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Changes in Planktonic Diatoms and Water Transparency in Hatchery Bay, Bass Island Area, Western Lake Erie Since the Establishment of the Zebra Mussel

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ABSTRACT. Total planktonic diatoms were analyzed from water samples collected in 1984-1986 (pre-zebra mussel period) and 1990-1992 (post-zebra mussel period) in Hatchery Bay of western Lake Erie. Planktonic diatom abundances for one post-zebra mussel year, 3 April 1990-26 March 1991, and weekly April/May frustules for 1990, 1991, and 1992 were compared to counts from the 1980s and to counts in the literature for the years 1960-1965. Water transparency (Secchi disk depth), measured concomitantly with the collection of plankton samples, was compared between the two periods, 1984-1986 and 1990-1992. Transparency was found to be 100% higher in the post-zebra mussel period. Mean numbers of total planktonic diatoms in the full post-zebra mussel year were lower than in the pre-zebra mussel periods: 86% lower than in 1984-1986 and 92% lower than in 1961-1965. Abundances of total diatoms in the weekly April/May samples for 1990, 1991, and 1992 were within 9% of each other and between 82% and 91% lower than in any of the weekly April/May periods of the 8 pre-zebra mussel years. The recent increase in water transparency and decrease in planktonic diatoms in Hatchery Bay are most likely the direct result of the filtering activities of the zebra mussel, *Dreissena polymorpha.* The changes may signal an alteration in the food web in western Lake Erie.

INDEX WORDS: Planktonic diatoms, water transparency, zebra mussel, Dreissena polymorpha Lake Erie.

INTRODUCTION

The zebra mussel, *Dreissena polymorpha* Pallas, was first discovered in North America in Lake St. Clair in June of 1988 (Hebert *et al.* 1989) after a suspected introduction via ballast water, probably in 1986 (Griffiths *et al.* 1991). It was first collected in the western basin of Lake Erie in July of 1988 (Leach 1992), and by 1989 was estimated to have spread throughout the lake (Griffiths *et al.* 1991). It is now found in all the St. Lawrence Great Lakes as well as some smaller North American lakes and inland waterways (National Fisheries Research Center 1993). Western Lake Erie has been especially suitable for colonization because of its expanses of rocky substrate, productive plankton communities, moderate temperatures, and scarcity of predators. These favorable environmental conditions, coupled with the reproductive capacity of *Dreissena* (Stanczykowska 1977), made it possible for zebra mussel densities to reach 342,000 per square meter in western Lake Erie in 1990 (Leach 1992). *D. polymorpha* is a suspension feeder which filters indiscriminately but ingests selectively, rejecting unsuitable particles as pseudofeces (Morton 1969a, Ten Winkle and Davids 1982). Thus, the zebra mussel is capable of removing abiotic as well as biotic material from the water. By removing large amounts of suspended matter, abundant zebra mussels have the capacity to alter transparency and plankton abundance thereby changing the ecosystem and the aquatic food web. This study examines water transparency and the abundance of planktonic diatoms at one location in western Lake Erie before and after the establishment of *D. polymorpha.*

METHODS

The site (north: 41°40'01", west: 82°49'61") for this study was Hatchery Bay, also known as Fishery Bay, in the Bass Island region of western Lake Erie, between Gibraltar Island and the hatchery dock on South Bass Island. Hatchery Bay was chosen because it is amenable to year-round study and because it was the site of earlier extensive studies on planktonic diatoms by Matthew Hohn (Hohn 1969). Hohn (1969) also examined planktonic diatoms from a survey of five index stations in the Bass Island region and one located north of East Sister Island in June, July, and August of 1961 and 1962. He found uniform diversity and occurrence of planktonic diatom flora at all depths in the Bass island area. and concluded that reliable estimates of their diversity and quantity could be obtained from a single station. Samples for my present study were collected once a week. year-round, by personnel of the Franz Theodore Stone Laboratory of Ohio State University from 9 August 1983-31 March 1987, prior to the establishment of *D. polymorpha,* and sent to me for analysis. These personnel resumed sampling 3 April 1990 and have continued sampling as part of my ongoing study of' the diatom community.

