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ABUNDANCE, BIOMASS, AND SPECIES COMPOSITION OF BENTHIC MACROINVERTEBRATE POPULATIONS IN SAGINAW BAY, LAKE HURON, 1987-96

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1.0 INTRODUCTION

This technical report gives the basic results of benthic macroinvertebrate surveys conducted in Saginaw Bay between 1987 and 1996. Yearly surveys were conducted over this time period to assess trends in macroinvertebrate density, biomass, and species composition. When the surveys were initiated in 1987-88, the main objective was to assess the response of the benthic community to phosphorus abatement programs that were implemented in the mid-1970s. Improvements in water quality were reported after these programs (Bierman et al. 1984), and a two-year sampling program in 1987-88 was designed to determine if similar improvements were evident in the macroinvertebrate community. When the zebra mussel (*Dreissena polymorpha*) became established in the Great Lakes in 1988 (Hebert et al. 1989), sampling was resumed in 1990 and continued through 1996 with the objective of assessing impacts of *Dreissena*. *Dreissena* colonized the bay in 1991 (Nalepa et al. 1995). Thus, the data collected during the time of this study can be divided into two distinct periods: post-phosphorus abatement/pre-*Dreissena* (1987-90) and post-*Dreissena* (1991-96).

Data are presented in this report with little attempt at interpretation; detailed analysis and discussions of relevance will be provided in other publications. Rather, the purpose of this report is to provide the raw data and basic details of the sampling program, including station locations and characteristics, sampling methods, and laboratory procedures. In addition, results of a comparative study of two samplers, the Peterson and Ponar grabs, is presented. The former grab was used in benthic surveys conducted in the bay in the 1950s and 1960s, while the latter grab has been used since the early 1970s. The relative efficiency of these two grabs was examined to more accurately depict density trends from the 1950s to the present.

2.0 DESCRIPTION OF STUDY SITE

Saginaw Bay is a shallow, well-mixed extension of the western shoreline of Lake Huron (Figure 1). The bay is 21-42 km wide, about 82 km long, and has a drainage basin of about 21,000 km^2. Total area of the bay is 2.77 x 10^9 m^2, and total water volume is 24.54 x 10^9 m^3. The bay can be functionally divided into an inner and outer region by a line extending along its narrowest width (21 km) from Sand Point to Point Lookout (Figure 1). A broad shoal and several islands (Charity Islands) along this line provide a natural demarcation between the two regions. The outer bay can be differentiated from Lake Huron by a line from Pte. aux Barques to Au Sable point. Differences in physical and chemical features of the inner and outer bay regions are distinct (Beeton et al. 1967; Smith et al. 1977). The inner bay has a mean depth of 5.1 m, is nutrient-rich, and is heavily influenced by input from the Saginaw River, which accounts for over 70% of the total tributary flow into the bay. The outer bay has a mean depth of 13.7 m and is more influenced by the colder, nutrient-poor waters of Lake Huron.

Circulation within the inner and outer bay is generally weak; currents average about 7 cm s^{-1} in the inner bay and about 11 cm s^{-1} in the outer bay (Danek and Saylor 1977). Exchange and flushing of water in the inner bay occurs when winds blow along the long axis of the bay (southwest/northeast). Dominant winds in the summer are from the southwest. Little exchange occurs when winds are perpendicular to the long axis (west/east). Most water exhange/flushing between the inner and outer bay occurs on the northern side of the bay within a deep channel between Point Lookout and Charity Island. Although some water may exit the inner bay along the southern shoreline, it is of minor significance because of the shallowness of the region (Danek and Saylor 1977).

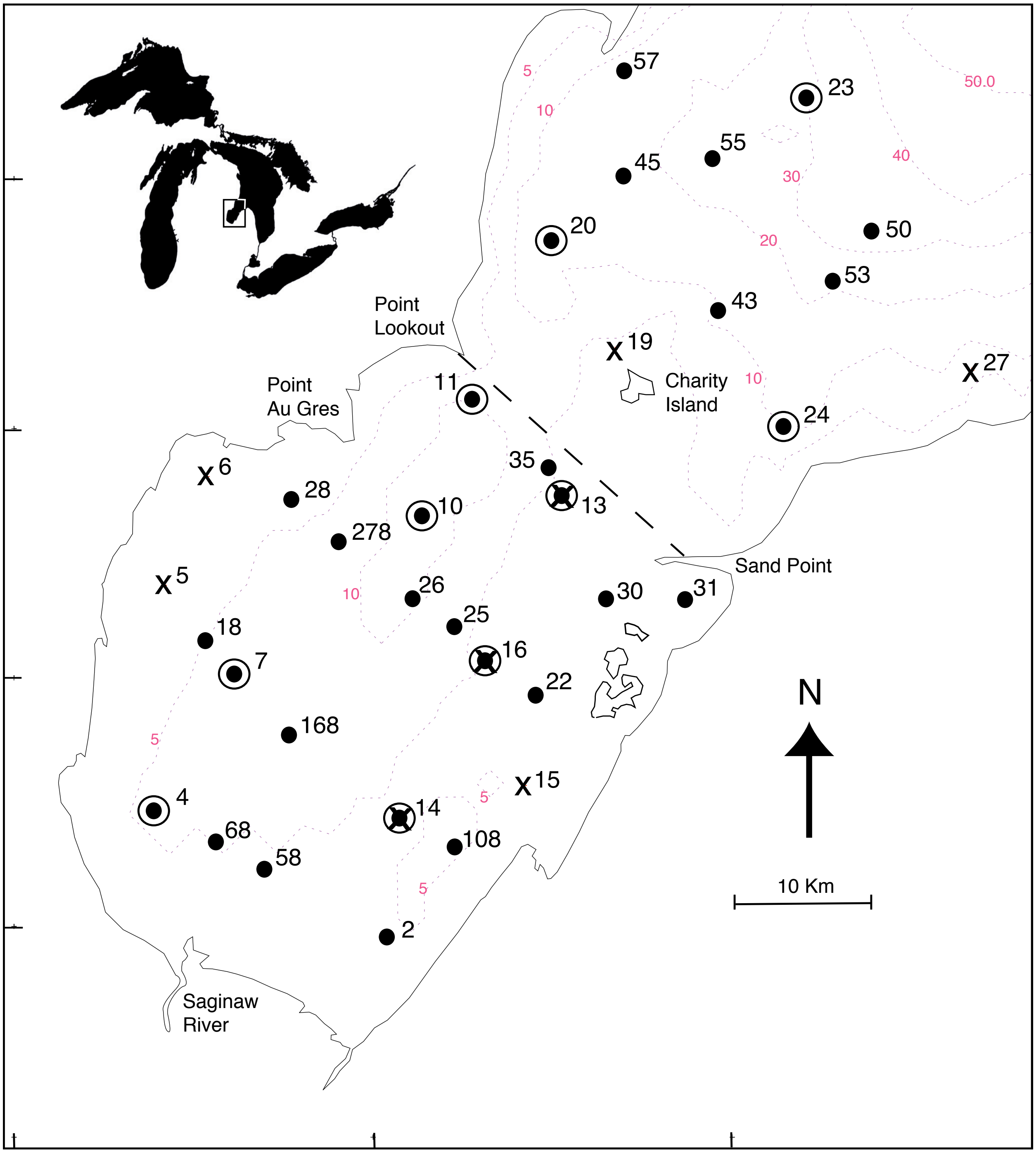

Figure 1. Location of sampling sites in Saginaw Bay, 1987-96. Dashed line separates the inner bay from the outer bay. Depth contours are given in meters. • = sampled in 1987 and 1988 only; ◉ = sampled in 1987-96; X = sampled in 1991-96 for *Dreissena* using SCUBA divers.

Furthermore, preliminary results of Lagrangian current measurements in the outer bay during the summers of 1992 and 1993 suggest that the flushing of inner bay waters into Lake Huron is episodic in nature (M. McCormick unpublished data).

Bottom substrates within the bay range from mostly cobble/rock to silt. The inner bay has a shallow sand bar that extends along the eastern side of the bay from the Saginaw River to Charity Island. Another sand bar extends along the western shoreline to Point Au Gres. Both sand bars have irregular areas of cobble with patches of gravel, pebbles, and varying amounts of overlying silt. The bars extend into the shorelines as extensive flats grade into marshes. Water depth between the two sand bars gradually increases to a maximum of 14 m. The proportion of fine-grained material gradually increases along this depth gradient as a function of sediment deposition (Robbins 1981). At depths greater than 6 m, the substrate consists of fine-grained material (silt and clay) and sediment deposition ranges from 0.04 to 0.70 $g/cm^2/yr$ (Robbins 1981). Based on areal estimates of substrate type given by Wood (1964) and Robbins (1981), we estimate that 70% of the bottom in the inner bay consists of sand, gravel, and cobble, and 30% consists of silt/mud.

In the outer bay, the east shore is rocky, as is the area around the Charity Islands. The western shore has extensive sandy areas, with rock and clay found near Point Lookout. Most of the offshore region of the outer bay has a bottom consisting of silty sand.

3.0 METHODS

3.1 Sampling Dates, Station Locations, and Field Procedures

Samples for benthic macroinvertebrates were collected at 30 sites in 1987 and 1988, and at 10 sites in 1990-96 (Figure 1). The exact location (longitude, latitude), water depth, and prevalent substrate type at each of the sites are given in Table 1. Samples were collected three times a year (spring, summer, and fall) except in 1996 when samples were collected only in summer and fall (Table 2). Because of poor weather conditions or mechanical failures, not all sites were sampled on each sampling date. One site (Station 28) was not sampled after summer 1987. Each site sampled corresponded to a site that was sampled in an previous investigations within the bay. Decisions on which sites to re-sample were based on type of sampler used, detail of benthic data provided, and overall spatial coverage of the bay. In 1987 and 1988, triplicate samples were collected at each site with both a Ponar and a Peterson grab, but only the Ponar was used thereafter. Sampling area of the Ponar was 0.047 m^2, while that of the Peterson was 0.069 m^2. After collection, each replicate sample was washed from the grab into a large tub, and then into an elutriation device (Nalepa et al. 1985). The device was fitted with a sleeve made of 0.5-mm mesh nitex. All collected material was washed through the sleeve and into a collection jar. The retained material was then preserved in 5% buffered formalin containing rose bengal stain.

Beginning in fall 1991 and continuing each fall through 1996, we took additional samples specifically for *Dreissena* at eight sites using SCUBA divers. These sites were mostly in areas with cobble (Stations 5, 6, 15, 19, 27) that could not be effectively sampled with a grab sampler. Three of the eight sites were also sampled with the Ponar grab (Stations 13, 14, 16) (Figure 1). At each site, divers randomly placed a 0.25 or 0.5 m^2 frame on the bottom and hand-collected all hard material within the frame area. After all material had been removed, the surface area within the frame was re-sampled using a diver-operated suction device fitted with a nitex net with 0.5-mm openings (Winnell and Jude 1987). This procedure ensured that all loose mussels were included in the sample. Triplicate samples were randomly collected at each site, with divers moving 2-3 m between replicates.

