A HISTORY OF OLIVER LAKE #2, CHIPPEWA COUNTY, WISCONSIN, BASED ON DIATOM OCCURRENCE IN THE SEDIMENTS

RODNEY GONT *and* LLOYD OHL
University of Wisconsin-Eau Claire

Abstract

A general history of Oliver Lake #2, Chippewa County, Wisconsin, has been constructed. Interpretations were based on a diatom analysis of a vertical profile of bottom sediments taken from the deepest part of the lake using two types of coring devices. Evidence indicates that a shallow, slightly alkaline lake, moderately high in nutrient content, evolved into a relatively deep, highly acidic lake, low in available nutrients. Diatom communities of the most recent sediments indicate these trends may now be reversed.

INTRODUCTION

Techniques of interpreting changes in lakes by analyzing fossil diatom communities of the sediments are well established. Studies by Conger (1939), Andrews (1966), Charlton (1969), Florin and Wright (1969), Florin (1970), Andresen (1976) and Stoermer (1977), in the Great Lakes region; and by Patrick (1954), Round (1957 and 1961), Stockner and Benson (1967), and del Prete and Schofield (1981), elsewhere, are representative. There are many publications available outlining diatom identification which is based on the size, shape, and ornamentation of easily-preserved, glass-like walls. Many species have narrow habitat requirements, being greatly affected by temperature, available nutrients, and chemical properties of the water (Patrick 1948). There is also information available concerning their pH preferences, and even though pH is less indicative of water conditions than factors such as mineral content (Patrick 1945), it is still useful.

This study was based on a single sediment profile. Although relying on a single site increases the probability of taking a sample that does not represent the lake as a whole, there is precedence for doing so (Patrick 1954, Florin 1970, Stoermer 1977). Florin (1970) briefly discusses the problem. By using the deepest, most stable part of the lake, it seems that unnecessary effort can be eliminated while still collecting an adequately representative sample.

Only the prevalent species (relative density > 3%) have been used in the majority of the analyses and interpretations. Patrick (1948) discusses the use of the largest populations as the best interpretive indicators.

Certain problem taxa were encountered but only restricted interpretive use was made of them. In a few instances identification was not possible and these were assigned numbers and recorded as such. By taking a conservative, selective approach, it is believed that the taxonomic and ecological problems have been minimized without excessive loss of information.

STUDY SITE

Oliver Lake #2, in sec 24, T31N, R8W, Chippewa county, Wisconsin, lies on an irregular terrain deposited as stagnant, ice-core moraine, just within the maximum advance of the most recent continental glaciation (Cahow 1976). This dark water, bog-rimmed, acidic (surface pH, 5.1) lake has characteristics that reduce disturbance of the bottom: 1) a small surface area of 1.6 hectares accompanied by a relatively great depth of 21 meters, 2) a wind sheltered location

bordered by uplands some 6 to 12 meters above the lake surface, and 3) a bottom oxygen deficit (instrumental determination) in the winter which, as Simola (1977) points out, would eliminate large, bottom crawling animals. Lakes with these characteristics are susceptible to chemical stratification. However, with uniform conductivity throughout the water profile, and a standard, winter inverse temperature stratification, the lake was apparently not meromictic at the time of data collection.

Procedure

A vertical profile of the bottom sediments at the deepest part of the regularly shaped, slightly oblong, bowl-like basin was obtained using two different coring devices. A 195 cm long core of the uppermost sediments was taken through the ice on 5 January 1983 using a freeze-core device (Swain 1973). The upper end of the sample was marked by the clearly visible, water-sediment interface, indicating disturbance of the sediments had been minimal. This core was wrapped in aluminum foil to reduce dessication and transported on dry ice to the laboratory for storage.

