FINAL REPORT

LAKE ERIE PROTECTION FUND PROJECT LEPF-SG-88-98

Analysis of 1997-98 Lake Erie Plankton Dynamics Samples

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Summary Changes in the Lake Erie algae, zooplankton, benthos, and fish abundance could be the result of changes in input of nutrients or toxics from the drainage basin, or biological impacts of introduced species such as zebra mussels, quagga mussels, *Bythotrephes*, or round gobies. Many researchers are currently working to model the relationships among these components to evaluate their relative roles in modifying lake function. Because all these stressors act directly or indirectly through the plankton, the availability of samples reflecting the temporal and spatial variability of phytoplankton and zooplankton is critical to all the modeling efforts. This project provided funds for analysis of samples collected in 1997 and 1998, including those collected by the Canada Centre for Inland Waters and the Ontario Ministry of Natural Resources from the three basins of the lake to complement those analyzed in 1995 and 1996.

All of the samples have been analyzed taxonomically, and we have quantitative estimates of abundance and biomass for 63 genera of algae and 39 taxa of zooplankton. Data from this study will be distributed to interested researchers and managers through the preparation of CD-ROM disks containing compressed files of the data for phytoplankton and zooplankton and associated physical parameters (station location, depth, temperature, Secchi transparency, oxygen concentration, chlorophylls, etc.).

Comparing our results with historical samples, phytoplankton abundance has declined since 1970, at an average of 16%/year in the West Basin, 8% per year in the Central Basin, and 6%/year in the East Basin. Zooplankton biomass has also declined since 1970, but at a much slower pace than has phytoplankton. Curiously, zooplankton biomass has increased by about 50% in the year 2000 relative to the average biomass for 1996-1999.

Dreissenid veliger biomass has become equal to crustacean zooplankton in our plankton samples, suggesting that dreissenid veliger clearance rates might equal those of crustaceans. That is, dreissenid veligers might be competing with crustacean zooplankton, decreasing the algae available for the latter. Calculations from our plankton samples, adult zebra mussel abundance, and clearance rate measurements made for crustacean zooplankton, veligers, and adult dreissenids in western Lake Erie suggest that while crustacean are still the highest, veligers and

zebra mussel adults are increasing with time. When we calculate nutrient excretion rates, however, we find that dreissenid adults have much higher excretion rates than do crustacean zooplankton and the rate of increase per year is very high as zebra mussels increasingly occupy the soft sediments as well as the hard substrates they had already covered by the mid-1990s.

Our results suggest that while phytoplankton abundance has declined over time and zooplankton have decreased much less, the potential impacts of dreissenid veliger grazing and adult dreissenid excretion are increasing with time.

Introduction

Recent changes in the nutrient inputs to Lake Erie and the impacts of nonindigenous species, particularly the zebra and quagga mussels, have elicited concern about the stability of the plankton communities in the lake (Heath et al. 1995, Frost 1997, Gopalan et al. 1998, Charlton et al. 1998, Makarewicz et al. 2000). This project builds on a previous project to monitor the plankton in the lake for 1995 and 1996, by extending the monitoring to four years, constructing the most extensive sampling of the phytoplankton and zooplankton of Lake Erie that has ever been performed, while maintaining continuity of methods and personnel. Having four years of data enables us to better test the effects of variation in weather, nutrient loading (including variation in time and space), circulation dynamics, etc., on the dynamics of the plankton in the lake. The results are needed for modeling projects underway sponsored by Ohio Sea Grant, the Ohio Division of Wildlife, and the Lake Erie Protection Fund (e.g., Project LEPF-98-17). The current project thus performed analyses needed by a diversity of researchers who study food web dynamics, phosphorus dynamics, and fish recruitment in the lake (e.g., Knight and Vondracek 1993).

Goals and Objectives

Our research group seeks to understand processes affecting how changing phosphorus and nitrogen availability and the activities zebra mussels interact to alter the function of the lower trophic levels as they influence water quality and fish recruitment in the lake. Our objectives are to model the dynamics of nutrients, phytoplankton, zooplankton, zebra mussels, and planktivorous fish in the lake through a study of spatial and temporal variation in their abundance and productivity in conjunction with the Lake Erie Lakewide Management Plan (LaMP). This project has helped provide the biological data needed for these efforts by sponsoring the laboratory analysis of phytoplankton and zooplankton samples from Lake Erie.

Methods

In conjunction with members of the Lake Erie LaMP group (Ohio Division of Wildlife (ODW), the Ohio Environmental Protection Agency (OEPA), the National Water Resources Institute of Canada (NWRI), and the Ontario Ministry of Natural Resources (OMNR)), we arranged to extend the 1995-96 plankton sampling to include 1997 and 1998 field years. We analyzed the 1203 quantitative plankton samples collected from these two years and added them to those from 1995-96. The work provides a four-year sequence of chlorophyll, phytoplankton, and zooplankton abundances and biomass from as many as 71 stations sampled monthly (and in some cases weekly) throughout the summer for use in constructing mathematical models of the lower trophic levels in the lake.

This project depended upon the extensive sampling efforts of ODW, NWRI, and OMNR. ODW collected samples in conjunction with their 1995-98 fish trawling activities, and have provided funds to analyze the samples. During 1995, ODW collected samples weekly from 17 sites and monthly from 24 sites, all in the western basin of Lake Erie (Table 1, Figure 1). Sampling increased to 20 weekly sites and 24 monthly sites in the western basin for 1996, but was then reduced to 16 sites in 1997 and 17 in 1998 (Table 1, Figures 2, 3). Since this project was completed, sampling has continued in 1999, 2000, and 2001 at 8 sites in the western basin (Figure 3). Starting in 1996, ODW began sampling in the central basin of Lake Erie at 8 sites during bi-monthly cruises. This sampling has continued through 2001 (Table 2, Figures 2, 3). All ODW sampling took place from May through September or October.

OEPA funded the analysis of samples from NWRI (part of the Canada Centre for Inland Waters (CCIW)) for 1996, but NWRI collected additional samples from 20 stations in all three basins of the lake, from May to September, in 1997 and 1998 (Table 3, Figures 3, 4). Sampling continued in 1999, 2000, and 2001 as well (Table 3, Figure 5). As part of the LaMP, OMNR collected samples from a series of 8 stations on either side of Point Pelee monthly in 1996 and weekly in 1997 and 1998 (Table 4, Figures 2, 3). Our LEPF-funded project focused on analysis of the 1997 and 1998 phytoplankton and zooplankton samples from NWRI and OMNR. All other sample analysis was funded by other projects. Analyses of zooplankton samples through 2000 have been completed and will be summarized in this report, although the project was designed to analyze samples through 1998. Conversely, phytoplankton analyses for the whole lake have only been completed through 1997 to date, although those from the western basin are complete. The remainder of the central and eastern basin analyses will be completed during 2002.

Phytoplankters were identified to genus and enumerated to generate estimates of numbers/ml, size frequency (µm), wet weight biomass (μm^3/individual, and ml/m^3), and their summations by phylum, and by edible and inedible forms. Biomass determinations (cell volume based on geometric formulae) required measurements of representative cell dimensions (20 specimens) for each taxon in addition to enumeration of the specimens found in whole water samples that were quantitatively concentrated by settling. Zooplankton were identified to species and enumerated to yield data in numbers/l, eggs/l, size (mm), dry weight biomass/individual, and biomass/l. Biomass estimates once again required length measurements of individual specimens (20/taxon) in each sample using our previous length-weight regression determinations (Culver et al. 1985). Zooplankton productivity was estimated from size-frequency measures, biomass, egg counts, and development times as a function of temperature. All zooplankton data were then summed by higher taxa (rotifers, cladocerans, copepods, *Dreissena*).

Data will be distributed to interested researchers and managers through the preparation of CD-ROM disks containing compressed files of the data for phytoplankton and zooplankton and physical and chemical parameters (station location, depth, temperature, Secchi transparency, oxygen, chlorophylls, etc.) associated with each sample.

Results and Discussion

Stations sampled for plankton, chlorophyll, and various physicochemical parameters were widely distributed in space and time throughout Lake Erie (Tables 1-4, Figures 1-5). We have chosen to provide an inclusive list, as this will be more useful at this time than one limited to the original objectives for this project. In general, 1996 provided the greatest number of sites sampled on the greatest number of dates, but the less frequent sampling from 1997-2000 provided a broader spatial coverage of the lake including offshore sites.

Phytoplankton and zooplankton samples contained a wide diversity of taxa. We identified phytoplankton only to genus, and found 28 genera of green algae, 19 genera of diatoms, 3 genera of cryptophytes, 10 genera of cyanobacteria, and 3 genera of dinoflagellate (Table 5). Taxa less frequently encountered (various pennate diatoms, cyanobacteria, and greens) or those that were abundant but difficult to identify in Lugol's preserved samples at 400x (e.g., small coccoid greens and thin cyanobacterial filaments) were labeled by such descriptive groupings rather than keying them to genus. Zooplankters were identified to species for the most part, resulting in data on 14 cladoceran, 9 cyclopoid copepod, 9 calanoid copepod species, plus 6 rotifer genera and dreissenid (zebra mussel + quagga mussel) veligers (Table 6). Nauplii were only differentiated as cyclopoid or calanoid. The plankton samples collected from these sites are being curated for inclusion in The Ohio State University's Museum of Biodiversity, 1315 Kinnear Road, Columbus, OH 43212.

Graphical presentation of the diversity of all the phytoplankton data is difficult, since we counted 63 taxa in hundreds of samples. For the purposes of this report, therefore, we have limited our presentation to a comparison of annual means of biomass by space and time (Figure 6) to allow comparison with historical samples even when the frequency of the sampling and the locations of sample sites differed from ours. Data in Figure 6 were based on sample collections made in 1970 (Munawar and Munawar 1976, 1996), 1978-79 (Devault and Rockwell 1986), 1983-1987 (Makarewicz 1993a), 1993 (Makarewicz et al. 1999), and our own results from 1995-1997. Despite the lack of continuity in sampling location and dates, it is evident that phytoplankton abundance has declined since 1970, at an average of 16%/year in the West Basin, 8% per year in the Central Basin, and 6%/year in the East Basin. A lot of the reduction has been through decreases in cyanobacterial blooms and in large filamentous diatoms and cyanobacteria. However, recent years (1995 and 1998) have seen a resurgence of cyanobacterial blooms, particularly *Microcystis*. For example, the July and August chlorophyll data from the western basin in 1998 are very high primarily because of a bloom of this genus (Figure 7). Algal counts indicate that domination of the western basin phytoplankton by *Microcystis* continued through September. This bloom is also reflected in the seasonal average chlorophyll for the western basin (Figure 8).

