J. Great Lakes Res. 14(2):164-170
Internat. Assoc. Great Lakes Res., 1988

ALGAL REMAINS IN SOME SURFACE SEDIMENTS OF LAKE ERIE

Timothy J. Keilty[1], Eugene F. Stoermer, and David S. White
Great Lakes Research Division
The University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT. Algal remains, primarily diatoms, were examined in the 0–1 cm fraction of sediment cores collected at eight stations along a west-to-east transect in Lake Erie to determine species composition, cell density, and flux rates. Sixty-two taxa were identified of which 13 were common to all stations. Highest densities and flux rates occurred in the western and eastern basins. Species composition, cell density, and flux rates in the sediments did not appear to correlate well with previous reports of water-column phytoplankton distribution and abundance. The distribution of diatom remains in the sediments more likely resulted from the effects of near-bottom west-to-east energy zones and transport mechanisms operating within the western and central basins of Lake Erie. The distribution of algal remains demonstrated that caution should be used in applying paleolimnological data to trophic status changes in Lake Erie.
ADDITIONAL INDEX WORDS: Diatoms, sedimentation, bottom currents, paleolimnology, Cyclotella.

INTRODUCTION

The distribution and abundance of algal remains, particularly diatoms, in lake sediments are products of co-occurring biotic and abiotic events which can provide clues to biological and physical forces operating in the overlying waters if factors affecting deposition and preservation are known. Ideally, one would want to know the numbers of cells that were produced in the water column, the rate of cell flux to the sediment, the degree of preservation, and the origin of the cells (Merilainen 1971, Batterbee 1978a, Dixit and Evans 1986). Most often, water column biomass, flux rates, and preservation factors are not known but are inferred from the algal remains themselves (Dixit and Evans 1986).

As part of a 1976 physicochemical study, sediment cores had been taken at eight stations along a transect from the western to eastern basins of Laker Erie (Fig. 1). The top 1-cm fraction for one core from each station was made available to us for analysis of algal remains. Much information has been published on the biological, physical, and chemical properties of Lake Erie which allows some comparison of algal remains with factors affecting deposition and preservation. There have been several studies of the pelagic algae (Verduin 1964, Hohn 1969, Vollenweider *et al.* 1974, Munawar and Munawar 1976, Munawar and Burns 1976) that give data on the biomass and species composition of cells being produced in the water column prior to the 1976 coring. Sediment composition and accumulation rates are reasonably well understood for Lake Erie (Thomas *et al.* 1976 and others), and mass-sedimentation rates for each of the eight stations at the time of coring were available from Robbins *et al.* (1988). Mass sedimentation rates permit diatom flux calculations once densities of algal remains are known.

Our primary objective was to examine the species composition and density, and to calculate flux rates of algal remains in the surficial sediments. Secondarily, we attempted to relate the data to the conditions and processes occurring in the overlying waters. Because of the suspected high decomposition rates of some algal divisions (e.g., greens and bluegreens), we limited our analyses primarily to the diatom remains. Even interpretation of diatom remains can be complicated by high silica dissolution rates in surficial sediments (Schleske *et al.* 1983, Conley 1987). Evidence suggests, however,

[1]To whom correspondence should be addressed at Great Lakes Environmental Research Laboratory, 2205 Commonwealth Blvd., Ann Arbor, MI 48105

TABLE 1. Mass-sedimentation rates (gm cm^{-2} yr^{-1}) (Robbins et al. *1988), total diatom cell densities (no cm^{-3} × 10^2), and total diatom cell flux rates (no cm^{-2} × 10^2 yr^{-1}) for eight stations in Lake Erie.*

	Stations							
	6	10	13	24	30	33	47	58
Mass-Sed. Rate	120	70	17	50	30	10	140	40
Cell Density	9,230	6,344	7,791	9,902	5,868	3,478	17,100	10,226
Cell Flux Rate	768	280	92	307	50	20	1,168	243

that under conditions of high sedimentation rates and focusing such as is thought to occur in several areas of Lake Erie (Robbins *et al.* 1988), decomposition of diatom frustules may be insignificant in altering stratigraphic records (Batterbee 1978b).

In this paper, therefore, we began with the assumptions 1) that there was little physical or chemical degradation of the surficial layer of diatom remains and 2) that cores from the middle of small shallow lakes often contain remains of both the pelagic populations and some fractions of the littoral and benthic communities, while cores from the middle of large systems more often represent only the remains of the open-lake water-column populations (Round 1964, Duthie and Sreenivasa 1972, Bradbury and Winter 1976, Brugam 1978, Fritz and Carlson 1982, Dixit and Evans 1986).

