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A 12600 Year Perspective of the Acidification of Lilla Oresjon, Southwest Sweden

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A 12600 year perspective of the acidification of Lilla Öresjön, southwest Sweden

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The pH history of Lilla Öresjön was studied by using diatom analyses of a 3.5 m long sediment core (700 contiguous 0.5 cm samples). Four pH periods were distinguished; (i) an alkaline period (12600–7800 BP) following deglaciation, (ii) a naturally acidic period (7800–2300 BP) when pH decreased from 6.0 to 5.2, (iii) a period with higher pH (greater than 6) (2300 BP–1900 A.D.), which started at the same time as agriculture expanded, and (iv) the recent acidification period that began with a deterioration phase around 1900 A.D. and developed into an acute acidification phase during the 1960s (pH 4.5). This post-1960 phase has no similarity with any of the previous periods identified.

Introduction

Several investigations of Holocene lake development have been made in Europe (cf. reviews by Battarbee (1984) and Charles *et al.* (1989)). Except for Jones *et al.* (1989), few studies are from lakes sensitive to acidification and sample intervals in the sediment cores are usually so large that only general trends with a resolution of 10^2–10^3 years are revealed. This project aimed to study the detailed pH history of a 12600 year old lake, which is severely acidified today, and to assess whether the recent acidification is a unique phenomenon, or if any short-term acidification episodes have occurred in the past, for example, due to climatic fluctuations, vegetation and related soil changes, or any other factors.

Study site and methods

Lilla Öresjön is a typical lake of southwest Sweden; many such lakes have acidified. The lake surface area is 0.6 km^2, max. depth 17 m, retention time 10 months, pH 4.5, alkalinity 0, catchment area 4 km^2 of which 60% is spruce and pine forest. The bedrock is gneiss and soils are generally thin. See also Battarbee & Renberg (this symposium).

Overlapping Russian sediment cores (together more than 3 m long) were taken from ice in winter and correlated by stratigraphic changes in sediment colour and texture, or by diatom analysis. Freeze coring was used for recent sediments (see Renberg *et al.*, this symposium). Contiguous 0.5 cm subsamples, prepared for diatom analysis by a modified standard method by using hydrogen peroxide, were analysed. About 100 valves were counted on each slide (*ca.* 500 in the freeze core). Nomenclature follows Williams *et al.* (1988) and pH classifications follow the Surface Water Acidification Project (SWAP) list. Values for pH were inferred by using weighted averaging (Birks *et al.*, this symposium). Radiocarbon dates, here presented as calibrated ages, were done by the Laboratory for Isotope Geology, Swedish Museum of Natural History, and ^{210}Pb dates are from El-Daoushy (this symposium).

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Results and discussion

As one of the aims of this investigation was to consider if any short-term acidification periods (less than 10^2 years) had occurred before, it was necessary to take contiguous subsamples, each comprising only a few years. Because of the very large number of samples (700) the valve count for each level was reduced from the SWAP standard of 500 to 100. Although the low number of valves counted caused more variability, it is not particularly large (figure 1). The count of 100 valves is sufficient to identify previous short-term acidification episodes, and is compensated for by the high number of levels, which gives an excellent picture of the long-term trend (figure 2).

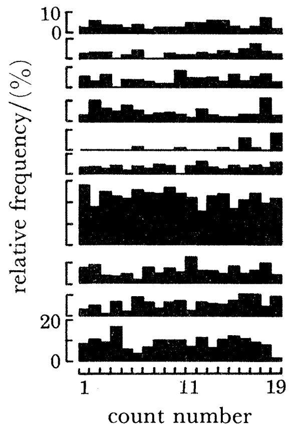

Figure 1. Test of slide preparation and diatom counting methods. Counts 1–10 were made on slides prepared from ten sediment subsamples from one particular level and 11–19 are replicate counts from one of those slides. Taxa with more than 5% in any count are shown.

The lake was formed after deglaciation, about 12600 years ago (Björck *et al.* 1988). Each analysed sample therefore represents about 20 years, or less in the most recent sediment. About 250 taxa were recorded, classified into Hustedt's pH categories, and the relative frequency of diatom valves belonging to each category calculated. The diatom assemblages change considerably during the lake's history. Four major periods are discernible (figure 2).