Zooplankton biomass has also declined since 1970 (Figure 9), but at a much slower pace than has phytoplankton. Curiously, zooplankton biomass has increased by about 50% in the year 2000 relative to the average biomass for 1996-1999. This may reflect decreased consumption by the planktivorous juveniles of Lake Erie fish, because 2000 was not a good year for the recruitment of game fish in the lake (Roger Knight, ODW, personal communication).

Having data on phytoplankton and zooplankton for a series of years, allows us to examine the roles of changes in loading of nutrients and dreissenids on the dynamics of plankton in the lake. For example, blooms of the toxic alga *Microcystis aeruginosa* might be stimulated by heavy rainfall in August and September, months when warm water temperatures favor cyanobacterial growth. Nutrient loading, particularly for nitrogen and phosphorus is highly correlated with rainfall in the basin. Although monthly rainfall varies greatly (Figure 10), there is no obvious correlation between August's or September's rainfall and the years with maximal *Microcystis* blooms, 1995 and 1998.

Dreissenid veliger biomass has become equal to crustacean zooplankton in our plankton samples (Figure 11), suggesting that dreissenid veliger clearance rates might eventually equal those of crustaceans. That is, dreissenid veligers might compete with crustacean zooplankton, decreasing the algae available for the latter. Calculations from our plankton samples, adult zebra mussel abundance (Haltuch et al. 2000, Weisgerber 1999), and clearance rate measurements made for crustacean zooplankton, veligers, and adult dreissenids in western Lake Erie (Pontius 2000) suggest (Figure 12) that while crustacean clearance rates are still the highest, those for veligers and zebra mussel adults are increasing with time. Note that clearance rates are expressed as m^3/m^2/day so we can compare the volume of water processed by benthic zebra mussels with that processed by crustacean zooplankton and veligers in the water column above them. These clearance rates do not tell us how much algae has been removed by the individual groups because each has its own size selectivity and is feeding in a different part of the water column. Zebra mussel adult clearance rates are lower than those of veligers and crustacean zooplankton because they are limited by the locations where they can successfully grow and because they refilter water already cleared of algae by their neighbors (Yu and Culver 1999).

When we calculate nutrient excretion rates (Heath et al. 1995, Arnott and Vanni 1996, James et al. 1997), we find that dreissenid adults have much higher excretion rates than do crustacean zooplankton and the rate of increase is very high (Figure 13) as zebra mussels increasingly occupy the soft sediments as well as the hard substrates they had already covered by the mid-1990s (Haltuch et al. 2000). Note that the excretion rates are calculated (g/L/day) so that one can calculate the fraction of the inorganic N and P in the water that is replaced each day by dreissenids and crustacean zooplankton. Unfortunately no weight-specific excretion rates for dreissenid veligers have been measured. We propose to perform these measurements this summer under sponsorship of the USEPA, so we can apply the rates to the veliger biomass values we have collected as part of this project.

Benefits and Information Dissemination

This project has contributed to the formation of the most comprehensive study of phytoplankton and zooplankton composition that has ever been done for Lake Erie. At its initiation, we only had analyses from 1995 and 1996 and had been unable to analyze plankton samples collected from a large number of sites by the Canada Centre for Inland Waters and the Ontario Ministry of the Environment in the offshore and north shore regions of Lake Erie, particularly in the central and eastern basins. The new data complement those from analysis of samples in Ohio waters of Lake Erie funded primarily by the Ohio Division of Wildlife.

The merged data are being used in modeling changes in Lake Erie function in projects funded by the Ohio Lake Erie Protection Fund ("Calibration of Lake Erie foodweb models with field data"), the Ohio Sea Grant College Fund ("Spatial dynamic modeling of large lake lower trophic level dynamics: Effects of zebra mussel and nutrient loading"), and a new project funded by the USEPA through Case Western University ("Trophic Status of Lake Erie: Investigating Mechanisms and Extent of Internal Phosphorus Loading in Support of Modeling"). The data are also being used in our other LEPF-funded project ("Development of a Planktonic Index of Biotic Integrity for Lake Erie." Because the dataset is so complete, we have cited it as an asset for use in new projects in collaborative research proposals totaling $5,900,000 to the NSF Biocomplexity program ("Interactions among human, biological, and physical processes within large lake ecosystems") and the NSF/USEPA/NOAA ECOHAB Program ("The Ecology, Detection, Prediction and Toxicity of *Microcystis* Blooms in Lake Erie").

The data produced in this project have been used in a total of 11 undergraduate and graduate research projects (Table 7). Clearly the work has already supported a great deal of student education, and will continue to do in the future.

To date, we have presented results of this and related research to scientific and stakeholder groups on at least 15 occasions (Table 8, and in the Appendix) and have used the data in publishing 7 scientific papers on Lake Erie ecology (Table 9). Additional publications are in preparation.

The data (date, station location, water depth, water temperature, chlorophyll, phytoplankton taxonomic composition in cells/ml and biomass (wet weight)/mL and cell dimensions, and zooplankton taxonomic composition in numbers/L and biomass (dry weight)/L and length measurements for each taxon) have been combined in a database in Microsoft Access. The data will be made available to Great Lakes researchers on a Compact Disk and also on the Ohio Sea Grant research website at http://www.sg.ohio-state.edu/.

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TABLES

Table 1: Sites sampled by the Ohio Division of Wildlife, Sandusky, OH. Sites are designated both by number (e.g., 1) and grid location (e.g., 990).

Site	Latitude	Longitude	Basin	Years Sampled
1-990	41°27′23″	82°38′34″	WB	1995-1996
2-996	41°26′43″	82°37′40″	WB	1995-1996
3-996	41°26′51″	82°37′04″	WB	1995-1996, 1998-2001
4-996	41°27′23″	82°35′48″	WB	1995-1997
5-989	41°28′17″	82°38′56″	WB	1995-1996
6-984	41°29′46″	82°40′59″	WB	1995-1996
7-984	41°29′22″	82°40′32″	WB	1995-1998
8-994	41°31′40″	82°36′02″	WB	1995-2001
9-987	41°34′10″	82°38′25″	WB	1995-1997
10-982	41°34′50″	82°40′35″	WB	1995-1996
11-992	41°36′10″	82°35′56″	WB	1995-1996
12-986	41°36′26″	82°38′27″	WB	1995-1996, 1998
13-972	41°33′49″	82°47′35″	WB	1995-1997
14-972	41°34′18″	82°46′12″	WB	1995-2001
15-967	41°33′42″	82°48′08″	WB	1995-1996
16-970	41°38′25″	82°45′57″	WB	1995-2001
17-975	41°38′11″	82°44′32″	WB	1995-1996
18-969	41°39′35″	82°45′56″	WB	1995-1996
19-958	41°40′17″	82°51′22″	WB	1995-1996, 1998
20-952	41°36′11″	82°53′56″	WB	1995-1996
21-961	41°34′01″	82°51′39″	WB	1995-1996
22-954	41°32′07″	82°53′26″	WB	1995-1996
23-943	41°38′08″	82°55′43″	WB	1995-1996
24-943	41°40′00″	82°55′26″	WB	1995-1996, 1998
25-34	41°46′02″	82°53′34″	WB	1995-1996
26-931	41°46′10″	82°58′14″	WB	1995-1996, 1998
27-918	41°46′32″	83°03′17″	WB	1995-2001
28-911	41°50′47″	83°06′12″	WB	1995-1996
29-905	41°51′59″	83°08′07″	WB	1995-2001
30-8	41°53′31″	83°05′44″	WB	1995-1998
31-896	41°53′26″	83°11′20″	WB	1995-1996
32-886	41°51′16″	83°13′43″	WB	1995-1996
33-898	41°48′58″	83°11′58″	WB	1995-1996
34-879	41°49′40″	83°16′03″	WB	1995-1996, 1998
35-888	41°46′46″	83°13′44″	WB	1995-1996
36-873	41°46′06″	83°18′03″	WB	1995-2001
37-890	41°42′09″	83°14′53″	WB	1995-2001
38-875	41°42′09″	83°13′47″	WB	1995-1996
39-874	41°44′35″	83°13′25″	WB	1995-1997
40-867	41°44′28″	83°20′32″	WB	1995-1996, 1998
41-979	41°29′12″	82°44′52″	WB	1995-1996
42-916	41°39′47″	83°10′07″	WB	1996-1998
43-914	41°43′14″	83°07′14″	WB	1996-1997
44-927	41°41′29″	83°10′41″	WB	1996-1997

Table 2: Sites sampled by the Ohio Division of Wildlife, Fairport, OH. Sites are designated by grid location (e.g., 1046) and water depth (e.g., 10m).

Site	Latitude	Longitude	Basin	Years Sampled
1046 10m	41°36′10″	82°16′14″	CB	1996
1049 10m	41°28′35″	82°16′14″	CB	1996
1057 5m	41°28′35″	82°13′37″	CB	1996
1070 15m	41°36′10″	82°06′24″	CB	1996
1109 20m	41°43′32″	81°56′13″	CB	1996
1110 20m	41°40′56″	81°56′13″	CB	1996
1112 5m	41°36′10″	81°56′13″	CB	1996
1114 10m	41°31′11″	81°55′57″	CB	1996
1125 5m	41°29′21″	81°53′37″	CB	1996
1170 5m	41°30′32″	81°43′29″	CB	1996
1179 20m	41°40′56″	81°41′22″	CB	1996
1181 15m	41°35′50″	81°41′04″	CB	1996
1182 10m	41°33′47″	81°41′39″	CB	1996
1250 10m	41°43′32″	81°26′48″	CB	1996
1251 5m	41°41′35″	81°26′00″	CB	1996
1268 20m	41°50′41	81°21′16″	CB	1996
1269 15m	41°47′52″	81°21′33″	CB	1996, 1999
1279 15m	41°50′35″	81°18′38″	CB	1996
1279 20m	41°51′46″	81°18′38″	CB	1996-2001
1280 10m	41°47′38″	81°18′38″	CB	1996, 1998
1280 15m	41°48′44″	81°18′38″	CB	1996-2001
1281 5m	41°45′55″	81°18′38″	CB	1996-2001
1281 10m	41°45′01″	81°18′38″	CB	1996-2001
1317 20m	41°56′06″	81°08′44″	CB	1996, 1999-2001
1318 20m	41°53′30″	81°08′44″	CB	1996-2001
1319 15m	41°50′28″	81°08′44″	CB	1996-2001
1320 5m	41°48′44″	81°08′44″	CB	1996-2001
1320 10m	41°49′23″	81°08′44″	CB	1996-2001
1328 15m	41°53′30″	81°06′16″	CB	1996
1329 10m	41°50′15″	81°06′16″	CB	1996
1339 5m	41°50′54″	81°03′47″	CB	1996, 1999
1346 15m	41°55′14″	81°01′27″	CB	1996
1346 20m	41°55′01″	81°01′27″	CB	1996
1348 5m	41°50′54″	81°01′27″	CB	1996, 1999
1357 10m	41°53′17″	80°58′33″	CB	1996
1392 20m	42°01′18″	80°48′38″	CB	1996
1393 15m	41°59′34″	80°49′13″	CB	1996
1403 5m	41°55′01″	80°46′00″	CB	1996
1403 10m	41°55′40″	80°46′00″	CB	1996
1453 20m	42°05′12″	80°31′10″	CB	1996
1454 15m	42°04′33″	80°31′10″	CB	1996
1455 10m	42°01′18″	80°31′10″	CB	1996
1456 5m	41°58′55″	80°31′10″	CB	1996

Table 3: Sites sampled by the National Water Research Institute, Burlington, Ontario.

