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Great Lakes Research Consortium

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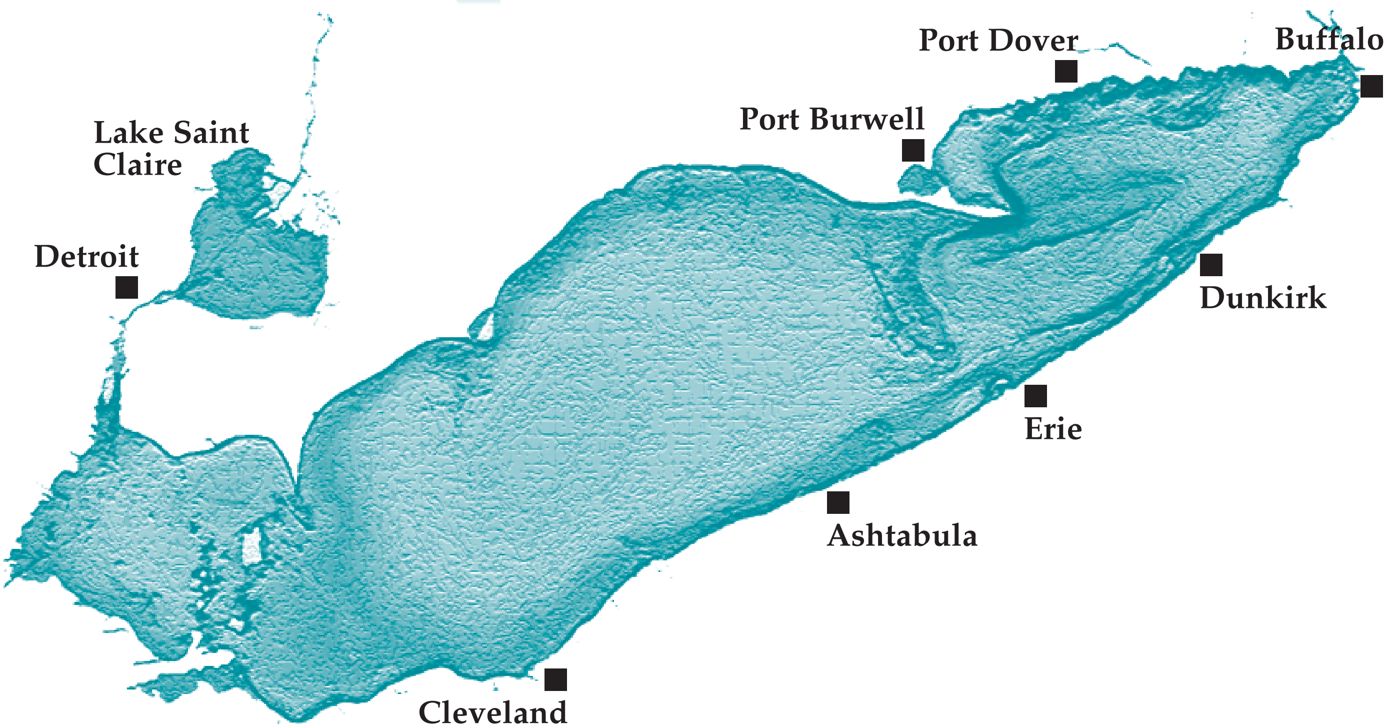
Great Lakes Research Review

great lakes program
GREAT LAKES RESEARCH CONSORTIUM
Sea Grant New York
Working together for Great Lakes research and education

Lake Erie Ecosystem



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Great Lakes Research Review

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ABOUT THIS PUBLICATION:

Several years ago, staff from the Great Lakes Program, the Great Lakes Research Consortium, and New York Sea Grant realized an information gap existed between peer reviewed journal articles and newsletter type information related to Great Lakes research. The Great Lakes Research Review was created to fill that gap by offering a substantive overview of research being conducted throughout the basin. This publication is designed to inform researchers, policy-makers, educators, managers, and stakeholders about Great Lakes research efforts.

This fifth volume focuses on the Lake Erie ecosystem. Other issues have focused on the fate and transport of toxic substances, fisheries issues, exotic species and the Lake Ontario–St. Lawrence ecosystem.

The Great Lakes Program at the University at Buffalo gratefully acknowledges all of the contributing authors who willingly shared their research efforts for this publication.

Questions concerning this issue may be addressed to the editor, Helen M. Domske, Associate Director, Great Lakes Program. Those who are interested in obtaining copies of the first four issues may contact the Great Lakes Program.

THE UPCOMING ISSUE:

The second issue of Volume Five will also address the topic of the Lake Erie Ecosystem. Those who may have questions concerning the next issue, or authors interested in contributing material, should contact Jack Manno, Executive Director of the Great Lakes Research Consortium.

DEDICATION:

This issue marks the final version produced under the guidance of Dr. Joseph DePinto, who served as Director of the Great Lakes Program for the past decade.

Dr. DePinto was one of the originators of this publication and has been a contributor in several issues. We wish him well as he moves to LimnoTech in Ann Arbor, Michigan. Hopefully, he will again share his research results in future issues of the GLRR.

Great Lakes Research Review
Volume 5, No. 1, Summer 2000

Introduction

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This issue of the Great Lakes Research Review brings together papers related to Lake Erie and its fishery, exotic species, aquatic macrophyte communities and the resurgence of its mayfly populations. Lake Erie has been the focus of research on these topics for a number of years. The research was necessitated by the ecological problems that have been brought on by the stresses of urbanization, industrialization and agriculture.

Lake Erie is the smallest in volume of the Great Lakes, and the second smallest in surface area. Its shallow waters allow the lake to warm quickly in the spring and summer and cool quickly in the fall. The shallowness of the basin and the warmer temperatures contribute to Lake Erie's biological productivity. As the most biologically productive of the Great Lakes, the lake has been impacted by commercial overfishing and resource exploitation.

Although biological productivity has been a great ecological benefit to Lake Erie, increased nutrient loading that took place between the 1950s and 1970s actually made the lake too productive, causing a serious eutrophication problem. This accelerated eutrophication created extensive algae blooms that were harmful to the environment and unpleasant to human senses. Mats of *Cladophora* — a long, green, filamentous algae, covered the shoreline in slimy masses and gave off a foul odor as it decayed. As algae died and settled to the bottom to decay, it used up oxygen in the bottom waters of the lake, creating anoxic areas. The central basin of Lake Erie is particularly susceptible to oxygen depletion and this basin suffered from periods of anoxia during these decades. During anoxic periods, biological communities are stressed or eliminated and chemical processes at the bottom of the lake are altered, impacting the recycling of pollutants and sediments. The decline of *Hexagenia* populations were related to these anoxic conditions and the inhospitable environment it created for mayfly nymphs.

Intensive agriculture and increased urbanization contributed to the eutrophication problems. These decades also saw significant increases in industrialization and the formulation of new chemicals which eventually led to the accumulation of persistent toxic chemicals in water, sediment, fish and wildlife. Along with problems related to its fishery, eutrophication and chemical pollution, Lake Erie also suffered from habitat destruction and other ecological problems such as the introduction of exotic species that have had ecological impacts.

Actions have been taken to deal with Lake Erie's ecological problems. In accordance with the Great Lakes Water Quality Agreement, the governments of Canada and the United States initiated planning for the development of a Lakewide Management Plan (LaMP) for Lake Erie. The U.S. Environmental Protection Agency and Environment Canada are the federal co-leads for the Lake Erie LaMP. In 1995, the Lake Erie LaMP Concept Paper was developed to provide a framework for LaMP activities

(U.S.EPA 1995). Binational committees were established to begin the actual development of the Lake Erie LaMP. Since that time, a Status Report was completed in 1999 (U.S. EPA and Environment Canada 1999) and the Lake Erie LaMP 2000 has just been produced.

The recently completed Lake Erie LaMP 2000 report states that "the Great Lakes Water Quality Agreement specifies that LaMPs be completed in four stages: 1) definition of the problem; 2) determination of load reduction schedules; 3) selection of remedial measures; and 4) indication that the contribution of critical pollutants to impairment of beneficial uses has been eliminated. These stage descriptions suggest that the LaMPs are to focus solely on the impact of critical pollutants to the lakes. However, the group of government agencies designing the Lake Erie LaMP felt it was also an opportunity to address other equally important issues in the lake." Instead of focusing only on critical pollutants, the Lake Erie LaMP uses an ecosystem approach, integrating environmental protection and natural resource management.

"In order to explain clearly the geographic scope of the Lake Erie LaMP, three aspects need to be defined. First, beneficial use impairments were assessed within the waters of Lake Erie, including the open waters, nearshore areas, and river mouth/lake effect areas. Second, the search for the sources or causes of impairments to beneficial uses is being conducted in the lake itself, the Lake Erie watershed, and even beyond the Great Lakes basin. Third, management actions needed to restore and protect Lake Erie may need to be defined and implemented outside of the Lake Erie basin." (Lake Erie LAMP 2000)

Realizing that the LaMP process was both resource and time intensive, efforts were undertaken by a Binational Executive Committee to accelerate LaMP efforts in 1999. This effort focused on action steps and efforts to streamline LaMP review and approval processes. The Lake Erie LaMP 2000 is an outcome of this new approach that treats problem identification, selection of remedial and regulatory measures, and implementation as concurrent, integrated actions rather than sequential ones. The 2000 report is a working document that is based on the current body of knowledge and it states what remedial actions can be presently implemented. The report tries to identify gaps that still exist with respect to research and information, and the LaMP's management committee will recommend actions to close those gaps.

According to the Lake Erie LaMP 2000 report, "the BEC endorsed application of the concept of adaptive management to the LaMP process. By that, we adapt an iterative process with periodic refining of the LaMPs that build upon the lessons learned, successes, information, and public input generated pursuant to previous versions. The LaMPs will adjust over time to address the most pertinent issues facing the lake ecosystems. This revised approach is particularly important to Lake Erie, given the current instability of the Lake Erie ecosystem."

