconstruction methods of Nygaard, Merilainen and Renberg were based on diatoms in the surficial sediments of lakes.

In extremely acid pools and lakes, as in parts of The Netherlands, Belgium and Germany, the pH reconstruction indices cannot be used, as only acidobiontic diatoms are present. In Denmark, however, where lakes are less acid, there was an opportunity to calibrate the inferred pH (Index B applied to plankton and periphyton samples) against the measured pH. This yielded a correlation coefficient of 0.89 (n = 17).

Until recently diatomists involved in acidification research have focussed on standing waters, although acidification of running waters is also an important problem. Flowing waters are poor in sediments and comparison of old and recent samples is the only way to assess acidification using diatoms.

ACIDIFICATION OF SMALL CLEAR-WATER LAKES IN FINLAND AS INDICATED BY SEDIMENTARY DIATOMS

by

Mikko Liukkonen

The pH history of the small forest lakes in southern and central Finland has been studied from sedimentary diatoms. All the lakes are oligotrophic and, with two exceptions, are clear-water lakes. The catchment areas are undisturbed or only slightly disturbed. The bedrock of the study areas is granitic, and catchments, where not bare rock, are covered by sand, gravel, or moraine. Most of the lakes are seepage-basin lakes. The lakes are located in the regions where the pH of precipitation is the lowest (pH 4.4 to 4.90 and deposition of SO_4 highest (160 to 320 mg^{-2} per month) in Finland (1971-1977)). The measured pH of the lake water (1977-1984) varied between 4.3 and 5.9, with one lake being 6.7.

The pH was reconstructed using both index alpha after Meriläinen's calibration and index B. About 300 diatom frustules were counted at each level. In the surface sediment the diatoms were counted at 0.5-1.0 cm intervals, in the deeper parts less frequently.

Four of the lakes proved to have been acid for thousands of years, whereas six lakes showed a rapid decline in pH in the surface sediment. ^{210}Pb dating showed that this rapid change began about 30 years ago. Species succession within the genus Tabellaria Ehr. towards T. quadriseptata Knuds. and T. binalis Grun. was typical for these small lakes. The other acidobiontic taxa found in the sediments were Actinella punctata Lewis, Eunotia exigua (Breb.) Grun., Anomoeoneis serians v. serians (Breb.) Cleve and Navicula subtilissima Cleve (including N. hoefleri Cholnoky). In these recently acidified lakes the sum of acidobiontic taxa varied between 7 and 20% of all the diatom frustules, in the surface samples.

Around some of the lakes there may have been changes in catchment land use, whereas some of the lakes have only bare rock and small pine forests in their catchments. In these cases it is unlikely that changes in land-use have occurred.

We conclude that air-borne acid loading is the likely reason for the acidification of these lakes.

PALEOECOLOGICAL INVESTIGATIONS OF RECENT LAKE ACIDIFICATION (PIRLA) IN NORTH AMERICA

by

John C. Kingston and Keith E. Camburn

The project "Paleoecological Investigation of Recent Lake Acidification" is a multidisciplinary effort to reconstruct lake acidification in four areas in North America (New England, Adirondack Mountains, Great Lakes States, and Florida). The PIRLA project is funded by the Electric Power Research Institute, and is coordinated by Drs. Charles and Whitehead of Indiana University. PIRLA brings together specialists in many biological, chemical, and geological disciplines to use standardized methodologies in the four study areas and eventually to create a single data base for acid-sensitive areas across the continent. Much of the reconstruction of lake pH is based on analysis of diatom assemblages in lake sediments, and special effort is put into standardizing taxonomy for the project. A report containing the project description and all methods will soon be published by EPRI.

Recent progress is as follows:

1. Adirondack Mountains - pH reconstructions have been completed for Big Moose Lake (Charles 1984) and Deep Lake (unpublished). Deep Lake was apparently quite acidic (pH c. 5.0) prior to recent acidificaton; large changes in species composition occur after 1950, and the 65% dominance of several acidobiontic species indicates a drop in pH to 4.3. However, the actual pH of Deep Lake is around 4.7, and this may demonstrate the limitations of predicting pH in very acidic lakes. Variation of diatom surface assemblages is being investigated in Big Moose Lake. Radioisotope dating is done for all Adirondack cores, and geochemistry has been completed for two cores.

2. New England - effort is being placed on solving taxonomic problems and expanding the regional diatom photographic file. Little Long Pond and Haystack Pond cores have been analysed, and no strong acidification trend is noted; this may go along with previous findings from Maine which indicate that land use changes might have had the greater influence over preserved diatom assemblages. Dennis Anderson's presentation in this workshop includes recent work with *Tabellaria* taxonomy. Eight more surface sediment assemblages have been added to the New England data base (previously containing 31 surface assemblages), and water chemistry continues to be collected for the entire set of lakes.