3.2 Laboratory Procedures

Material collected in the grab samplers and retained by the 0.5-mm sleeve was placed into a white enamel pan and organisms were picked, counted, and sorted into major groups (amphipods, oligochaetes, sphaeriids, chironomids, *Dreissena*, and others) with the aid of a 1.5x lighted magnifier lamp. When the number of organisms in a sample was extremely large, the sample was proportionately split and only a portion picked and sorted. All organisms in the Ponar samples were identified to the lowest practical taxonomic level. Turbellarians and nematodes were observed in the samples but, since methods were not quantitative for these groups, their numbers were not recorded. For oligochaetes, between 75-100 individuals in a replicate (proportionately split with a Folsom plankton splitter when numbers were high) were cleared in lactophenol before identification. Oligochaetes were mounted on microscope slides (in glycerine) and their images were then projected onto a sheet of paper using a microscope drawing tube and traced. Individuals were identified, and taxonomic designations placed alongside the respective traced image. Only individuals with a prostomium were identified and tabulated; fragments (without prostomium) traced but not counted. For chironomids, head capsules were teased off the body, cleared in lactophenol, and mounted on microscope slides with mentum side up. The corresponding body was mounted alongside the head capsule and the image traced as for oligochaetes. Up to 100 chironomids were identified in a given sample. If the number of individuals exceeded 100 in a given sample, the sample was proportionately split with a folsom plankton splitter such that at least 50 individuals were identified.

3.3 Biomass Determination

For most taxa (Amphipoda, Isopoda, Oligochaeta, Chironomidae), biomass (ash free dry weight) was derived from length-weight relationships taken from the literature (Table 3). If a length-weight relationship for a given taxa was not available, it was assigned the relationship of a closely-related form. When length-weight relationships were available for only dry weight, ash-free dry weight (AFDW) was assumed to be 90 % of dry weight (Johnson and Brinkhurst 1971). A length weight relationship was determined directly on two taxa, *Chironmus semireductus -gr*. and *Dreissena polymorpha*. Freshly collected individuals were placed into pre-weighted, aluminum planchets, dried at 60ºC for 48 h, and weighed to the nearest 0.1 mg. AFDW was obtained by re-weighing the specimens after ashing at 550ºC for 1 h. Lengths were measured directly or determined from traced images using a digitizer (Quigley and Lang 1991). Weights of *C. semireductus-gr*. were determined on at least 25 individuals collected on various dates in 1988 and in 1996. Weights of *Dreissena* were measured on at least 23 individuals collected in late summer/fall of each year, 1991-96. Individuals for length-weight conversions were collected at Station 5 (inner bay) every year, and at Station 19 (outer bay) in 1995 and 1996 (Table 4).

Biomass was determined by measuring lengths of individuals in a given sample and then converting to weight. When samples were split for the identification of oligochaetes and chironomids, lengths of all identified individuals were converted to weight and then proportionately multiplied to get total biomass. Length-weight conversions are based on the finding that preservation does not alter length (Erman and Erman 1975). For *Dreissena,* lengths were measured on up to 500 animals in each sample using a computer scanner and adapted software. If more individuals were present in the sample, the sample was proportionately split. Biomass of other benthic groups (Sphaeriidae, Gastropoda, Tricoptera, Ephemeroptera, Hirudinea, and Diptera other than Chironomidae) were determined directly from preserved specimens within a given sample; that is, all individuals were placed in pre-weighed planchets and weights determined as described above. While sphaeriidae do not lose weight upon preservation (Johnson and Brinkhurst 1971), other taxa do, and therefore biomass of these other taxa may be underestimated. These taxa, however, generally constituted only a small portion of total biomass at a given site.

4.0 RESULTS

4.1 Data Presentation

The abundance (number per grab) of all taxa collected between 1987 and 1996 with the Ponar grab is provided in Appendix 1. Variables in the appendix include year, season (spring=1, summer=2, fall=3), station, replicate number, and taxa. In the appendix, individual taxa were assigned a 4-letter code as shown in Table 3. Mean annual density and biomass for the major benthic groups at sites sampled every year (Stations 4, 7, 10, 11, 13, 14, 16, 20, 23, 24) are given in Tables 5 and 6. Mean annual density and biomass of *Dreissena* from the diver-collected samples are given in Tables 7 and 8.

Spatial distribution patterns of total macroinvertebrate density in 1987/88 are given in Figure 2. Data collected in these two years were used to depict distribution patterns because of the large number of sites sampled (30 compared to 10 in other years). To further summarize spatial patterns, sites in the inner bay were grouped into three habitat categories based on water depth and substrate type: (1) sand/gravel, 3.0-4.8 m; (2) silty sand, 4.0-9.0 m; and (3) silt, 6.7-11.8 m (Table 9). The only site that did not fit into one of these categories was Station 31. Water depth at this site was only 3.2 m, and the substrate differed from all other sites, consisting of coarse plant debris/silt. This site was located in the center of a shallow, confined embayment (Wildfowl Bay) and was not representative of the bay in general. In comparing these three habitat categories, total density in the inner bay was clearly related to increased water depth and the amount of fine grained material (Table 9). In the outer bay, substrates consisted of silty sand at all sites, and depths ranged from 10 to 30 m (Table 1). Since substrates were generally similar, the nine outer bay sites were grouped into three categories based on water depth: 10-13 m, 16-22 m, and 28-30 m. These depth categories are consistent with prior characterization of depth-macroinvertebrate associations in other regions of the Great Lakes for similar depths and substrate types (Cook and Johnson 1974, Mozley and Howmiller 1977). In contrast to the inner bay, total density decreased with increased water depth (Table 9).

4.2 Sampler Comparisons

A number of benthic surveys have been conducted in Saginaw Bay beginning in the mid-1950s, and of interest were trends in populations from that time period to the 1987-96 time period of this study. When assessing long term trends based on data derived from different studies, an important consideration is the comparability of sampling techniques employed. A list of previous benthic surveys conducted in Saginaw Bay along with the type of sampler and mesh size used is given in Table 10. While all surveys used comparable mesh sizes to separate organisms from the sediment, different samplers were used to collect the organisms. Surveys in the 1950s and 1960s used either the Petersen or Ekman grabs, while surveys in the early 1970s and thereafter used the Ponar. Previous studies have shown that the Peterson and Ekman have different efficiencies relative to the Ponar. The Peterson grab is less efficient at collecting organisms than other samplers, including the Ponar (Sly 1969, Flannagan 1970). The main reason for this inefficiency is that the jaws of the Peterson have solid tops that impede the free flow of water during descent. This creates a preceding shock wave that blows away organisms at the sediment surface just before impact. In addition, the Peterson lacks side plates which allows sediments to be squeezed out the sides as the jaws close. The Ekman has an open top and, because it does not create a shock wave, takes a representative sample in soft substrates (mud/silt); however, it is not as efficient on hard substrates because of its relatively light weight (Flannagan 1970, Howmiller 1971). Further, the Ekman has a closing mechanism that is triggered by a messenger deployed from the surface. For various reasons, this limits its use in deeper waters and under rough weather conditions. With a recognized need for a sampler that can be used in the Great Lakes in a variety of substrates and conditions, the Ponar grab was developed in the late 1960s and became the sampler of choice by the early 1970s (Powers and Robertson 1967). Modifications of the Ponar included screens on top of the jaws to permit water flow during descent, and side plates to retain sediments during jaw closure. Yet, despite the former modification, the Ponar probably still generates somewhat of a shock wave since it collects fewer organisms compared to the Ekman or diver-collected cores in soft sediments (Howmiller 1971, Nalepa et al. 1988).

We compared the relative efficiency of the Peterson and Ponar by taking samples with both grabs at select sites in the inner bay in 1987 and 1988. The intent was to generate a correction factor so densities reported in earlier surveys that used the Peterson might be corrected to Ponar equivalents. Mean densities of the major macroinvertebrate groups derived from both samplers are given in Table 11. The efficiency of the Peterson relative to the Ponar varied depending upon the substrate. At sites with a soft substrate (silt), the Peterson collected significantly fewer oligocheates and chironomids than the Ponar ($P > 0.05$, paired t-test, ln +1 transformed). On average, oligochaete densities were 2.88 times greater in the Ponar, while chironomid densities