On 26 February 1983 a piston-core device (Livingstone 1955) was used through the ice at the same site to remove successively deeper, 1 meter long segments, resulting in an additional 268 cm long composite core. Since 21 meters of water was above the sediment-water interface, a rigid pipe casing, slightly larger in diameter than the piston corer, was used, not only to prevent bending of the sampler thrust rod when pressure was applied to take the sample, but also to ensure that each time the sampler was lowered it entered the same hole in the sediments. Based on a subsequent comparison of diatom communities from this core to the previously-taken freeze-core sample as well as on certain trends which were continuous between the two cores—a declining number of alkaliphilic species, a constant number of acidophilic species, a rising number of *Eunotia* individuals, and constant diversity —the piston core portion began an estimated 250 cm below the water-sediment interface and continued to 500 cm.

A small cork borer was used to take 7 mm diameter by 20 mm long subsamples, spaced 50 cm apart, from the composite profile. Several mm of each end of each plug were discarded to reduce the chance of contamination from other levels. These subsamples were oxidized (van der Werff 1953) before preparing strewn-mounted microscope slides (Patrick and Reimer 1966) with Hyrax (R.I., 1.65) as the mounting medium. A slide from each subsample level was examined at 1250× with a Zeiss research microscope. Randomly selected transects were taken until a minimum of 400 diatom valves were identified and tabulated from each slide. McIntire and Overton (1971) have used information diversity measures for various diatom counts in establishing sample size adequacy for an ecological study of diatoms of similar scope.

Numerous publications were used to identify the diatoms, but those of Patrick and Reimer (1966 and 1975) and of Hustedt (1930 and 1930-66) were the primary sources. Subsamples were labelled (as levels) using their distance, in cm, below the sediment-water interface.

Results

Based on a preliminary visual inspection, only the deepest 30 cm (Level 470 to 500) of the profile had noticeable amounts of inorganic material. Wet mount examinations of this portion at a magnification of 500× before any treatments revealed: 1) both Levels 496 and 490 had small amounts of "sand" (particles > 7 μm diameter) mixed with organic matter, 2) Level 496 had a slightly lower proportion of "sand" than Level 490, 3) Level 480 was "gravel" comprised of sand and pebbles (up to 20 mm diameter) with very little organic matter, and 4) Level 470 was almost entirely a reddish clay (< 7 μm diameter). The 1250× study of

subsamples prepared for diatom identification also showed: 1) Level 490 had a very diverse diatom flora devoid of pelagic and terrestrial species, 2) Level 480 had many diatoms and a wide array of species (based only on a cursory inspection), and 3) Level 470 had an insufficient number of diatoms to even count. All other levels consisted primarily of organic material interspersed with diatom valves and fragments. Figure 1 summarizes these observations.

Twenty eight prevalent species were found in one or more of the 11 sediment levels examined. The relative densities and distribution of these species are shown in figure 2.

Many techniques are available to group data into more interpretable groups. Although the efforts to condense seemed to fail, they were valuable in showing that each sediment level was unique. The following examples are representative.

The degree of association between species was measured using Cole's Index (Cole 1949) with signficance tested by Chi square. Among the 28 prevalent species there were only three significant ($P < .05$) relationships: 1) *Asterionella formosa* Hass. and *Fragilaria pinnata* Ehr. were negatively associated, 2) *Eunotia paludosa* Grun. and *F. pinnata* were negatively associated, and 3) *Eunotia flexuosa* Breb. ex Kutz. and *E. paludosa* were positively associated. A subsequent cluster analysis (Williams and Lambert 1959), which uses a Chi square distance measure, resulted only in one significant ($P < .05$) division—those levels with *F. pinnata* present (the 7 deepest levels) and those with it absent (the 4 shallowest levels).

Bray and Curtis (1957) used a $1\text{-}2w/a+b$ index to objectively measure the degree of dissimilarity between samples. The indices calculated for Oliver Lake #2 were high, indicating high level to level dissimilarity.

Curtis (1959) proposed a ratio of prevalent modal species to prevalent species for detecting hybrid communities. A comparable ratio, disregarding prevalence, could also be used to give more weight to the rare species.