Water was obtained by Kemmerer bottle 1 meter below the surface. A measured volume, between 200 mL and 1,000 mL, varying with the ease of filtration of that day's sample. was run through a membrane filter with a pore size of 0.45μm. Duplicate filters were placed in individual petre dishes. Diatom frustules were identified and counted directly from a portion of dried filter which had been made transparent with immersion oil. All counts were made using a Zeiss phase research microscope at a magnification of 970X. At least 500 frustules were counted for each sample.

Concurrent with the collection of water for planktonic diatoms, measurements of transparency were made with a standard 25 cm black and white Secchi disk, and beginning in late February. 1984. concurrent samples were collected for analysis of major nutrients by autoanalyzer following the procedures of Davis and Simmons (1979).

In this paper. diatom data for 1 full post-f *Dreissena* year, 3 April 1990-26 March 1991, as well as weekly diatom data for the months of April and May for the post- *Dreissena* years of 1990, 1991, and 1992 were compared to diatom data of 8 pre-zebra mussel years. Water transparency for 1990, 1991, and 1992 was compared to transparency for 1984, 1985, and 1986. Annual diatom data from this study, and also from those of Hohn. were treated with a smoothing technique in order to clarify visual presentation and comparison of the data sets. The smoothing algorithm employed was the average of the two "smooths": "3RSSH twice" and "4253H twice" as described by Velleman and Hoaglin (1981) and implemented in the subroutine RSM from that source. Standard parametric and non-parametric rank tests were employed to determine whether population locations of the diatoms were significantly different. Transparency data are presented as three-point moving means. Because smoothing obscures the real maximum and minimum values, these values are given in a table. A standard T test was used to determine the degree of significant difference between The transparency of the pre- and post-l *Dreissena* periods.

RESULTS

Water Transparency

Water transparency. as measured by Secchi disk, was highest in the pre-zebra mussel waters of the 1980s in winter. under ice cover (Table 1). Post-zebra mussel transparency was still high under ice cover, 1990-1992. but maximum light penetration was observed in autumn or spring, and transparency, in general. was noticeably increased spring into autumn (Fig. 1). Transparency measurements of the present study were sometimes made as the Secchi disk rested on the bottom of the lake, so that in realty, if the water had been deeper. the disk depth might have been greater. During the pre-mussel period, the disk was read from the lake bottmm during ice cover and varied from 3.5 m to 3.8 m. On the other hand, in the post-zebra mussel period. the maximum disk reading was observed during the ice-free season at 5.3 m, which was on that particular day not the maximum depth at the station. In 1992, the disk was visible on the bottom at 3.5 m on 18 February; 9 weeks later, on 21 April, it was visible on the bottom at 4.7 m. The Secchi disk was observed on the bottom three times during the 1980s, all under ice cover, and 18 times during the 1990s, once under ice cover. When considering the potential for maximum light penetration, one should be aware that, as Chandler observed years ago, the water level of Lake Erie may vary appreciably with season and year due to variations in rainfall, the amount of evaporation from the lake surface, and seiches. Chandler (1944) noted fluctua-

TABLE I. Secchi disk measurements (m) in Hatchery Bay, western Lake Erie, for three pre-zebra mussel years (1984-1986) and three post-zebra mussel years (1990 - 1992).

Observations	Year.	Mean	Median	Minimun	Maximum	Time of Maximum
53	1984	1.3	1.3	0.1	3.5*	14,21 Feb
53	1985	1.1	0.9	0.3	3.8*	26 Feb
52	1986	1.3	1.0	0.4	3.0	18 Feb-11 Mar
39	1990	2.2	2.0	0.5	4.6*	18 Sep
52	1991	2.3	2.4	0.3	5.3	19 Nov
51	1992	2.6	2.8	0.3	5.0	12 May

*Secchi disk on lake bottom.

