Effects of increased salinity on the diatom assemblage in Fonda Lake, Michigan

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Abstract

A salt storage facility has been located adjacent to Fonda Lake since 1953. In February 1981 a core was taken from the profundal sediments of the lake and analyzed to determine the effects of salt perturbation on the diatom community over a 32-year period. Diatom assemblages from different levels were compared using multivariate techniques including cluster analysis and principal component analysis. Shifts in diatom composition related to salinification were revealed most clearly by subdominant taxa. Five distinct groups of diatom taxa were found to correspond with 5 depth intervals. The diatom component of the lake up to 1960 included two groups of taxa which were alkaliphilous and chloride indifferent. A reduction in species diversity beginning in 1960 may indicate a salt effect. By 1968, when diversity reached a minimum, a variety of halophilic taxa (including *Diatoma tenue, Navicula gregaria* and *Synedra fasciculata*) attained their highest relative abundances. At the top of the core, diversity increased slightly and some halophilic taxa decreased in relative abundance, which suggests a possible decrease in salt loading to the lake.

Introduction

Winter road deicing has contributed to increases in salt levels in many northern freshwater systems. During the past decade, a number of studies have been conducted on the effects of these loadings upon aquatic habitats (Judd, 1970; Bubeck *et al.*, 1971; Dickman & Gochnauer, 1978; Hoffman *et al.*, 1981).

Algae, and diatoms in particular, are known to exhibit habitat preferences based on salinity levels (Patrick, 1948). Petersen (1943) speculated that 100 mg l^{-1} was the chloride threshold level at which the diatom flora is influenced. A number of classification schemes have been constructed attempting to categorize diatoms according to their salt preferences (Kolbe, 1927; Budde, 1931, 1933; Petersen, 1943; Hustedt, 1953; Carpelan, 1978).

Few studies have dealt with the effects of increased salinity on the algal component of natural systems. Dickman & Gochnauer (1978) artificially added sodium chloride to a stream and analyzed periphyton community development on slate tiles. Most of the recent work testing the effects of chloride on diatoms has been conducted in the laboratory, with uni-algal cultures (Desikachary & Rao, 1972; Liu & Hellebust, 1976; Kopczynska, 1979).

This paper reports on the effects of increased salt concentration on the diatom assemblage of Fonda Lake located in southeastern Michigan. This lake has been perturbed by runoff and leaching from a salt storage shed located adjacent to the lake since 1953. In order to study changes in diatom composition prior to the salt intrusion to the present, a core of the lake sediments was obtained and analyzed.

Materials and methods

Fonda Lake, located in Livingston County, Michigan, is spring fed and has no permanent inlet

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or outlet. Its maximum depth is 13 m. In February 1981 chemical measurements of major chemical ions were obtained using an AutoAnalyzer II (Davis & Simmons, 1979). Chloride values averaged about 235 mg l^{-1} through the water column. Silica concentrations ranged from 0.2 to 1.2 mg l^{-1} and ortho-phosphate values ranged from 0.2 to 1.2 μg l^{-1}. Typical chloride values for lakes in the area are approximately 12 mg l^{-1} for Frains Lake and 15 mg l^{-1} for Portage Lake (unpubl. data).

On February 17, 1981, a core was taken from the profundal sediments with a Shapiro (1958) freeze corer. The lake sediments were highly unconsolidated, thus making the freeze corer the most effective sampling device. A 20 cm core sample was obtained. The crust, or sediment frozen to the outside of the core barrel was cut at 1 cm intervals in the laboratory. The uppermost 16 cm of crust were used for analysis.

Diatoms were cleaned according to methods described by Patrick & Reimer (1966). Two strewn slides mounted in Hyrax® were made for each sample depth. Diatoms were examined under 1 200X magnification with a Leitz Ortholux microscope fitted with fluorite oil immersion objectives with a nominal Numerical Aperature of 1.32. At least 1 500 valves were counted per slide.

For statistical analysis, means of 47 common taxa were used, with all data recorded as relative abundance. Any taxon having a maximum abundance of at least 2% of the total assemblage at any level was included in the analysis. Two multivariate analyses were used to compare diatom assemblages at different levels in the core. Cluster analyses were performed using Euclidean distance measure and average-distance clustering method (Carney, 1982) implemented through the MIDAS statistical package (Fox & Guire, 1980) available at the University of Michigan Computing Center. In order to provide a visualization of relationships, principal components analysis using the variance-covariance matrix was performed. Ordinations were then constructed by plotting the samples (cases) relative to their scores on the first three principal components and plotting the taxa (variables) relative to their loadings (Stoermer & Ladewski, 1978). In the graphic representations (Figs. 5, 6) these results are superimposed upon groupings delineated by cluster analysis. Species diversity (Shannon & Weaver, 1949) calculations were based on mean values of replicate samples from a given depth. A smooth curve is drawn through data values on plots of the individual taxa (Figs. 7–11). A smoothed data point q_i is calculated as:

$$q_i = 1/2\ P_i + 1/4\ P_{i-1} + 1/4\ P_{i+1}$$

where P_i is the percentage of the taxon at depth i, P_{i-1} is the percentage at depth i-1, and P_{i+1} is the percentage at depth i+1.