MATERIAL AND METHODS

Cores were collected (Table 1, Fig. 1) with a 6.66 cm ID Benthos™ corer. Sediments were hydraulically extruded from the cores, fractioned at 1-cm intervals, and preserved in 4% $CaCO_3$ buffered formalin. We examined only the top 1-cm fraction from each core.

A 2-mL aliquot of the core fraction was diluted with 40 mL distilled water, and a 0.4-mL subsample from the dilution was pipetted onto each of two 18-mm^2 glass coverslips. The coverslips were heated, and Hyrax™ mounts were made after the water had evaporated. A minimum of 1,000 cells was counted on each slide. Student T-test comparisons between paired slides showed no significant differences; therefore, data presented here are from the mean of the two slides for each station.

RESULTS AND DISCUSSION

Sixty-two algal taxa, predominantly diatoms, were identified from the surficial sediments, of which 13 taxa were common to all eight Lake Erie stations. Species lists are available from the Great Lakes Research Division upon request. Total cell densities per cm^3 of surface sediment were highest at Station 47 in the eastern basin and lowest at the central basin Station 33 (Table 1). Cell densities were not that different from each other at the remaining stations. When mass-sedimentation rates were used to calculate cell flux, i.e., the number of cells being incorporated into the surface sediments per cm^3 per year, a different pattern emerged (Table 1, Fig. 2). Although there were large numbers of cells in the surface sediments at Stations 13, 30, and 33, relatively fewer new cells were being incorporated each year compared with the eastern or western basin stations.

Although not directly comparable to data from this study, previous water-column phytoplankton (diatom) biomass and species composition studies for Lake Erie allowed us to speculate on the patterns found for the surficial sediments in this study. Most of the taxa found in our core fractions had been recorded from the water column (Verduin 1964, Munawar and Burns 1976, Munawar and Munawar 1976); however, relative abundance patterns differed. Munawar and Burns (1976) found that the highest water-column mean annual biomass (April-December) occurred in the western basin (4–7.9 g m^{-3}). Mean annual biomasses in the central and eastern basins were similar to each other but lower than in the western basin and ranged from 2–3.9 g m^{-3}. Munawar and Munawar (1976) listed the dominant diatoms of the western basin as *Fragilaria crotonensis*, *Stephanodiscus tenuis*, *Melosira islandica*, and *Stephanodiscus binderanus* (= *Melosira binderana*). The dominant taxa in the central basin were *Fragilaria crotonensis*, *Fragilaria capucina*, and *Stephanodiscus niagarae*. Dominant eastern basin diatoms were *Stephanodiscus tenuis*, *Stephanodiscus niagarae*, and *Fragilaria crotonensis*. Data from this study