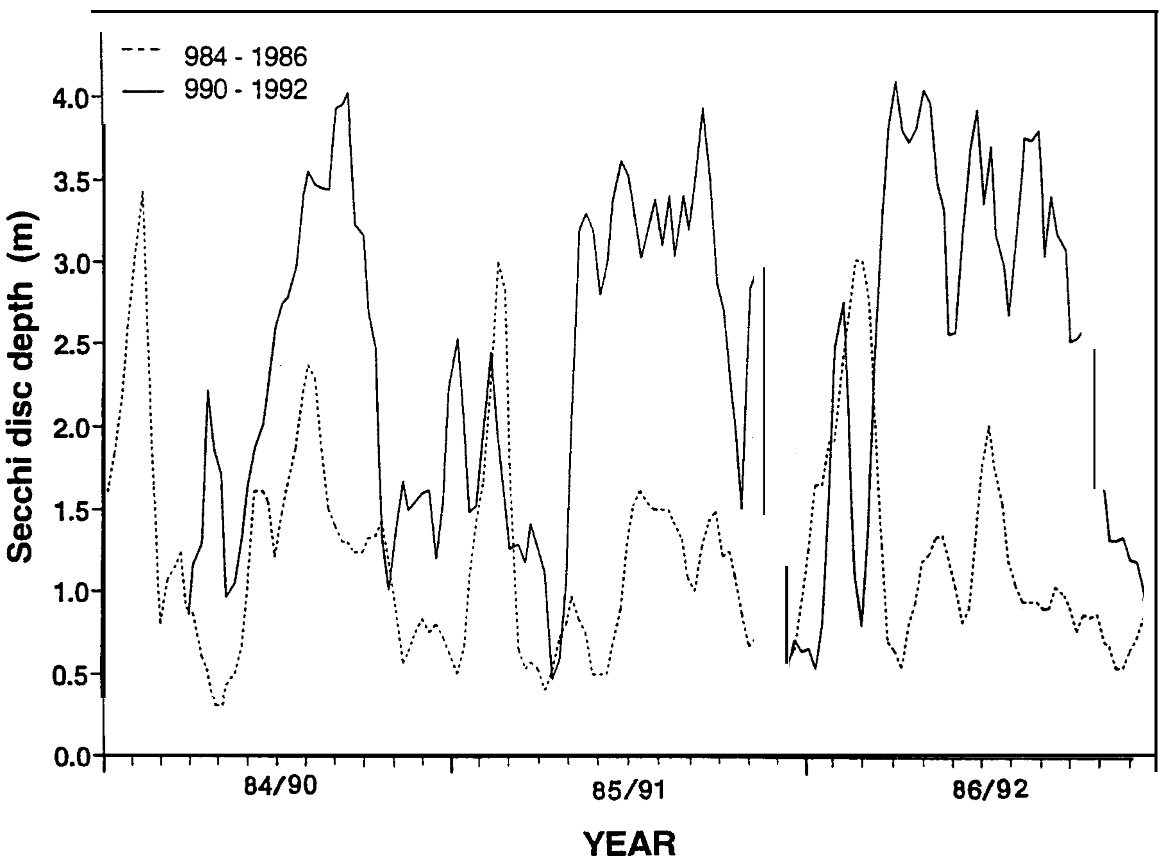

FIG. 1. Water transparency as measured by Secchi disk in Hatchery Bay, the Bass Island region, western Lake Erie for 1984-1986 (pre-zebra mussel years) and 1990-1992 (post-zebra mussel years). Each line represents a three point moving mean.

tions in water level of up to 1.5 m at Put-in-Bay in 1941 which he attributed to seiches .