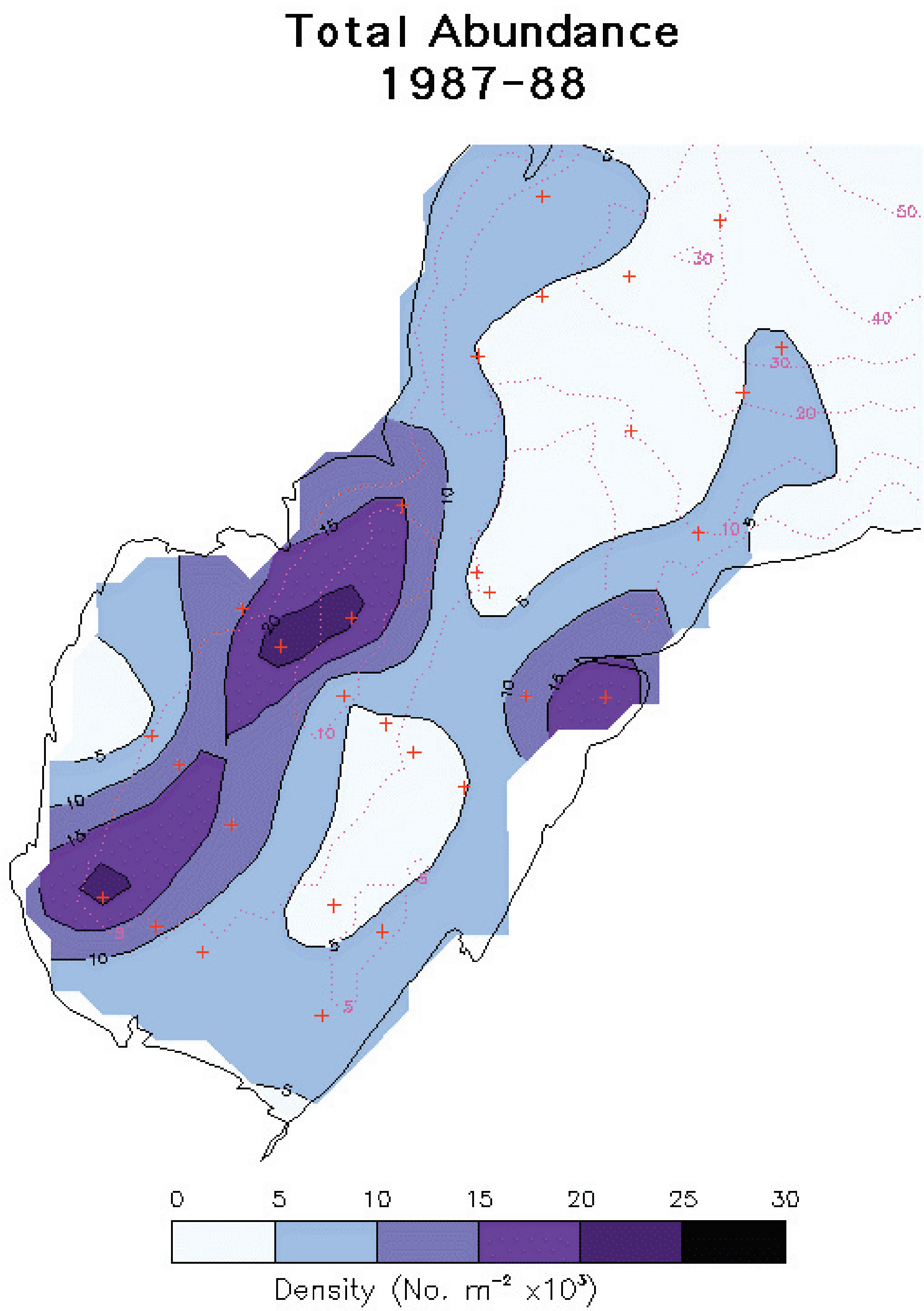

Figure 2. Mean total density (no./m^2 x 10^3) of benthic macroinvertebrates in Saginaw Bay, 1987-88.

were 3.76 times greater. Sphaeriid densities were 15 times greater in the Ponar, but the difference was not significant because of low and variable density estimates. At sites with sand substrate, the two samplers gave comparable densities for all groups (Table 11). The lower efficiency of the Peterson in silt, but not sand, is consistent with the "shock-wave" effect. The greater shock wave generated by the Peterson is more likely to displace fine-grain, flocculent sediments (along with associated organisms) than coarser, heavier sediments. We did not compare the relative efficiencies of the Ekman and Ponar, but others have shown that the comparability of the two samplers is also substrate dependent. For instance, a study in Green Bay, Lake Michigan, showed that the Ekman collected 1.8 times more oligochaetes and 1.3 times more chironomids than the Ponar in silt, but that the two samplers gave comparable densities in sand (Howmiller 1971).

5.0 HISTORIC TRENDS IN TOTAL DENSITY

We focused on examining macroinvertebrate trends in the inner bay because most earlier surveys were conducted in this portion of the bay. Also, because the inner bay is a semi-confined system, macroinvertebrate populations in the inner bay should closely reflect long-term shifts in nutrient loads and system productivity. To examine trends, sites sampled in earlier studies were placed into two regions based on sampling depth and substrate type. Sites in the deep-water/silt region had a water depth of > 6 m and a soft bottom (silt/mud), while sites in the shallow-water/sand region had a water depth of < 5 m and a hard bottom (sand/gravel). These two site groupings were representative of the depositional and non-depositional regions of the inner bay, respectively, and benthic communities at sites with these habitat characteristics were distinctly different (Table 9). Sites for comparative analysis were chosen based on their general location and proximity to sites sampled in 1987-96. If collections were made with a Peterson grab, densities of oligochaetes and chironomids at sites in the deep-water/silt region were multiplied by 2.88 and 3.76, respectively, and if collections were made with an Ekman grab, densities were divided by 1.8 and 1.3 (see conversion factors above). Mean densities of these earlier surveys were thus converted to Ponar equivalents. No correction factors were applied to densities at sites in the shallow-water/sand region. Densities and converted densities of the major groups from earlier surveys are given in Table 12. Sites sampled in 1987-96 that were considered representative of the deep-water/silt region were Stations 4, 7, 10, and sites considered representative of the shallow-water/sand region were Stations 13, 14, and 16. These inner bay sites were sampled over the entire 1987-96 period.

Between the mid-1950s and the early-1970s, trends in total density were similar in the deep-water/silt region and shallow-water/sand region. In both regions, total density generally increased from the mid-1950s to reach a peak in the mid-1960s, and then decreased in the early-1970s (Figure 3). Yet, while general trends in total densities were similar, temporal differences in total densities were far more pronounced in the deep-water/silt region. Densities in this region increased from < 2,500 m^{-2} in the 1950s to 43,000 m^{-2} in the mid-1960s, and then declined to 15,000 m^{-2} in the early 1970s. In contrast, total densities in the shallow-water/sand region only ranged from 2,500 to 5,200 m^{-2} over the entire time period.

Increases in total density between the 1950s and 1960s were likely a result of increasing nutrient loads and high system productivity (Vollenweider et al. 1974). Standing stocks of macroinvertebrate populations are directly related to pelagic productivity in lake systems (Rasmussen and Kalff 1987, Saether 1980). Nutrient abatement programs were implemented in the mid-1970s, and total phosphorus in the inner bay declined up to 14%, and chlorophyll declined up to 61% by 1980 (Bierman et al. 1984). Given these declines in pelagic productivity, it may be expected that total macroinvertebrate density would decrease. Total density indeed declined in the shallow-water/sand region, but not in the deep-water/silt region. Mean total density in 1987-90, which may be considered the post-phosphorus abatement/pre-*Dreissena* period, was 871 m^{-2} in the shallow-water/sand region and 20,359 m^{-2} in the deep-water/silt region (Figure 3). Thus, total mean density in the former region was lower than found just before abatement efforts in the early 1970s as might be expected, but mean density in the latter region was actually higher. Reasons for the atypical response of the benthic community in the deep-water/silt region are not clear, but likely related to elevated river loadings in the mid-1980s. Most organic input into the bay enters via

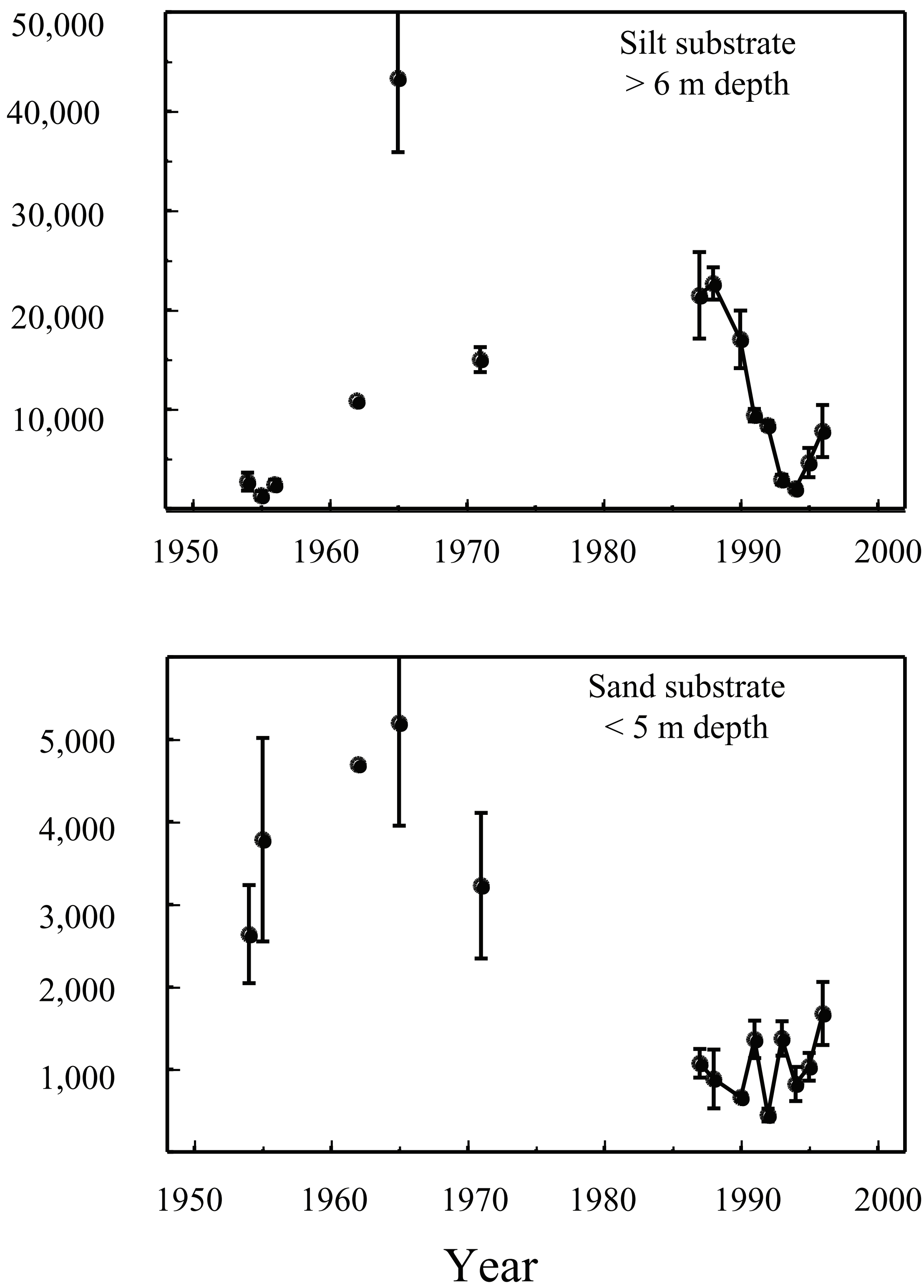

Figure 3. Mean (±SE) total density of benthic macroinvertebrates in inner Saginaw Bay from various surveys. The standard error represents between-station variation. Densities in 1987-96 are from this study.

the Saginaw River, and high river discharge rates were observed in both 1985 and 1986 (Limno-Tech 1995). In particular, 1986 was marked by a 100-year flood event that displaced 8-200 cm of surface sediment material from river margins into the bay (Ludwig et al. 1993). High densities observed in 1987-90 may have been a response to these elevated inputs. Organic material from these discharge events would most likely settle into the deep-water/silt region (depositional zone) and serve as food for the benthos. Declines in total density between 1988 and 1991 would indicate that populations were returning to levels more at equilibrium with the carrying capacity of the bay prior to these discharge events (Figure 3).

After *Dreissena* became established in the bay in 1991 and peaked in 1992 (Table 7), total densities (excluding *Dreissena*) varied by bay region. Mean annual density in the shallow-water/sand region tended to increase between 1993 and 1996 (Figure 3), but total density in 1996 was still lower than densities found in the pre-abatement period. Mean annual density in the deep-water/silt region declined just after *Dreissena* peaked in 1992, but by 1996 had increased to near levels found in1991 just prior to the peak, but still below densities found in the pre-abatement period.