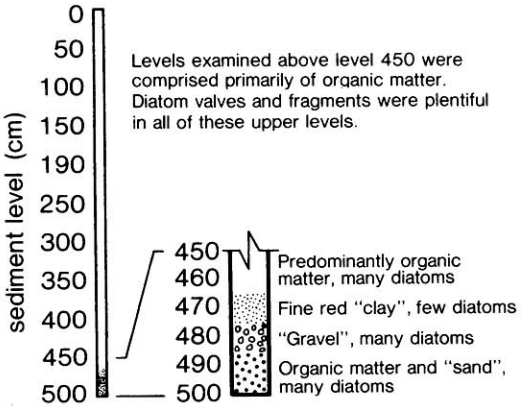

Fig. 1. Characteristics of the bottom 50 cm of the sediment profile taken from Oliver Lake #2. The proportion of "sand" at Level 496 was slightly lower than at Level 490.

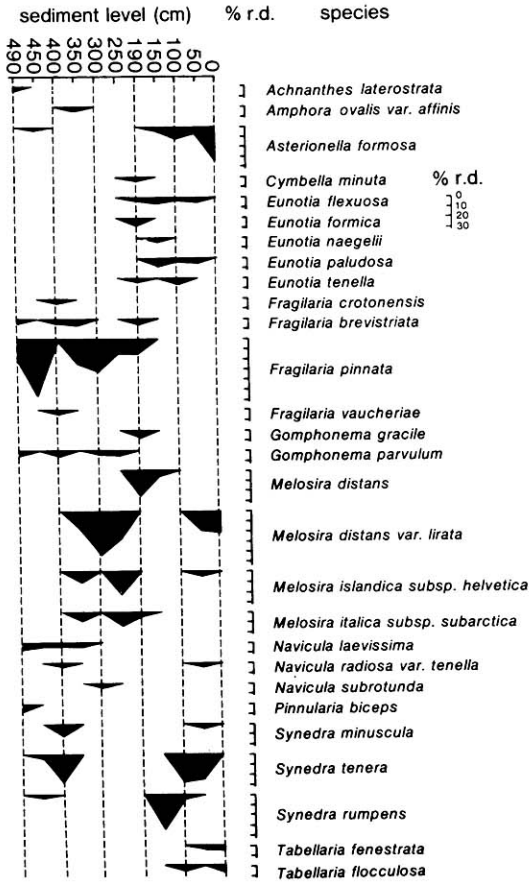

Fig. 2. Percent relative densities of the prevalent fossil diatoms for each sediment level examined from Oliver Lake #2. Relative densities less than 3% are shown as 0.

Low ratios indicate a lack of uniqueness. Figure 3 shows that these two indices are simultaneously low only at Levels 50 and 350.

In effect, the species present at various times in the history of Oliver Lake #2 have varied greatly, with little continuity between adjacent levels. This is not as unusual as it first appears to be. Even in an unchanging environment, the kinds of diatom species can fluctuate greatly while the number of species and the relative sizes of the popula-

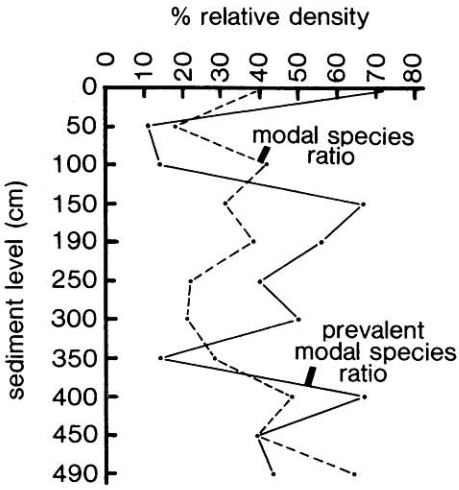

Fig. 3. Modal and prevalent modal species ratios for each sediment level examined from Oliver Lake #2. Low values indicate that the diatom community at that level has a hybrid composition. Only Level 50 and Level 350 have simultaneously low values.