Site	Latitude	Longitude	Basin	Years
23	42°30′05″	79°53′21″	EB	1997-1999, 2001
84	41°56′03″	81°39′30″	WB	1997-1999
340	41°45′24″	82°24′02″	CB	1997-1999
342	41°48′48″	82°10′02″	WB	1997-1999
343	41°50′50″	83°04′57″	WB	1996
344	41°46′59″	82°50′33″	WB	1996
357	41°49′36″	82°58′08″	WB	1996-2000
358	41°53′36″	82°52′03″	CB	1996
438	42°44′36″	78°57′21″	EB	2001
439	42°47′17″	79°04′21″	EB	2001
440	42°51′12″	79°10′00″	EB	2001
441	42°40′00″	79°05′15″	EB	2001
442	42°50′30″	79°23′36″	EB	2001
443	42°41′12″	79°16′36″	EB	2001
444	42°32′36″	79°15′06″	EB	2001
445	42°48′06″	79°42′00″	EB	2001
446	42°40′00″	79°44′00″	EB	2001
447	42°26′00″	79°38′60″	EB	2001
448	42°17′42″	79°42′48″	EB	2001
449	42°46′03″	79°58′15″	EB	2001
450	42°41′51″	79°57′00″	EB	2001
451	42°38′54″	79°53′40″	EB	2001
452	42°35′00″	79°55′18″	EB	2001
931	42°51′00″	78°56′30″	EB	2001
933	42°49′30″	79°34′01″	EB	1996-2000
934	42°42′30″	79°30′30″	EB	2001
935	42°35′25″	79°28′01″	EB	1997-1999, 2001
936	42°38′31″	79°24′30″	EB	1996-2001
937	42°42′58″	80°14′57″	EB	1996-2000
938	42°38′00″	80°03′30″	EB	2001
942	42°15′32″	79°49′59″	EB	1996-2000
943	42°34′28″	80°38′32″	CB	1996
944	42°32′02″	80°38′30″	CB	1997-1999
946	42°09′58″	80°38′30″	CB	1997-1999
948	41°57′24″	80°38′26″	CB	1996-2000
950	42°35′16″	81°26′28″	CB	1996-2000
956	41°41′32″	81°26′30″	CB	1996-2000
959	42°11′41″	82°10′58″	CB	1996-2000
964	41°29′03″	82°11′00″	CB	1996
966	41°59′03″	82°37′34″	WB	1996-2000
967	41°53′30″	82°40′01″	WB	1996-2000
971	41°56′57″	83°03′04″	WB	1996-2000
972	41°51′58″	83°12′00″	WB	1996-2000

Table 4: Sites sampled by the Ontario Ministry of Natural Resources, Wheatley, Ontario.

Site	Latitude	Longitude	Basin	Years Sampled
1	42°04′36″	82°20′24	CB	1997, 1998
2	42°06′18″	82°08′24	CB	1997, 1998
3	41°59′00″	82°08′24″	CB	1997, 1998
4	41°52′48″	82°20′24″	CB	1997, 1998
5	41°53′00″	82°36′48″	WB	1997, 1998
6	41°52′00″	82°45′48″	WB	1997, 1998
7	41°59′30″	82°45′48″	WB	1997, 1998
8	41°59′12″	82°34′30″	WB	1997, 1998

Table 5: Algal genera found in Lake Erie phytoplankton sample analyses, 1995-1997.

Chlorophyta	**Chrysophyta**	**Cryptophyta**	**Cyanophyta**	**Pyrrhophyta**
Actinastrum	*Asterionella*	*Chroomonas*	*Anabaena*	*Ceratium*
Ankistrodesmus	*Cocconeis*	*Cryptomonas*	*Aphanizomenon*	*Gymnodinium*
Carteria	*Coscinodiscus*	*Rhodomonas*	*Aphanocapsa*	*Peridinium*
Characium	*Cyclotella*		*Aphanothece*	
Chlamydomonas	*Cymbella*		*Chroococcus*	
Closteriopsis	*Dinobryon*		*Merismopedia*	
Closterium	*Fragilaria*		*Microcystis*	
Coelastrum	*Gomphonema*		*Lyngbya*	
Cosmarium	*Mallomonas*		*Oscillatoria*	
Crucigenia	*Melosira*		*Spirulina*	
Dictyosphaerium	*Navicula*			
Dimorphococcus	*Nitzschia*			
Franceia	*Opephora*			
Gonium	*Rhizosolenia*			
Kirchneriella	*Rhoicosphenia*			
Lagerheimia	*Stephanodiscus*			
Micractinium	*Surirella*			
Oocystis	*Synedra*			
Pandorina	*Tabellaria*			
Pediastrum				
Scenedesmus				
Schroederia				
Sphaerocystis				
Spirogyra				
Staurastrum				
Synura				
Tetraedron				
Treubaria				

Table 6: Zooplankton taxa found in analyses of samples from Lake Erie, 1995-2001.

Cladocerans	**Cyclopoid Copepods**	**Calanoid Copepods**	**Rotifers**
Bosmina longirostris	*Acanthocyclops vernalis*	*Epischura lacustris*	*Asplanchna* sp.
Cercopagis pengoi	*Cyclops scutifer*	*Eurytemora affinis*	*Brachionus* spp.
Ceriodaphnia spp.	*Diacyclops bicuspidatus thomasi*	*Leptodiaptomus ashlandi*	*Kellicottia* spp.
Chydorus spp.	*Ergasilus* sp.	*Leptodiaptomus minutus*	*Keratella* spp.
Daphnia ambigua	*Eucyclops agilis*	*Leptodiaptomus sicilis*	*Ploesoma* spp.
Daphnia galeata mendotae	*Eucyclops speratus*	*Leptodiaptomus siciloides*	*Polyarthra* spp.
Daphnia longiremis	*Mesocyclops edax*	*Limnocalanus macrurus*	Unidentified Rotifers
Daphnia parvula	*Paracyclops fimbriatus poppei*	*Skistodiaptomus oregonensis*	
Daphnia pulex	*Tropocyclops prasinus mexicanus*	*Skistodiaptomus reighardi*	
Daphnia retrocurva	Cyclopoid Nauplii	Calanoid Nauplii	
Daphnia schodleri			**Mollusks**
Diaphanosoma spp.			*Dreissena* veligers
Eubosmina coregoni			
Leptodora kindti			

Table 7. Graduate and undergraduate research programs that have used data generated by this project.

Doctoral Students:

Lisa Babcock-Jackson. 2000. Toxic *Microcystis* in western Lake Erie: Ecotoxicological relationships with three non-indigenous species increase risks to the aquatic community. Currently employed at American Chemical Society's Chemical Abstracts Service in the Toxicology Section, Columbus, OH.

Ruth Pontius. 2000. The impact of zebra mussels (*Dreissena polymorpha*) on pelagic food webs. Currently employed: Assistant Professor, Biology, Ohio University- Chillicothe, Chillicothe, OH.

William Edwards. (2002) The role of turbulent mixing in pelagic-benthic coupling in Lake Erie. Assistant Professor, Environmental Sciences, Niagara University, Niagara, NY (August 2002).

Hongyan Zhang. (2003) Relative importance of nutrient loading and zebra mussel impacts in Lake Erie changes: A modeling approach.

Doug Kane. (2004) Development of an Index of Biotic Integrity for Lake Erie based on phytoplankton and zooplankton analyses.

Master's Students:

Leon Boegman. 1999. Application of a Two-Dimensional Hydrodynamic and Water Quality Model to Lake Erie. Department of Mechanical and Industrial Engineering, University of Toronto, Canada. Currently a doctoral student in Australia.

Paul Frost. 1997. Temporal and spatial variability in plankton in Lake Erie. Completed Ph.D. at Arizona State University. Currently Postdoctoral Fellow, Notre Dame University, West Bend, Indiana.

Gouthaman Gopalan. 1998. Development of an Electron Transport System enzyme assay for measuring respiration rates in free-ranging juvenile fish. Currently in an Environmental Science position, Vancouver, BC, Canada.

Kristina Weisgerber. 1999. Lower trophic level dynamics in western basin, Lake Erie: Changes in biomass, clearance, and nutrient excretion rates in crustacean zooplankton versus zebra mussels. Currently in Environmental Education, Martinez, Georgia.

Undergraduate Research Projects (Honors students):

Julie Richey (2003). Length-weight relationships in three Great Lakes calanoid copepods: *Epischura lacustris, Limnocalanus macrurus,* and *Eurytemora affinis.*

Jenny Drust (2002). A comparison of three methods for estimating Great Lakes zooplankton productivity from biomass and water temperature estimates.

Table 8. Presentations related to this project. Those for which abstracts may be found in the appendix are so marked.

Culver, David A. Trends in Lake Erie zooplankton, 1970-1998. Presentation to the Lake Erie Zooplankton Summit, Canada Centre for Inland Waters, Burlington, Ontario, Canada. 26 March 1999.

Culver, David A. Zebra Mussels, Eutrophication, and Fluid Mechanics -OR- Why Aquatic Biologists and Engineers Should Occasionally Confer. Department of Civil and Environmental Engineering, University of Illinois, Champaign, IL. 14 April 1999. Abstract included in Appendix to this report.

Culver, David A., Hui Li, and Lisa Babcock-Jackson. Lake Erie Phytoplankton at the Millenium: Nutrients, Zebra Mussels, and the Future. Invited presentation to the Binational Conference on Lake Erie at the Millenium - Changes, Trends, and Trajectories. University of Windsor, Windsor, Ontario, Canada, 26-28 April 1999. Abstract included in Appendix to this report.

Culver, David A. Ecological Modeling of Lake Erie Trophic Dynamics - 1999. USEPA/International Joint Commission on the Great Lakes invited White Paper. Presented to the Lake Erie Modeling Summit at the International Association of Great Lakes Research Meetings, Case Western Reserve University, 27 May 1999. Abstract included in Appendix to this report.