The core was dated with Cesium-137 according to the method of Robbins & Edgington (1975). Cesium-137 first appeared in the sediments in 1954, with a maximum fallout in 1963. The Cesium-137 profile for Fonda Lake is represented in Fig. 1. The 1963 maximum occurs at 8.5 cm and the 1954 level at 13 cm. The first year of salt storage adjacent to Fonda Lake was 1953. Sedimentation rates based on the ^{137}Cs dating are 0.55 cm a^{-1} from 1954 to 1963 and 0.50 cm a^{-1} after 1963.

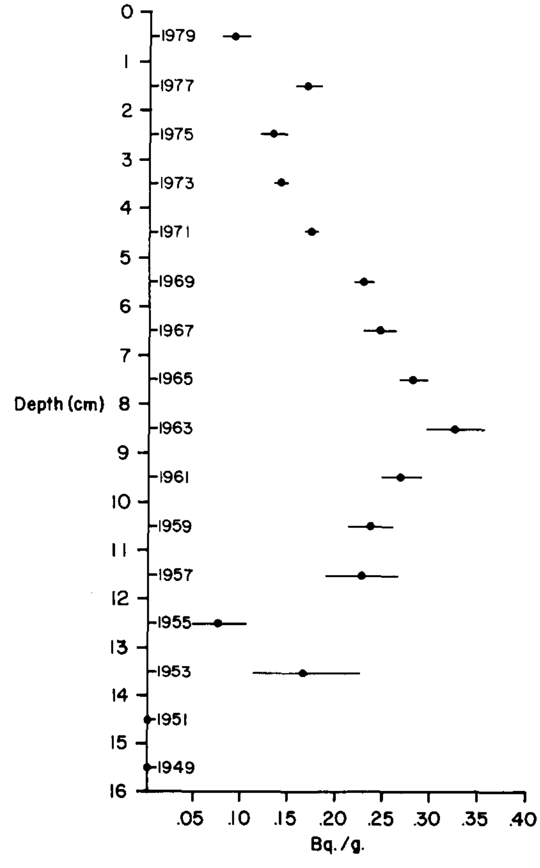

Fig. 1. Cesium-137 dating by depth in Becquerels per gram.

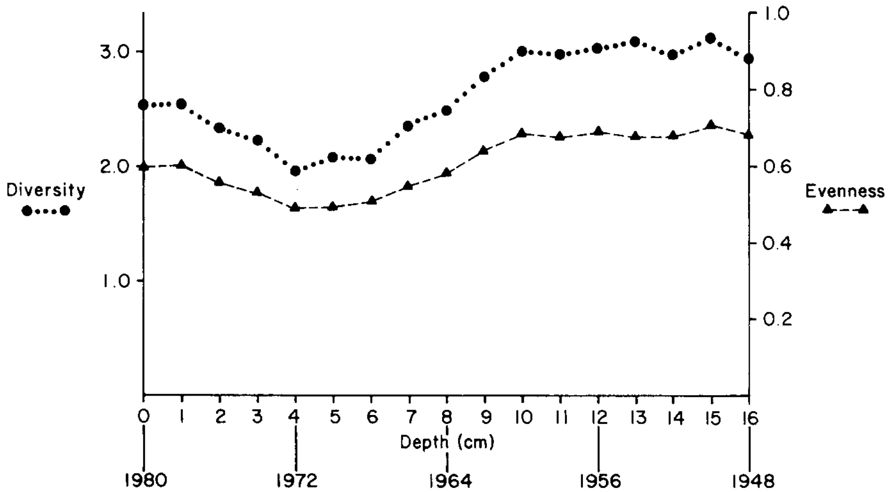

Fig. 2. Diversity (H′) and evenness values for the diatom assemblage.

Results

Diatom assemblage

A total of 183 diatom taxa representing 33 genera were identified. Overall, the four most abundant taxa are *Fragilaria brevistriata* var. *inflata* (Pant.) Hust., *F. crotonensis* Kitton, *Melosira granulata* (Ehr.) Ralfs, and *M. granulata* v. *angustissima* O. Müll. From the sediment surface down to 8 cm (1964), these taxa account for at least 60% of the total assemblage. Below 8 cm, they typically do not comprise over 40% of the total community. This is reflected in diversity and evenness values (Fig. 2), which exhibit an increase at the 9 cm depth and are maintained to the bottom of the core. *Fragilaria crotonensis* is dominant at most depths, except at 4 cm where *M. granulata* v. *angustissima* predominates, and at 15 and 16 cm where *F. brevistriata* v. *inflata* is dominant.