The issues of concern on Lake Erie have certainly changed over the years, reflecting shifts in land use around the basin and lake use changes. Changes in the fishery, pollution, eutrophication, contaminants and exotic changes are all issues of concern clearly represented in the timeline illustrated in Figure 1 of the Lake Erie LaMP 2000 report.

The 2000 report explains that, "the development and implementation of Lakewide Management Plans (LaMPs) are an essential element of the process to restore and maintain the chemical, physical, and biological integrity of the Great Lakes ecosystem. Through the LaMP process, the Parties, with extensive stakeholder involvement, have been defining the problems, finding solutions, and implementing actions on the Great Lakes for almost a decade."

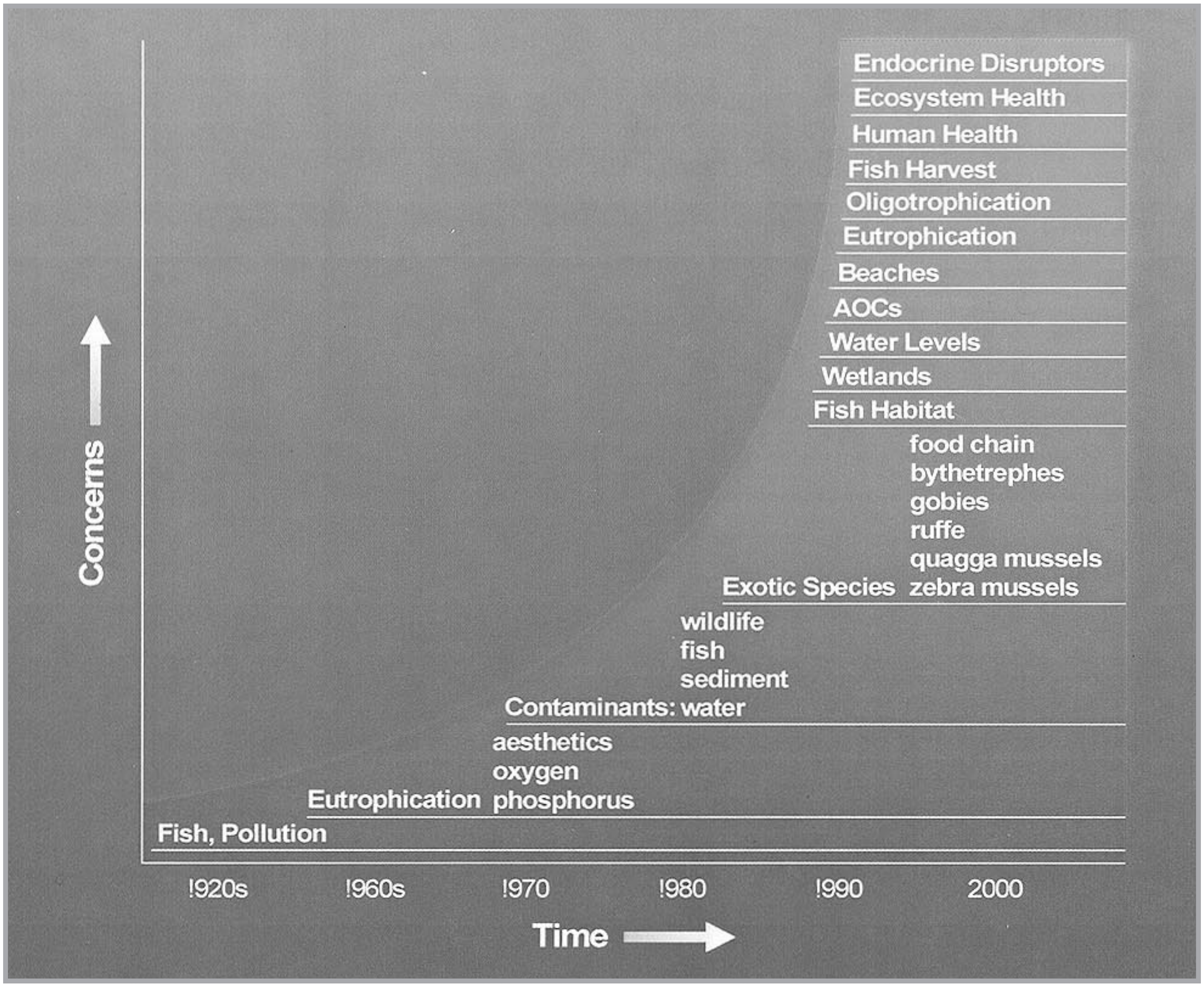

Figure 1: *Changing issues in Lake Erie over time.* (*Taken from Lake Erie LaMP 2000 Report*)

The Lake Erie LaMP has successfully incorporated stakeholder involvement in its development and implementation. One of the most involved groups of stakeholders is the Lake Erie Binational Forum, which provides input on the planning and implementation of the LaMP, and a means of fostering effective two-way communication with the diverse population of the Lake Erie basin. Lake Erie Binational Forum members come together several times each year, at locations around the basin, to work on tasks associated with the goals of the Lake Erie LaMP. Forum members include political representatives, representatives from industry and agriculture, environmentalists, agency representatives, and others interested in Lake Erie.

In order to maximize efforts of the Binational Forum, membership was broken down into a number of technical and non-technical Task Groups. Forum members selected membership on Task Groups based on their interest and expertise. The Task Groups have each developed their own objectives and action plans that are consistent with LaMP goals. Existing Task Groups include: Beneficial Use Impairment, Ecosystem Objectives, Education and Outreach, Funding, Internal Communications, Land Use, Membership, Roles and Objectives, Sources and Loadings, Environmental Justice and Pollution Prevention.

The Forum membership continues to change and grow over time and continues to seek interested, involved citizens to join this binational group. The Binational Forum was involved in the review of the 2000 report. In fact, many of the sections of the report share the same focus of the established Task Groups. To learn more about the Lake Erie LaMP Binational Forum, visit the website at: www.erieforum.org

Interested researchers, managers and stakeholders are strongly urged to read the document, which is available on the Internet. The website addresses are: www.cciw.ca/glimr/lakes/erie or www.epa.gov/glnpo/lakeerie

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New York's Lake Erie Fisheries: Response to Change

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INTRODUCTION

Over the past 50 years, Lake Erie has been subjected to some of the most intense environmental abuses ever forced upon a natural system. Human mismanagement of fish stocks and the environment brought Lake Erie to the brink of disaster by 1970. History has documented the long list of abuses and resultant environmental responses - increased erosion and sedimentation created by human population expansion, and misuse of riparian lands covered critical aquatic habitats used for spawning and altered the lake's productivity potential; domestic and industrial effluents accelerated the natural nutrient loading (eutrophication) (i.e. aging) process and, in many cases, introduced toxic pollutants (i.e. mercury) into the lake, creating health hazards; commercial overexploitation, in conjunction with environmental degradation, led to depressed stocks (i.e. walleye, sturgeon, whitefish, cisco, sauger) and, in some cases, extinction (i.e. blue pike, lake trout); exotic introductions (i.e. gizzard shad, smelt, alewife, white perch, sea lamprey) have colonized the lake and now dominate niches once occupied by native species.

Thanks to the prophetic vision of a handful of scientists and decision-makers, the United States and Canada entered into an agreement to reduce phosphorus loading into Lake Erie via the Great Lakes Water Quality Agreement of 1972. The success of this international agreement, in conjunction with the application of sound agricultural practices and elevated public awareness of environmental issues, has turned trends of the past around. Although many of the primeval lake conditions can never be recovered, many others are showing signs of reversal from past trends and some are still ongoing, therefore, making it too early to speculate on their outcome.

THE RESOURCE

New York has jurisdiction over approximately 6 percent (354,000 surface acres) of the entire Lake Erie resource, all of which is located on the south shore and within the eastern basin (Figure 1). The eastern basin thermally stratifies each summer, providing a diverse habitat for cold, cool and warmwater fish communities. Fisheries have evolved by capitalizing on this diversity.

THE PAST

Lake Erie has a rich fishery history dating back to the mid-1800s. The growth of our young country used Lake Erie's water corridor for easier movement west, and this movement brought with it many problems associated with human populations centered in cities like Buffalo, Erie, Cleveland, Toledo and Detroit. The lake's native fish populations were exploited for their food value due to the development of foreign and domestic markets, facilitated by completion of the Welland Canal, the Erie