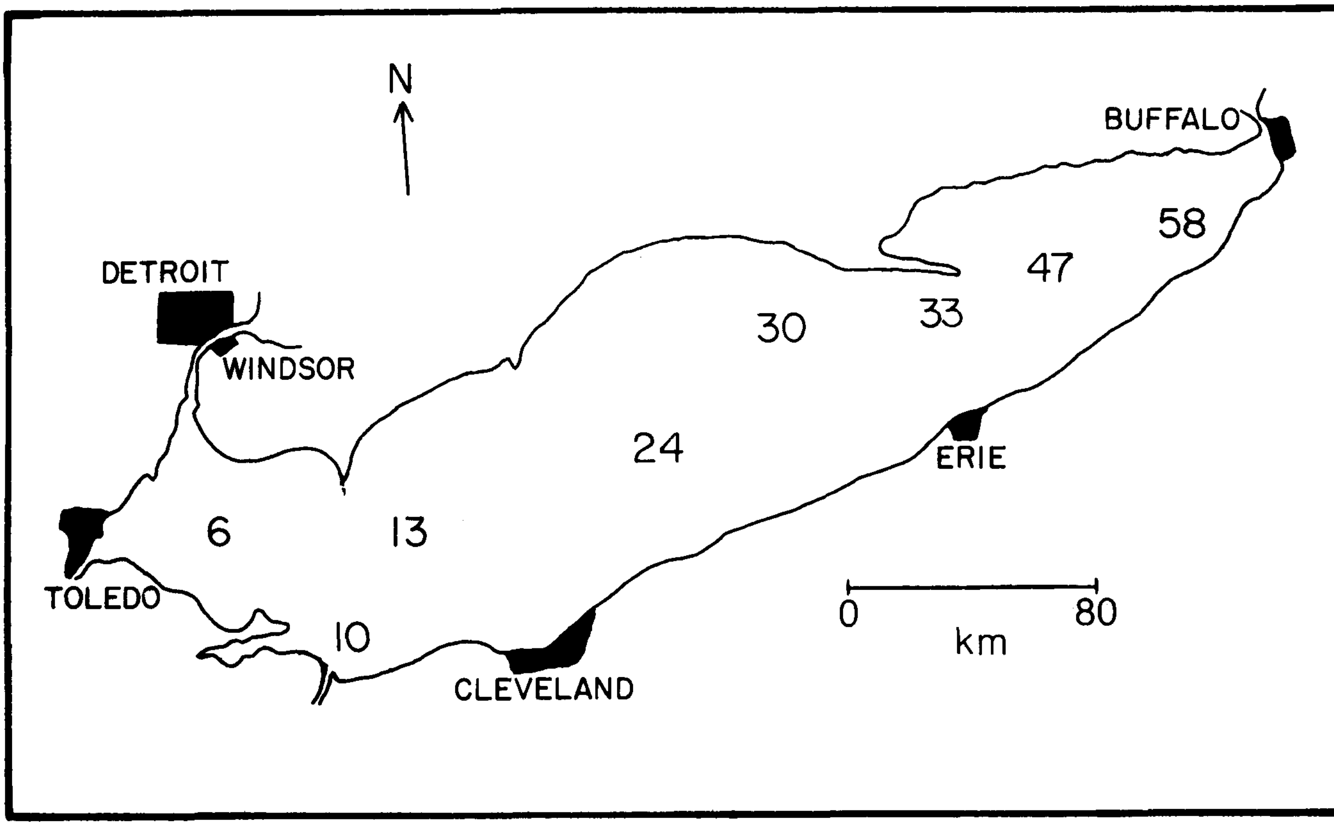

FIG. 1. Map of Lake Erie depicting the locations of sites cored.

differed particularly in the distributions of *Asterionella formosa*, *Stephanodiscus binderanus*, *Actinocyclus normanii* f. *subsalsa*, *Fragilaria capucina*, *Tabellaria fenestrata*, *Melosira granulata*, and *Cyclotella comensis* (Table 2, Fig. 3), most of which showed high densities and fluxes in both the eastern and western basins (Stations 6, 10, and 47, 58) and very low densities and fluxes (with the exception of Station 24) in the central basin (Stations 13, 30, 33) (Table 2, Fig. 3).

Prior to 1950, *Asterionella formosa* was one of the dominant species in the western basin (Verduin 1964), but had declined and was not abundant anywhere in the lake by 1970 (<5% of the eastern basin biomass, Munawar and Munawar 1976). *Tabellaria fenestrata* also was quite abundant in the western basin before 1950 and had since declined throughout the lake (Hohn 1969); therefore, it was possible that shifts in other species had occurred between 1970 (Munawar and Munawar 1976) and 1976 and that the shifts might have been reflected in the surface sediment core samples. The presence of large numbers of *Cyclotella comensis* in the eastern and western basin sediments suggests, however, that the deposition patterns in offshore Lake Erie simply do not reflect the water-column community. *Cyclotella comensis* had not been reported from any Lake Erie pelagic samples prior to 1976 (Munawar and Munawar 1976; M. Munawar, Canada Centre for Inland Waters, Burlington, Ontario, pers. comm.), and the authors are unaware of any specimens being found in more recent collections. Apparently cells originated from populations in the upper Great Lakes, probably Lake Huron (Schelske *et al.* 1972, 1974; Stoermer 1978; Stoermer and Kreis 1980) and were transported into Lake Erie through the St. Clair/Detroit River system. Because no *Cyclotella comensis* have been reported in the water column, transport through the connecting channels to the eastern basin must have occurred at or just above the bottom.