Community analysis

Cluster analysis was utilized to group depths within the core on the basis of diatom composition similarity (Fig. 3), and to group diatom taxa which had closely related occurrence trends (Fig. 4). Depth cluster analysis delineated five zones (Fig. 3) which are graphically represented by a principal component ordination (Fig. 5). The five depth zones of Fig. 5 are based on the cluster analysis. Zone 1 includes depths 14–16 cm (1952–1948), Zone 2 includes 10–13 cm (1960–1954), Zone 3 clusters 7–9 cm (1966–1962), Zone 4 clusters 4–6 cm (1972–1968), and Zone 5 includes the uppermost sediments (1974–1980).

Individual species loadings are plotted in Fig. 6. Again, five groups are delineated on the basis of the cluster analysis. Locations of these taxa in Fig. 6 correspond to locations of the depth cluster in Fig. 5. That is, a species grouping located in a cer-

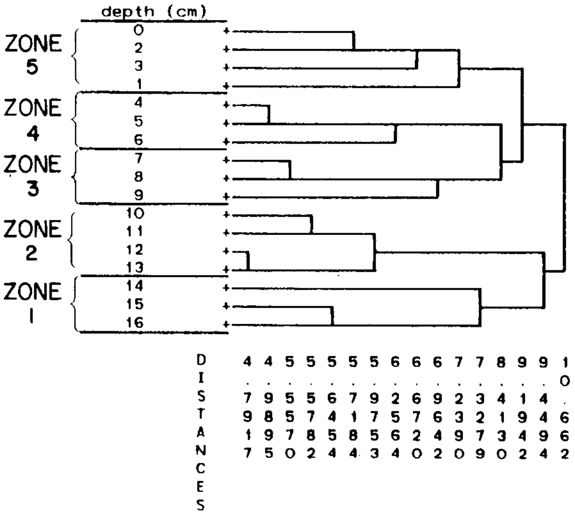

Fig. 3. Cluster analysis by depth with 5 groups delineated. Euclidean distances are provided at the bottom of the cluster.