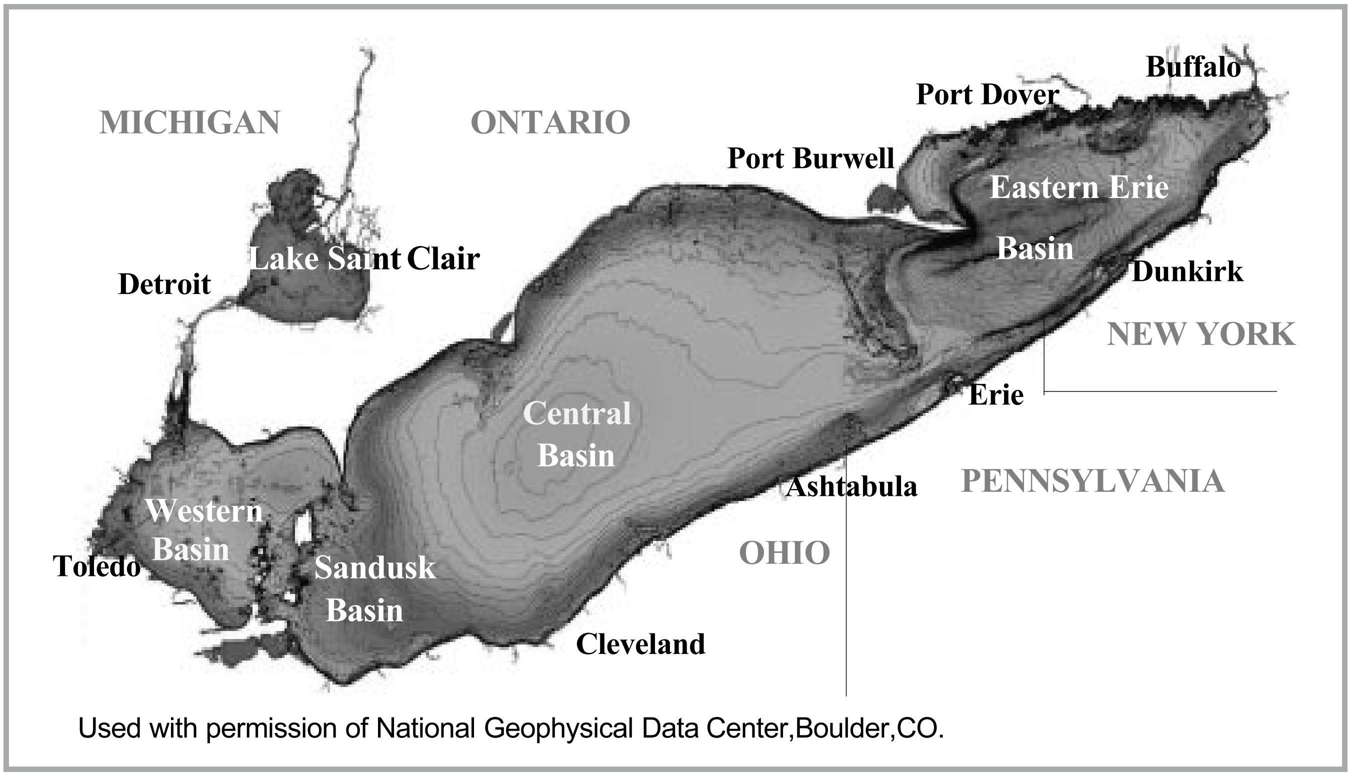

Figure 1. *Area map of Lake Erie showing basins, depth contours and major cities.*

Canal, and the transcontinental rail system. Fish communities of this bygone era were completely unlike those present today.

By the 1950s, habitat damage and overfishing had taken their toll on lake trout, whitefish, cisco, and blue pike populations. Invasion of the rainbow smelt may have been the death knell for these species due to smelt predation efficiency on larval fish.

THE PRESENT

Although dramatic changes have occurred in more modern times resulting from efforts to right the wrongs of the past 70+ years, things are still not where managers want them to be. Three major events have helped shape today's fisheries:

1) Smelt were first reported in Lake Erie in 1935, and they quickly filled the niche vacated by the crash of lake herring in 1925. Smelt were commercially important by 1952, and landings approached 7 million pounds in 1959. Smelt quickly assumed prominence as the primary forage species for most predator populations in the eastern half of the lake, as well as supporting a multi-million dollar commercial fishery in Canadian waters. Such conflicting uses make for a very unstable situation when fisheries are based on an exotic species such as smelt. Current indices of smelt abundance are in a downward trend, and Dermott *et al.* 1999 suggests that low lake productivity (reduced phosphorus) has influenced reduced smelt growth and condition by way of serious declines in deep water amphipod populations (a primary food source of smelt). Poor smelt condition leads to post-spawn die-offs that, in combination with predation and commercial exploitation, have produced annual smelt mortality rates exceeding 90 percent (Ryan *et al.* 1999). Collapse of the smelt population would have dramatic, negative impacts on current fisheries.

2) Reduction of the total phosphorus load, generated by the success of the Clean Water Act in 1972, has had a profound effect on today's fishery. Reduced nutrient levels in the eastern basin have resulted in oligotrophic conditions of high transparency and low productivity. Several populations (smelt, yellow perch and white perch) have declined drastically as an apparent response to declines in productivity. Others, like lake trout, whitefish and burbot have increased over this same time frame.

3) Invasion by other exotic species, most notably zebra/quagga mussels (*Dreissena*) and more recently round goby, raises additional questions about where Lake Erie's fish community will settle in the future. The filtering capacity of dreissenids and their benthic nature have shifted energy flow cycles from favoring pelagic (open water) communities to those benefitting benthic (bottom) communities. The recent emergence of round goby in eastern basin waters floats a very dark cloud of uncertainty over their potential predatory impact on populations of juvenile, native fishes.

Change has happened so rapidly in recent years that environmental managers have been hard-pressed to keep abreast. In many cases, managers are reacting to change instead of having the luxury of anticipating change and then implementing studies to monitor it accordingly.

New York's Department of Environmental Conservation (NYS DEC) office on Lake Erie in Dunkirk has been monitoring fish populations since the late 1970s. Annual assessments targeting specific species provide time series that depict population trends, in general. Many of the current trends can be attributed to one or all of the three significant events outlined previously.

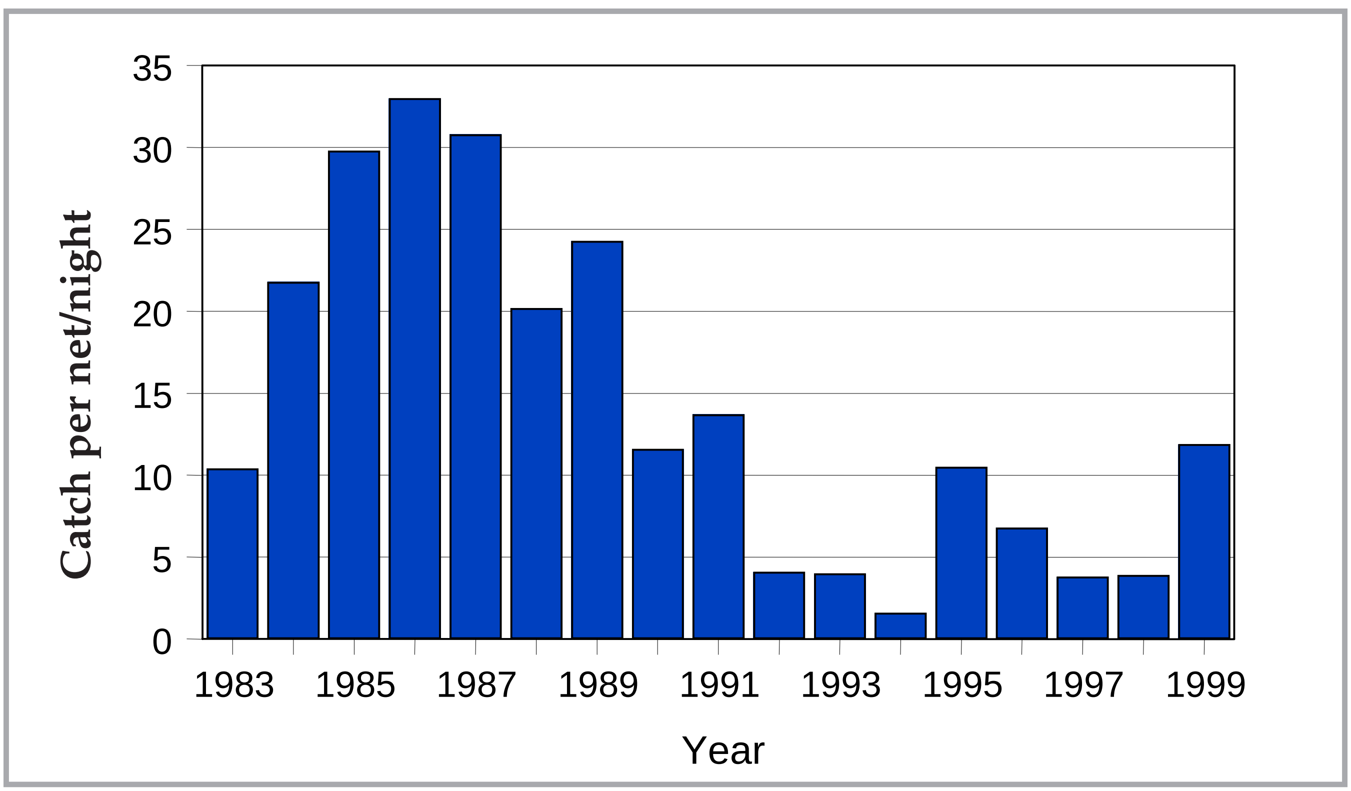

Figure 2. *Relative abundance of WALLEYE sampled each year from New York waters of Lake Erie using standard assessment gill nets, each fall.*