If a west-to-east near-bottom transport mechanism was controlling the deposition of imported

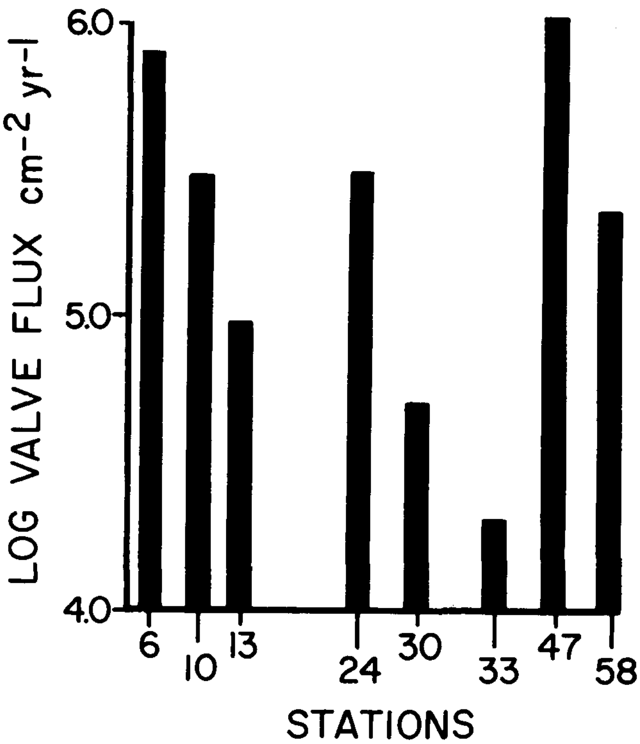

FIG. 2. Total diatom cell fluxes (log no. cm^{-2} yr^{-1}) into the surficial sediment at eight stations in Lake Erie. Stations on x-axis are spaced proportionately to represent distance from the west end of the lake.

Cyclotella comensis, then it could be expected that some proportion of diatom cells actually produced in and settling out of the western and central basins would continually be displaced down-lake as well. Flux rates for total cells (Table 1, Fig. 2) and for six of the dominant taxa in the core fractions (Fig. 3) further illustrate the probability of west to east transport. High flux rates in the western basin would result, in part, from the water-column species composition and high production there (Munawar and Burns 1976, Munawar and Munawar 1976) and, in part, from import into the basin through the connecting channels. Stations 13, 24, 30, and 33 are in the less productive central basin, but the number of cells being deposited there, with the exception of Station 24, was much lower than might be expected considering the biomass estimates from Munawar and Munawar (1976).

Station 47 is the deepest portion of the lake and had the highest mass-sedimentation rate (Table 1). This part of the eastern basin appeared to be the focusing point for west-to-east transported materials (Robbins *et al.* 1988). While the overlying water-column algal biomass in the eastern basin was approximately equal to algal biomass in the central basin (Munawar and Burns 1976, Munawar and Munawar 1976), it was found that diatom cell flux rates for the eastern basin were greater than rates for the central basin and were equal to or greater than rates for the western basin. The species composition of algal remains in the surface sediments of the eastern basin, therefore, most

TABLE 2. Species flux percentages (flux of species i at station j/sum of fluxes of species i at all stations) for species common to all sampling locations.

SPECIES	STATIONS 6	10	13	24	30	33	47	58
Asterionella formosa	10.7	4.0	1.7	4.1	0.7	2.0	58.9	17.9
Actinocyclus normanii	16.0	40.2	6.0	13.8	0.5	0.1	17.5	6.0
Cyclotella comensis	80.1	8.0	0.7	0.8	0.09	0.06	5.9	3.7
Diatoma tenue v. elongatum	41.1	30.4	0.4	5.2	0.6	0.1	9.7	12.6
Fragilaria capucina	26.9	8.8	4.7	14.2	1.2	0.6	40.7	2.8
Fragilaria crotenensis	16.9	7.6	3.2	14.3	2.7	0.5	48.2	6.5
Melosira granulata	40.0	25.6	2.3	4.8	0.2	0.1	24.4	2.8
Tabellaria fenestrata	29.5	11.1	3.2	8.2	2.5	0.5	40.8	4.2
Stephanodiscus alpinus	7.4	9.6	2.6	14.3	1.4	1.0	48.4	15.4
Stephanodiscus binderanus	12.0	8.0	0.6	5.3	0.3	0.2	52.2	21.3
Stephanodiscus niagarae	3.3	9.2	4.8	29.6	4.6	0.9	43.2	4.4
Stephanodiscus hantzchii	33.9	8.4	2.8	6.3	3.8	1.6	37.3	5.9
Stephanodiscus subtilis	34.8	7.3	3.6	5.8	1.7	1.2	36.5	9.1