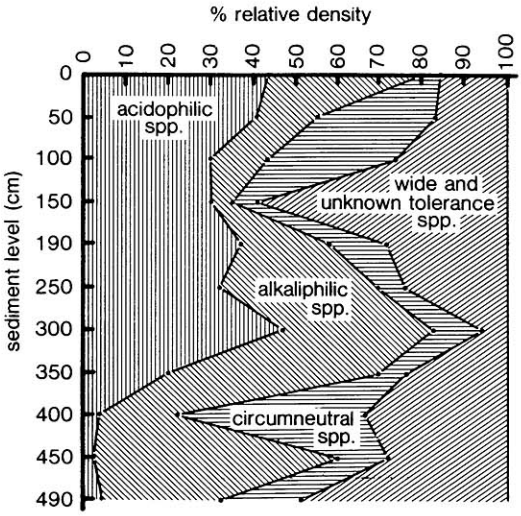

Fig. 5. Distribution of individuals when classified by their pH preferences for each sediment level examined from Oliver Lake #2. Acidophilic: pH preference < 6.5. Alkaliphilic: pH preference > 7.5. Circumneutral: pH preference 6.5 to 7.5.

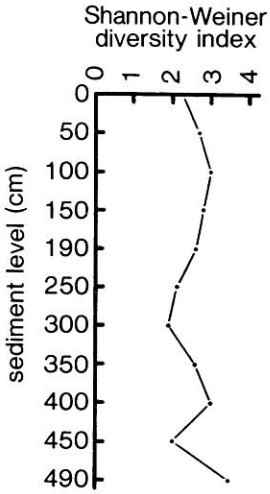

Fig. 4. Shannon-Weiner diversity index for each sediment level examined from Oliver Lake #2. Level to level variation is much greater in the older sediments.

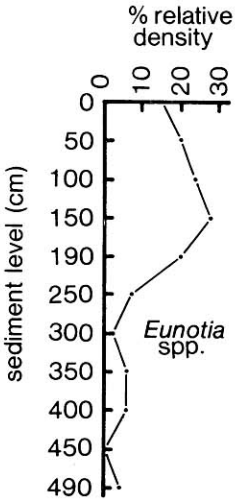

Fig. 6. Percent relative density of the genus *Eunotia* for each sediment level examined from Oliver Lake #2. This genus is much more common in the younger sediments.

tions of the species remain quite constant (Patrick 1962, 1963). There are so many diatom species available that any one of a number of these, in the right place and time, can reproduce rapidly enough to fill niche openings. The Shannon-Weiner diversity index (Shannon and Weiner 1963) uses just these two criteria (number of species and sizes of populations). Remaining constant, it would then indicate relatively stable ecological conditions. As shown in figure 4, the index fluctuates erratically in the earliest stages of lake development but dampens considerably in more recent times.

Species can be grouped by their pH preferences (Foged 1981). As shown in figure 5, acidophilic species are absent from the deepest sediments but become prominent in the more recent sediments. A comparison with fig. 6 shows that the genus *Eunotia* roughly parallels this trend and in fact contributes to it. This would be expected since *Eunotia* taxa are virtually all acidophilic. *Eunotia* genera peak at Level 150. Figure 5 also shows that the combined alkaliphilic-circumneutral pH species are at a minimum at Level 150.

Discussion

Level to level diversity has fluctuated more in the older fossil communities studied than in the recent ones. Since Richardson (1969) has correlated stratigraphic variability to low water levels, this may well mean that Oliver Lake #2 was shallower than at the present. To account for the later stability, a subsequent increase in depth is proposed which provided extra volume to better absorb the effect of factors that influence lake ecosystems. The analyses at each individual level support this contention as well as indicating that conditions became more acidic and more dystrophic.

Level 490 (oldest sediments)

At this time, Oliver Lake #2 was apparently mildly eutrophic. Of the prevalent diatoms, *F. pinnata, Gomphonema parvulum* Kutz and *Fragilaria brevistriata* Grun. are usually found in such water, while only *Pinnularia biceps* Greg. prefers water of low mineral content. The marked lack of acidophilic species indicates somewhat alkaline conditions.