Edwards, William J., and David A. Culver. Algal consumption in the western basin, Lake Erie: the impacts of turbulent mixing. American Society of Limnology and Oceanography, Santa Fe, NM, June 1999.

Culver, David A. Modeling Lake Erie lower trophic level dynamics. Presented to Collaborative research plan development conference, Canada-US researchers. Natural Sciences and Engineering Research Council of Canada, Collaborative Research Opportunity. Great Lakes National Program Office, USEPA, Grosse Ile, MI. 7 October 1999.

William J. Edwards, David A. Culver, Chris R. Rehmann, David Rockwell, and Sandra Hellman. 2000. Mixing processes and oxygen depletion in the central basin of Lake Erie: Current status of lake recovery. Ocean Sciences Meetings of the American Geophysical Union. January 24-28, 2000, San Antonio, Texas

Culver, D. A. 2001. Zebra mussels, eutrophication, and fluid mechanics - OR - Why aquatic biologists and engineers should occasionally confer. Dept. Earth and Environmental Sciences, Lehigh University, Bethlehem, PA, 1 March 2001.

Culver, D. A. 2001. Recent changes in the plankton dynamics of Lake Erie. Binational Conference, Lake Erie in the Millennium -- Progress and New Issues, University of Windsor, Windsor, Ontario, Canada, March 28-29, 2001.

Culver, D. A. 2001. Dreissenid mussels and the boundary layer: Restrictions on benthic-pelagic coupling. Invasive Species Conference, Kent State University, 4 April 2001.

Edwards, W. J. and D. A. Culver. 2001. Water motion and primary production in the central basin of Lake Erie. 44th Conference of the International Association for Great Lakes Research, Univ. of Wisconsin, Green Bay, WI, June 10-14, 2001.

Kane, D. D. and D. A. Culver. 2001. Development of a planktonic Index of Biotic Integrity for Lake Erie. 44th Conference of the International Association for Great Lakes Research, University of Wisconsin, Green Bay, WI, June 10-14, 2001.

Pontius, R. A. and D. A. Culver. 2001. An ecosystem approach to estimating zebra mussel impact. 44th Conference of the International Association for Great Lakes Research, Univ. of Wisconsin, Green Bay, WI, June 10-14, 2001.

Zhang, H. and D. A. Culver. 2001. Ecological modeling of *Daphnia* in Lake Erie. 44th Conference of the International Association for Great Lakes Research, University of Wisconsin, Green Bay, Wisconsin, June 10-14, 2001.

Culver, D. A. 2001. Recent ecological changes in Lake Erie. Ohio Coastweeks Celebration, 6 September 2001, Mentor, OH.

Table 9. Peer-reviewed papers published or in press that directly resulted from this project.

Brittain, Scott M., Jim Wang, Lisa Babcock-Jackson, Wayne W. Carmichael, Kenneth L. Rinehart, and David A. Culver. 2000. Isolation and characterization of microcystins, cyclic heptapeptide hepatotoxins, from a Lake Erie strain of *Microcystis aeruginosa*. *Journal of Great Lakes Research* 26:241-249.

Pontius, Ruth A., and David A. Culver. 2000. Estimating zebra mussel impact on pelagic food webs: The role of size-specific grazing rates. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie* 27(5): 3025-3028.

Budd, J.W., A. M. Beeton, R. P. Stumpf, D. A. Culver, and W. C. Kerfoot. 2000. Satellite observations of *Microcystis* blooms in western Lake Erie and Saginaw Bay, Lake Huron. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie* 27: 3787-3793.

Culver, David A. 2000. Ecological modeling of Lake Erie trophic dynamics – 1999, Pages 65-70. *In* L. A. Tulen and J. V. DePinto, Eds. Great Lakes Modeling Summit: Focus on Lake Erie. Council of Great Lakes Research Managers, International Joint Commission on the Great Lakes, Windsor, Ontario.

Boegman, Leon, Mark R. Loewen, Paul F. Hamblin, and David A. Culver. 2001. Application of a two-dimensional hydrodynamic reservoir model to Lake Erie. *Canadian Journal of Fisheries and Aquatic Sciences* 58:858-869.

Frost, Paul C. and David A. Culver. 2001. Spatial and temporal variability of phytoplankton and zooplankton in western Lake Erie. *J. Freshwater Ecology* 16:435-443.

Culver, David A., Hui Li, and Lisa Babcock-Jackson. (2002) Lake Erie phytoplankton at the Millennium: Nutrients, zebra mussels, and the future. Lake Erie at the Millenium (in press).

1995 Lepas Sampling Sites

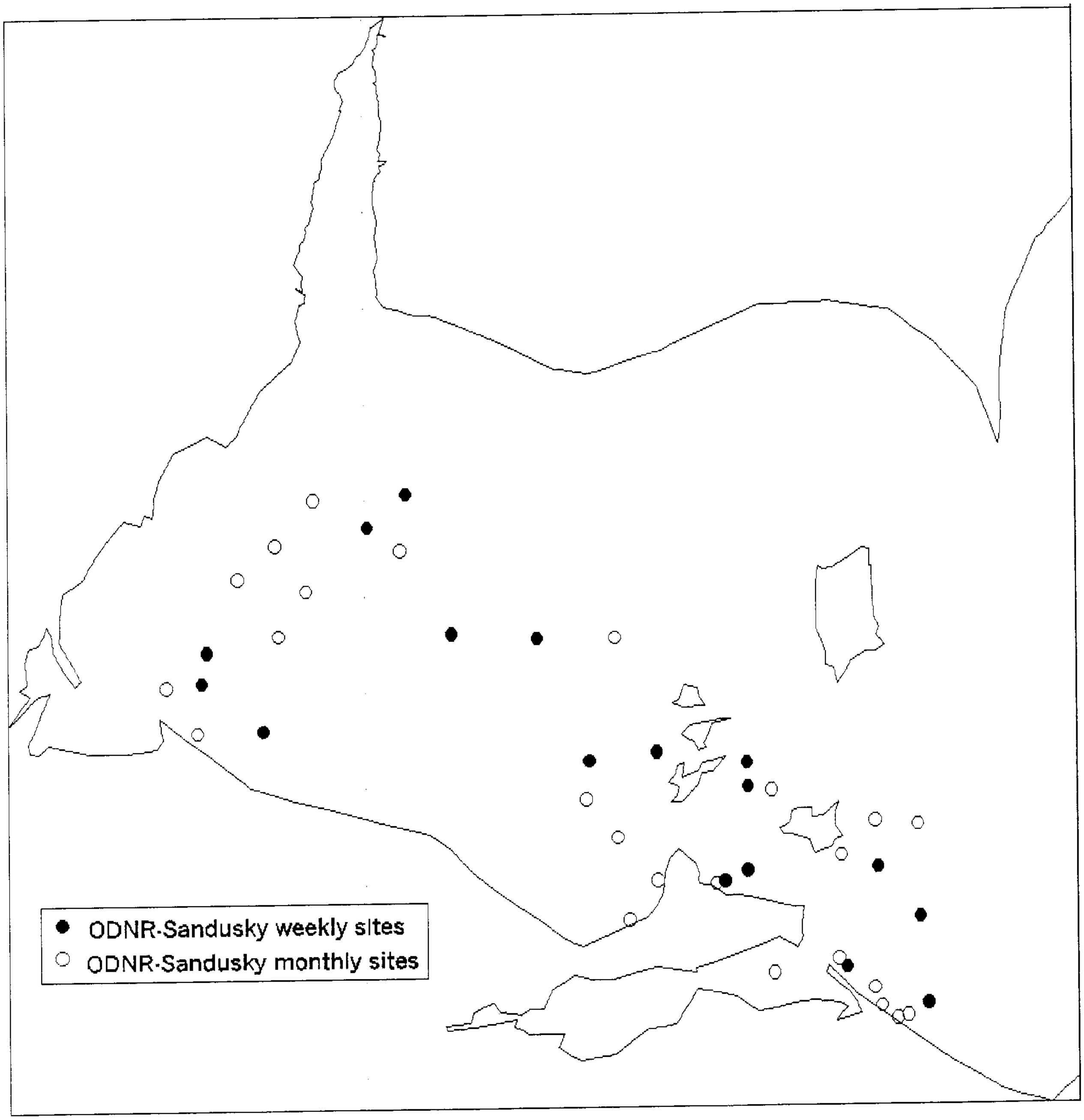
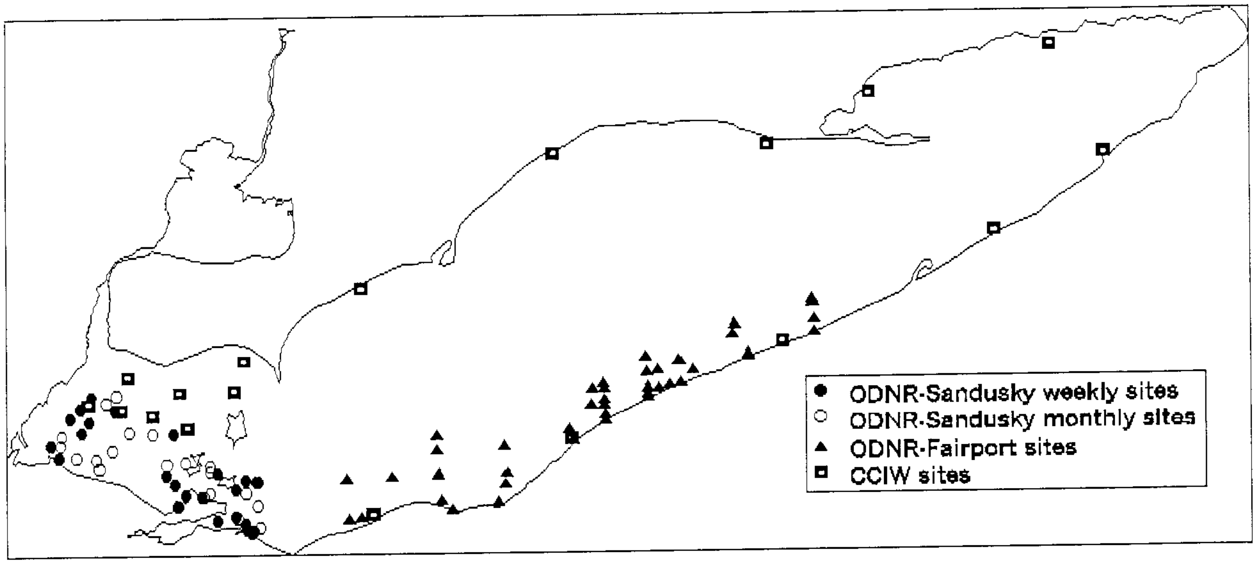


Figure 1. Locations of western Lake Erie sample sites for 1995. "Lepas" refers to the Lake Erie Plankton Abundance Study. All sites were sampled by the Ohio Division of Wildlife's Sandusky Laboratory, either weekly (solid circles) or monthly (hollow circles).