Beeton (1969) re-examined the original U.S. Fish and Wildlife Service field notations, summarized by Wright (1955). which included 228 Secchi disk measurements made in ice-free waters of the western basin of Lake Erie in 1929-1930, and observed that the average disk depths at a number of frequently-visited-stations ranged from 0.8 m to 1.5 m. Chandler had found average disk depths in summer to be 1.1 m in 1939, 1.1 m in 1940, and 1.7 m in 1941 (Chandler 1940, 1942, 1944). Beeton (1961) had found a mean disk depth of 1.5 m in the summer of 1958; he concluded that transparency in western Lake Erie had not changed between 1929 and 1958. Our year-round Secchi disk measurements from the 1980s are similar to those found under ice-free conditions between 1929 and 1958, but when mean values of the 1980s are compared to those of the post- *Dreissena* 1990s, there is an increase of 100% in light penetration (Table 1). Transparency is different between the '80s and the '90s at a significance level of 0.01.

Planktonic Diatoms

Planktonic diatoms in 1984-1986 exhibited an annual bimodal distribution. with maximum numbers in spring, and a secondary peak in autumn (Fig. 2). A spring pulse was also observed in the post-zebra mussel year (3 April 1990-26 March 1991) with only a slight increase in frustules in autumn. Mean numbers in the full post-zebra mussel year were lower than during 1984-1986 by 86% (Table 2).

Hohn (1969) also observed a bimodal abundance pattern for planktonic diatoms with maximum numbers in spring 1963-1965 (Table 2). Except for the peak on 10 April 1984. mean, median, and maximum numbers were higher in the 1960s than in subsequent years and lowest during the 1990s (Table 2). The decline in abundance of total diatoms from the 1960s to the 1980s is contemporaneous with a 33% reduction in total phosphorus loadings to Lake Erie between 1972 and 1982 (Great Lakes Water Quality Board 1985). and possibly related to that reduction. Abundance of frustules in the post- *Dreissena* year was lower than in any pre- *Dreissena* year at a significance level of 0.01.

The study of year-round post- *Dreissena* planktonic diatoms since March, 1991, is incomplete, but a comparison of average weekly total frustules for April/May, which incorporates part of the spring pulse. is presented in Figure 3 for 8 pre-zebra mussel years and 3 post-zebra mussel years to indicate the trend of diatom assemblages. The abundances for 1990, 1991, and 1992 are within 9% of each other. and are 82% to 91% lower than any of those from the pre-zebra mussel years. Diatom assemblages of 1990-1992 were low despite adequate concentrations of major nutrients (Holland, Johengen, and Beeton, unpublished data).

Population sizes for April/May of the post- *Dreissena* years are different from those of any of the pre- *Dreissena* years at a significance level of 0.01.