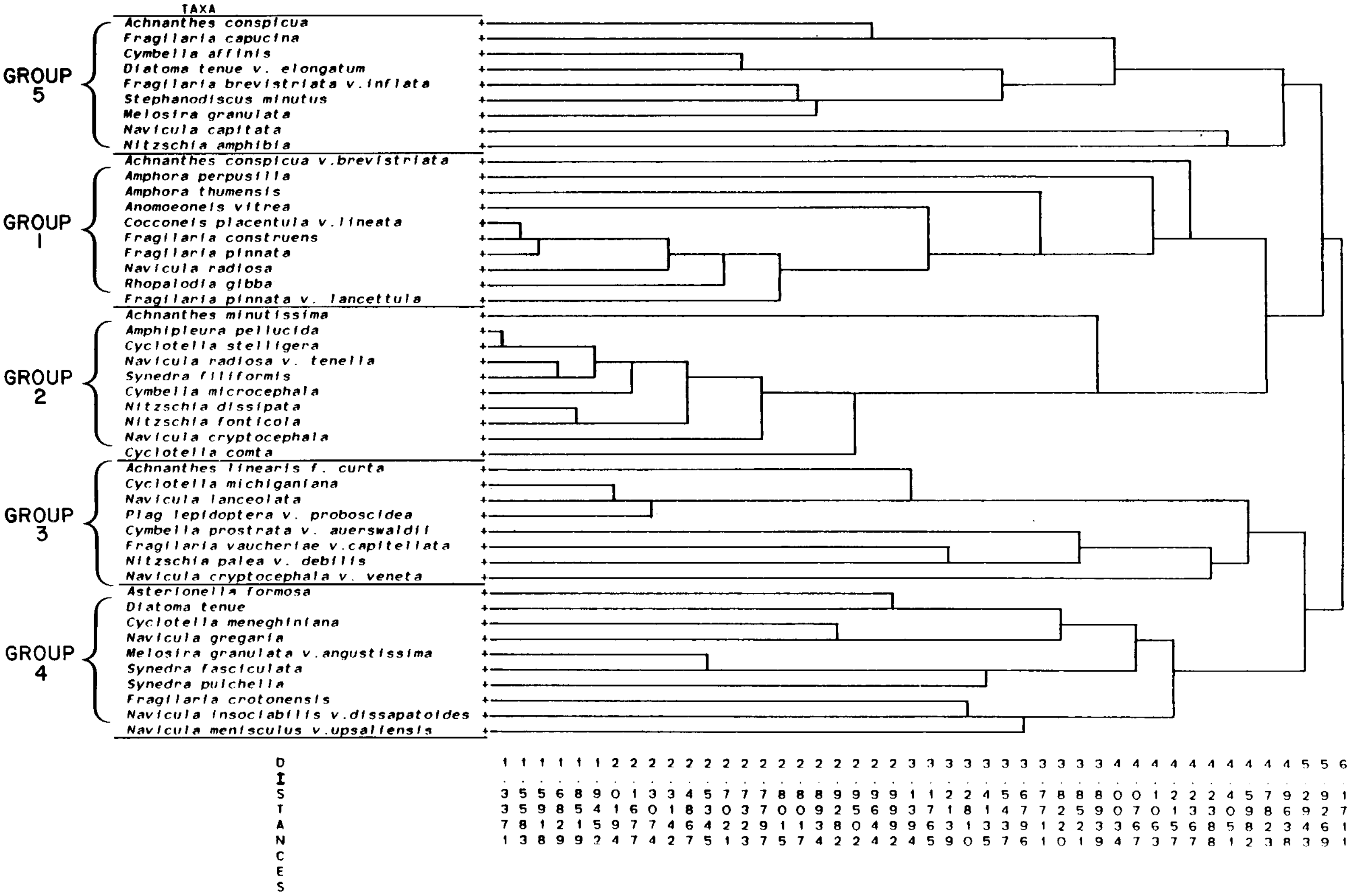

Fig. 4. Cluster analysis by taxa with 5 groups delineated. Euclidean distances are provided at the bottom of the cluster.

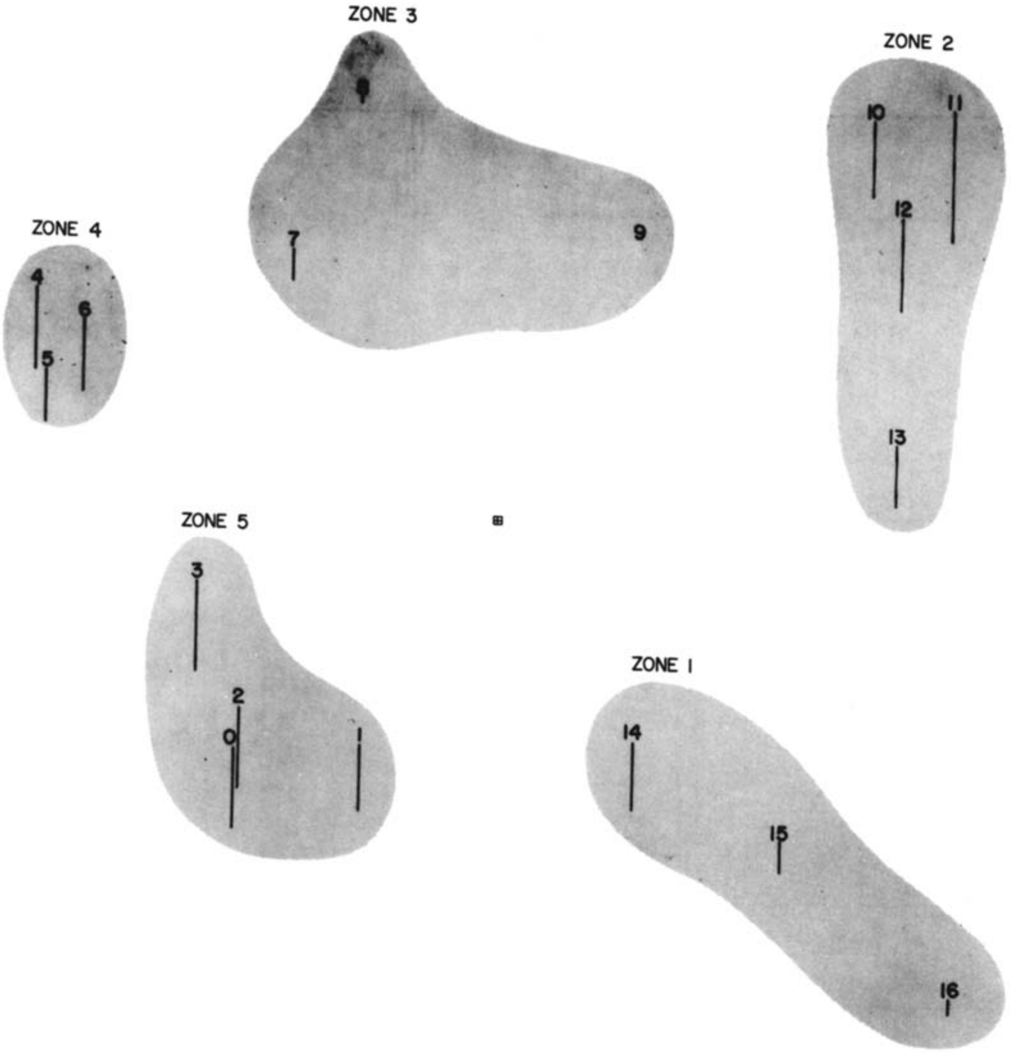

Fig. 5. Principal component analysis by depth, with each number representing depth (cm). The axis of PC 1 ranges from -5.46 (4 cm) to 5.51 (11 cm), PC 2 ranges from -5.97 (16 cm) to 4.90 (8 cm), and PC 3 ranges from -3.40 (9 cm) to 4.43 (11 cm). The 5 groups determined from the cluster analysis are shaded. The vertical line adjacent to each depth represents the third principal component, which is a relative value. The longer the line, the higher the loading on PC 3.

tain quadrat in Fig. 6, is most abundant in the depths of the same quadrat in Fig. 5.