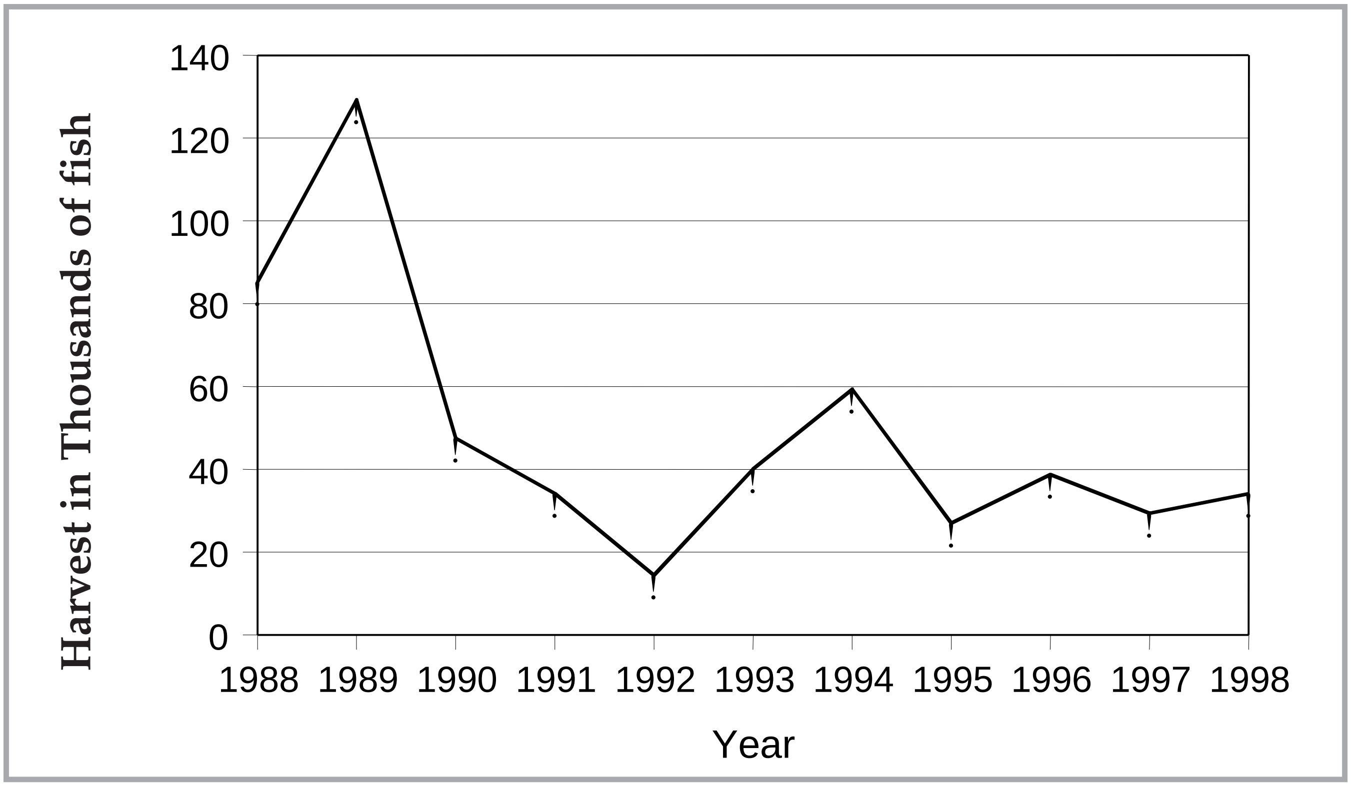

Figure 3. *WALLEYE sport harvest in New York waters of Lake Erie, May-October, 1988-1998.*

WARMWATER FISHERIES

Walleye

Variable mesh, fall gill net sets at nearshore sites along New York's Lake Erie shoreline have shown dramatic fluctuations in walleye abundance since 1983 (Figure 2). The increases in abundance of the early 1980s peaked in 1986 due to recruitment of a very strong 1984 year class, the largest walleye year class in the last 20 years. Following declines throughout the late 1980s, walleye abundance has stabilized somewhat at a lower level to where 1999 mean abundance is only 14 percent lower than the previous 16-year mean. The 1999 collections were heavily influenced by the strong representation of the 1998 (1+) year class, however. New York angler harvest estimates for walleye (Figure 3) mirror trends in abundance over essentially the same period.

Trends in New York's walleye resource are clouded by contributions from an unquantifiable western/central basin adult walleye migration that occurs annually.

Biologists feel that increased water transparency in the 1990s, created by low phosphorus (nutrient) levels and the tremendous filtering abilities of a very large dreissenid population, have possibly affected walleye distribution, forcing them into deeper water. Higher light intensity at greater depths tends to drive light-sensitive walleye deeper, and it is possible that anglers have not yet fully adjusted to this change. Annual monitoring adjustments have been made by the NYS DEC to accommodate distribution changes (i.e. moving to deeper water), and catch rates probably continue to reflect walleye abundance.

Lakewide walleye stock size estimates concur with NYS DEC's local assessment from New York waters that walleye populations since 1990, on average, are nearly 20 percent lower than from the 1983-1989 period (1999 Walleye Task Group Report).

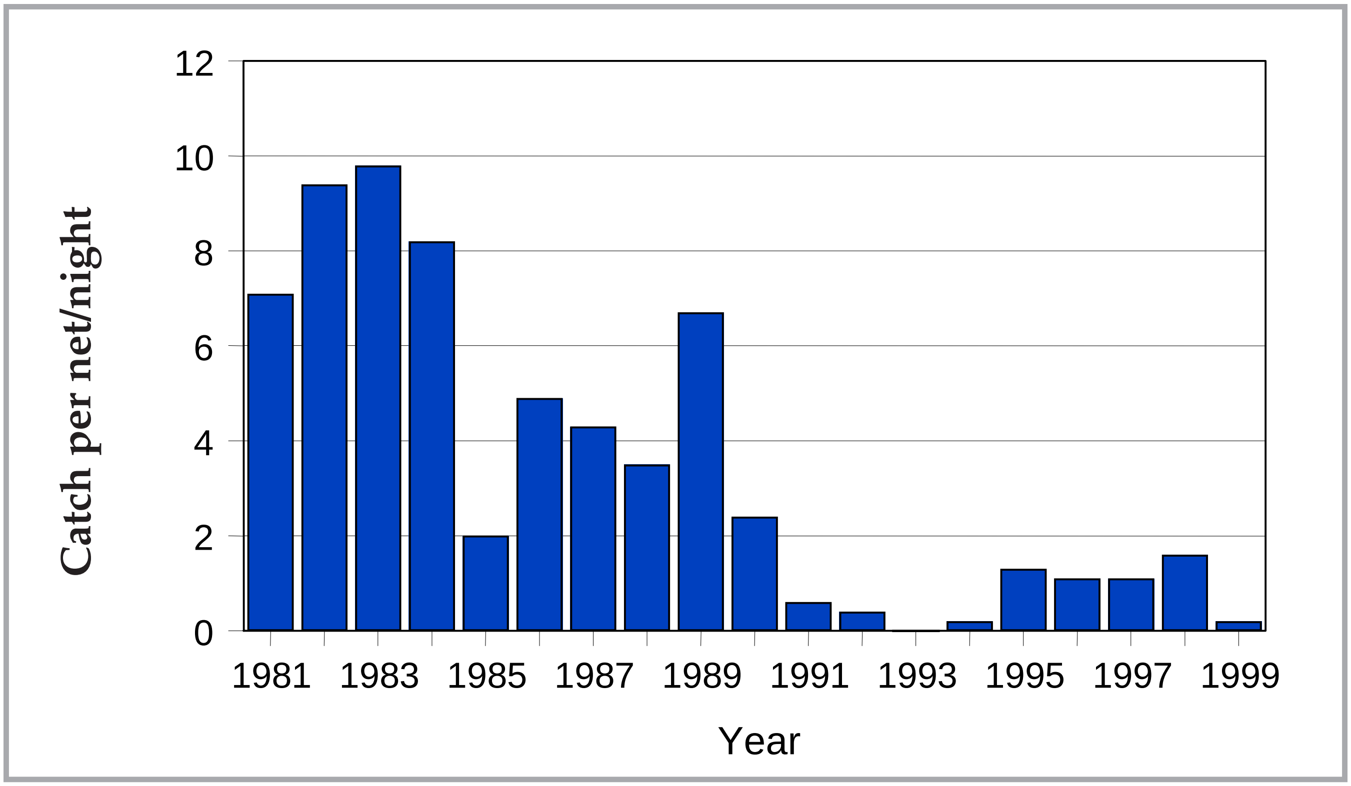

Figure 4. *Relative abundance of YELLOW PERCH sampled each year from New York waters of Lake Erie using standard gill net assessments, each fall.*

Yellow Perch

Yellow perch from New York's fall gill net assessment have also declined significantly since the early 1980s (Figure 4). Samples in 1999 were only 6 percent of the previous 18-year mean. Angler harvest shows a similarly abrupt downturn in 1990, following a peak in 1989 (Figure 5).

Management Unit 4 (eastern basin, United States and Canadian waters) yellow perch population estimates from the 1999 Yellow Perch Task Group (GLFC) show a relatively low population since 1990, based on model results, which corroborates DEC data.

White perch and white bass have also exhibited declining abundance, with 1999 mean catch rates 8 and 15 percent of the previous 18-year mean, respectively. Gizzard shad and white sucker are other notable declines in abundance, evident in annual assessments since 1981 (Figure 6).

Smallmouth Bass

Bass, on the other hand, have held their own quite well for the 19-year time series of fall gill netting (Figure 7). Recruitment indices for age-3 smallmouth bass reflects the frequency of strong year classes that support an abundant bass population (Culligan *et al.* 1999).

Bass fishing effort has increased dramatically, while sport harvest has remained relatively steady over the past 11-year period (Figure 8).

Rock bass populations have also apparently increased in abundance, with mean catch rates from the 1999 gill net catch being nearly 21 percent above the 18-year mean. 1998 catch rates were nearly 200 percent above the long-term average (Culligan *et al.* 1999).

Coldwater Fisheries

Coldwater species are a minor element in the grand picture of Lake Erie's fish community plans. The vast majority of Lake Erie's area is