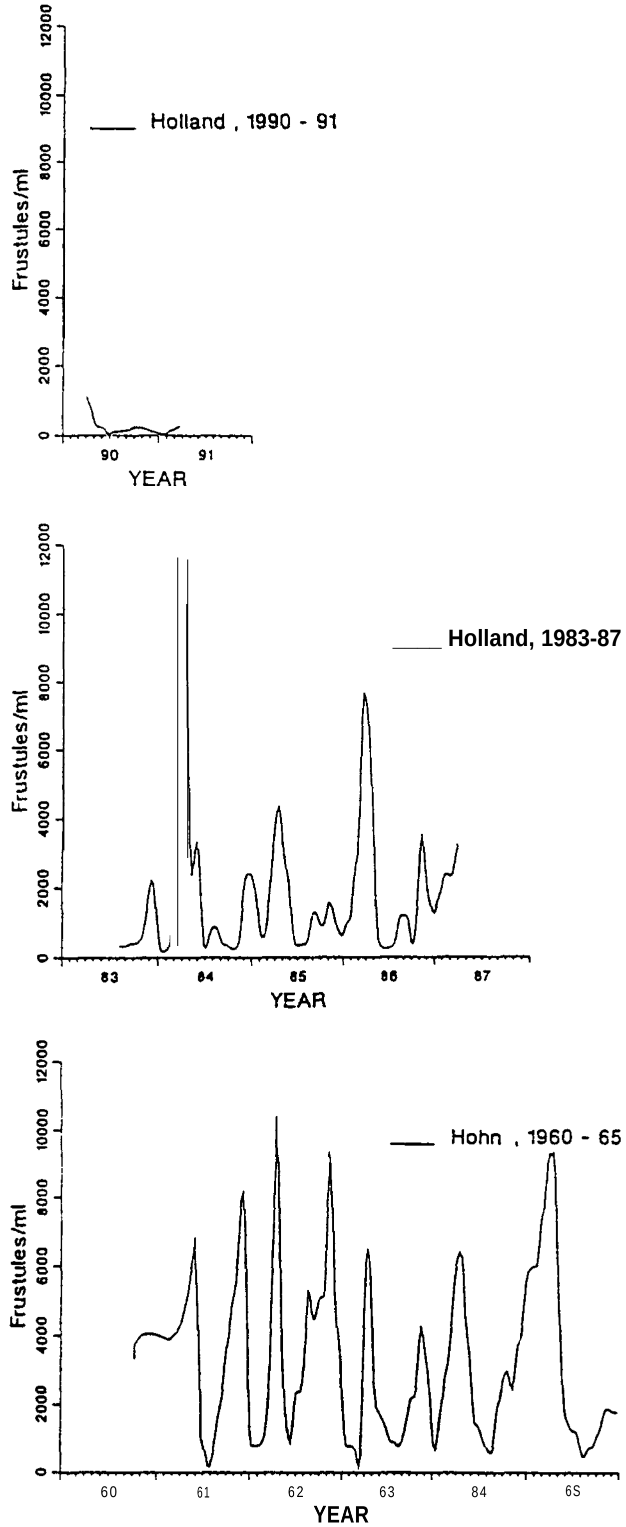

FIG.2. Total planktonic diatom frustules in Hatchery Bay, the Bass Island region, western Lake Erie for 1960-1965 and 1983-1987 (pre-zebra mussel years) and 3 April 1990-26 March 1991 (a post-zebra mussel year).

TABLE 2. Total planktonic diatoms (frustules/ml) in Hatchery Bay, western Lake Erie, for eight pre-zebra mussel years (1961-1986) and one post-zebra mussel year (3 Apr 90-26 Mar 91).

Year	Observations	Source	Mean	Median	Minimum	Maximum	Time of Maximum
1961	39	Hohn	3,618	3,434	25	20,240	27 Nov
1962	48	Hohn	4,236	2,575	374	22,611	27 Dec
1963	45	Hohn	2,392	1,454	66	10,820	7 Apr
1964	52	Hohn	2,948	1,298	278	12,027	7 Mar
1965	52	Hohn	3,309	1,787	173	13,897	10 Apr
1984	52	This study	2,293	688	117	17,967	10 Apr
1985	52	This study	1,470	1,128	182	5,507	23 Apr
1986	53	This study	1,942	1,155	64	8.565	25 Mar
3 Apr 90-26 Mar 91	52	This study	275	147	19	2,083	3 Apr