The first principal component axis (PCl) separates samples at the bottom of the core (10–16 cm) from those representing the top of the core (0–6 cm). Samples in the middle of the core (7–9 cm) appear near the zero point of PCl.

The taxa from Groups 1 and 2 (Fig. 6) are positively loaded on PCl. Group 1 species includes *Fragilaria construens* (Ehr.) Grun. and *F. pinnata* Ehr. (Fig. 7) among others. These taxa reach maximum abundances at the bottom of the core and have closest affinities with Zone 1 in the depth analysis. They decrease in abundance up the core to about 7–8 cm and then maintain constant but low numbers to the sediment surface. Two other taxa closely associated with this group are *Fragilaria brevistriata* v. *inflata* and *Stephanodiscus minutus* Grun. (Fig. 11). They have peaks at the top and bottom of the core and are placed in Group 5 but also have close affinities with Group 1.

Species of Group 2, which have positive loadings

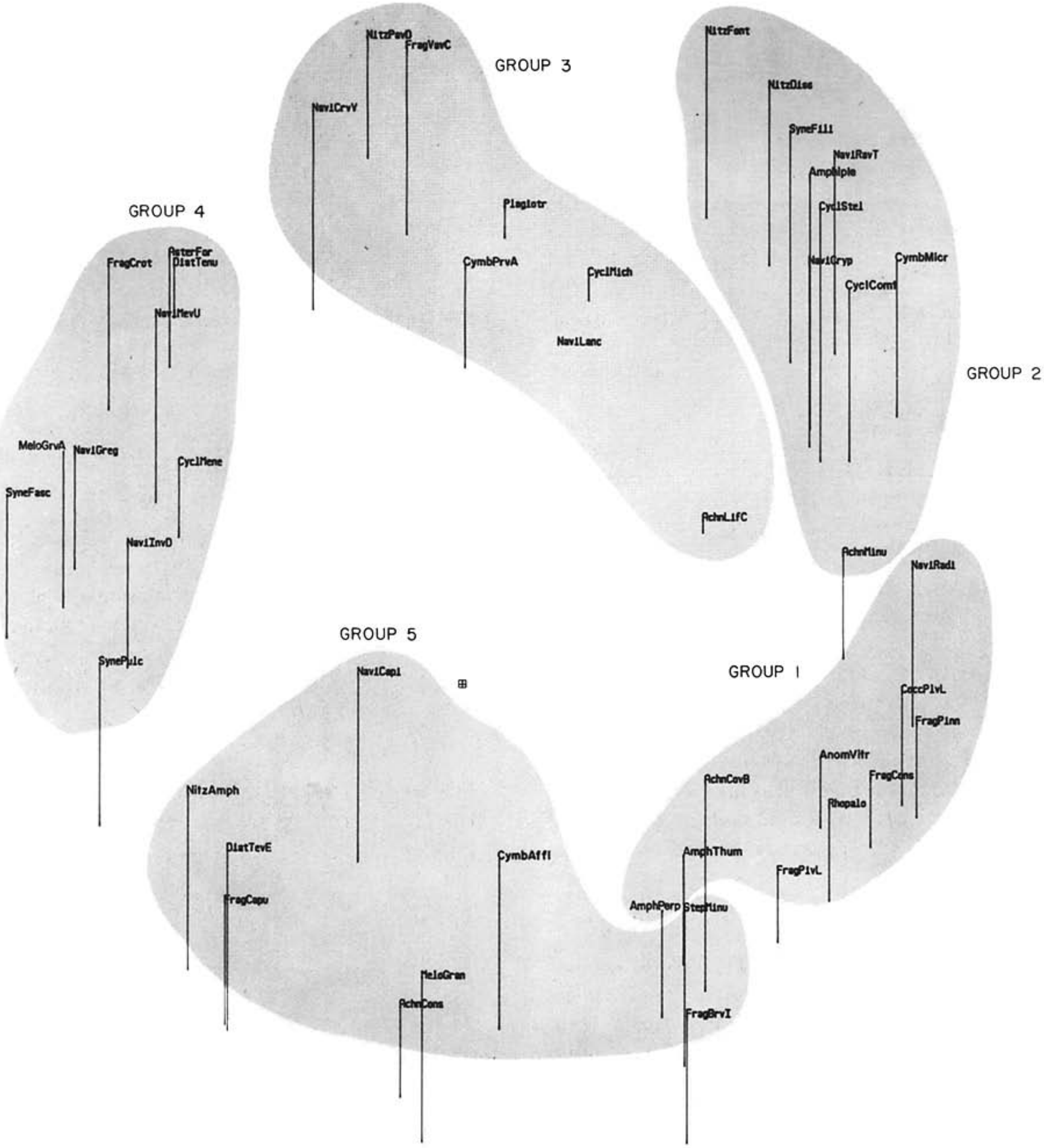

Fig. 6. Principal component analysis by taxa with groups based on cluster analysis. The axis of PC 1 ranges from −.22 (SyneFasc) to .22 (FragPinn), PC 2 ranges from −.21 (FragBrvI) to .26 (NitzPavD), and PC 3 ranges from −.32 (NaviLanc) to .23 (Amphiple). (Taxa abbreviations are as follows: AchnCons = *Achnanthes conspicua,* AchnCovB = *A. conspicua* v. *brevistriata,* AchnLifC = *A. linearis* f. *curta,* AchnMinu = *A. minutissima,* AmphPerp = *Amphora perpusilla,* AmphThum = *A. thumensis,* AnomVitr = *Anomoeoneis vitrea,* Amphiple = *Amphipleura pellucida,* AsterFor = *Asterionella formosa,* CymbAffi = *Cymbella affinis,* CymbMicr = *C. microcephala,* CymbPrvA = *C. prostrata* v. *auerswaldii,* CoccPlvL = *Cocconeis placentula* v. *lineata,* CyclComt = *Cyclotella comta,* CyclMene = *C. meneghiniana,* CyclMich = *C. michiganiana,* CyclStel = *C. stelligera,* DiatTenu = *Diatoma tenue,* DiatTevE = *D. tenue* v. *elongatum,* FragBrvI = *Fragilaria