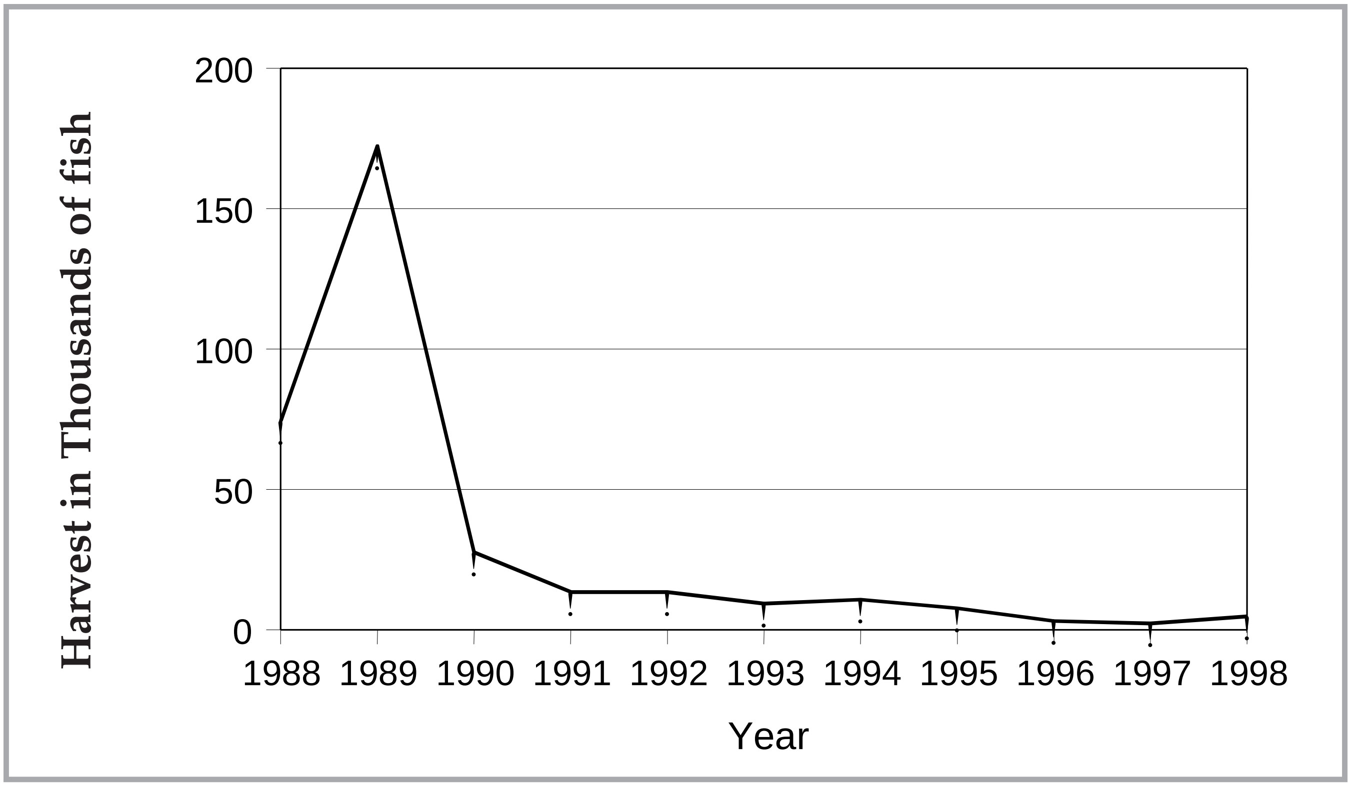

***Figure 5**. YELLOW PERCH sport harvest in New York waters of Lake Erie, May-October, 1988-1998.*

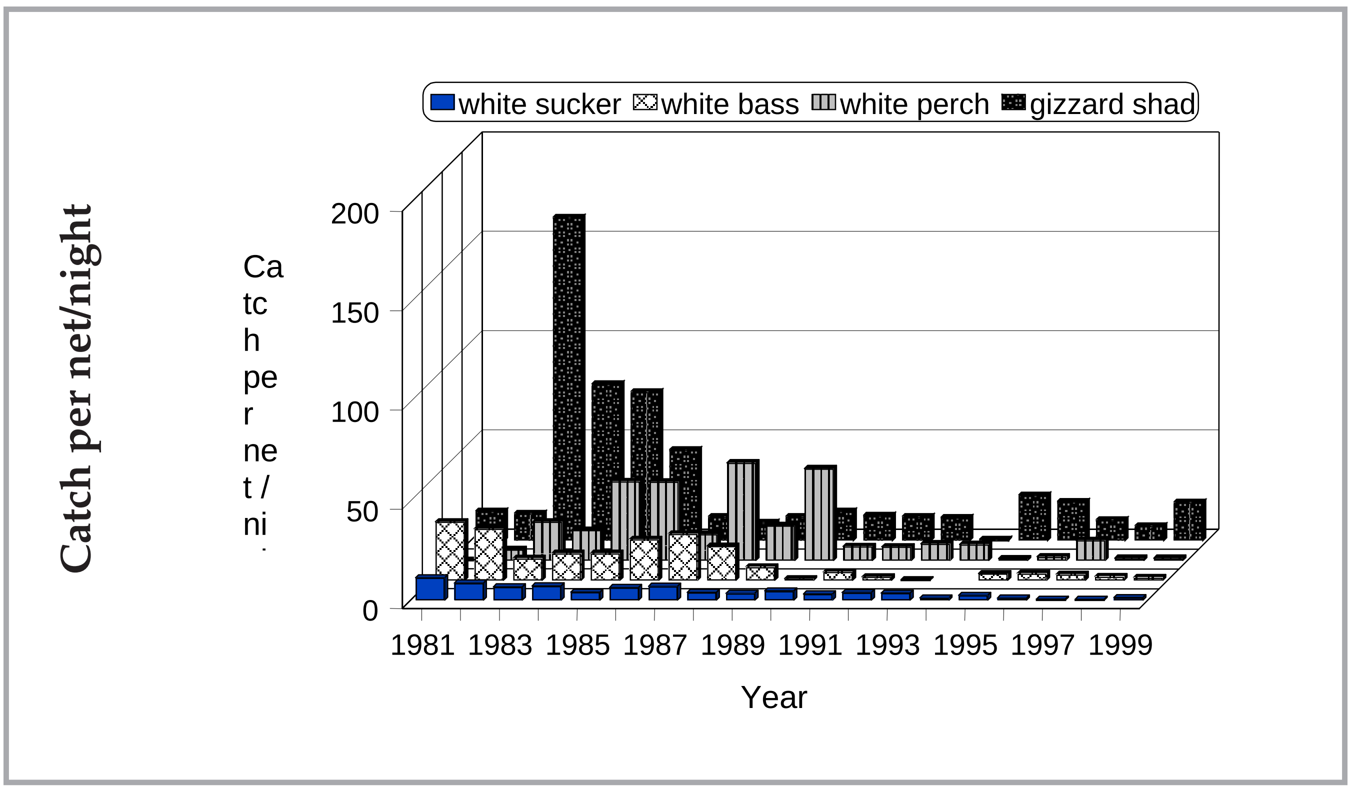

***Figure 6.** Relative abundance of selected secondary species sampled each year from New York waters of Lake Erie using standard gill net assessments, each fall.*

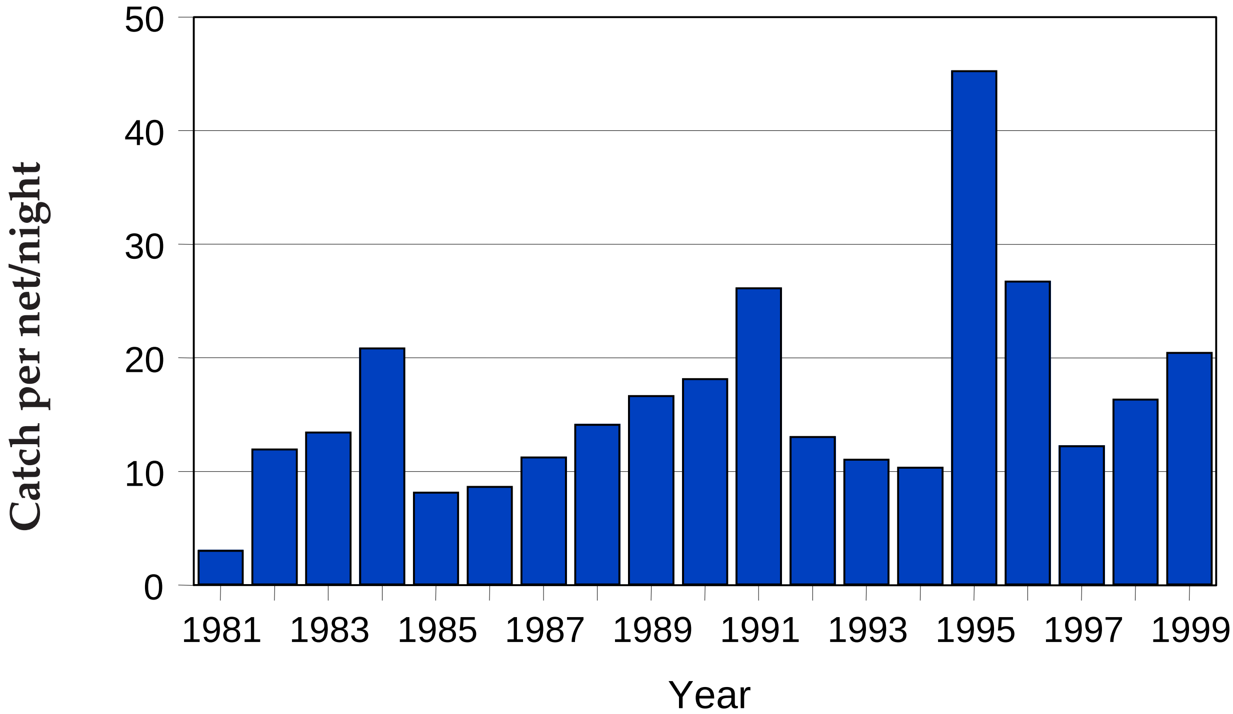

Figure 7. *Relative abundance of SMALLMOUTH BASS sampled each year from New York waters of Lake Erie using standard gill net assessments, each fall.*