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Table 1. Location, water depth, and dominant substrate type at each of the sites sampled in Saginaw Bay, Lake Huron. Samples for *Dreissena* in 1991-96 were taken by divers using SCUBA.

Station	Latitude	Longitude	Water Depth (m)	Substrate
Sampled, 1987-88				
2	43 39.63	83 39.17	4.2	Medium to coarse sand, some silt
18	43 51.49	83 49.20	4.5	Coarse sand, some silt
22	43 49.30	83 30.80	4.5	Silty sand
25	43 52.00	83 35.40	7.6	Silty sand
26	43 51.18	83 36.08	11.8	Silt
28	43 56.90	83 43.80	5.5	Medium to coarse sand
30	43 53.17	83 27.17	4.0	Silty sand
31	43 53.14	83 22.48	3.2	Silt, organic plant debris
35	43 58.43	83 30.08	6.4	Medium to coarse sand
43	44 04.40	83 21.00	11.8	Coarse sand, pebbles
45	44 10.10	83 26.20	17.9	Silty sand
50	44 07.90	83 12.10	30.3	Sandy silt
53	44 06.00	83 14.40	22.2	Silty sand
55	44 10.90	83 21.10	22.4	Silty sand
57	44 14.30	83 26.16	10.1	Silty sand
58	43 42.30	83 46.20	5.8	Silty sand
68	43 43.40	83 48.90	5.8	Silty sand
108	43 43.20	83 35.60	4.8	Medium to coarse sand, some silt
168	43 47.70	83 44.50	7.8	Silt
278	43 55.30	83 41.60	9.1	Silt
Sampled, 1987-96				
4	43 44.65	83 52.07	6.7	Silt
7	43 50.28	83 47.57	7.0	Silt
10	43 56.50	83 37.43	11.0	Silt
11	44 01.23	83 34.42	9.0	Silty sand
13	43 57.57	83 29.32	3.0	Sand, pebbles/gravel
14	43 44.30	83 38.45	3.6	Sand, pebbles/gravel
16	43 50.82	83 33.75	3.0	Sand, pebbles/gravel
20	44 07.57	83 30.00	16.0	Silty sand
23	44 13.25	83 15.75	28.0	Sand, some silt
24	44 00.08	83 17.00	12.5	Silty sand
Sampled for *Dreissena*, 1991-96				
5	43 53.72	83 51.63	3.0	Cobble, pebbles/gravel, sand patches
6	43 58.08	83 49.25	4.0	Sand, gravel, some cobble
13	43 57.57	83 29.32	3.0	See above
14	43 44.30	83 38.45	3.6	See above
15	43 45.67	83 31.58	5.0	See above
19	44 03.17	83 26.52	4.0	Cobble, bedrock, sand patches
27	44 02.33	83 06.66	5.5	Cobble, bedrock

Table 2. Stations sampled during each sampling period in 1987-96.

Sampling Date	Station																												
	4	7	10	11	13	14	16	20	23	24	2	18	22	25	26	28	30	31	35	43	45	50	53	55	57	58	68	108	168	278
1987																														
Apr 29-30, May 14-16	x	x	x	x	x	x		x	x	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x		x		x
Jul 4-10	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x
Oct 17-19, 27-29, Nov 11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x	x
1988																														
May 4-5, 12	x	x	x			x	x	x	x	x	x	x		x	x		x				x	x	x	x	x	x	x	x	x	x
Jul 5-8	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oct 21, Nov 2-4	x	x	x	x		x	x	x	x		x		x	x	x		x	x			x	x	x	x	x	x	x	x		x
1990																														
May 30	x	x	x	x	x	x	x	x	x	x																				
Jul 17,19	x	x	x	x	x	x	x	x	x	x																				
Sep 5	x	x	x	x	x	x	x	x	x	x																				
1991																														
Jun 17-18	x	x	x	x	x	x	x	x	x	x																				
Jul 23-25	x	x	x	x	x	x	x	x	x	x																				
Sep 9-11	x	x	x	x	x	x	x	x	x	x																				
1992																														
May 27-30, Jun 3	x	x	x	x	x	x	x	x	x	x																				
Jul 20-21	x	x	x	x	x	x	x	x	x	x																				
Sep 9, 14	x	x	x	x	x	x	x	x	x	x																				
1993																														
May 17-18	x	x	x	x	x	x	x	x	x	x																				
Jul 11	x	x	x	x		x	x	x																						
Sep 8	x	x	x	x	x	x	x	x	x	x																				
1994																														
Jun 6, 9-10	x	x	x	x	x	x	x	x	x	x																				
Jul 11-13	x	x	x	x	x	x	x	x	x	x																				
Sep 8-9	x	x	x	x	x	x	x	x	x	x																				
1995																														
May 17-19	x	x	x	x	x	x	x	x	x	x																				
Jul 12	x	x	x	x	x	x	x	x	x	x																				
Sep 12	x	x	x	x	x	x	x	x	x	x																				
1996																														
Jul 22,31	x	x	x	x	x	x	x	x	x	x																				
Oct 4-5	x	x	x	x	x	x	x	x	x	x																				

Table 3. List of taxa collected in Saginaw Bay, 1987-96. The 4-letter code identifies each taxa in Appendix 1. Also given is the length-weight relationship used to determine AFDW biomass. The number in parenthesis refers to the equation used to determine the AFDW of that particular taxa. Length-weight relationships for *Dreissena polymorpha* are given in Table 4.

Taxa	Code	Weight Determination	Reference
Amphipoda			
Pontoporeiidae			
Diporeia spp	DIPO	LnAFDW = -4.856+2.501LnL	Johnson and Brinkhurst (1971)
Gammaridae			
Gammarus sp.	GAMM	LnAFDW = -4.264+2.444LnL	Johnson and Brinkhurst (1971)
Hyalellidae			
Hyallela sp.	HYAL	LnAFDW = -4.264+2.444LnL	
Isopoda			
Ascellidae			
Caecidotea racovitzai	CRAC	LnAFDW = -4.366+2.489LnL	Johnson and Brinkhurst (1971)
Polychaeta			
Manyunkia speciosa	MSPE		
Hirudinea			
Glossiphoniidae			
Helobdella stagnalis	HSTA		
Piscicolidae			
Piscicola sp.	PISC		
Oligochaeta		0.25 mg DW per cm body length	Nalepa and Quigley (1980)
Enchytraeidae	ENCH		
Lumbriculidae			
Stylodrilus heringianus	SHER		
Tubificidae			
Aulodrilus americanus	AMME		
Aulodrilus limnobius	ALIM		
Aulodrilus pigueti	APIG		
Aulodrilus pluriseta	APLU		
Branchiura sowerbyi	BSOW		
Ilyodrilus templetoni	ITEM		
Isochaetides freyi	IFRE		
Limnodrilus cervix	LCER		
Limnodrilus claparedianus	LCLA		
Limnodrilus hoffmeisteri	LHOF		
Limnodrilus hoffmeisteri variant	LHOV		
Limnodrilus maumeensis	LMAU		
Limnodrilus profundicola	LPRO		
Linmodrilus spiralis	LSPI		
Limnodrilus udekemianus	LUDE		
Potamothrix bavaricus	PBAV		
Potamothrix bedoti	PBED		
Potamothrix moldaviensis	PMOL		
Potamothrix vejdovskyi	PVEJ		
Quistadrilus multisetosus	QMUL		
Rhyacodrilus coccineus	RCOC		
Rhyacodrilus sodalis	RSOD		
Spirosperma ferox	SFER		
Spirosperma nikolskyi	SNIK		
Tasserkidrilus americanus	TAME		
Tasserkidrilus superiorensis	TSUP		
Tubifex ignotus	TIGN		

Table 3. Continued

Taxa	Code	Weight Determination	Reference
Tubifex tubifex	TTUB		
Varichaetadrilus angustipenis	VANG		
Immatures			
without hair setae	IMWO		
with hair setae	IMWH		
Naididae			
Amphicaeta leydigi	ALEY		
Arcteonais lomondi	ALOM		
Chaetogaster sp.	CHAE		
Dero digitata	DDIG		
Nais sp.	NAIS		
Nais alpina	NALP		
Nais barbata	NBAR		
Nais bretscheri	NBRE		
Nais communis	NCOM		
Nais elinguis	NELI		
Nais pardalis	NPAR		
Nais pseudobtusa	NPSE		
Nais simplex	NSIM		
Nais variabilis	NVAR		
Opistonais serpentina	OSER		
Piguetiella michiganensis	PMIC		
Pristina longiseta	PLON		
Slavina appendiculata	SAPP		
Specaria josinae	SJOS		
Stylaria fossularis	SFOS		
Stylaria lacustris	SLAC		
Uncinais uncinata	UUNI		
Vejdovskyella intermedia	VINT		
Diptera			
Ceratopogonidae			
Bezzia sp.	BEZZ		
Chironominii			
Chironomus sp.	CHIR	1	
Chironomus anthracinus	CANT	LnDW = 0.0359 + 2.844 LnL (1)	Nalepa and Quigley (1980)
Chironomus halophilus gr.	CHAL	(1)	
Chironomus plumosus gr.	CPLU	(1)	
Chironomus semireductus- gr.	CSEM	LnDW = -4.441 + 2.262 LnL (2)	This study
Chironomus semireductus- gr.A	CSEA	(2)	
Chironomus semireductus- gr.B	CSEB	(2)	
Chironomus semireductus- gr.C	CSEC	(2)	
Cladopelma sp.	CLAD	(1)	
Cryptochironomus sp.	CRYP	(1)	
Cryptochironomus cf.digitatus	CDIG	(1)	
Cryptochironomus eminentia	CEMI	(1)	
Cryptochirnomus fluviatilis	CFLU	(1)	
Cryptochironomus cf. fulvus	CFUL	(1)	
Cryptochironomus cf. rolli	CROL	(1)	
Demicryptochironomus sp.	DEMI	(1)	
Dicrotendipes sp.	DICR	(1)	
Dicroneomodestus sp.	DNEO	(1)	
Endochironomus sp.	ENDO	(1)	
Endochironomus subtendens	ESUB	(1)	