brevistriata* v. *inflata,* FragCapu = *F. capucina,* FragCons = *F. construens,* FragCrot = *F. crotonensis,* FragPinn = *F. pinnata,* FragPivL = *F. pinnata* v. *lancettula,* FragVavC = *F. vaucheriae* v. *capitellata,* MeloGran = *Melosira granulata,* MeloGrvA = *M. granulata* v. *angustissima,* NaviCapi = *Navicula capitata,* NaviCryp = *N. cryptocephala,* NaviCrvV = *N. cryptocephala* v. *veneta,* NaviGreg = *N. gregaria,* NaviInvD = *N. insociabilis* v. *dissapatoides,* NaviLanc = *N. lanceolata,* NaviMevU = *N. menisculus* v. *upsaliensis,* NaviRadi = *N. radiosa,* NaviRavT = *N. radiosa* v. *tenella,* NitzAmph = *Nitzschia amphibia,* NitzDiss = *N. dissipata,* NitzFont = *N. fonticola,* NitzPavD = *N. palea* v. *debilis,* Rhopalo = *Rhopalodia gibba,* StepMinu = *Stephanodiscus minutus,* SyneFasc = *Synedra fasciculata,* SyneFili = *S. filiformis,* SynePulc = *S. pulchella,* Plagiotr = *Plagiotropis lepidoptera* v. *proboscidea.*)

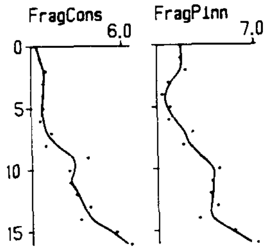

Fig. 7. Depth profiles of Group 1 taxa: *Fragilaria construens* and *F. pinnata.*

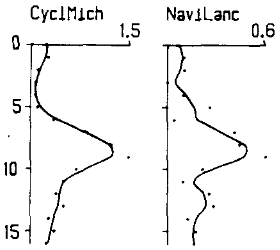

Fig. 9. Depth profiles of Group 3 taxa: *Cyclotella michiganiana* and *Navicula lanceolata.*

on PCl, include *Cymbella microcephala* Grun., *Nitzschia fonticola* Grun., *Cyclotella stelligera* (Cl. and Grun.) V.H. and *Synedra filiformis* Grun. (Fig. 8). These taxa exhibit an increase from 16 cm (1948) to 10–13 cm (1960–1954), then steadily decline to low relative abundances at the top of the core. These taxa are most closely associated with Zone 2 of the depth analysis, thus accounting for their peak abundances at 10–13 cm.

Taxa from Group 3 are spread out along PCl. These include species that exhibit no obvious trends through the core (such as *Navicula cryptocephala* v. *veneta* (Kütz.) Rabh.), as well as taxa which exhibit a singular peak at 8 or 9 cm, such as *Cyclotella michiganiana* Skv. and *Navicula lanceolata* (Ag.) Kütz. (Fig. 9).