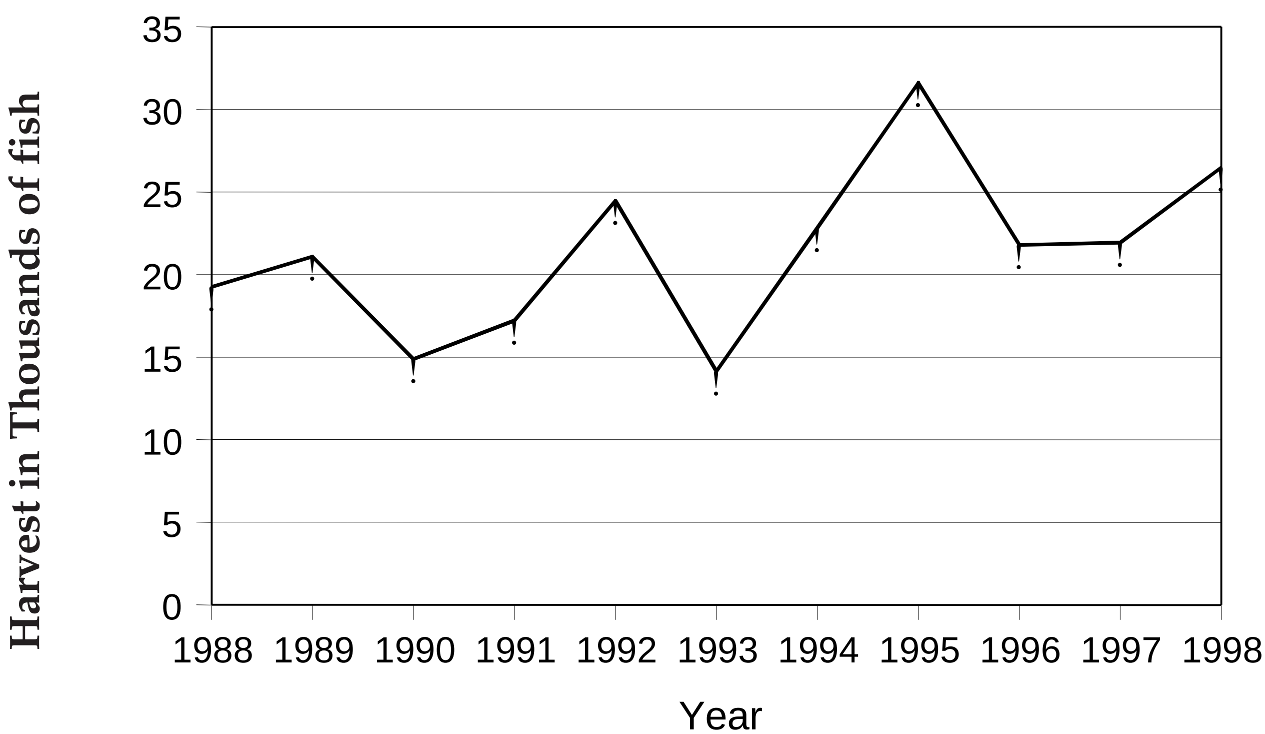

Figure 8. *SMALLMOUTH BASS sport harvest in New York waters of Lake Erie, May-October, 1988-1998.*

more suited to warmwater and coolwater species. However, the eastern basin lends itself proportionally more toward coldwater communities than the western and central basins due to its volume of colder, oxygenated hypolimnetic waters during summer stratification. Nutrient loading and filtering trends of dreissenids are creating more and more oliogtrophic conditions in the eastern basin, which favor deep coldwater communities.

New York, after more than 10 years of stocking five salmonine species (coho salmon, chinook salmon, brown trout, rainbow/steelhead trout and lake trout), has finally settled on a stocking policy for two species: lake trout and rainbow/steelhead.

Lake Trout

A standardized, August, deepwater lake trout assessment has been in place since 1986 to monitor progress toward rehabilitation resulting from stocking this native salmonine. Indices of abundance for age-5-and-older lake trout from New York waters illustrate adult population expansion (Figure 9), following initial sea lamprey treatments in 1986 and subsequent expansion toward equilibrium. Recent declines in the adult lake trout population are not considered a direct result of the same environmental factors influencing warmwater populations, though. Rather, increased mortality resulting from elevated sea lamprey attacks and reduced stocking rates are considered the cause for this recent decline. Indirectly, as a result of reduced productivity, stocking was reduced in 1995 in response to threatened smelt populations, which are the lake trout's primary forage.

New York's open lake, lake trout fishery has been maintained at very low levels in New York through restrictive creel limits (1 per angler per day). This is consistent with rehabilitation goals that call for low mortality.

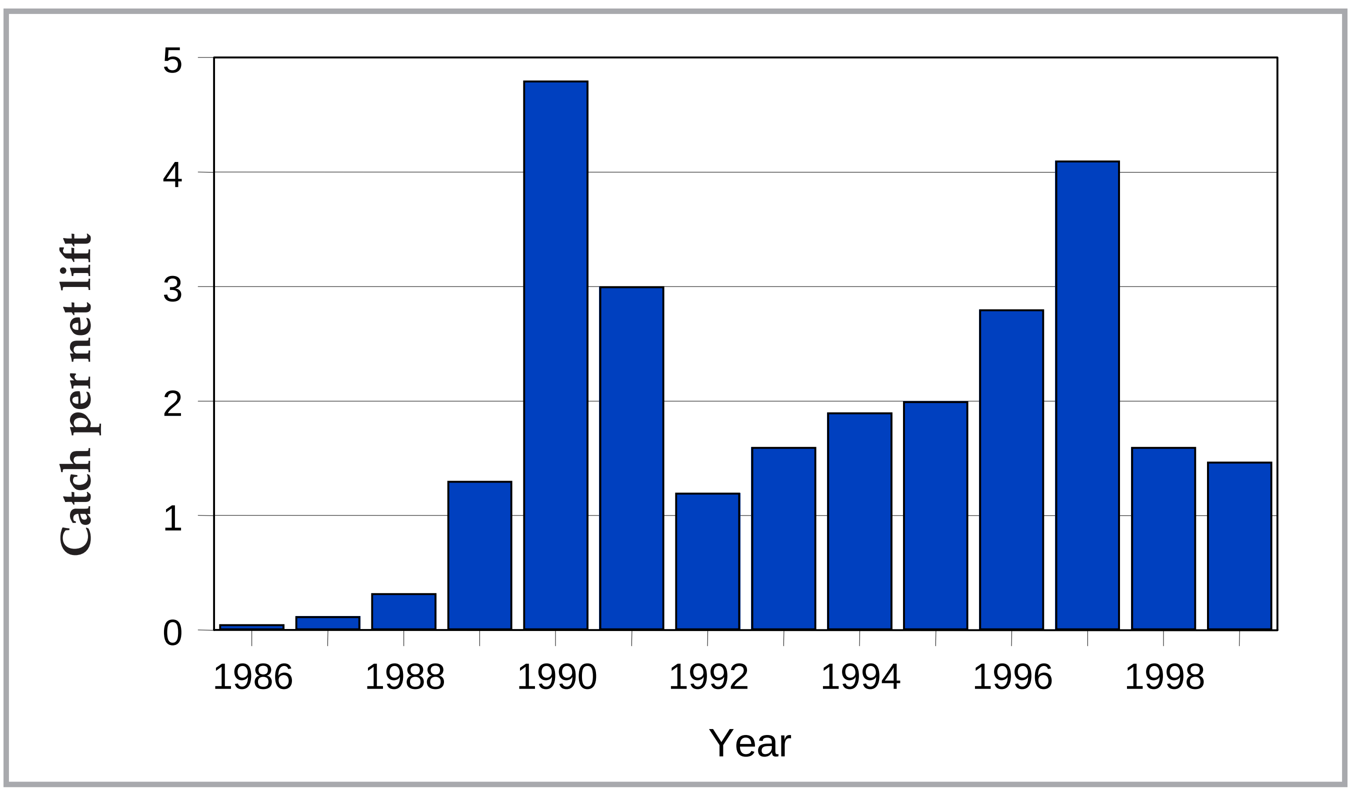

Figure 9. *Relative abundance of age 5 and older (adult) lake trout sampled each year from New York waters of Lake Erie using standard gill net assessments, each fall.*

In spite of apparent successes in lake trout rehabilitation, no successful natural reproduction has been documented, to date, and modeling suggests that the adult population is and will continue to be in decline under the current stocking and annual mortality regime. Stocking will have to be maintained indefinitely under these conditions to assure lake trout's existence in Lake Erie.

Rainbow/Steelhead

Stocking programs by all five riparian jurisdictions around Lake Erie average over 1.7 million rainbow/steelhead planted annually since 1990 (Coldwater Task Group 1999). Natural movements of this species have created limited open lake fisheries with exceptional fall-winter-spring stream fisheries. The fishery from hatchery-stocked fish is augmented by naturalized, wild populations around the lake. Cattaraugus Creek is New York's largest tributary, and estimates of wild fish contributions to that fishery approach 20 percent (Mikol 1977, Goehle in preparation).

Special fishing regulations, prohibiting all fishing from January 1 through March 31 each year on two high-quality natal streams in the Cattaraugus Creek watershed, have recently been imposed to protect spawning adults and maintain high-quality fisheries for this species in the future.

Whitefish

Whitefish have demonstrated significant population growth lakewide, based on Canadian commercial harvests (Coldwater Task Group 1999), as well as from state assessment programs. New York's whitefish abundance index is based on incidentally-caught fish from its lake trout sampling. A high degree of variability exists between annual catches, due to the random nature of sampling locations and the specific location of whitefish in New York waters during August. Whitefish catches tend to be centralized around a specific location, rather than evenly spread over the entire sampling area. Therefore, New York catch does not show as strong a trend, due to annual variability (Figure 10).