Although shallow water species can exist in deep water if the water is clear enough to allow sufficient light penetration (Conger 1939), only an oligotrophic lake would likely be clear enough. As discussed above, Oliver Lake #2 was apparently mildly eutrophic at this time, so that the abundance of shallow-water species would indeed imply shallow water. Since pelagic species normally abound in deep, mildly eutrophic water, but not in shallow water, their absence here further supports the shallow water proposal.

Diatom diversity is particularly high. Water chemistry apparently had not greatly changed for a long time and an abundance of available niches due to an extended period of favorable habitat development seems probable. However, it is unlikely that the situation was totally static. Maximum diversity may well occur when there is some intermediate disturbance (Huston 1979, van Dam 1982). Presence of some sand at this level further substantiates a somewhat dynamic situation.

It is speculated that the lake at this time was located above a large block of buried glacial ice. Florin and Wright (1969) have proposed the melting of buried ice blocks to be a common means of lake basin formation in glaciated regions. Cahow (1976) felt that most of the lake basins in the area resulted from the melting of buried ice blocks. The gradual deepening of the shallow lake, indicated by the fossil diatom community at this level, to the present day depth of 21 meters, fits well into this buried ice block concept.

Level 480 and 470

These levels were not a part of the diatom analysis, but were included because of their obviously different physical appearance

when the entire sediment core was visually inspected. The "gravel" layer of Level 480 would have required a powerful earth-moving force for its transportation to this location. It is conceivable that glacial events—large volumes of swift-flowing water, rafting via chunks of ice, or landslides—provided the impetus. Diatoms in this "gravel" may have been transported from reworked, upstream sites.

On the other hand, subsequent deposition of the easily suspendible clay particles of Level 470 would have required greatly reduced flows. Glacially fed runoff may have been depleted due to recession of the glacier. The insufficient number of diatoms present at this level to even count is consistent with Round's proposal that deposition of clay dramatically reduces diatom populations (Round 1956).

Level 450

Apparently, organic deposition in a shallow lake was renewed. Extensive amounts of the benthic *F. pinnata* and a lack of pelagic species once again indicate shallowness. Sand and clay are no longer present, so that material being transported overland appears to be trapped by some sink surrounding the lake. The establishment of emergent and submergent vegetation at the periphery of the lake may have been that sink. Retarded water movement would cause a dropping of sediment loads before the lake was reached. The organic matter of the sediments would then have come only from production within the lake and from wind-blown sources (e.g. leaf litter).

With acidophilic species still rare, the water was probably somewhat alkaline. Diversity at this level is low and the widely tolerant and benthic *F. pinnata* is very abundant, implying that conditions were harsh for diatom growth. Warm water may have been one of those conditions. Benthic species would have been scarce in a cold, shallow lake (Patrick 1948).

Level 400

An increase in the proportion of circumneutral species, a decrease in alkaliphilic ones, and a concurrent slight rise in acidophilic ones indicate a pH decline. The presence of *Fragilaria crotonensis* Kitton, a pelagic species, would have required some deeper, open water—presumably provided by the sagging of the lake bottom as the buried ice block slowly melted. With *F. crotonensis, F. brevistriata* and *G. parvulum* present, the lake was probably still mildly eutrophic.

Level 350

The lake apparently continued its pH decline. Although alkaliphilic species (*F. pinnata* in particular) still were abundant, acidophilic species such as *Melosira distans* var. *lirata* Ehr. had also become prevalent. Water depth and nutrient content were apparently sufficient to support pelagic species such as *Melosira italica* subsp. *subarctica* O. Mull. and *A. formosa* in small numbers. The lower diversity might be attributed to acidic conditions "weeding out" less tolerant species. A small bog may have developed at the perimeter—not only increasing acidity, but also donating water-darkening humic substances that would be resistant to breakdown in the more acidic conditions.