An alkaline period following deglaciation (*level* 350–275 *cm*, *ca.* 12600–7800 *BP*) (I)

The bottom 5 cm are characterized by alkaliphilous *Fragilaria* species such as *F. construens*, *F. construens* var. *venter*, *F. brevistriata* and *F. pinnata*. High percentages of *Fragilaria* spp. are often found in sediments deposited at deglaciation and lake isolation stages and this is thought to depend on the alkaline environment and a higher nutrient supply (Haworth 1976; Stabell 1985). The rest of the period is dominated by *Cyclotella* species, particularly *C. kuetzingiana*, but also *C. comensis*, *C. comta* and *C. stelligera* and *Asterionella formosa*. The end of the period is marked by the disappearance of these species and a decline in *Achnanthes minutissima* agg. Acidophilous taxa increase gradually during period I. Inferred pH values decrease from 7.2 to 6.0 (notice weighted averaging is a method independent of Hustedt's categories, but that both give a consistent picture). This pH decrease and oligotrophication is due to a progressive leaching of the catchment and subsequent decrease of the input of base cations and nutrients to the lake and is a process recorded elsewhere (see Battarbee (1984)). The loss of the planktonic *Cyclotella*

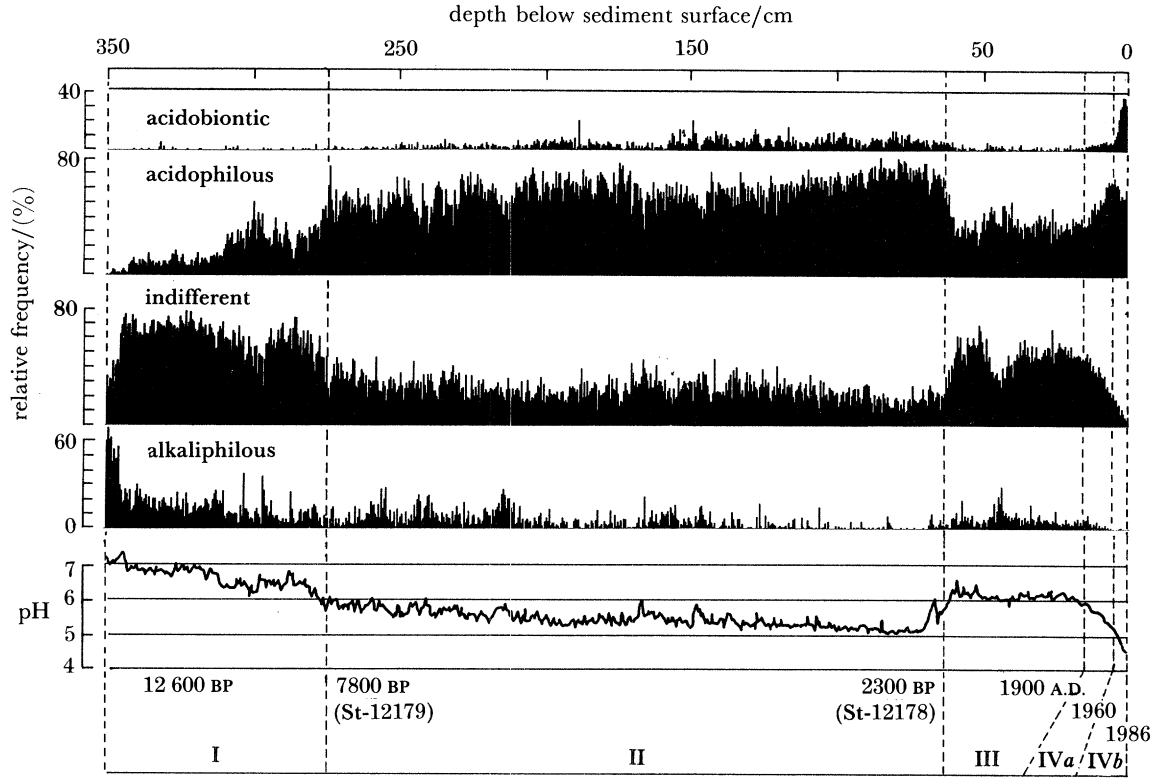

FIGURE 2. Hustedt pH categories, diatom inferred pH values (weighted averaging), calibrated radiocarbon dates, ^{210}Pb dates and pH periods in the history of Lilla Öresjön, southwest Sweden.

flora took place at later dates in two other studied lakes in S.W. Sweden (Lysevatten 6400 BP and Härsvatten 6000 BP). Gårdsjön (Renberg & Hellberg 1982) never completely lost its *Cyclotella* flora. This indicates that the rate of this pH decrease depended on catchment characteristics, rather than common external forces such as climate.