Table 3. Continued

Taxa	Code	Weight Determination	Reference
Glyptotendipes sp.	GLYP	(1)	
Harnischia sp.	HARN	(1)	
Lenziella sp.	LENZ	(1)	
Microtendipes pedellus-gr	MPED	(1)	
Parachironomus arcuatus-gr.	PARC	LnDW = 0.0800 + 2.2817 LnL (3)	Nalepa and Quigley (1980)
Paracladopelma camptolabis	PCAM	(4)	
Paracladopelma cf. nais	PNAI	(4)	
Paracladopelma udine	PUDI	LnDW = 0.9879 + 2.4456 LnL (4)	Nalepa and Quigley (1980)
Paracladopelma winnelli	PWIN	(4)	
Paralauterborniella sp.	PLAU	(5)	
Paratendipes sp.	PTEN	(1)	
Polypedilum sp.	POLY	(5)	
Polypedilum fallax	PFAL	LnDW = 1.0890 + 2.3190 LnL (5)	Nalepa and Quigley (1980)
Polypedilum cf halterale	PHAL	(5)	
Polypedilum cf. laetum	PLAE	(5)	
Polypedilum nereis	PNER	(5)	
Polypedilum cf. scalaenum	PSCA	(5)	
Polypedilum simulans	PSIM	(5)	
Polypedilum tuberculum	PTUB	(5)	
Pseudochironomus sp.	PSEU	(1)	
Pseudochironomus nr. fulviventris	PFUL	(1)	
Stempellinella sp.	STEM	(1)	
Stichochironomus sp.	STIC	(1)	
Tanytarsini			
Cladotanytarsus sp.	CTAN	LnDW = 0.1557 + 3.1419 LnL (6)	Nalepa and Quigley (1980)
Cladotanytarsus mancus gr.	CMAN	(6)	
Cladotanytarsus vanderwulpi gr.	CVAN	(6)	
Micropsectra sp.	MICR	(6)	
Paratanytarsus sp.	PARA	(6)	
Rheotanytarsus sp.	RHEO	(6)	
Tanytarsus sp.	TANY	(6)	
Othocladiinae			
Heterotrissocladius changi	HCHA	LnDW = 0.8129 + 2.1946 LnL (7)	Nalepa and Quigley (1980)
Heterotrissocladius oliveri	HOLI	(7)	
Hydrobaenus pilipes	HPIL	(7)	
Nanocladius sp.	NANO	(7)	
Orthocladius sp.	ORTH	(7)	
Paracladius cf.conversus	PCON	(7)	
Parakiefferiella sp.	PKIE	(7)	
Psectrocladius sp.	PSEC	Ln DW = 0.5524 +2.7083 LnL (8)	Nalepa and Quigley (1980)
Psectrocladius psilopterus gr.	PPSI	(8)	
Pseudosmittia sp.	PSMI	(7)	
Thienemannimyia sp.	THIE	(7)	
Tanypodinae	TAYP		
Ablabesmyia sp.	ABAL	(9)	
Ablabesmyia monilis	AMON	(9)	
Hayesomyia senata	HAYE	(9)	
Procladius sp.	PROC	LnDW = -5.413 + 2.275 LnL (9)	Nalepa and Quigley (1980)
Tanypus neopunctipennis	TNEO	(9)	
Diamesinae			
Cricotopus sp.	CRIC	(10)	
Cricotopus festivellus	CFES	(10)	
Cricotopus ornatus	CORN	(10)	

Table 3. Continued

Taxa	Code	Weight Determination	Reference
Cricotopus slyvestris-gr.	CSLY	(10)	
Monodiamesia depictinata	MDEP	(10)	
Monodiamesia tuberculata	MTUB	LnDW = 0.7460 + 2.661 LnL (10)	Nalepa and Quigley (1980)
Potthasia cf. longimanus	PLOG	(10)	
Pelecypoda			
Sphaeriidae			
Pisidium sp.	PISI		
Dreisseniidae			
Dreissena polymorpha	DPOL		
Gastropoda			
Hydrobiidae			
Amnicola limosa	ALMO		
Probythinella lacustris	PLAC		
Bithyniidae			
Bithynia tentaculata	BTEN		
Physidae			
Physa sp.	PHYS		
Pleuroceridae			
Pleurocera acuta	PACU		
Valvatidae			
Valvata sincera	VSIN		
Valvata tricarinata	VTRI		
Ephemeroptera			
Baetidae			
Caenis sp.	CAEN		
Ephemeridae			
Hexagenia sp.	HEXA		
Tricoptera			
Leptoceridae			
Oecetis sp.	OECE		

Table 4. Relationship between shell length (SL) and ash free dry weight (AFDW) for *Dreissena polymorpha* in late summer/fall, 1991-96. The relationship was described by the linear regression equation: LnAFDW = a + bLnSL, where AFDW is given mg and SL is given in mm.

Station	Date	n	a	b	r^2
5	16 Nov 91	25	-6.986	3.375	0.96
5	10 Sep 92	24	-5.613	2.681	0.94
5	9 Sep 93	23	-6.383	2.752	0.95
5	17 Oct 94	25	-3.293	1.737	0.84
5	18 Sep 95	25	-3.382	1.713	0.82
5	29 Aug 96	26	-2.456	1.521	0.74
19	25 Sep 95	25	-3.648	2.136	0.60
19	29 Aug 96	24	-2.615	1.809	0.69

Table 5. Mean (X ± SE) annual density (no. per m^2) of major macroinvertebrate groups at the stations sampled over the entire 1987-96 period. The standard error (SE) was derived from the mean density in the spring, summer, and fall (n=3) of each year. The group "Others" includes Isopoda, Ephemeroptera, Hirudinea, Tricoptera, and Gastropoda.

	Macroinvertebrate Group					
Station/Year	Oligochaeta	Chironomidae	Sphaeriidae	Amphipoda	*Dreissena*	Others
Station 4						
1987	26,058 ± 6,939	2,559 ± 1,554	100 ± 100	0 ± 0	0 ± 0	0 ± 0
1988	20,744 ± 1,431	1,287 ± 588	105 ± 56	0 ± 0	0 ± 0	0 ± 0
1990	20,337 ± 2,891	1,825 ± 735	52 ± 27	0 ± 0	0 ± 0	0 ± 0
1991	8,175 ± 1,987	1,216 ± 352	33 ± 13	0 ± 0	21 ± 12	0 ± 0
1992	7,597 ± 2,019	1,573 ± 699	12 ± 12	0 ± 0	0 ± 0	0 ± 0
1993	2,249 ± 581	1,233 ± 299	137 ± 30	10 ± 6	21 ± 12	0 ± 0
1994	1,791 ± 566	666 ± 31	31 ± 17	26 ± 13	0 ± 0	0 ± 0
1995	4,570 ± 1,433	2,511 ± 1,531	5 ± 2	14 ± 14	0 ± 0	0 ± 0
1996	7,633 ± 1,577	4,537 ± 3,088	36 ± 14	7 ± 7	0 ± 0	4 ± 4
Station 7						
1987	12,048 ± 6,907	1,430 ± 844	150 ± 150	0 ± 0	0 ± 0	0 ± 0
1988	18,552 ± 1,446	1,299 ± 312	240 ± 80	2 ± 2	0 ± 0	0 ± 0
1990	15,297 ± 1,777	1,285 ± 521	33 ± 17	0 ± 0	0 ± 0	0 ± 0
1991	8,666 ± 452	1,595 ± 485	152 ± 114	0 ± 0	0 ± 0	0 ± 0
1992	6,940 ± 1,726	1,097 ± 516	112 ± 52	0 ± 0	26 ± 19	2 ± 2
1993	976 ± 203	605 ± 243	348 ± 87	12 ± 12	86 ± 12	0 ± 0
1994	588 ± 183	471 ± 101	233 ± 157	12 ± 6	114 ± 62	0 ± 0
1995	1,479 ± 645	3,234 ± 2,420	12 ± 2	14 ± 14	0 ± 0	14 ± 14
1996	1,817 ± 46	1,135 ± 36	182 ± 46	7 ± 7	21 ± 21	0 ± 0
Station 10						
1987	20,056 ± 3,515	1845 ± 1,106	52 ± 33	0 ± 0	0 ± 0	0 ± 0
1988	24,290 ± 2,270	1321 ± 572	73 ± 31	0 ± 0	0 ± 0	0 ± 0
1990	11,400 ± 418	757 ± 353	33 ± 5	2 ± 2	0 ± 0	0 ± 0
1991	6,947 ± 1,149	1,228 ± 643	98 ± 52	14 ± 11	21 ± 12	0 ± 0
1992	6,631 ± 1,950	900 ± 228	109 ± 57	0 ± 0	0 ± 0	0 ± 0
1993	1,940 ± 1,192	614 ± 357	519 ± 194	5 ± 5	0 ± 0	0 ± 0
1994	1,247 ± 466	671 ± 104	212 ± 101	7 ± 7	14 ± 14	0 ± 0
1995	1,016 ± 262	873 ± 338	102 ± 48	12 ± 12	7 ± 7	0 ± 0
1996	4,405 ± 1,656		543 ± 179	4 ± 4	0 ± 0	0 ± 0
Station 11						
1987	10,757 ± 5,567	1,654 ± 777	490 ± 71	5 ± 2	0 ± 0	0 ± 0
1988	7,104 ± 164		664 ± 79	0 ± 0	0 ± 0	0 ± 0
1990	2,535 ± 1,218	3,810 ± 1,261	450 ± 57	14 ± 0	0 ± 0	5 ± 2
1991	1,457 ± 345	1,483 ± 666	455 ± 258	10 ± 6	0 ± 0	10 2
1992	3,023 ± 1,530	4,489 ± 3,164	395 ± 120	17 13	114 ± 63	0 ± 0
1993	1,616 ± 360	904 ± 368	835 ± 281	76 ± 53	2,884 ± 2,788	36 ± 18
1994	2,232 ± 222	1,269 ± 300	74 ± 30	57 ± 25	50 ± 26	12 ± 2
1995	4,627 ± 3,099	3,232 ± 2,134	50 ± 31	43 ± 39	0 ± 0	0 ± 0
1996	2,945 ± 75	1,935 ± 764	225 ± 39	54 ± 11	36 ± 26	14 ± 7