1996 Lepas Sampling Sites



1997 Lepas Sampling Sites

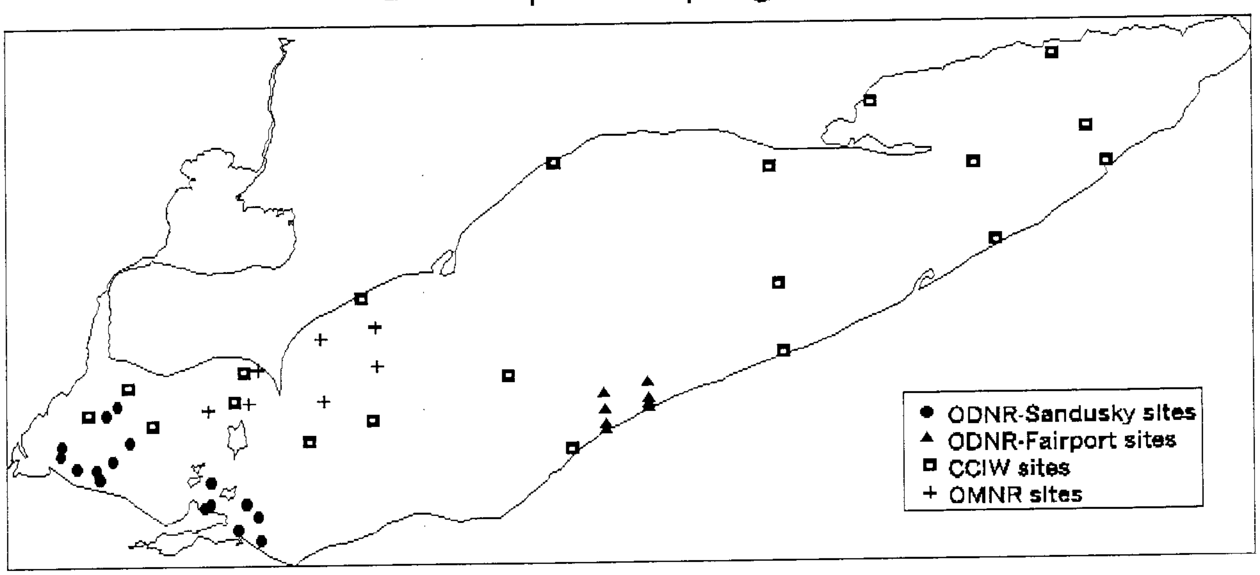
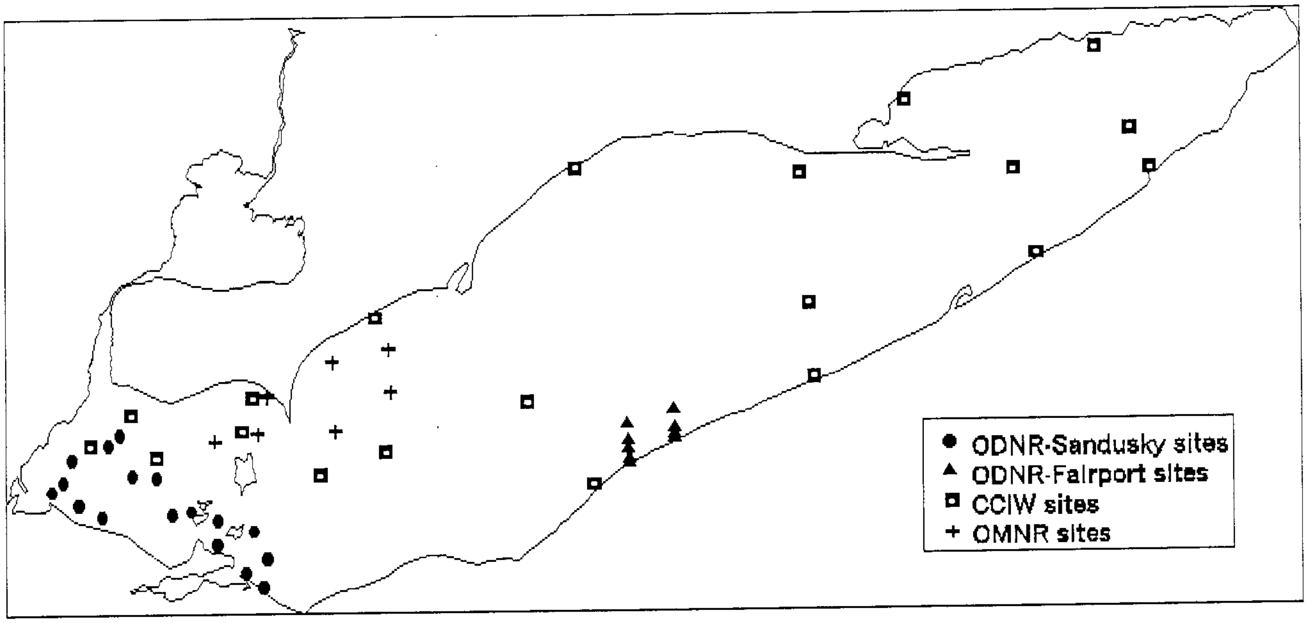


Figure 2 (upper) and Figure 3 (lower). Locations of Lake Erie field sampling in 1996 and 1997. Sites sampled by the Ohio Division of Wildlife's Sandusky Laboratory are indicated by solid circles, those by the ODW Fairport Laboratory by solid triangles, those by the Canada Centre for Inland Waters as hollow squares, and those by the Ontario Ministry of Natural Resources by a plus (+) sign.

1998 Lepas Sampling Sites



1999-2000 Lepas Sampling Sites

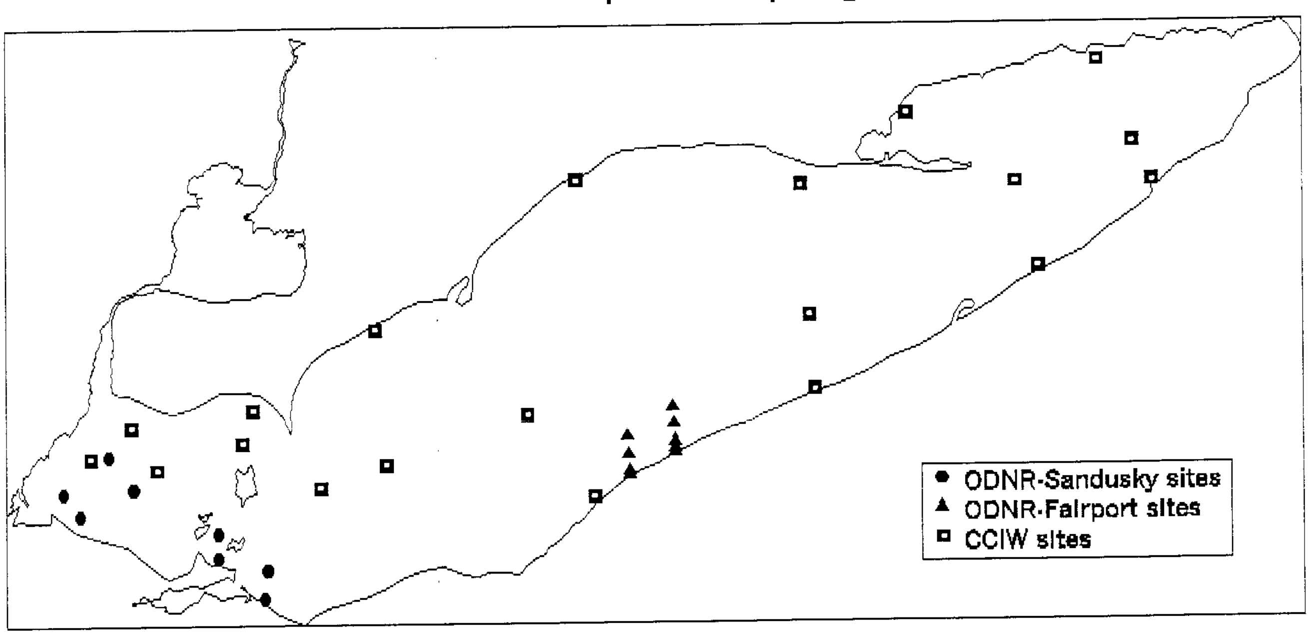


Figure 4 (upper) and Figure 5 (lower). Locations of Lake Erie field sampling in 1998 and 1999-2000. Sites sampled by the Ohio Division of Wildlife's Sandusky Laboratory are indicated by solid circles, those by the ODW Fairport Laboratory by solid triangles, and those by the Canada Centre for Inland Waters as hollow squares.