A period of acid conditions with slightly increasing acidity through time (*level* 275–65 *cm*, *ca.* 7800–2300 *BP*) (II)

Acidobiontic and acidophilous taxa increase slightly and indifferent (= circumneutral) and alkaliphilous taxa decrease, and pH falls from 6.0 to 5.2. This is a very slow natural acidification process over about 5000 years. There are no signs in the diatom record of any episodes with pH values below 5.0 during this naturally acidic period. There are, however, frequent short-term episodes with slightly higher pH values. Common taxa are *Aulacoseira distans* var. *tenella*, *Brachysira vitrea*, *B. brebissonii*, *Eunotia incisa*, *E. naegelii*, *Frustulia rhomboides* var. *saxonica*, *Peronia fibula*, *Tabellaria flocculosa* var. *flocculosa*, and towards the end of the period *Tabellaria flocculosa* agg., *Asterionella ralfsii* var. *americana*, *Navicula leptostriata* and *Tabellaria quadriseptata*.

A period with higher pH (*level* 65–15 *cm*, *ca.* 2300 *BP*–1900 *A.D.*) (III)

Cyclotella kuetzingiana suddenly returns, together with *Achnanthes minutissima* agg. and *Asterionella formosa* and other indifferent and alkaliphilous diatoms. The frequency of

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acidophilous taxa decreases from *ca.* 70 % to 30 %, and *Tabellaria quadriseptata* (acidobiontic) becomes less abundant. Inferred pH increases from 5.2 to 6.3. The start of period III coincides with the appearance of cereal pollen in the sediment, an increase in the abundance of other pollen indicative of agriculture, and a significant decrease of oak pollen. The same development is recorded in Lysevatten (60 km north of Lilla Öresjön) for both diatoms and pollen, and for diatoms in Härsvatten (near Lysevatten, pollen not yet analysed). The change in Lysevatten dates to 1800 BP. It is very likely that the changes in the diatom flora and the marked pH rise resulted from an increase in human land use. Archaeological investigations and earlier pollen analyses suggest a cultural expansion in this part of Sweden about 2000 years ago (Digerfeldt & Welinder 1988). Both Lilla Öresjön and Lysevatten have land suitable for agriculture in their catchments (10 % and less than 1 % of cultural land today, respectively), but the catchment of Härsvatten is very broken and rocky and has no known history of agriculture. This might indicate that the improvement of pH–nutrient conditions was not strictly related to agriculture in the catchments but influenced by more diffuse use and disturbance of the landscape. Whether this cultural eutrophication and alkalinization about 2000 years ago is a widespread regional process cannot be assessed by this investigation, but at least, the phenomenon is observed in two different areas 60 km apart.

The recent acidification period (*level* 15–0 *cm*, *ca.* 1900 *A.D.* – *the sampling year*, 1986) (IV)

This period can be divided into two phases.

(*a*) *A deterioration phase*

Lasting from *ca.* 1900 A.D. to the 1950s, with decreasing abundance of *Cyclotella kuetzingiana* and other species favoured during the previous period, i.e. a return to the natural conditions prevailing before 2300 BP. Although it cannot be ruled out that changed land use and recovery of forest vegetation and soils, as proposed as a major reason for acidification by Rosenqvist (1977), has contributed to this development, it is more likely that acid deposition plays the most important role already during this phase (see discussion in Renberg *et al.*, this symposium).

(*b*) *An acute acidification phase*

Species such as *Navicula leptostriata*, *Eunotia naegelii*, *Tabellaria quadriseptata*, but also acidobiontic species that were hardly present before, such as *Tabellaria binalis*, become very abundant. *T. binalis*, which is a characteristic species in severely acidified lakes in Fennoscandia, reaches 10 %. Acidobiontics exceed 35 %, indifferents decrease to 5 % and alkaliphilous taxa become extinct. This diatom assemblage never occurred before in the history of the lake. Both inferred pH values and historical data show that pH decreased to *ca.* 4.5 during the 1960s. Acid deposition is the most reasonable explanation (see Renberg *et al.*, this symposium). Although Lilla Öresjön was rather acid before human activity in the catchment caused an increase in pH, it is important to note that no acid period similar to the recent one has occurred before in this lake or in the other studied lakes referred to above.

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