Greatest negative loadings on PCl are displayed by the taxa in Group 4 which peak in the 4–6 cm range. Taxa in this group include *Diatoma tenue* Ag., *Fragilaria crotonensis, Melosira granulata* v. *angustissima* and *Synedra fasciculata* (Ag.) Kütz. (Fig. 10), among others. This group exhibits a peak in abundance between 4–6 cm with a slight decrease at the surface (0–3 cm). Many taxa in this group decrease to very low abundances below the peak, becoming very rare below 9 cm.

Group 5 does not load heavily on PCl. Included in this group are some species with two peaks, one at the top and the other at the bottom of the core with lowest abundances in the middle. Taxa in this group include *Diatoma tenue* v. *elongatum* Lyngb., *F. brevistriata* v. *inflata, Melosira granulata* and *Stephanodiscus minutus* (Fig. 11).

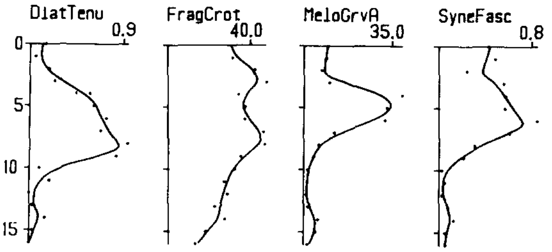

Fig. 10. Depth profiles of Group 4 taxa: *Diatoma tenue, Fragilaria crotonensis, Melosira granulata* v. *angustissima* and *Synedra fasciculata.*

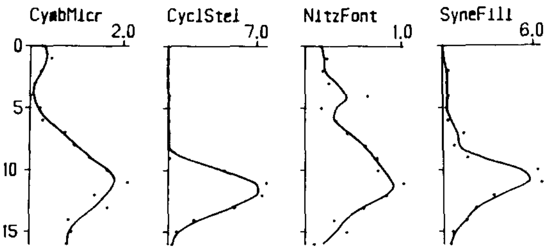

Fig. 8. Depth profiles of Group 2 taxa: *Cymbella microcephala, Cyclotella stelligera, Nitzschia fonticola* and *Synedra filiformis.*

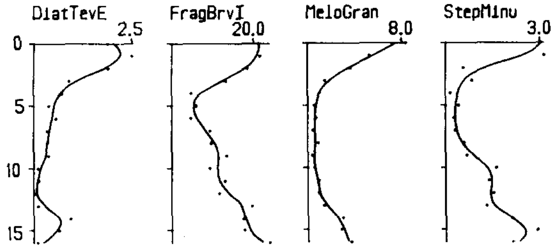

Fig. 11. Depth profiles of Group 5 taxa: *Diatoma tenue* v. *elongatum, Fragilaria brevistriata* v. *inflata, Melosira granulata* and *Stephanodiscus minutus.*

Discussion

The diatom assemblage changed considerably during the time interval represented by the core. Very few species remained static in their relative abundances. The statistical analyses employed segregate the assemblages sampled into 5 similarity groups, but it is clear that the diatom flora reflects a continuous change in response to modified environmental parameters over the 32-year period represented by the core.

Through the core, three eurytopic species (*Fragilaria brevistriata* v. *inflata, F. crotonensis* and *Melosira granulata* v. *angustissima*) maintain an overall dominance. Although their relative abundances do change, they remain major components of the assemblages at all levels studied. Apparently, these eurytopic, dominant taxa are relatively insensitive to changing salinity levels, although minor changes in their relative abundances are reflected in diversity values and in the multivariate analyses.

Subdominant taxa show the largest range of response. This might be expected, since such species seem to have a narrower range of environmental tolerance and distribution than the eurytopic dominants. In the case of Fonda Lake, this trend is accentuated as the algal flora is mainly dominated by blue-green algae. Qualitative samples have shown an unusual abundance of blue-green algae, including atypical cold weather blooms of *Aphanizomenon flos-aquae* (L.) Ralfs. Unfortunately, the remains of these populations are not well enough preserved in the sediments to provide reliable estimates of their abundance over time.

The diatom component of Group 1, with peak abundances at 14–16 cm (1952–1948), was deposited before the salt intrusion and is composed mainly of benthic alkaliphilous diatoms. These include the dominant taxon *Fragilaria brevistriata* v. *inflata,* as well as the subdominant forms *Amphora perpusilla, Anomoeoneis vitrea, Cocconeis placentula* v. *lineata, Fragilaria construens, F. pinnata* and *Rhopalodia gibba* (Patrick & Reimer, 1966, 1975; Lowe, 1974). The plankton component includes *Fragilaria crotonensis* and *Stephanodiscus minutus,* both of which have been categorized as alkaliphilous (Lowe, 1974). The predominance of alkaliphilous taxa in the lake is not unexpected since the pH, according to a 1951 study, ranged from 7.2 to 8.6 (Michigan DNR, unpubl. data).