3. Florida - emphasis is being placed on diatom taxonomy and generation of a photographic file, and SEM is being used for problem taxa. Surface sediment assemblages have been counted in five lakes. Six cores have been dated with ^{210}Pb, and preliminary pollen counts have been done. Surface water chemistry sampling has been completed.

4. Northern Great Lakes Region - emphasis has been placed on diatom taxonomy and photographic file. A paper concerning 19 softwater *Melosira* taxa will be published in the forthcoming book by Smol *et al.* (eds.). A regression equation has been generated using the Renberg and Hellberg Index B for 16 Wisconsin lake assemblages vs. pH. About half of the surface sediments (17/36) are counted, and cores from two lakes are being processed. Land use and vegetation surveys have been completed for the ten cored lakes. ^{210}Pb dating is completed on four cores.

The PIRLA database

In order to facilitate the generation of a comparable data set from each of the four regions involved in the PIRLA project it is necessary to coordinate the diatom taxonomy of each of the laboratories involved. The backbone of this coordination is the Taxa List which is a standardised listing of all the taxa identified from each of the four regions. The Taxa List will ensure that each of the nine individuals identifying diatoms for the PIRLA project will be utilizing the same nomenclature. The coordination of taxonomy is important because of divergence of the taxonomic literature and because the data from each region will ultimately be combined and treated as a single data set.

Each diatom taxon encountered in the PIRLA project is assigned a unique 5-digit code. The first two digits of this code are a standardized genus number. Each of the potential 70 diatom genera which may be encountered in the project have been assigned a unique 2-digit number. Unidentified genera will be identified with the number 90. The remaining 3-digits of the 5-digit code allow for species 001 to 990 within each genus. Each taxon is also assigned a 8-character alphanumeric code which includes a 2-letter standardized generic code. A 20-character alphanumeric code is also assigned which includes a 4-letter standardized code for each genus. The Taxa List also includes a complete listing of each taxon including the authority. It is envisaged that the 5-digit and 8-character alphanumeric codes will be utilized for data entry while the 20-character alphanumeric code will be used for data output. A 3-digit reference code (which provides a literature citation) is included for each taxon. Example: 23018 CMPERPUS Cymb perpusilla Cymbella perpusilla A.Cl. var. perpusilla. 33003 EUBACTRI Euno bactriana Eunotia bactriana Ehr. var. bactriana.

The initial Taxa List contains 720 taxa and was compiled from analyses already completed in the Adirondacks and northern New England. In the early stages of data generation, numerous taxa will undoubtedly be encountered which are not included in the Taxa List. It is anticipated that following a period of rapid expansion, the Taxa List will reach a stage where the need to submit new taxa will greatly diminish.

RECONSTRUCTION OF WATER QUALITY DATA, ESPECIALLY pH, USING SEDIMENTARY DIATOM ASSEMBLAGES

by

Dennis Anderson

Due to lack of adequate historical records of pH (and other limnological parameters) for acidification-susceptible lakes, paleo-ecologists examine the sedimentary diatom record to reconstruct past lakewater pH. The techniques developed can potentially be used at any site with good diatom preservation and can provide a continuous, dated record of past pH. When integrated with other paleolimnological techniques (e.g. geochemistry, chrysophytes, cladocera, etc.), more confident interpretations can be made. However, there are disadvantages and problems using the paleolimnological approach, among them:

1. How well does the surface sediment sample represent the living diatom communities? Recent studies, as yet unpublished, by Jones and Flower and by De Nicola, are beginning to clarify this problem.
2. Problems exist regarding differential diatom preservation, both within a species and between species groups. At this time, there is not much one can do about these problems, except to be aware of them when making interpretations.
3. Inadequate knowledge and conflicting reports of species ecology can make interpretations rather equivocal.
4. The taxonomy of many groups in this particular flora is not well-known, and the available literature is often contradictory. Good, consistant taxonomy and more complete knowledge of species' ecology is critical. Recent work, as yet unpublished, carried out in conjunction with acidification studies, include Camburn and Kingston's work on _Melosira_, Charles' work on _Fragliaria acidobiontica_ and Flower and Battarbee's useful papers on _Tabellaria quadriseptata_ and _T. binalis_.