Table 5. Continued

Station/Year	Macroinvertebrate Group					
	Oligochaeta	Chironomidae	Sphaeriidae	Amphipoda	*Dreissena*	Others
Station 13						
1987	1,142 ± 883	157 ± 116	7 ± 4	71 ± 22	0 ± 0	0 ± 0
1988	1,221	93	71	171	0	0
1990	362 ± 91	157 ± 122	2 ± 2	67 ± 56	0 ± 0	7 ± 4
1991	938 ± 389	545 ± 427	21 ± 14	133 ± 51	57 ± 29	31 ± 24
1992	231 ± 77	36 ± 25	19 ± 17	21 ± 15	164 ± 26	0 ± 0
1993	521 ± 114	296 ± 46	43 ± 43	203 ± 132	7 ± 7	21 ± 14
1994	328 ± 83	133 ± 123	7 ± 4	267 ± 113	942 ± 795	2 ± 2
1995	621 ± 433	48 ± 29	2 ± 2	57 ± 37	0 ± 0	5 ± 5
1996	818 ± 225	68 ± 39	0 ± 0	207 ± 7	157 ± 134	7 ± 7
Station 14						
1987	518 ± 196	226 ± 95	5 ± 5	29 ± 18	0 ± 0	0 ± 0
1988	555 ± 182	44 ± 10	38 ± 13	67 ± 41	0 ± 0	49 ± 15
1990	476 ± 28	150 ± 136	38 ± 23	19 ± 19	0 ± 0	71 ± 49
1991	659 ± 170	74 ± 34	95 ± 19	52 ± 28	21 ± 21	38 ± 13
1992	371 ± 46	131 ± 64	21 ± 8	55 ± 10	92 ± 82	7 ± 4
1993	436 ± 198	95 ± 28	5 ± 2	655 ± 367	1,291 ± 266	69 ± 13
1994	812 ± 293	38 ± 28	10 ± 10	338 ± 155	871 ± 697	17 ± 17
1995	681 ± 82	60 ± 56	5 ± 5	552 ± 338	2,228 ± 1,001	5 ± 5
1996	789 ± 318	707 ± 671	0 ± 0	857 ± 350	10,339 ± 7,400	43 ± 43
Station 16						
1987	844 ± 662	37 ± 27	61 ± 61	116 ± 23	0 ± 0	0 ± 0
1988	275 ± 131	10 ± 5	12 ± 6	14 ± 14	0 ± 0	29 ± 29
1990	488 ± 188	79 ± 44	10 ± 6	33 ± 30	0 ± 0	17 ± 9
1991	872 ± 299	552 ± 449	17 ± 9	36 ± 12	36 ± 26	19 ± 19
1992	345 ± 64	55 ± 10	0 ± 0	36 ± 26	0 ± 0	2 ± 2
1993	616 ± 321	512 ± 437	0 ± 0	624 ± 269	2,185 ± 1,913	21 ± 18
1994	343 ± 58	40 ± 34	0 ± 0	117 ± 52	0 ± 0	5 ± 5
1995	864 ± 353	33 ± 11	2 ± 2	167 ± 84	1,178 ± 348	0 ± 0
1996	1189 ± 39	211 ± 104	25 ± 25	107 ± 36	7 ± 7	0 ± 0
Station 20						
1987	2,454 ± 1,017	1,568 ± 1,009	107 ± 77	7 ± 4	0 ± 0	2 ± 2
1988	2,430 ± 1,069	1,409 ± 445	666 ± 296	0 ± 0	0 ± 0	2 ± 2
1990	797 ± 275	1,171 ± 345	345 ± 261	2 ± 2	0 ± 0	2 ± 2
1991	659 ±145	778 ± 529	109 ± 29	0 ± 0	0 ± 0	0 ± 0
1992	1,473 ± 175	605 ± 321	50 ± 27	0 ± 0	7 ± 7	0 ± 0
1993	1,196 ± 321	646 ± 227	98 ± 68	13 ± 10	14 ± 14	2 ± 2
1994	1,366 ± 940	486 ± 159	98 ± 77	12 ± 2	0 ± 0	0 ± 0
1995	4,127 ± 963	2,306 ± 1,325	100 ± 25	12 ± 9	0 ± 0	0 ± 0
1996	2,253 ± 425	2,599 ± 1,985	61 ± 18	7 ± 7	0 ± 0	0 ± 0
Station 23						
1987	482 ± 175	252 ± 156	219 ± 135	574 ± 401	0 ± 0	107 ± 50
1988	469 ± 178	281 ± 97	350 ± 31	1,190 ± 536	0 ± 0	109 ± 13
1990	212 ± 66	121 ± 23	114 ± 28	693 ± 84	0 ± 0	98 ± 77
1991	569 ± 192	186 ± 143	93 ± 46	1,154 ± 824	0 ± 0	7 ± 7
1992	202 ± 52	45 ± 2	50 ± 25	240 ± 178	0 ± 0	5 ± 5
1993	246 ± 75	134 ± 27	66 ± 34	590 ± 62	0 ± 0	4 ± 4
1994	431 ± 10	233 ± 66	102 ± 29	371 ± 33	0 ± 0	0 ± 0
1995	793 ± 233	707 ± 397	167 ± 71	50 ± 39	0 ± 0	0 ± 0
1996	957 ± 21	607 ± 514	336 ± 57	82 ± 32	0 ± 0	4 ± 4

Table 5. Continued

Station/Year	Macroinvertebrate Group					
	Oligochaeta	Chironomidae	Sphaeriidae	Amphipoda	*Dreissena*	Others
Station 24						
1987	5,581 ± 1,936	840 ± 461		12 ± 6	0 ± 0	0 ± 0
1988	2,517 ± 1,839	1,535 ± 1,271	75 ± 39	7 ± 7	0 ± 0	0 ± 0
1990	1,169 ± 185	521 ± 173	24 ± 13	7 ± 7	0 ± 0	2 ± 2
1991	1,792 ± 559	593 ± 184	57 ± 26	4 ± 4	0 ± 0	0 ± 0
1992	1,454 ± 849	797 ± 384	40 ± 25	10 ± 6	0 ± 0	5 ± 5
1993	1,100 ± 778	685 ± 557	57 ± 36	32 ± 18	0 ± 0	0 ± 0
1994	878 ± 294	386 ± 116	2 ± 2	14 ± 8	0 ± 0	2 ± 2
1995	4,370 ± 470	3,823 ± 3,067	15 ± 9	0 ± 0	0 ± 0	0 ± 0
1996	1,489 ± 296	725 ± 632	0 ± 0	43 ± 14	0 ± 0	0 ± 0

Table 6. Mean (X ± SE) annual biomass (g AFDW per m^2) of major macroinvertebrate groups (excluding *Dreissena*) at the stations sampled over the entire 1987-96 period. The standard error (SE) was derived from the mean density in the spring, summer, and fall (n=3) of each year. The group “others” includes Isopoda, Ephemeroptera, Hirudinea, Tricoptera, and Gastropoda.

	Macroinvertebrate Group					
Station/Year	Oligochaeta	Chironomidae	Sphaeriidae	Amphipoda	Other	Total
Station 4						
1987	2.05 ± 0.55	4.85 ± 2.62	<0.01 ± <0.01	0 ± 0	0 ± 0	6.90 ± 0.314
1988	1.42 ± 0.41	2.78 ± 1.01	0.01 ± <0.01	0 ± 0	0 ± 0	4.20 ± 1.41
1990	1.65 ± 0.15	8.73 ± 3.47	<0.01 ± <0.01	0 ± 0	0 ± 0	10.38 ± 3.53
1991	0.72 ± 0.16	4.13 ± 2.56	<0.01 ± <0.01	0 ± 0	0 ± 0	4.85 ± 2.51
1992	0.61 ± 0.11	3.45 ± 1.76	0 ± 0	<0.01 ± <0.01	0 ± 0	4.06 ± 1.72
1993	0.25 ± 0.06	3.31 ± 0.58	0.01 ± 0.0	<0.01 ± <0.01	0 ± 0	3.57 ± 0.63
1994	0.23 ± 0.08	0.80 ± 0.47	<0.01 ± <0.01	0.01 ± 0.01	0 ± 0	1.05 ± 0.52
1995	0.52 ± 0.12	3.73 ± 1.43	0 ± 0	<0.01 ± <0.01	0 ± 0	4.26 ± 1.33
1996	0.67 ± 0.04	3.18 ± 1.76	<0.01 ± 0.0	0.01 ± 0.01	<0.01 ± <0.01	3.86 ± 1.80
Station 7						
1987	1.34 ± 0.29	2.23 ± 0.28	<0.01 ± <0.01	0 ± 0	0 ± 0	3.57 ± 0.51
1988	1.73 ± 0.06	3.04 ± 0.59	0.01 ± <0.01	0 ± 0	0 ± 0	4.78 ± 0.59
1990	1.33 ± 0.19	6.55 ± 2.50	<0.01 ± <0.01	0 ± 0	0 ± 0	7.89 ± 2.68
1991	0.84 ± 0.04	4.87 ± 2.62	0.01 ± <0.01	0 ± 0	0 ± 0	5.71 ± 2.66
1992	0.59 ± 0.14	5.56 ± 2.45	0.01 ± <0.01	0 ± 0	0 ± 0	6.16 ± 2.44
1993	0.11 ± 0.04	1.30 ± 1.14	0.01 ± <0.01	0.01 ± 0.01	0 ± 0	1.43 ± 1.14
1994	0.08 ± 0.03	0.42 ± 0.28	0.01 ± 0.01	0.02 ± 0.01	0 ± 0	0.53 ± 0.30
1995	0.17 ± 0.07	5.65 ± 1.31	<0.01 ± <0.01	0.01 ± 0.01	0 ± 0	5.83 ± 1.38
1996	0.20 ± 0.05	1.01 ± 0.78	0.01 ± <0.01	0.01 ± 0.01	0 ± 0	1.23 ± 0.83
Station 10						
1987	1.62 ± 0.29	1.83 ± 0.12	<0.01 ± <0.01	0 ± 0	0 ± 0	3.45 ± 0.22
1988	1.84 ± 0.11	2.21 ± 0.41	0.01 ± <0.01	0 ± 0	0 ± 0	4.06 ± 0.51
1990	1.05 ± 0.04	3.25 ± 0.27	<0.01 ± <0.01	0 ± 0	0 ± 0	4.30 ± 0.24
1991	0.59 ± 0.10	5.25 ± 3.02	0.01 ± <0.01	<0.01 ± <0.01	0 ± 0	5.85 ± 2.95
1992	0.47 ± 0.13	4.52 ± 1.46	0.01 ± <0.01	0 ± 0	0 ± 0	5.01 ± 1.34
1993	0.19 ± 0.11	2.84 ± 2.45	0.02 ± 0.01	<0.01 ± <0.01	0 ± 0	3.05 ± 2.56
1994	0.15 ± 0.04	1.18 ± 0.57	0.01 ± <0.01	<0.01 ± <0.01	0 ± 0	1.34 ± 0.60
1995	0.11 ± 0.02	2.30 ± 1.62	0.02 ± 0.01	0.01 ± 0.01	0 ± 0	2.43 ± 1.60
1996	0.41 ± 0.08	5.90 ± 2.75	0.02 ± <0.01	<0.01 ± <0.01	0 ± 0	6.33 ± 2.84
Station 11						
1987	0.62 ± 0.29	0.80 ± 0.47	<0.01 ± <0.01	<0.01 ± <0.01	0 ± 0	1.46 ± 0.52
1988	0.59 ± 0.02	1.51 ± 0.47	0.09 ± 0.02	0 ± 0	0 ± 0	2.19 ± 0.52
1990	0.27 ± 0.15	2.59 ± 0.86	0.41 ± 0.01	<0.01 ± <0.01	0.07 ± 0.06	2.96 ± 0.80
1991	0.14 ± 0.03	0.61 ± 0.36	0.04 ± 0.02	<0.01 ± <0.01	0.01 ± 0.01	0.80 ± 0.40
1992	0.25 ± 0.08	1.17 ± 0.42	0.03 ± 0.02	0.01 ± <0.01	0 ± 0	1.46 ± 0.47
1993	0.15 ± 0.01	0.49 ± 0.39	0.03 ± 0.01	0.04 ± 0.03	0.01 ± <0.01	0.72 ± 0.37
1994	0.24 ± 0.02	0.38 ± 0.18	0.01 ± <0.01	0.02 ± 0.01	0.04 ± 0.03	0.69 ± 0.13
1995	0.34 ± 0.22	2.46 ± 0.88	0.01 ± <0.01	0.02 ± 0.01	0 ± 0	2.81 ± 0.89
1996	0.27 ± 0.03	1.03 ± 0.25	0.01 ± <0.01	0.02 ± 0.01	<0.01 ± <0.01	1.33 ± 0.24
Station 13						
1987	0.08 ± 0.04	0.01 ± 0.01	<0.01 ± <0.01	<0.01 ± <0.01	0 ± 0	0.14 ± 0.04
1988	0.08 ± 0.08	<0.01 ± <0.01	0.01 ± 0.01	0.09 ± 0.09	0 ± 0	0.18 ± 0.18
1990	0.03 ± <0.01	0.01 ± 0.01	0 ± 0	0.01 ± 0.01	<0.01 ± <0.01	0.05 ± 0.01
1991	0.06 ± 0.02	0.05 ± 0.01	<0.01 ± <0.01	0.02 ± 0.01	<0.01 ± <0.01	0.13 ± 0.03
1992	0.03 ± <0.01	0.01 ± 0.01	<0.01 ± <0.01	0.15 ± 0.01	0 ± 0	0.05 ± 0.02
1993	0.05 ± <0.01	0.02 ± <0.01	<0.01 ± <0.01	0.08 ± 0.02	<0.01 ± 0	0.16 ± 0.02
1994	0.04 ± 0.01	0.01 ± 0.01	0 ± 0	0.12 ± 0.04	0.09 ± 0.09	0.26 ± 0.09
1995	0.04 ± 0.02	0.01 ± <0.01	0 ± 0	0.02 ± <0.01	0.01 ± 0.01	0.08 ± 0.03
1996	0.06 ± 0.02	0.01 ± <0.01	0 ± 0	0.07 ± 0.01	0.03 ± 0.03	0.16 ± <0.01