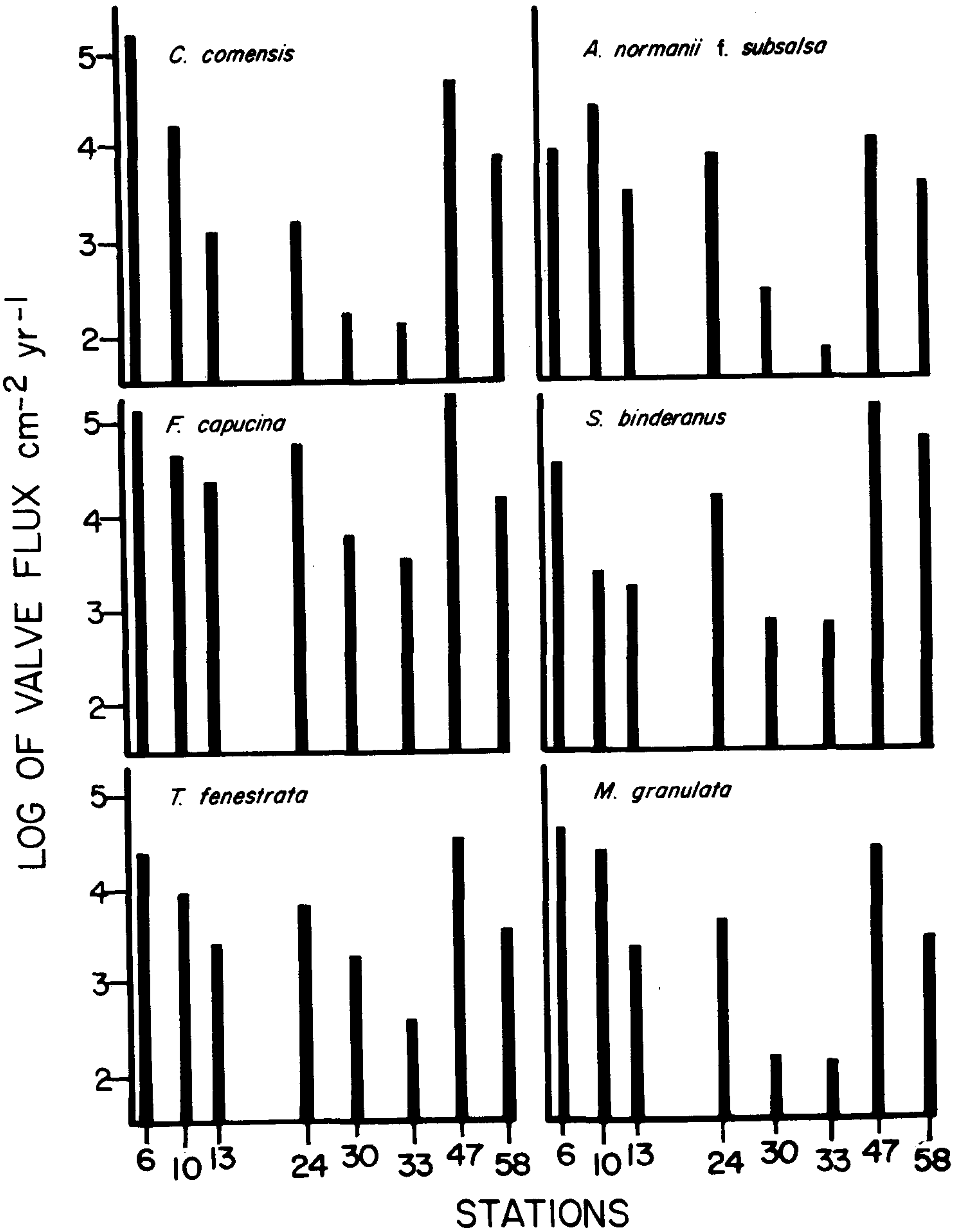

FIG. 3. Valve fluxes (log no. cm^{-2} yr^{-1}) for the six dominant diatom taxa into the surficial sediments of eight stations in Lake Erie. Stations on x-axis are spaced proportionately to represent distance from the west end of the lake.

likely represented a composite of taxa imported from the connecting channels and the western and central basins.