Group 2 includes diatoms with peaks at 10–13 cm (1960–1954), depths that correspond with the beginning of salt storage adjacent to the lake. However, there does not appear to be any marked effect on the diatom component over this period. The taxa are again alkaliphilous as well as chloride indifferent. There was, however, a shift in secondarily dominant taxa from typically benthic forms to planktonic forms with *Cyclotella comta, Cyclotella stelligera,* and *Synedra filiformis* together averaging approximately 10% of the assemblage.

Group 3, with maximum abundances at 7–9 cm (1966–1962), appears to reflect a transition between the alkaliphilic forms of Groups 1 and 2, and the more halophilic species of Group 4. One noticeable trend over this 4-year period is the decline in diversity and evenness (Fig. 2). Dickman and Gochnauer (1978) also found a decline in algal diversity at their chloride stressed station. Therefore, this decrease may indicate that salt has begun to increase in the lake and affect the diatom flora. The diversity decrease coincided with a combined increase in abundance of *F. crotonensis* and *M. granulata* v. *angustissima* (Fig. 10), two eurytopic, chloride-indifferent taxa. Trends related to the secondarily dominant taxa were not very apparent in this group although certain species did exhibit selective peaks over this range.

Some species of Group 4 with peaks at 4–6 cm (1972–1968) have been documented in the literature as halophiles. This is the first occurrence in the core of halophilic taxa to any significant extent. These halophilic taxa include *Diatoma tenue* (Petersen, 1943; Patrick & Reimer, 1966), *Cyclotella meneghiniana* (Hustedt, 1930; Petersen, 1943; Lowe, 1974), *Navicula gregaria* (Petersen, 1943; Patrick and Reimer, 1966), *Synedra fasciculata* (Hustedt, 1930; Patrick & Reimer, 1966), and *Synedra pulchella* (Kolbe, 1927). At this zone in the core, diversity and evenness values attained their lowest levels since *F. crotonensis* and *M. granulata* v. *angustissima* together accounted for 65 to 70% of the total population. Both of these dominant taxa also clustered within this group.

The species most closely associated with Group 5 have peak abundances at the top of the core, 0–3 cm (1980–1974). Most of the halophilic forms that attained highest abundances in Group 4 have either maintained those values or decreased slightly at this depth interval. However, they all maintained higher abundances as compared to their values below 9 cm before salt was affecting the diatom flora of the lake. One halophilic form that did increase at the top is *Diatoma tenue* v. *elongatum* (Hartmann, 1967). It is interesting to note that *Fragilaria brevistriata* v. *inflata* and *Stephanodiscus minutus* increased in abundance at the top of the core and attained values similar to the bottom (14–16 cm). Additionally, diversity and evenness values increased in this zone.

Analysis of the uppermost core segment suggests a decrease in salt levels from the early 1970's to the present chloride concentrations of about 220 mg l^{-1}. The reason for this possible reduction may be the construction of an asphalt pad for the salt-storage facility in the early 1970's. It is possible that chloride levels attained a maximum in the late 1960's and early 1970's, and have since decreased and remained relatively constant at about 220 mg l^{-1}. Unfortunately, no chloride measurements of Fonda Lake water were made prior to 1979.

Diatom composition and diversity can be very useful indicators of overall salinity changes. It is very important that the total diatom assemblage be monitored, not only the dominant taxa, since the subdominant taxa appear to be more sensitive to salinity changes than the few eurytopic dominant taxa. If salt levels in the lake continue to decrease, it will be very informative to continue monitoring the lake, following future shifts in the diatom assemblage. It would also be most interesting to study effects on other elements of the lake's biocoenosis (Bergland, 1979) in order to evaluate ecosystem response to salinification.

Summary

Over the 23-year period represented by the core, the subdominant diatom taxa, in particular, exhibited a variety of changes. The bottom of the core (1948–1952) was characterized by a benthic, alkaliphilous, chloride-indifferent flora. This changed to a more planktonic flora over the following six years with the taxa also being chloride-indifferent. By 1962 (Zone 3), a decrease in diversity and evenness was noted, possibly indicating the first effects of salt loadings into the lake. The 9-year lag effect from between the time salt storage first began in 1953 to when loadings apparently affected the diatom component, is not totally unexpected since the effects of leaching into the ground water and run-off into the lake may have taken a period of time. Unfortunately, no chloride values are available for this period. By 1968 (Zone 4) halophilic taxa attained peak abundances, and diversity and evenness values reached minimum levels. From 1968 to 1972, it appears that chloride levels in the lake were highest and had their greatest effect on the diatom component. At the top of the core, there was a decline in abundance of some halophilic taxa which exhibited peaks in Group 4, as well as an increase in diversity and evenness values suggesting a possible decrease of salt levels in the lake. Additionally, a few taxa that increased in this zone also had abundance peaks at the bottom of the core.

Acknowledgments

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