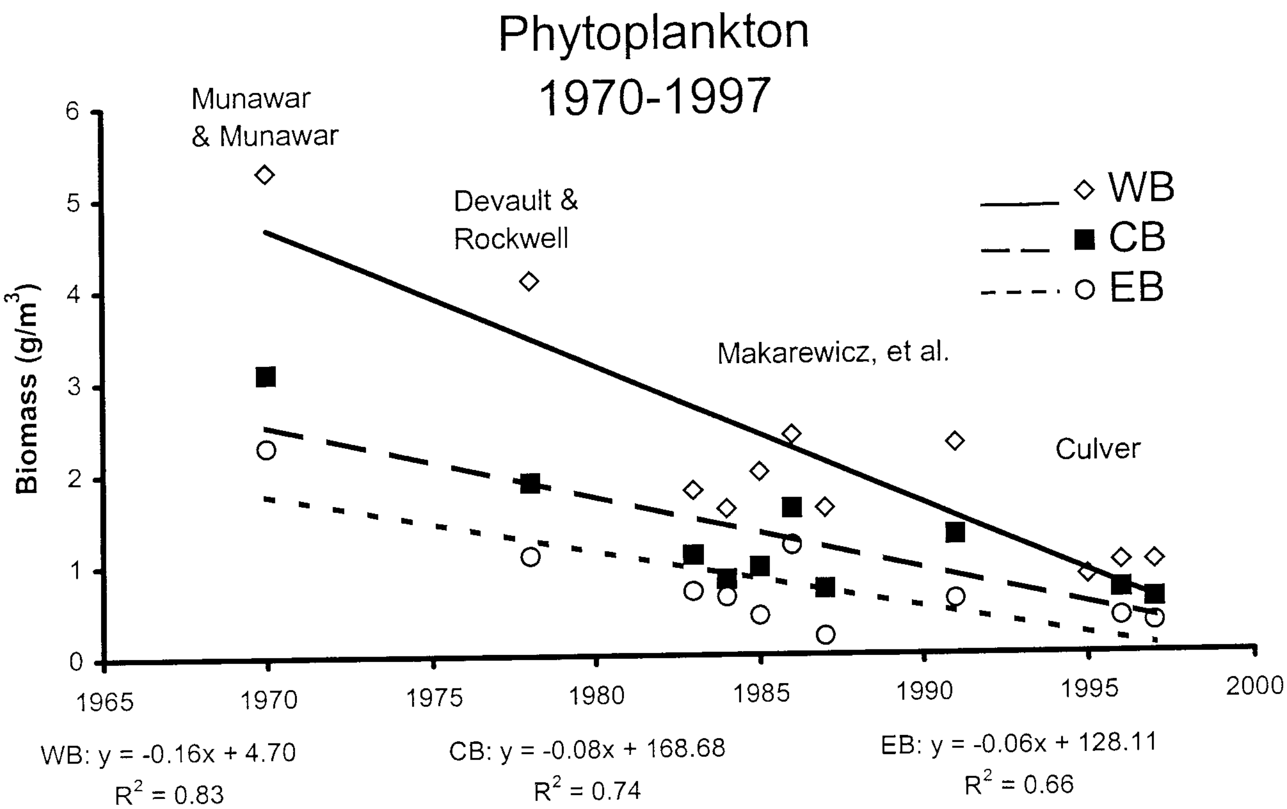


Figure 6. Historical changes in seasonal and spatial average phytoplankton wet weight biomass (all taxa combined) in the western (WB), central (CB), and eastern basins (EB) of Lake Erie since 1970. Samples analyzed as part of the current project are shown for 1997. References for previous studies are listed in the text. Note that locations and dates of samplings were not constant among the different studies. Equations at the bottom of the figure are linear regressions of biomass as a function of time for each basin. Historical data are from Munawar and Munawar (1976), Reutter (1979), Devault and Rockwell (1986), and Makarewicz (1993a).

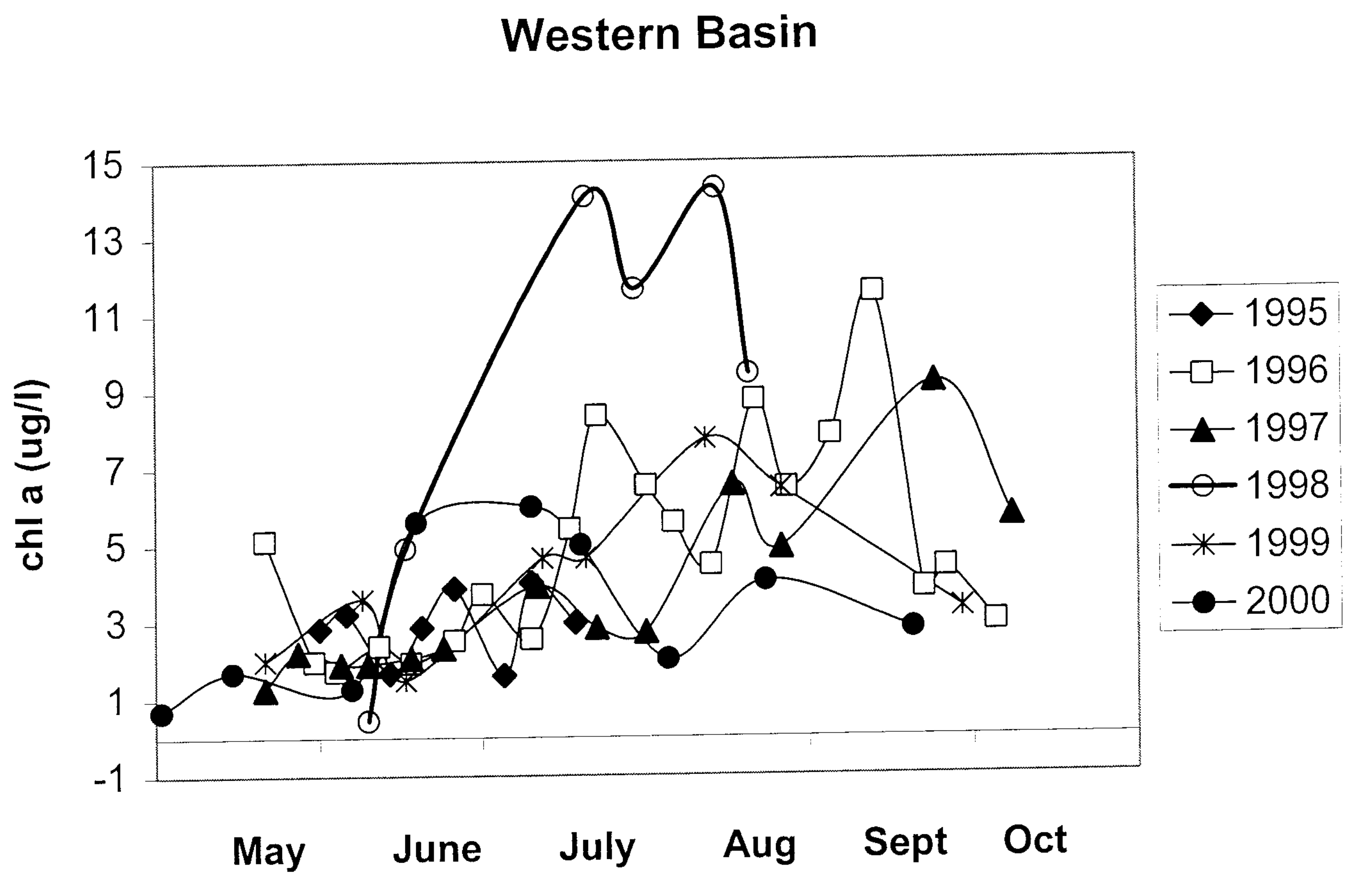


Figure 7. Monthly average chlorophyll *a* concentration in western Lake Erie, 1995 through 2000.

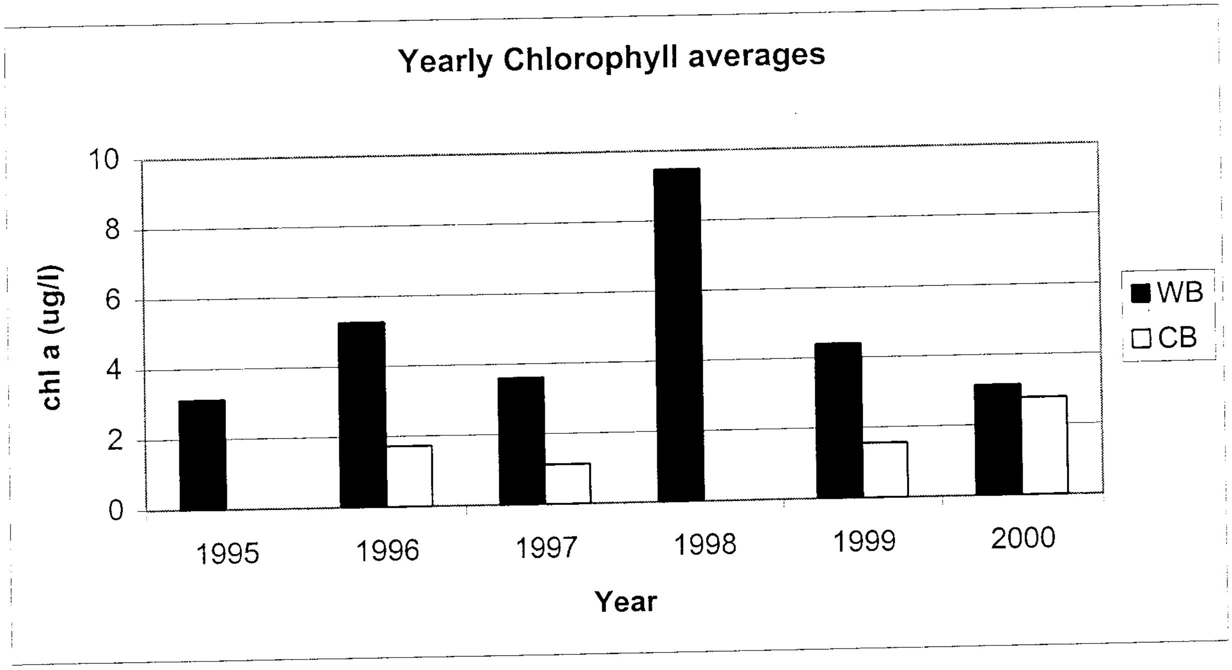


Figure 8. Temporal and spatial average chlorophyll *a* concentration in the western (WB) and Central (CB) Basins of Lake Erie. No data area available for CB from 1995 or 1998.