A combination of near-bottom water current patterns and sediment resuspension events may have accounted for much of the observed distribution of diatoms in the surface sediments. The eastern portion of the central basin, including Stations 13, 30, and 33, is an area of high bottom energy currents as determined from sediment textural analysis (Thomas *et al.* 1976). Mass-sedimentation rates (Table 1) and diatom flux (Figs. 2, 3,

Table 2) showed that relatively little new material was being incorporated into the bottom sediments at these stations. Station 24 appeared to be outside the area of high bottom energy (Table 1), and diatom flux possibly more likely reflected water-column diatom populations for the central basin. It is not known, however, if west-to-east near-bottom Lake Erie currents alone from the connecting channels through the central basin would be sufficient to entrain diatoms cells.

Some west-to-east transport of both living and dead cells is expected to occur in the water column, but diatom settling rates may be quite rapid. Settling rates are in part dependent on the algal species, their particular form and morphology, their physiological state, and if the cells are dead or alive (Kilham *et al.* 1986). For example, settling rates for *Asterionella formosa* vary from 0.2 to 1.5 m per day (Titman and Kilham 1976, Burns and Rosa 1980). Kreis *et al.* (1983) found that dislodged benthic diatoms entering Lake Huron from the St. Marys River plume had settling rates from 0.76 to 5.99 m per day and were all but gone from the water column after 32 km into the lake.

Kang *et al.* (1982) have demonstrated that storm-generated waves are a primary energy source for sediment entrainment in the shallow western and central basins of Lake Erie. Post-depositional resuspension of sediments and diatom remains combined with differential settling rates and west-to-east near-bottom currents probably have a great impact on the surficial diatom assemblages present at any one time. Similar physical processes have been demonstrated to be the primary mechanism for the redistribution of littoral assemblages toward the middle of smaller lakes (Dixit and Evans 1986).

The distribution and abundance of algal remains, particularly diatoms, in the surficial sediments of Lake Erie appeared to be products of co-occurring biotic and abiotic events in the overlying water; however, remains may provide many more clues to the physical forces in operation than to biological forces. Lake Erie, with its short water retention time (≃ 920 days, Hartman 1973), functions more like a broad river or riverine impoundment (Burns 1985), continually transporting materials to the high sedimentation areas of the deeper eastern basin. These data imply that one should be cautious in using paleolimnological data to assess changes in the trophic status of Lake Erie or lakes with similar physical regimes.

ACKNOWLEDGMENTS

We gratefully acknowledge Dr. John A. Robbins of the Great Lakes Environmental Research Laboratory—NOAA, Ann Arbor, for supplying data on sedimentation rates in Lake Erie and for many useful discussions of the data. Our thanks are extended to Luanne Frey and Dr. Russell G. Kreis, Jr. for taxonomic assistance and to Deborah Woodland and Constance Millenbach for data assistance. Contribution No. 487 of the Great Lakes Research Division, University of Michigan, was supported by Grant no. R-813831 from the United States Environmental Protection Agency, Office of Exploratory Research.

REFERENCES

Batterbee, R. W. 1978a. Relative composition, concentration and calculated influx of diatoms from a sediment core from Lough Erne, Northern Ireland. *Pol. Arch. Hydrobiol.* 25:9–16.

________. 1978b. Observations on the recent history of the Lough Neagh and its drainage basin. *Phil. Trans. Roy. Lond. Series B* 218:303–345.

Bradbury, J. B., and Winter, T. S. 1976. Areal distribution and stratigraphy of diatoms in the sediments of Lake Sallie, Minnesota. *Ecology* 57:1005–1014.

Brugam, R. B. 1978. Human disturbance and the historical development of Linsely Pond. *Ecology* 59: 19–36.

Burns, N. M. 1985. *Erie The Lake That Survived.* Totowa, New Jersey: Rowman & Allanheld, Publ.

________, and Rosa, F. 1980. In situ measurements of the settling velocity of organic particles and 10 species of phytoplankton. *Limnol. Oceanogr.* 25: 855–864.

Conley, D. J. 1987. *Mechanisms controlling silica flux from sediments and implications for the biogeochemical cycling of silica in Lake Michigan*. Ph.D. dissertation, Univ. of Mich., Ann Arbor, Mich.

Dixit, S. S., and Evans, R. W. 1986. Spatial variability in sedimentary algal microfossils and its bearing on diatom-inferred pH reconstruction. *Can. J. Fish. Aquat. Sci.* 43:1836–1845.