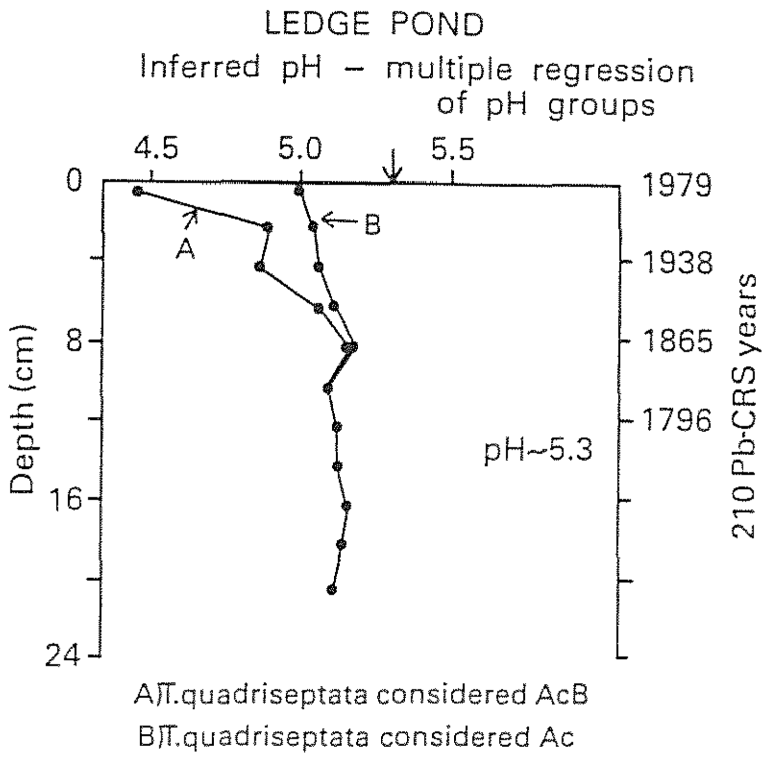

Fig. 2 Inferred pH comparing T. quadriseptata as an acidobiontic species (A) and as an acidophilous species (B).

Figure 2 demonstrates problems (3) and (4). If one were to misidentify T. quadriseptata (generally designated acidobiontic, AcB) as T. flocculosa (an acidophil, Ac), a clear reduction in pH (line A) becomes a straight line (line B). Paleoecological interpretations of lake acidification are often based on the responses of very few dominant taxa. A graph using Index B regression on the same data depicted similar results, although not as extreme. The present measured pH of the lake is 5.3, based on 3 readings. Using a regression of the first principal component results in a reconstruction paralleling line B, but closer to the measured pH. This demonstrates another problem that different regression techniques, with comparable standard errors, can give different actual results (although the trends are usually the same). Recently published work by Davis and Anderson attempts to evaluate different reconstruction methodologies. One should not draw any conclusions from the Ledge Pond example regarding the pH preference of *T. quadriseptata* or the suitability of one regression technique over another; although line B, which considers *T. quadriseptata* as acidophilic (Ac), agrees more closely with the present measured pH at level 0.0, there are other cases which show the opposite effect. Most evidence indicates that *T. quadriseptata* is AcB. Likewise, in the Ledge Pond example, the regression of the first PC best predicts the measured pH, but in other cases Log B or regression of pH groups comes closest. Despite these drawbacks the paleolimnological approach continues to be used successfully in many geographic regions.

DIATOM PLANKTON AND ACID LAKES

by

John C. Kingston

Several researchers have noted that planktonic (euplanktonic?) diatom species are found in lower abundance in acidic lakes, and that these species disappear from the lakes at pH below ca. 5.7. To go from this generality to a more specific observation, *Cyclotella* species are rare in the more acidic lakes. Exceptions to the generality of planktonic diatom absence at low pH include *Asterionella ralfsii* var. *americana*, planktonic ecophenes of *Tabellaria flocculosa*, and perhaps even some of the *Cyclotella* species. In the Adirondack Mountains of New York, USA, declines in planktonic abundance are highly correlated with high concentratkons of total aluminium (Charles, pers. commun.).

However, I would stress that we have a poor understanding of diatom life-form in these acidic lakes. The most complete studies of planktonic life cycles are Lund's work with *Asterionella formosa* and several *Melosira* species, all from hardwater lakes. In acidic lakes that might be the subject of pH reconstructions, the unpublished work of Sweets demonstrates that *Asterionella ralfsii* var. *americana*, *Rhizosolena eriensis*, *Cyclotella stelligera*, and an unidentified *Synedra* species grow abundantly in the plankton of Jellison Hill Pond, Maine. Sweets was able to trace the route of these planktons to the sediments by a regular sampling program for plankton, littoral benthos, deep-water surface sediments, and sediment-trapped detritus. His study is a good example of the kind of research that is needed in order to tie plankton ecology to diatoms remaining in the sediment record.