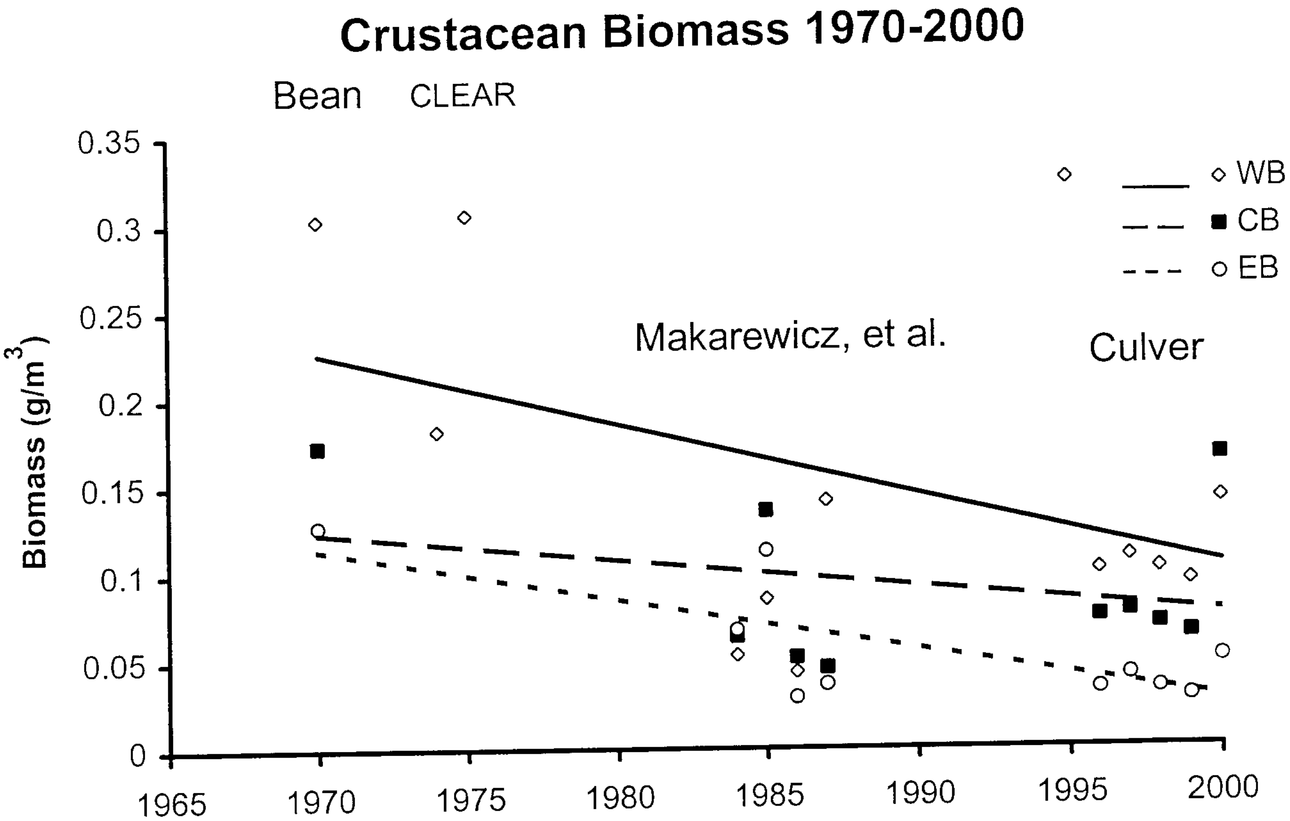


Figure 9. Historical variation in the seasonal and spatial mean of dry weight biomass of crustacean zooplankton in the Western (WB), Central (CB), and Eastern basins (EB) of Lake Erie from 1970-2000. Historical data are from Bean (1980) after Watson and Carpenter 1974, Weisgerber 1999, and Makarewicz 1993b.

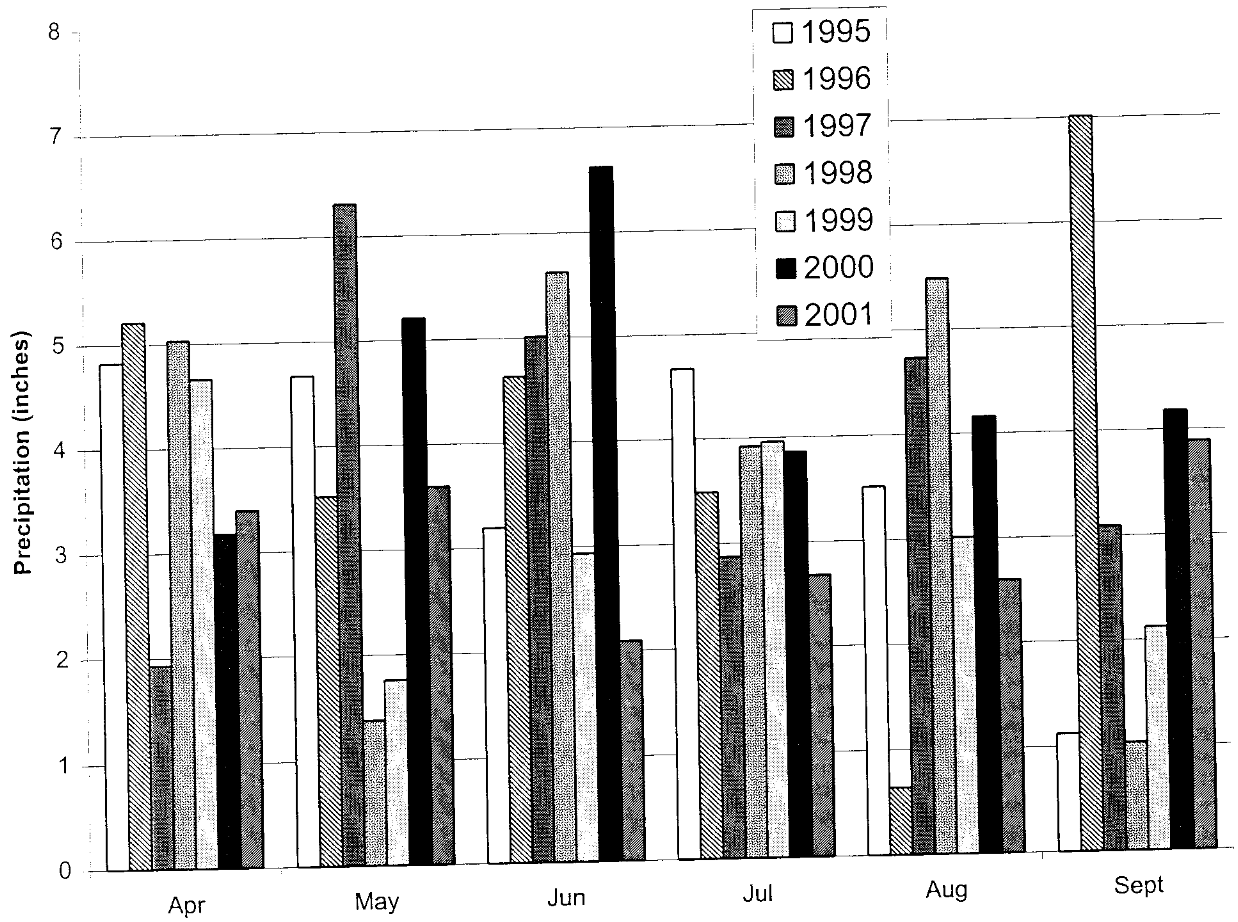


Figure 10. Year-to-year variation in rainfall (by month) in western Lake Erie (NOAA Ohio Region 2 data), for the Sandusky River drainage basin. There is no consistent relationship between summer rainfall and blue-green algal blooms. The years with the largest recent blooms were 1995 and 1998. Data are from USGS.

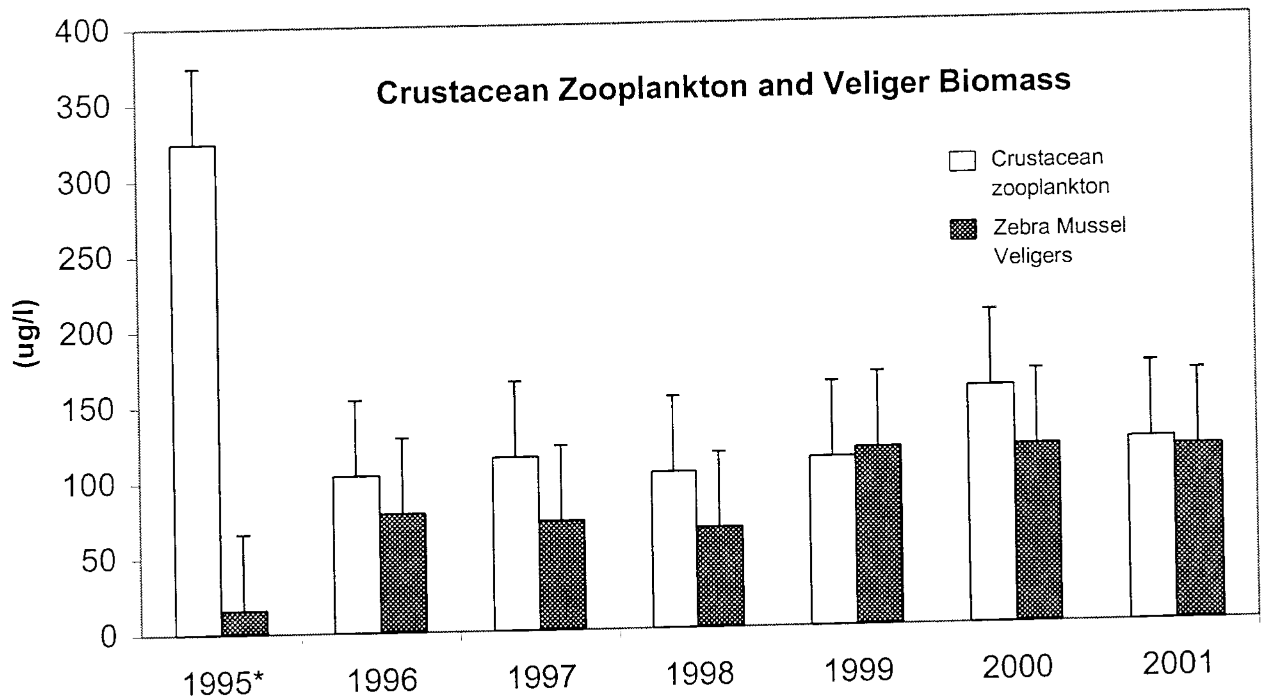


Figure 11. Comparison of spatial and temporal average biomasses of dreissenid veligers and crustacean zooplankton for western Lake Erie. Note that the average for 1995 is biased by the fact that sampling stopped in early July, whereas other years extended through September.

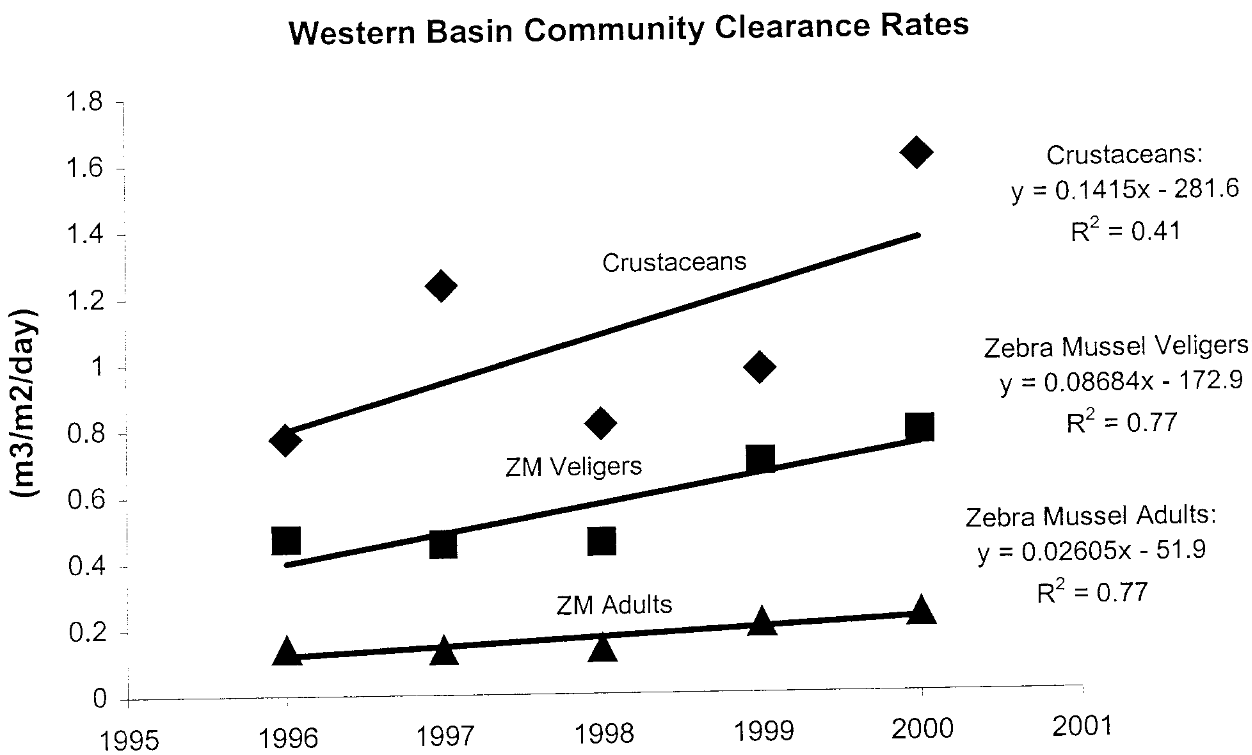


Figure 12. Seasonal and spatial average clearance rates ($m^3/m^2/day$) for crustacean zooplankton, dreissenid veligers (zooplankton), and dreissenid adults (benthos) in the Lake Erie Western Basin. Planktonic clearance rates are expressed in area units ($m^3/m^3/day$) x water depth (m) = ($m^3/m^2/day$) to facilitate comparison with the benthic adult dreissenids.