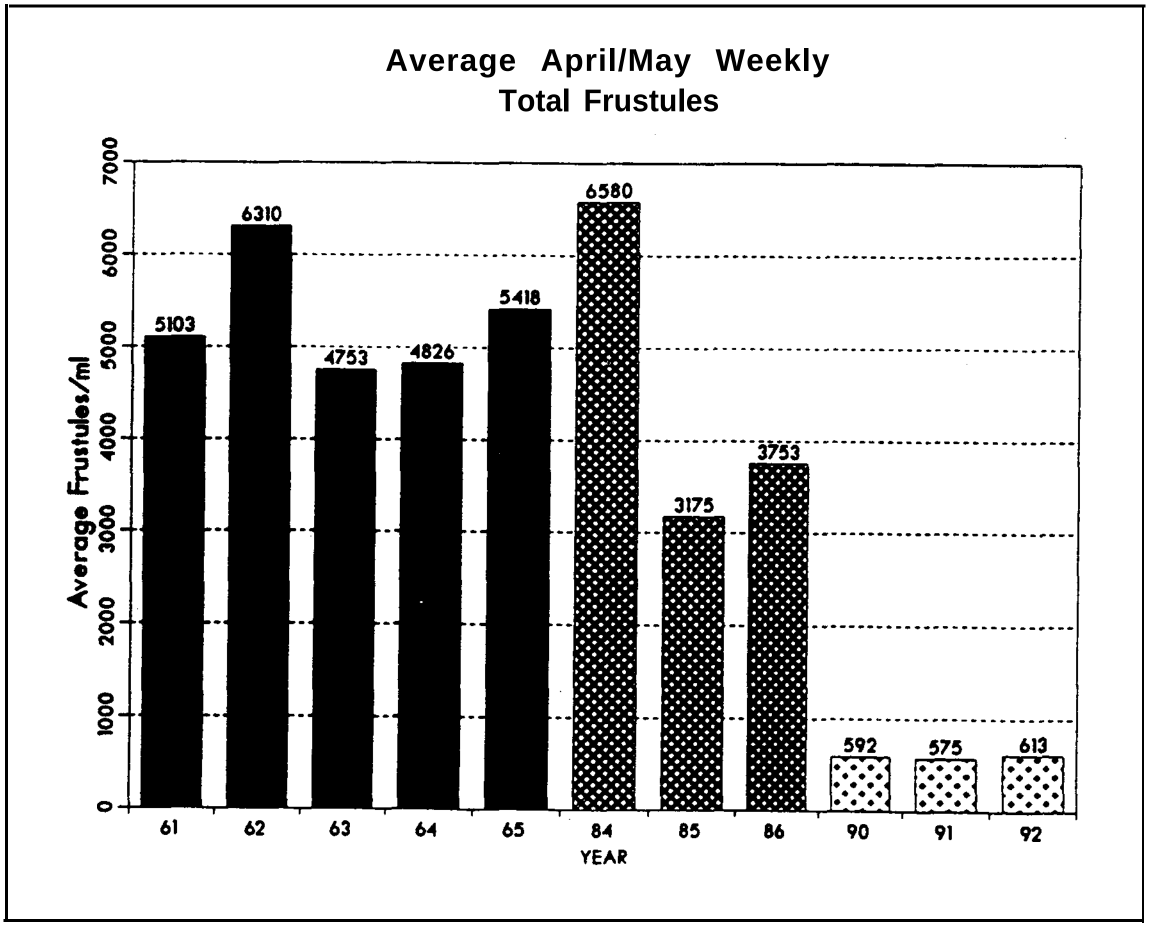

FIG. 3. *Average April/May weekly total planktonic diatom frustules in Hatchery Bay, the Bass Island region, western Lake Erie for 8 pre-zebra mussel years (1961-1986) and three post-zebra mussel years (1990-1992). The 1960s are represented by solid bars, the 1980s by cross-hatched bars, and the 1990s by diamond-stippled bars.*

Therefore, at least for the months of April and May, during the usual time of maximum abundance, the reduced numbers of diatom frustules noted for the first full post-zebra mussel year studied has continued into 2 subsequent years.

DISCUSSION

It is logical to assume that transparency would increase as plankton decreased, but Beeton (1969) noted that transparency stayed about the same in western Lake Erie while plankton increased significantly between 1929 and 1958. Both he and Chandler (1942) concluded that transparency of the waters of the wind-driven basin has probably been determined by the amount of nonplanktonic material, e.g., silt, kept in suspension by turbulence. Consequently, the accelerated removal of plankton alone, even by an invading consumer such as *Dreissena* which appears to thrive on diatoms (Stanczykowska 1977, Ten Winkle and Davids 1982), would not account for the marked increase in transparency observed in the post-mussel period. Intensified removal of abiotic material would also be necessary. as by an indiscriminate filter feeder. Both *Daphnia,* to a large extent (Vanderploeg 1990, Kerfoot and Kirk 1991), and *D. polymorpha* (Morton 1969a. Ten Winkle and Davids 1982, Reeders et al. 1989) filter suspended particles from the water column indiscriminately over a broad size range and would. therefore, be capable of removing abiotic material as well as phytoplankton.