Table 6. Continued

Station/Year	Macroinvertebrate Group					Total
	Oligochaeta	Chironomidae	Sphaeriidae	Amphipoda	Other	
Station 14						
1987	0.03 ± 0.01	0.04 ± 0.02	0 ± 0	0.01 ± 0.01	0 ± 0	0.08 ± 0.02
1988	0.05 ± 0.01	0.01 ± <0.01	<0.01 ± <0.01	0.02 ± 0.01	0.01 ± 0.01	0.10 ± 0.04
1990	0.04 ± <0.01	0.02 ± 0.02	<0.01 ± <0.01	<0.01 ± <0.01	0.01 ± 0.01	0.08 ± 0.03
1991	0.05 ± 0.01	0.03 ± 0.02	<0.01 ± <0.01	0.02 ± 0.01	<0.01 ± <0.01	0.11 ± 0.01
1992	0.05 ± <0.01	0.02 ± 0.01	<0.01 ± 0.0	0.04 ± 0.02	<0.01 ± <0.01	0.10 ± 0.02
1993	0.05 ± 0.02	0.02 ± 0.01	0 ± 0	0.23 ± 0.11	0.01 ± <0.01	0.31 ± 0.13
1994	0.08 ± 0.02	0.01 ± 0.01	<0.01 ± <0.01	0.23 ± 0.14	0.01 ± 0.01	0.33 ± 0.13
1995	0.06 ± <0.01	0.03 ± 0.03	0 ± 0	0.64 ± 0.47	<0.01 ± <0.01	0.73 ± 0.51
1996	0.06 ± 0.03	0.03 ± 0.03	0 ± 0	0.42 ± 0.19	1.84 ± 1.84	2.34 ± 1.97
Station 16						
1987	0.06 ± 0.04	0.01 ± 0.01	0 ± 0	0.08 ± 0.04	0 ± 0	0.15 ± 0.01
1988	0.04 ± 0.02	<0.01 ± <0.01	<0.01 ± 0.0	0.02 ± 0.02	0.01 ± 0.01	0.06 ± 0.03
1990	0.04 ± 0.02	0.02 ± 0.01	<0.01 ± 0.0	0 ± 0	<0.01 ± <0.01	0.06 ± 0.02
1991	0.07 ± 0.02	0.10 ± 0.08	<0.01 ± 0.0	<0.01 ± 0.0	<0.01 ± <0.01	0.18 ± 0.06
1992	0.04 ± 0.02	0.01 ± <0.01	0 ± 0	0.01 ± 0.01	0 ± 0	0.06 ± 0.02
1993	0.06 ± 0.02	0.04 ± 0.04	0 ± 0	0.26 ± 0.10	0.02 ± 0.01	0.37 ± 0.10
1994	0.03 ± 0.01	0.01 ± <0.01	0 ± 0	0.06 ± 0.03	<0.01 ± <0.01	0.10 ± 0.03
1995	0.06 ± 0.02	0.01 ± <0.01	0 ± 0	0.10 ± 0.05	0 ± 0	0.17 ± 0.07
1996	0.09 ± 0.02	0.02 ± <0.01	0 ± 0	0.02 ± 0.01	0 ± 0	0.13 ± 0.01
Station 20						
1987	0.24 ± 0.09	0.25 ± 0.10	0.01 ± 0.01	0.01 ± <0.01	<0.01 ± <0.01	0.51 ± 0.12
1988	0.27 ± 0.13	0.16 ± 0.04	0.04 ± 0.01	0 ± 0	0 ± 0	0.46 ± 0.16
1990	0.08 ± 0.02	0.44 ± 0.11	0.01 ± <0.01	<0.01 ± <0.01	0 ± 0	0.52 ± 0.13
1991	0.07 ± 0.02	0.54 ± 0.36	0.01 ± <0.01	0 ± 0	0 ± 0	0.62 ± 0.38
1992	0.15 ± 0.03	0.49 ± 0.38	0.01 ± <0.01	0 ± 0	0 ± 0	0.64 ± 0.39
1993	0.13 ± 0.04	0.61 ± 0.56	0.01 ± <0.01	0.02 ± 0.01	<0.01 ± <0.01	0.76 ± 0.58
1994	0.13 ± 0.05	0.14 ± 0.07	0.01 ± 0.01	<0.01 ± <0.01	0 ± 0	0.27 ± 0.10
1995	0.34 ± 0.10	0.68 ± 0.55	0.01 ± 0.01	<0.01 ± <0.01	0 ± 0	1.04 ± 0.55
1996	0.20 ± 0.04	0.73 ± 0.58	<0.01 ± 0	0.01 ± 0.01	0 ± 0	0.93 ± 0.62
Station 23						
1987	0.05 ± 0.01	0.04 ± 0.02	0.01 ± 0.01	0.20 ± 0.07	0.06 ± 0.02	0.37 ± 0.12
1988	0.05 ± 0.01	0.05 ± 0.01	0.03 ± 0.01	0.31 ± 0.07	0.08 ± 0.01	0.52 ± 0.05
1990	0.02 ± 0.02	0.02 ± 0.01	0.01 ± <0.01	0.20 ± 0.05	0 ± 0	0.25 ± 0.05
1991	0.06 ± 0.02	0.01 ± <0.01	0.01 ± <0.01	0.20 ± 0.09	<0.01 ± <0.01	0.28 ± 0.11
1992	0.02 ± <0.01	0.01 ± <0.01	<0.01 ± <0.01	0.05 ± 0.03	0 ± 0	0.09 ± 0.03
1993	0.03 ± <0.01	0.02 ± <0.01	<0.01 ± <0.01	0.14 ± 0.06	0 ± 0	0.18 ± 0.06
1994	0.04 ± <0.01	0.03 ± 0.01	0.01 ± <0.01	0.09 ± 0.04	0 ± 0	0.17 ± 0.05
1995	0.07 ± 0.02	0.15 ± 0.06	0.01 ± <0.01	0.03 ± 0.02	<0.01 ± <0.01	0.26 ± 0.08
1996	0.10 ± 0.01	0.03 0.02	0.04 ± 0.01	0.02 ± <0.01	0 ± 0	0.19 ± <0.01
Station 24						
1987	0.38 ± 0.13	0.46 ± 0.22	0.01 ± <0.01	0.01 ± 0.01	0 ± 0	0.86 ± 0.25
1988	0.19 ± 0.13	0.17 ± 0.08	0.01 ± <0.01	0 ± 0	0 ± 0	0.37 ± 0.21
1990	0.09 ± 0.01	0.19 ± 0.09	<0.01 ± 0.0	<0.01 ± <0.01	0 ± 0	0.29 ± 0.09
1991	0.12 ± 0.03	0.42 ± 0.33	0.01 ± 0.01	<0.01 ± <0.01	0 ± 0	0.56 ± 0.32
1992	0.12 ± 0.05	0.19 ± 0.11	<0.01 ± <0.01	<0.01 ± <0.01	<0.01 ± <0.01	0.32 ± 0.17
1993	0.10 ± 0.06	0.17 ± 0.15	<0.01 ± <0.01	<0.01 ± <0.01	0 ± 0	0.28 ± 0.21
1994	0.07 ± 0.02	0.06 ± 0	0 ± 0	<0.01 ± <0.01	0 ± 0	0.13 ± 0.03
1995	0.35 ± 0.02	0.89 ± 0.34	<0.01 ± <0.01	0 ± 0	0 ± 0	1.24 ± 0.34
1996	0.13 ± 0.02	0.15 ± 0.13	0 ± 0	0.01 ± <0.01	0 ± 0	0.29 ± 0.11

Table 7. Mean (X ± SE) annual density (no. per m^2) of *Dreissena polymorpha* at sites in inner and outer Saginaw Bay in 1991-96. Samples were collected in the fall of each year by divers using SCUBA.