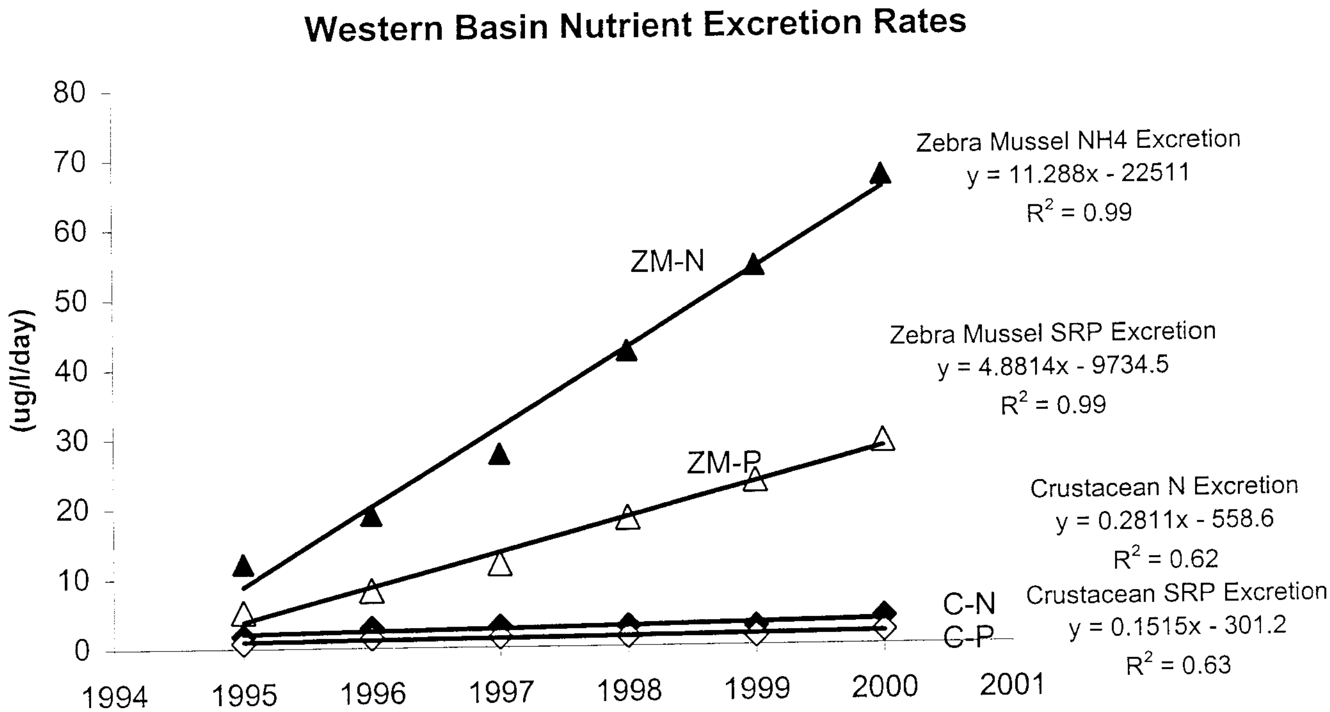


Figure 13. Comparison of estimates of ammonia and soluble reactive phosphate excretion by crustacean zooplankton and adult dreissenids in western Lake Erie. No excretion estimates for veligers are available.

APPENDIX Selected Abstracts from Presentations

Lake Erie Phytoplankton at the Millennium: Nutrients, Zebra Mussels, and the Future.

David A. Culver[1,2], Hui Li[1], and Lisa Babcock-Jackson[1]

[1]Department of Evolution, Ecology, and Organismal Biology, The Ohio State University, Columbus, OH 43210, USA
[2]Corresponding Author (culver.3@osu.edu)

Abstract Since 1970, decreased phosphorus and increased nitrogen input have affected the functioning of the Lake Erie pelagic ecosystem (including algal, zooplankton, and fish abundances), even before the introduction of dreissenids further altered biological balances in the lake. May-August mean algal biomass (mg wet weight/l) in the western basin declined from 5.3 (1970) to 2.0 (1985) to 0.9 (1995-97). Algal biomass data for the central and eastern basins for these years were (3.1, 1.0, 0.7) and (2.3, 0.4, 0.4), respectively.

The cyanophyte blooms that were so common in the 1970s have abated, with Chrysophyta and Cryptophyta dominating in 1996-97 in the western basin (67% and 21%, respectively). Central basin algae were dominated by Chrysophyta (55%), Cryptophyta (24%), and Pyrrhophyta (10%). Nevertheless, major blooms of toxic strains of Microcystis occurred in the western basin in 1995 and 1998, suggesting that phosphorus and ammonia availability may be increasing. Various lines of evidence suggest that zebra mussel excretion of phosphorus and nitrogen has increased nutrient content of the lake, at least in the western and west central basins. The highest algal concentrations occur in areas of agricultural runoff (e.g.. at the mouths of the Maumee and Sandusky Rivers), municipal discharge (e.g., around the Bass Islands and near Cleveland), and in areas where frequent upwelling bring nutrient-rich water to the surface (e.g., east of Long Point).

The algae not only form the base of the pelagic foodweb, but also contribute in major ways to toxin (e.g. microcystin), taste and odor (e.g., geosmin), and low oxygen (e.g., central basin hypolimnion) components of water quality.

If zebra mussels are responsible for the recent cyanophyte blooms, their expansion over soft sediments suggests that Lake Erie algal blooms may continue to increase. In effect, increased internal loading of nutrients will counteract progress made in limiting external loading.

Better understanding of the role of turbulent mixing on the impact benthic zebra mussels on pelagic algae is required. We also need much more information on spatial distribution and size distribution of zebra and quagga mussels, particularly as they expand to low turbulent energy, soft substrates. Most of our data on phytoplankton distribution are from surface samples, whereas it is clear that highest concentrations may be far below the surface. Even so, remote sensing of chlorophyll distribution will enable us to better model variation in surface algal abundance under the influences of rivers, cities, and upwelling events. Seasonal variation in phosphorus, nitrogen, and silica loadings are needed desperately for the modeling efforts, at a time when information is becoming increasingly scarce, particularly for the Detroit River.

Zebra Mussels, Eutrophication, and Fluid Mechanics -OR- Why Aquatic Biologists and Engineers Should Occasionally Confer

By David A. Culver
Department of Evolution, Ecology and Organismal Biology
The Ohio State University
Columbus, OH 43210

Presented to the Department of Civil Engineering, University of Illinois-Champaign/Urbana

When zebra mussels were found in Lake Erie in 1988, many looked at the 0.8 liters of water passing through the siphons of a 20 mm adult mussel and decided that soon all the algae would be gone from the lake and that the whole planktonic food web supporting the economically important sport fish community would collapse. Recent collapse of the yellow perch fishery in southern Lake Michigan has similarly been blamed by sum on the zebra mussel. These analyses ignore important boundary layer features of stratified and unstratified fluids. So long as the system involved dissolved nutrients being assimilated by algae, which are in turn consumed by zooplankton that migrated vertically, totally mixed reactor models worked fairly well. Once a major herbivore arrived on the lake bottom, however, fluid mechanics must be incorporated into models of the biological processes.

Once the boundary layer effects are taken into account, it may well be that zebra mussels may have greater impact via their excretion of dissolved phosphate and ammonia that encourage algal blooms than they are through their consumption of algae. In this seminar, Dr. Culver discusses the problems of zebra mussel impacts in Lake Erie, using the results of measurements he and Dr. Ellen McDonald have made using Acoustic Doppler Profiler (ADP) suspended over a zebra mussel bed in the western basin. In the central basin, they used a Temperature Gradient Microprofiler (TGMP) to estimate turbulent mixing variation with season, time of day, and depth in Lake Erie. Combining measures of turbulent diffusion with concentration gradients of algae, chlorophyll, oxygen, phosphate, and ammonia have enabled the estimation of fluxes of these materials throughout the water column. Studies of the growth of caged zebra mussels also illustrate the effects of the concentration boundary layer on the mussels' access to algae.

Ecological Modeling of Lake Erie Trophic Dynamics - 1999

by David A. Culver

Department of Evolution, Ecology, and Organismal Biology
The Ohio State University
Columbus, OH 43210
U.S.A.

Abstract Since1970, decreased phosphorus and increased nitrogen input have affected the functioning of the Lake Erie pelagic ecosystem (including algal, zooplankton, and fish abundances), even before the introduction of dreissenids further altered biological balances in the lake. The temporal and spatial heterogeneity of the lake requires mathematical modeling techniques to separate the effects of these changes, and to provide opportunities to allow prediction of long term variation in water quality and fish production. We include vertical turbulent transport of algae and nutrients in our model, because zebra mussels affect the ecology of the lake from their position within the benthic concentration boundary layer, both by consuming suspended and benthic algae and by mineralizing these materials and releasing nutrients at very high rates. The previous plankton-dominated system worked much differently. Accordingly, we are particularly interested in changes in the role of zebra mussels in the internal loading of nutrients and transfer of toxic compounds, both of which are reflected in the changes in the abundance and ecology of toxic cyanobacteria (e.g. *Microcystis*) in the lake. We are using intensive sampling of plankton and water quality from 1995 through 1998 to calibrate the models.