Wu and Culver (1991) hypothesized that grazing by *Daphnia* controlled edible algal density and water transparency in Lake Erie in 1989, even though *D. polymorpha* was abundant. They found increased water clarity in June and July when large numbers of *Daphnia galeata mendotae and Daph - nia retrocurva* were present. and proposed that a longer clean-water period would have occurred if increased transparency had been caused by the zebra mussel. Their conclusion does not preclude subsequent year increases in transparency to be the result of a large zebra mussel population which continued to grow into 1990 (Leach 1992).

Furthermore, zooplankton abundances decreased from 1990 into 1991 to very low numbers, much lower than recorded in any previous studies (Beeton and Hageman 1992). For example, *D.g. mendotae* and *D. retrocurva* were present in 65% to 100% of samples collected in western Lake Erie in the 1970s and 1980s, whereas they occurred in only 23% to 25% of samples collected in 1990.

MacIsaac *et al.* (1992) concluded that the major suspension-feeders in Lake Erie are now sessile *Dreissena* rather than *Daphnia.* Based upon size-frequency distributions and associated literature-derived clearance rates. they estimated that settled *D. polymorpha* populations on Hen Island Reef are theoretically capable of filtering a water column of 7 m (which they approximate to be the mean depth of Lake Erie's western basin) between 3.5 and 18.8 times per day. In another study, Bunt *et al.* (1993) found small-bodied (2- 11 mm). settled zebra mussels, which comprise up to 90% of individuals inhabiting reefs in western Lake Erie, to be theoretically capable of pumping between 39% and 96% of the water column daily. They concluded that recent changes in water quality in that basin may be primarily related to mussel filtering activities, including those of small-bodied individuals.

Water transparency in Hatchery Bay in winter is similar for both the pre- and post- *Dreissena* periods. but is markedly increased during the post-mussel warm weather season. Although *Dreissena* filters throughout the year. it suffers winter mortality (Stanczykowska 1977: Griffiths *et al.* 1991; J. Hageman, Ohio State University, personal communication 1993), and has a period of active growth from May to October under natural conditions (Morton 1969 b). Reeders *et al.* (1989) found that filtration rates measured during August-October were higher than in November-December, and Morton (1971) found that an increase in temperature coincided with an increase in filtration rate. Therefore, the period of increased water transparency corresponds to the time when *Dreissena* is more abundant and presumably more active, suggesting that the mussel's filtering activities may be responsible for the change.

Stanczykowska (1984) has found *D. polymorpha* to be important in cycling nitrogen and phosphorus in meso- and moderately eutrophic lakes. These nutrients are incorporated into the mussels themselves and are also expelled to the sediments as feces and pseudofeces. One might expect, therefore, that abundant zebra mussels could induce oligotrophication, or reduction of nutrients, with consequent reduction in planktonic diatoms, but nutrient data from water collected concurrently with the diatom samples does not support this hypothesis in Hatchery Bay (Holland, Johengen, and Beeton, unpublished data). When 149 year-round samples from 1984-1986 were analyzed for total phosphorus. soluble reactive phosphorus (SRP). nitrate nitrogen, and ammonium nitrogen and compared to 142 similar samples (139 for SRP) from 1990-1992, mean concentrations of these nutrients were similar or higher in the post-Dreissena period. As well, species of diatoms associated with eutrophic waters which were abundant in the 1960s and 1980s, e.g., *Fragilaria capucina* Desm. and *Stephanodiscus binderanus* (Kutz.) Krieger, remain major species.

Since the establishment of *D. polymorpha* in Hatchery Bay, the environment there has become anomalous in our traditional view of the St. Lawrence Great Lakes system, where we associate clear water and low numbers of planktonic diatoms with low nutrients (oligotrophy). In contemporary Hatchery Bay, water clarity appears to reflect the filtering activity of abundant zebra mussels. Water clarity is aesthetically pleasing, but the capacity of *D. polymorpha* to remove phytoplankton, as well as abiotic material, from the water justifies concern about consequences for the entire food web.

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