Duthie, H. C., and Sreenivasa, M. R. 1972. The distribution of diatoms on the superficial sediments of Lake Ontario. In *Proceedings 15th Conf. Great Lakes Res.*, pp. 45–52. Internat. Assoc. Great Lakes Res.

Fritz, S. C., and Carlson, R. E. 1982. Stratigraphic diatom and chemical evidence for acid strip-mine lake recovery. *Water Air Soil Pollut.* 17:151–163.

Hartman, W. L. 1973. *Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie*. Tech. Rept. No. 22, Great Lakes Fish. Comm., Ann Arbor, Mich.

Hohn, M. H. 1969. Quantitative and qualitative analysis of plankton diatoms, Bass Island area, Lake Erie. *Bull. Ohio Biol. Surv., New Series* 3:1-211.

Kang, S. W., Sheng, Y. P., and Lick, W. 1982. Wave action and bottom shear stresses in Lake Erie. *J. Great Lakes Res.* 8:482-494.

Kilham, P., Kilham, S. S., and Hecky, R. E. 1986. Hypothesized resource relationships among African planktonic diatoms. *Limnol. Oceanogr.* 31: 1169-1181.

Kreis, R. G., Jr., Ladewski, T. B., and Stoermer, E. F. 1983. Influence of the St. Marys River plume on northern Lake Huron phytoplankton assemblages. *J. Great Lakes Res.* 9:40-51.

Merilainen, J. 1971. The recent sedimentation of diatoms frustules in four meromictic lakes. *Ann. Bot. Fenn.* 8:160-176.

Munawar, M., and Burns, N. M. 1976. Relationships of phytoplankton biomass with soluble nutrients, primary production, and chlorophyll *a* in Lake Erie, 1970. *J. Fish. Res. Board Can.* 33:601-611.

________, and Munawar, I. F. 1976. A lakewide study of phytoplankton and biomass and its species composition in Lake Erie, April-December 1970. *J. Fish. Res. Board Can.* 33:581-600.

Robbins, J. A., Keilty, T. J., and Edgington, D. N. 1988. Correlations between tubificid abundances and sediment composition and accumulation rates in Lake Erie. *Can. J. Fish. Aquat. Sci.* (in press).

Round, F. E. 1964. The diatom sequences in lake deposits: some problems of interpretations. *Verh. Internat. Verein. Limnol.* 15:1012-1020.

Schelske, C. L., Felt, L. E., Santiago, M. A., and Stoermer, E. F. 1972. Nutrient enrichment and its effect on phytoplankton production and species composition in Lake Superior. In *Proceedings 15th Conf. Great Lakes Res.*, pp. 149-165. Internat. Assoc. Great Lakes Res.

________, Felt, L. E., Simmons, M. S., and Stoermer, E. F. 1974. Storm induced relationships among chemical conditions and phytoplankton in Saginaw Bay and western Lake Huron. In *Proceedings 17th Conf. Great Lakes Res.*, pp. 78-91. Internat. Assoc. Great Lakes Res.

________, Stoermer, E. F., Conley, D. J., Robbins, J. A., and Glover, R. M. 1983. Early eutrophication of the lower Great Lakes: new evidence from biogenic silica in the sediments. *Science* 222:320-322.

Stoermer, E. F. 1978. Phytoplankton as indicators of water quality in the Laurentian Great Lakes. *Trans. Am. Microsc. Soc.* 97:2-16.

________, and Kreis, R. G., Jr. 1980. *Phytoplankton composition and abundance in southern Lake Huron.* Great Lakes Res. Div. Spec. Rept. No. 65. Univ. of Mich., Ann Arbor, Mich.

Thomas, R. L., Jaquet, J. M., Kemp, A. L. W., and Lewis, C. F. M. 1976. The surficial sediments of Lake Erie. *J. Fish. Res. Board Can.* 33:385-403.

Titman, D., and Kilham, P. 1976. Sinking in freshwater phytoplankton: some ecological implications of cell nutrient status and physical mixing processes. *Limnol. Oceanogr.* 21:409-417.

Verduin, J. 1964. Changes in Lake Erie during the period 1948-1962. *Verh. Internat. Verein. Limnol.* 15:639-644.

Vollenweider, R. A., Munawar, M., and Stadelman, P. 1974. A comparitive review of phytoplankton and primary production in the Laurentian Great Lakes. *J. Fish. Res. Board Can.* 31:739-762.