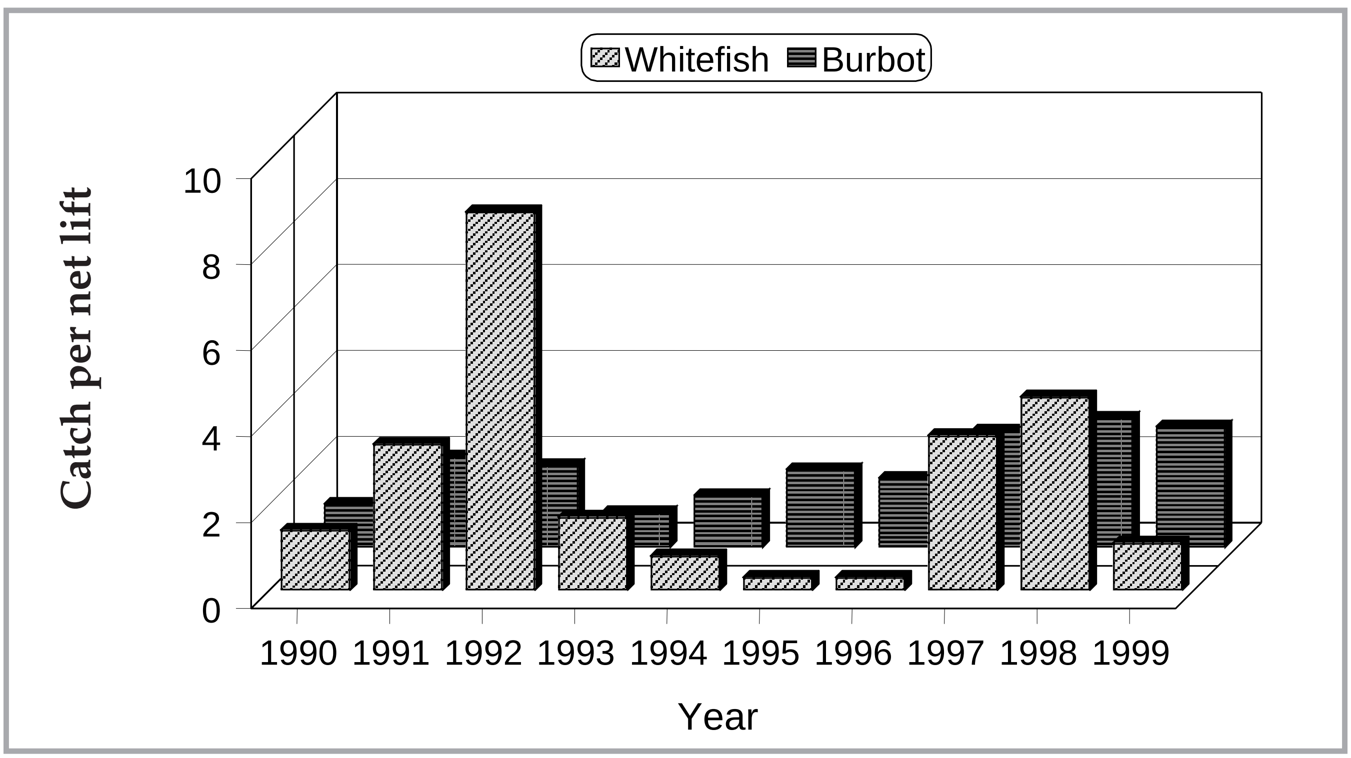

__Figure 10.__ Relative abundance of WHITEFISH and BURBOT sampled each year from New York waters of Lake Erie using standard gill net assessments, each fall.

Of special note is how the whitefish diet in 1999 consisted mainly of zebra/quagga mussels, instead of the usual amphipod mix.

Burbot

Burbot, a native coldwater predator, is experiencing very strong population growth, based on incidental catches from deepwater lake trout gill nets fished during August. In 1999, the non-target burbot catch rate equaled that of targeted lake trout (Figure 10).

Similar trends for burbot population expansion are evident from Canadian commercial harvests and the Ontario Ministry of Natural Resource's (OMNR) Partnership Index Fishing Program (Coldwater Task Group 1999).

FORAGE

The majority of discussion on fish community changes that have occurred in Lake Erie during the 20th Century focus more on "valuable" species, referring to their economic value. However, forage fishes probably harbor a greater overall value to the lake ecosystem as a whole, by serving as trophic vectors for energy transfer up the food web to top predators (identified as "valuable" species).

Rainbow smelt, gizzard shad, alewife, emerald and spottail shiners comprise the majority of Lake Erie's forage fishes. Rainbow smelt dominate New York trawl assessment catches in offshore waters, and it is the most abundant food item found in piscivore predator stomachs annually (Culligan *et al.* 1999). Unfortunately, there are no apparent population trends evident from New York data due to the relatively short period of time we have been able to monitor smelt abundance.

Trends of the smelt population decline are evident from Canadian commercial catch reports for their statistical districts OE4 and OE5 (extreme east central and eastern basin of Lake

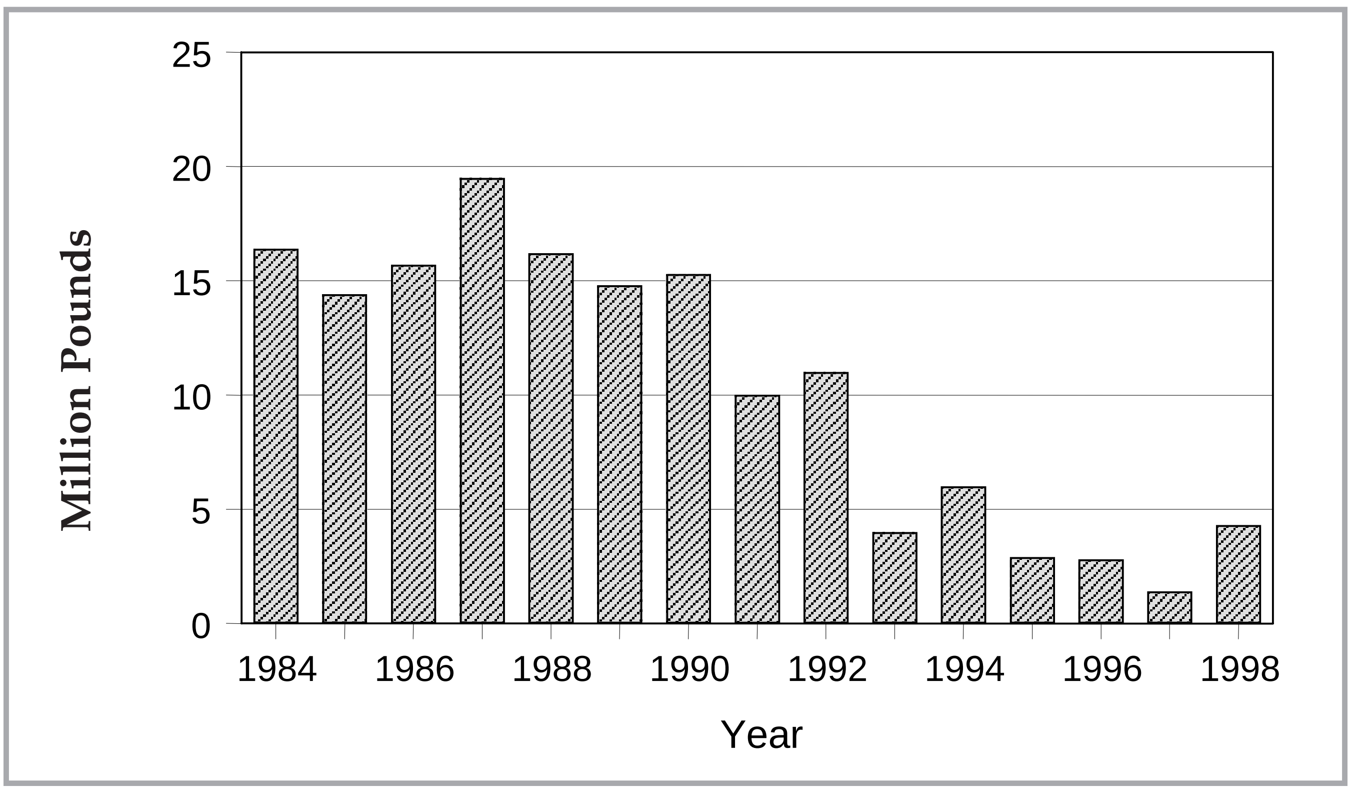

Figure 11. *Pounds of RAINBOW SMELT harvested from statistical districts OE4 and OE5 (Ontario waters of eastern Lake Erie) by the Canadian commercial fishery each year.*

Erie) (Figure 11). Canadian commercial smelt harvests peaked in 1982 at nearly 40 million pounds (compiled from OMNR Annual Reports to the Lake Erie Committee 1984-1998).

Planktivorous "valuable" species, (i.e. whitefish) have been impacted by significant biomass decreases in *Diporeia*, *Chironomids*, and *Pisidium* species (Forage Task Group 1998). Recent examinations of whitefish stomachs indicate that zebra/quagga mussels are now a major component of their diet during August in New York waters, indicating a diet shift from the normal mix of amphipods and mollusks.

FUTURE

Change is inevitable, and fisheries managers are challenged to keep up with the pace of Lake Erie's changes into the next millennium. Much has been learned in a relatively short time span, as fisheries agencies have reacted to observed changes. The future predicts more and continued change. Science must be in place to monitor trend changes and plan for the future.

For example:

a) Will smelt continue as the dominant forage species in eastern Lake Erie? If the population of this exotic species collapses, what will fill the void?

b) How do we manage an oligotrophic eastern basin for those "valued" species (walleye, yellow perch) that favor more mesotrophic or productive conditions as phosphorus levels decline further?

c) What part does the round goby play in impacting future fish community structure?

d) Can further introductions of exotic species be successfully blocked? If they can, how do our fish community goals fit in with yet unknown population levels of established exotic species?

The lake of the 1990s is much more similar to pre-development times than what was experienced during those difficult years of the 1960s and 1970s. Fish communities are now being dominated by benthic species, at the expense of those that are pelagic in nature. Native species such as burbot, whitefish, smallmouth bass and rock bass are increasing, while exotics such as smelt, alewife and white perch are in decline. This trend will likely continue in the near future, as many of our recent changes are continuing to ripple through the ecosystem. The challenge to Lake Erie's users will be to effectively adapt to this new and ever-changing environment.

REFERENCES

Coldwater Task Group. 1999. Annual Report of the Coldwater Task Group to the Standing Technical Committee of the Lake Erie Committee (GLFC), Ann Arbor, Michigan, USA.

Culligan, W. J., F. C. Cornelius, D. W. Einhouse, D. L. Zeller, R. C. Zimar, B. Beckwith and M. Wilkinson. 1999. 1999 Annual Report to the Lake Erie Committee. New York Department of Environmental Conservation, Albany. 25 pp.

Dermott, R., M. Munawar, L. Witzel and P. Ryan. 1999. An Assessment of food web changes in eastern Lake Erie: impact of *Dreissena* on smelt. *In* Munawar, M. and T. Edsall [eds.] State of Lake Erie (SOLE) — past, present, and future. Ecovision World Monograph Series, Backhuys, The Netherlands.

Forage Task Group. 1998. Annual Report of the Lake Erie Forage Task Group to the Standing Technical Committee of the Lake Erie Committee (GLFC), Ann Arbor, Michigan, USA.

Goehle, M. A. 1999. Estimation of Wild Steelhead (*Oncorhynchus mykiss*) abundance in the Cattaraugus Creek watershed. M.S. Thesis, Buffalo State College (in preparation).