Clear-water lakes with pH less than 6.0 in the north-central USA are usually shallow (less than 10 m deep) and have very high light transmission to the entire lake bottom. Jesse Ford finds that shallow lakes in New England may have higher abundances of acidobionts than deeper lakes with similar chemistry. Coloured lakes, on the other hand, often have a photic zone of only 3 m and relatively smaller volumes for both benthic and planktonic production. For each of these lake types, we would like to know whether physical variables confound our pH interpretations. Do *Cyclotella* species have significant benthic production in clear-water lakes? Do the 20-30 species of *Melosira* that we find in surface sediment assemblages each grow primarily as summer plankton? Do the life cycles of these organisms show us that some are better than others as indicators of epilimnetic water chemistry?

NON-PLANKTONIC DIATOMS AND ACID LAKES

by

Frank Round

Most diatoms in acid lakes are to be found not in the plankton but in the benthos and attached to sand, stones, and higher plants. These communities are not well understood and the diatoms are characterised by a great variation of form.

It is essential to look at uncleaned as well as cleaned material from these habitats since the benthic assemblages consist of living and dead diatoms. During acidification the uppermost forms in an assemblage may die whilst those beneath may survive for longer and a new flora may take some time to develop.

Short periods or episodes of unfavourable pH may not affect the species composition of diatom communities. It is likely that diatoms use various physical or physiological mechanisms such as moving into sediments or reducing cell metabolism to avoid such conditions. Continuous stress will however lead to community change. In a small acid lake in Wales it was not until some six months after liming that a change in the species structure of the community occurred.

DISCUSSION

Since no detailed record of the very informal discussion was taken we list below many of the points that were raised but without personal attribution.

pH reconstruction

1. pH measurements should take into account problems of daily and seasonal variations in lakes.

2. The range of occurrence as well as the 'optimum' occurrence of a species should be considered.

3. Since Index B and other reconstruction methods were developed using surface sediment assemblages it may not be valid to use them to reconstruct pH represented by old algal samples.

4. The pH indices are on weak ground when the community is dominated by a single taxon. A transformation to increase the weight of the rarer taxa might be useful.

5. If low pH episodes after snowmelt occur at the same time as diatom growth the community may be biased towards acidobiontic forms, and reconstructed pH will be lower than measured mean values.

6. At pH below 4.5 the relation between the indices and pH may be curved rather than linear.

7. PCA may not be a good technique for pH reconstruction because of the weighting it gives to rare species.

8. All pH reconstruction techniques in current use are in some way inadequate. The current methods are likely to become redundant but

at the present time we have to work with them to express the recent increased acidity of many upland lakes - at least to non-diatomists!

In order to improve current pH reconstruction methodology several points require further consideration and evaluation. Firstly, in addition to the necessity of correct and standardized taxonomy already emphasised there is a need to standardize pH preference categorization. The allocation, where pH preference is unknown or where the literature is conflicting, of species pH preference should only be made when autecological data are available and preferably following verification at an international meeting. Secondly, to account for discordance between measured pH values and values calculated using surface sediment assemblages more knowledge of the factors influencing the composition of this assemblage is required. At least if we can explain the discordance, then we have reasonable grounds to leave a particular site of the regression expressions. Our work so far indicates that at a particular lake, water pH, nutrient concentration, humic concentration, sea salt contribution, influx of catchment diatoms, inclusion of the surface sediment in the euphotic zone, nature of littoral substrate and local spatial variation in water quality are all influential factors which require site specific evaluation.

Ecological problems

1. Diatoms seem to be more diverse in humic rather than clear-water systems and this might be related to the complexation of toxic metals by humic substances.

2. The lack of plankton diatoms in acidic lakes may reflect purity of the water, of which low pH is just another expression. Plankton diatom cells encounter their nutrient ions only by passive sinking through the

medium, so they should require higher concentrations than mobile or attached algae that are moving in relations to the water at a very much faster speed. Further, epipelon and epiphyton may actually live in higher ambient nutrient concentrations than plankton, due to mineralization in the sediment and release of nutrients from macrophyte stems.

3. There is a need to experiment with acid diatoms in culture.

4. Substrate exerts a strong influence on diatom communities and this may be of more importance than pH.

5. There is a substantial spatial variability in diatom communities, especially the epipelon.

6. The diatom community growing at any site is always the outcome of resource competition, although competition is very difficult to prove in individual cases. It is obvious that many of the typically acidic species would grow as well or better in higher pH and more nutrients if those algae that are faster-growing in such environments were absent. An ecologically broad or eurytopic species could, in theory at least, be characteristic for two different kinds of marginal environments and scarce in conditions more normal for diatom growth. The difference between a taxon's potential and realized niche (that may vary at different sites!) makes the pH and other ecological classifications more or less vague.

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