Level 300

As indicated by the dissimilarity indices and the proportion of modal species, this was a hybrid level, showing some similarities to both Level 350 and Level 250. Acidophilic species peaked here due to the high proportion of *M. distans* var. *lirata*, but the alkaliphilic *F. pinnata* was still present in large numbers. Diversity was low indicating a major transition, presumably from alkaline to acidic water, was taking place.

Level 250

The increase in individuals within the genus *Eunotia* implies that pH had dropped

and that dystrophic, bog-like conditions were likely established. Most of the species of *Eunotia* indicate soft, somewhat acid water (Patrick 1977). This has been consistently confirmed, particularly in deep lakes (e.g. Ford 1982). A floating bog that covered shallow water and contributed humic material which would prevent sufficient light for photosynthesis from reaching the bottom, may have caused the decline of benthic species. None of the prevalent species were indicative of eutrophic conditions, implying that nutrient levels were low, possibly due to unavailability in acidic conditions rather than to an absolute deficiency.

Level 190

The relative proportion of *Eunotia* individuals was high and acidophilic species were plentiful. A well developed bog is proposed and the lake was likely dystrophic. High humic content and low available nutrient levels determined the biotic composition. Increased diversity might have been caused by a stable period of dependable resources. A wider array of specialist species could then have gained a competitive advantage, reducing the numbers of the more extensive generalist species (Smith 1980).

Level 150

The high proportion of *Eunotia* individuals and low proportion of alkaliphilic species indicate that by this time Oliver Lake #2 was a prime example of a dystrophic acid-bog lake. Although pH and calcium content of the water may be the most important factors in diatom distribution, proper substrate may have been the primary reason certain attached species were present (Bruno and Lowe 1980). The bog would have provided such a specialized habitat. This could also explain the rarity of benthic species as well as the commonness of littoral ones such as *Synedra rumpens* Kutz. Although *A. formosa* was present, it and other planktonic species were scarce. This could still have been due to a nutrient tie-up under the acidic conditions.

Level 100

The proportion of *Eunotia* individuals declined, but the density of acidophilic individuals had remained constant. Alkaliphilic species were still rare. Although still a dystrophic, acid-bog lake, it appears that bog expansion had stagnated. With the relatively high diversity, water conditions were apparently in a stable phase with only slight disturbance.

Level 50

The proportion of modal species and a low dissimilarity index indicate that this was a hybrid level which resembled Level 100. A surrounding bog continued to provide living space for littoral species such as *Synedra tenera* W. Sm. Hints of new, rather surprising, changes were also found here. The proportion of alkaliphils increased while that of *Eunotia* individuals decreased.

Level 0

The increasing alkaliphil and decreasing *Eunotia* trends became more marked. It becomes tempting to propose that lake acidity was decreasing and the dystrophic, bog-like conditions were being altered. Recent personal observation and instrumental measurements do not support such an interpretation. Oliver Lake #2 is still a highly acidic, dark water, dystrophic lake with low conductivity and depleted winter oxygen supply.

However, the great abundance of *A. formosa* (36.9% r.d.) cannot be totally ignored. There are some variations in the literature concerning its ecological preferences but it is usually considered an alkaliphilic species that is normally best developed in somewhat nutrient-rich water. If these qualities are truly not artifacts, the diatom analysis has been able to detect trends—decreasing acidity and increasing nutrient availability—that were not apparent in the restricted instru-

mental analyses. These same trends have been found in certain Swedish lakes and have been related to agriculural development of the drainage basin (Renberg 1976).

Summary

Immediately following the most recent glaciation, Oliver Lake #2 was apparently a shallow, slightly alkaline, mildly eutrophic lake. As uplands weathered and became vegetated, nutrient inputs were altered. A huge ice block buried beneath the lake slowly melted and a bog developed at the periphery. Several trends became apparent: 1) increasing depth, 2) increasing acidity, 3) increasing dystrophy, and 4) reduced availability of nutrients—so that the lake has become deep, acidic, and dystrophic, with very dark water. However, there are now indications that acidity may be decreasing and nutrient availability rising, possibly as a result of cultural modification of the drainage basin.

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