	Year					
Station	1991	1992	1993	1994	1995	1996
Inner Bay						
5	28,244 ± 2,457	75,296 ± 29,280	237 ± 48	2,959 ± 422	1,018 ± 348	3,067 ± 431
6	4,453 ± 1,387	3,620 ± 2,444	3,557 ± 1,616	10,724 ± 4,862	2,291 ± 774	61 ± 23
13		8,956 ± 6,720	376 ± 60	855 ± 449	211 ± 79	150 ± 71
14	209 ± 115	63,242 ± 18,999	7,506 ± 3,459	3,900 ± 880	2,564 ± 425	5,426 ± 809
15	43,117 ± 1,050	5,556 ± 2,492	7,341 ± 2,828	9,725 ± 2,336	6,728 ± 742	17,600 ± 186
16	27 ± 27	46,360 ± 7,780	4,831 ± 1,768	1,727 ± 614	60 ± 19	6,981 ± 947
Mean	15,210 ± 8,718	33,838 ± 13,003	3,975 ± 1,312	4,982 ± 1,716	2,145 ± 1,009	5,548 ± 2,663
Outer Bay						
19	2,480 ± 1,219	57,640 ± 19,985	3,328 ± 900	21,669 ± 7,773	17,776 ± 1,912	19,349 ± 2,116
27	3,408 ± 2,772	4,695 ± 2,542	5,813 ± 2,384	9,925 ± 1,590	3,824 ± 525	6,981 ± 1,670
Mean	2,944 ± 464	31,168 ± 26,473	4,570 ± 1,243	15,797 ± 5,872	10,800 ± 6,976	13,165 ± 6,184

Table 8. Mean biomass (g AFDW m^{-2}) of *Dreissena polymorpha* at stations in inner and outer Saginaw Bay in 1991-96. Samples were collected by divers in fall of each year.

	Year					
Station	1991	1992	1993	1994	1995	1996
Inner Bay						
5	10.48	106.86	0.18	5.65	2.05	5.88
6	4.39	8.88	6.72	16.18	6.27	0.23
13		24.66	0.74	2.55	0.66	0.26
14	0.09	143.98	11.55	8.84	6.05	17.99
15	34.14	8.60	3.38	12.95	9.38	33.46
16	0.01	78.23	4.39	3.83	0.14	22.53
Mean	10.02 ± 6.30	61.87 ± 23.14	4.49 ± 1.72	8.33 ± 2.19	4.09 ± 1.51	13.39 ± 5.51
Outer Bay						
19	0.57	88.20	12.28	56.52	99.27	137.98
27	0.73	19.49	15.29	32.55	27.10	57.54
Mean	0.65 ± 0.08	53.85 ± 34.36	13.79 ± 1.51	44.54 ± 11.99	63.19 ± 36.09	97.76 ± 40.22

Table 9. Type of grab sampler and mesh size used in previous macroinvertebrate surveys conducted in inner Saginaw Bay.

Year	Grab Sampler	Mesh Size	Reference
1954	Peterson, Ekman	0.595	Surber (1954)
1955	Peterson	0.595	Surber (1955)
1956	Peterson	0.595	Schneider (unpublished data)
1962	Ekman	0.595	Alexander (1963)
1965	Peterson	0.595	Shannon et al. (1967)
1971	Ponar	0.595	Batchelder (1973)
1987-96	Ponar	0.50	This study

Table 10. Densities (X ± SE) of the major benthic macroinvertebrate groups collected with the Ponar and Peterson grabs in Saginaw Bay in 1987/88. The source of variation (SE) was the mean density on each sampling date over the two-year period. The two samplers were compared using a paired t-test after ln+1 transformation. Each sampling date was considered an individual replicate. A conversion value (Ponar/Peterson) was determined only when the difference between samplers was significant ($P < 0.05$).

Station	Substrate	Ponar	Peterson	P-Value	Ponar/Peterson
Group:Oligochaeta					
4	Silt	30,453 ± 3611	11,677 ± 1,650	<0.001	2.61
7	Silt	23,472 ± 1,954	8,897 ± 1,533	0.002	2.64
10	Silt	27,583 ± 1,838	8,079 ± 1,692	0.002	3.41
13	Sand	1,420 ± 684	858 ± 257	0.497	
14	Sand	880 ± 201	835 ± 231	0.705	
16	Sand	746 ± 359	462 ± 149	0.592	
Group:Chironomidae					
4	Silt	2,019 ± 3,611	588 ± 162	0.001	3.43
7	Silt	1,556 ± 545	445 ± 68	0.011	3.50
10	Silt	1,633 ± 610	375 ± 60	0.006	4.35
13	Sand	147 ± 84	224 ± 157	0.599	
14	Sand	153 ± 70	208 ± 109	0.617	
16	Sand	20 ± 12	28 ± 21	0.882	
Group: Sphaeriidae					
4	Silt	147 ± 90	2 ± 1	0.068	
7	Silt	185 ± 80	11 ± 6	0.182	
10	Silt	66 ± 23	14 ± 3	0.309	
13	Sand	22 ± 17	26 ± 9	0.441	
14	Sand	25 ± 9	19 ± 7	0.728	
16	Sand	9 ± 4	11 ± 6	0.988	
Group: Amphipoda					
4	Silt	0 ± 0	0 ± 0	-	
7	Silt	1 ± 0	0 ± 0	-	
10	Silt	0 ± 0	0 ± 0	-	
13	Sand	76 ± 23	71 ± 25	0.415	
14	Sand	27 ± 10	22 ± 11	0.153	
16	Sand	54 ± 24	41 ± 13	0.713	

Table 11. Mean density (no./m^2 ± SE) of major benthic macroinvertebrate groups in 1987/88. Stations in the inner bay were grouped by substrate (I, II, III), and stations in the outer bay were grouped by depth (IV, V, VI). Differences between the groups for the inner and outer bay were tested using ANOVA (ln +1 transformed). ns = not significantly different.

Group	Station	Depth (m)	Substrate	Oligochaeta	Chironomidae	Amphipoda	Sphaeriidae	Total
Inner Bay								
I	13,14,16,18,28	3.0-4.8	sand/gravel	1,111 ± 281	202 ± 94	60 ± 21	58 ± 19	1,441 ± 374
II	2,11,22,25,30,35, 58,68,108	4.2-9.0	silty sand	5,870 ± 808	2,163 ± 801	15 ± 7	250 ± 49	8,327 ± 1,281
III	4,7,10,26,168,278	6.7-11.8	silt	20,954 ± 1,909	1,412 ± 159	<1 ± <1	86 ± 19	21,951 ± 2,019
				P < 0.01	P< 0.01	P < 0.01	P <0.01	P <0.01
Outer Bay								
IV	24,43,57	10-13	silty sand	4,952 ± 659	4,559 ± 439	117 ± 5	385 ± 298	10,025 ± 84
V	20,45,53,55	16-22	silty sand	3,043 ± 300	1,010 ± 282	93 ± 39	189 ± 72	4,337 ± 306
VI	23,50	28-30	silty sand	2,304 ± 1,094	191 ± 44	1,209 ± 254	222 ± 45	3,982 ± 1,159
				ns	P < 0.01	P < 0.05	ns	P < 0.01

Table 12. Density of major macroinvertebrate groups in previous surveys conducted in inner Saginaw Bay. The value given in parenthesis is the density corrected to Ponar equivalents. Correction factors are given in the text.

		Macroinvertebrate Group					
Year	Station	Oligochaeta	Chironomidae	Sphaeriidae	Amphipoda	Others	Total
Substrate:Silt							
1954[1]	1	5,165 (2,840)	516 (397)	43	0	861	4,141
	5	2,152 (1,183)	2,109 (1,623)	22	11	22	2,861
	8	5,816 (2,841)	65 (49)	43	22	43	2,998
Mean		2,288 ± 553	836 ± 787				2,667 ± 912
1955[2]	6	54 (156)	129 (485)	0	86	495	1,222
	8	43 (124)	64 (241)	0	0	204	569
	9	699 (2,013)	11 (41)	0	0	0	2,054
Mean		764 ± 624	256 ± 128				1,281 ± 430
1956[3]	7A	916 (2,688)	38 (133)				2,837
	60	230 (662)	339 (1,187)				1,901
Mean		1,892 ± 1132	660 ± 527				2,369 ± 468
1962[4]	2	19,669 (10,818)	0	0	0	0	10,818
1965[5]	7	8,005 (23,054)	452 (1,700)	22	0	0	24,776
	8	10,803 (31,113)	355 (1,335)	22	0	0	32,470
	9	26,695 (76,388)	1,388 (5,219)	32	0	0	81,639
	10	5,789 (16,672)	398 (1,496)	0	0	0	18,168
	11	12,513 (36,037)	1,399 (5,260)	0	0	0	41,279
	16	16,215 (46,699)	2,614 (9,898)	11	0	0	56,597
	34	8,055 (23,054)	2,486 (9,347)	0	0	0	32,401
	35	18,345 (52,834)	1,657 (6,230)	0	0	0	59,064
Mean		38,231 ± 6,972	4,692 ± 1123				43,302 ± 7452
1971[6]	18	14,956	1,790	0	0	0	16,746
	22	12,008	1,338	0	0	0	13,346
	23	11,534	749	43	0	0	12,326
	28	16,151	1,307	0	22	0	29,806
Mean		13,662 ± 1,123	2,499 ± 602				14,975 ± 1,261
Substrate:Sand							
1954[1]	2	2,313	183	0	0	0	2,496
	4	1,560	236	43	0	0	1,839
	6	817	193		32	118	1,160
	9	2,195	656	75	32	75	3,033
	10	4,271	291	0	11	75	4,648
Mean		2,231 ± 575	312 ± 88				2,635 ± 593
1955[2]	3	4,623	75	108	0	0	4,806
	4	8,737	108	32	0	32	8,909
	10	312	301	11	176	11	811
	11	3,692	570	368	0	43	4,673
	14	183	97	334	247	377	1,238
	15	1,496	161	463	0	129	2,249
Mean		3,173 ± 1332	219 ± 78				3,781 ± 1,235
1962[4]	3	4, 648	43	0	0	0	4,691
1965[5]	28	721	22	0	97	22	862
	29	6,681	753	0	43	11	7,488
	30	473	355	0	11	22	861
	32	3,518	581	0	11	0	4,110
	37	3,163	215	0	11	0	7,499
	38	8,339	495	0	0	0	8,834
	40	6,628	86	0	0	0	6,714
Mean		4,217 ± 1,162	358 ± 101				5,195 ± 1,243
1971[6]	21	1,689	1,858	0	0	0	3,547
	24	1,033	323	0	215	0	1,571
	25	4,100	484	0	0	0	4,584
	29	1,549	968	43	0	0	2,560
Mean		2,093 ± 684	858 ± 304				3,066 ± 647

[1]Surber (1954); [2]Surber (1955); [3]Schneider (unpublished data); [4]Alexander (1963); [5]Shannon et al. (1967); [6]Batchelder (1973)

Appendix 1.

The abundance (number per grab) of all taxa collected between 1987 and 1996 with the Ponar grab. Variables in the appendix include year, season (spring=1, summer=2, fall=3), station, replicate number, and taxa. Individual taxa were assigned a 4-letter code as shown in Table 3.

Data are contained in an MS Excel file at:
ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-122.