Mikol, G. 1977. Investigation of population dynamics of the lake-run rainbow trout (*Salmo gairdneri*) of the upper Niagara River and tributaries of eastern Lake Erie. M.S. Thesis, SUNY Buffalo.

Ryan, P. A., L. D. Witzel, J. R. Paine, M. J. Freeman, M. Hardy, S. Scholten, J. L. Sztramko and R. MacGregor. 1999. Recent trends in fish populations in eastern Lake Erie in relation to changing trophic state and food web. *In* Munawar, M. and T. Edsall [eds.] State of Lake Erie (SOLE) — past, present, and future. Ecovision World Monograph Series, Backhuys, The Netherlands.

Walleye Task Group. 1999. Annual Report of the Lake Erie Walleye Task Group to the Standing Technical Committee of the Lake Erie Committee (GLFC), Ann Arbor, Michigan, USA.

Yellow Perch Task Group. 1999. Annual Report of the Lake Erie Yellow Perch Task Group to the Standing Technical Committee of the Lake Erie Committee (GLFC), Ann Arbor, Michigan, USA.

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The Effect of Oligotrophication and Dreissenid Invasions on Eastern Lake Erie and its Primary Forage Species, the Rainbow Smelt (*Osmerus mordax*)

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INTRODUCTION

The Lake Erie ecosystem has historically undergone dramatic, large-scale changes. In the recent past, the process of cultural eutrophication (or nutrient enrichment) was reversed, significantly reducing phosphorus levels and dramatically altering the state of the lake. The invasion of zebra and quagga mussels (*Dreissena polymorpha*, *Dreissena bugensis*) into the eastern basin of Lake Erie has served to redirect much of the system's energy from the water column, where it is available to zooplankton, to the bottom where it is accessible by a more limited group of organisms (Koonce *et al.* 1996). These events have lead fisheries managers to question the sustainability of the Lake Erie fishery, specifically whether the primary forage species, the rainbow smelt (*Osmerus mordax*), is capable of supporting economically, and ecologically, vital species.

Rainbow smelt are known to dominate the diets of predatory sport fish species such as walleye, lake trout, and bass (Stewart *et al.* 1981; Jude *et al.* 1987, Einhouse *et al.* 1999). The sustainability of this planktivorous species is dependent on the yield of lower trophic levels, specifically zooplankton as its primary food resource, which have demonstrated a marked decline in the past years (Johannsson *et al.* 1999). In order to proactively manage the eastern Lake Erie fishery, managers require an assessment of smelt stock viability based on a comprehensive evaluation of lower trophic levels.

This project, with analyses still underway, seeks to develop an accurate picture of the current eastern Lake Erie food web and, therefore, a better understanding of the impact that phosphorus reductions and dreissenid mussel invasions have had on higher trophic levels. The consideration of factors influencing productivity in nearshore and offshore zones is particularly important as nearshore areas are used by species such as smelt during early life history stages and are, therefore, key to reproductive success. Dreissenid mussels are more likely to impact productivity and nutrient concentrations in these nearshore areas where more of the water column is accessible to these benthic filter feeders. For these reasons, particular consideration is given to the possibility of differential impact of dreissenid mussels in nearshore and offshore zones.

DATA COLLECTION

Sampling of lower trophic level components (zooplankton, phytoplankton, chlorophyll *a*, and total and soluble reactive phosphorus) was conducted in 1998 and 1999 in cooperation with the New York State Department of Environmental Conservation's (DEC) Lake Erie Fisheries Unit in Dunkirk, New York. Collections were made at a nearshore (10 m depth) and an offshore (35 m depth) site weekly during June, July, and August, and biweekly in May and September. Four sites, located east and west of Dunkirk, were sampled on a monthly basis to provide estimates of spatial variation (Figure 1). Samples of benthos and dreissenid mussels were also made at these sites.

Samples were also collected at 15-17 sites along transect lines across the eastern basin. These collections were made during a hydroacoustic and trawling survey conducted by the DEC in June, July, and October of both years. In addition to limnological collections, smelt of vari-

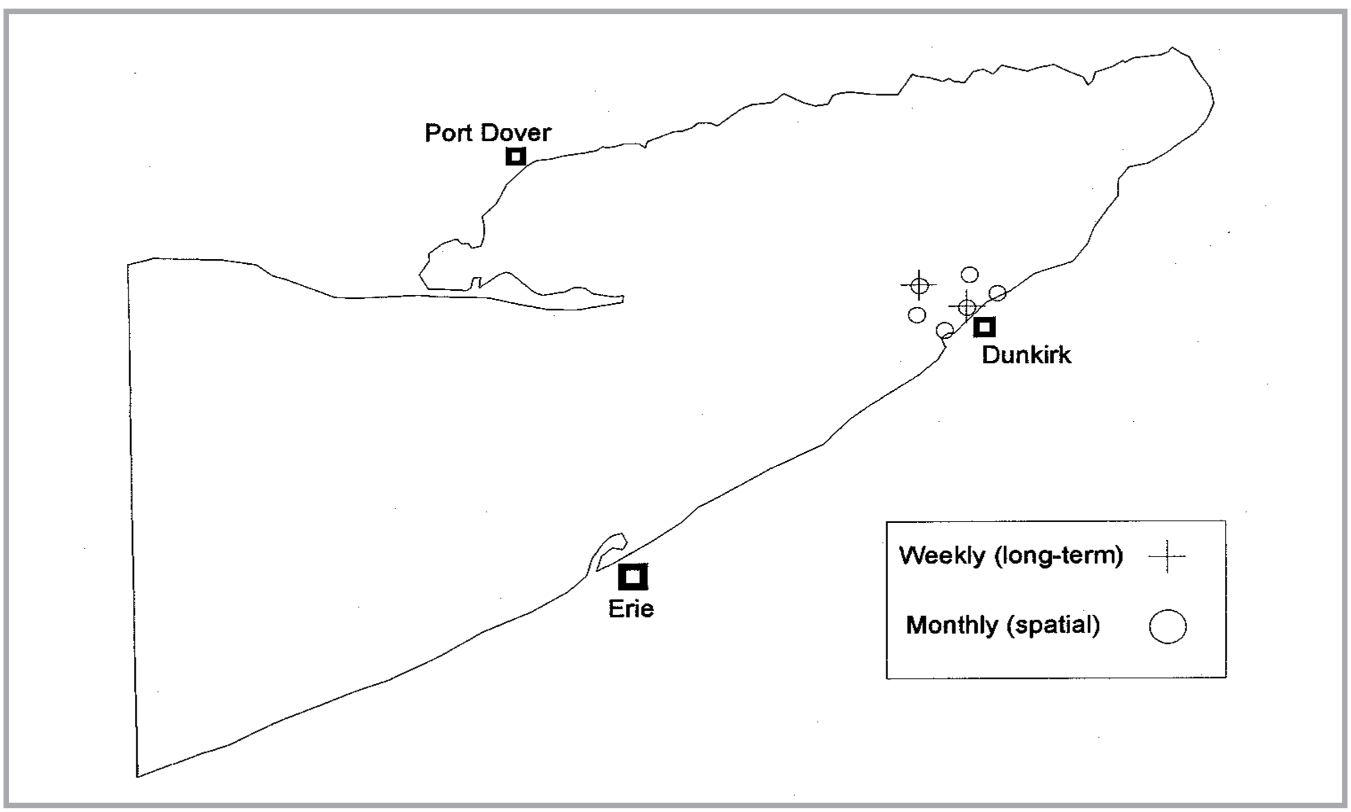

Figure 1. *Nearshore/offshore limnological stations sampled weekly or monthly.*

ous size classes were also collected for both manual identification of diet items and stable isotopic evaluation. During the DEC's coldwater and warmwater fisheries assessments, in August and September respectively, tissue samples were taken from piscivorous fish for inclusion in stable isotopic analyses.

DISCUSSION AND PERSPECTIVE

Prior to the establishment of phosphorus controls in the 1970s, total phosphorus levels in the eastern basin of Lake Erie often exceeded 20 ug/L (Neilson *et al.* 1995). This level corresponded to excessive algal growth and the reduction of some key fish stocks throughout Lake Erie. The Great Lakes Water Quality Agreement established a target level of 10 ug/L for Lake Erie (Dolan 1993); this goal was reached in 1987. Samples taken in 1998 indicate that total phosphorus in the nearshore of eastern Lake Erie is now 4.4 ug/L (n=9). Offshore concentrations were not significantly different (p-value=0.2, df=16) at 5.9 ug/L (n=10). Soluble reactive phosphorus, which frequently exceeded 5 ug/L prior to phosphorus abatement programs (Neilson *et al.* 1995), was 1.2 ug/L (n=10) in the nearshore zone and 0.9 ug/L (n=10) in the offshore zone. Nearshore concentrations were significantly different from offshore (p-value=0.01, df=18). Chlorophyll *a* concentrations, a measure of lower trophic production, were not significantly different between nearshore (1.2 ug/L, n=8) and offshore (2.1 ug/L, n=8) sites in 1998 (p-value=0.2, df=14).

The excessive growth of algae in the early 1970s, resulting from phosphorus enrichment, provided zooplankton with an abundant food resource. Basinwide, zooplankton biomass averaged 119 ug/L in 1970. After phosphorus abatement programs began, biomass was reduced to a mean of 60.8 ug/L in 1984-1987. Although the target phosphorus level of 10 ug/L was reached in 1987, the invasion of dreissenid mussels in 1989 further reduced available phytoplankton food resources and zooplankton biomass declined to a mean of 23.8 ug/L during 1993-1994 (Johannsson *et al.* 1999). This decline in biomass is probably the result of decreased algal abundance through the combined effect of oligotrophication and mussel filtering. Zooplankton biomass in 1998 was similar to the values in 1993-1994 (24.1ug/L (n=15) in the nearshore and 31.5 ug/L (n=15) in the offshore-epilimnion).

Both the relative abundance of yearling-and-older rainbow smelt and the recruitment of young-of-year smelt continue to be below the long-term average in the eastern basin (LEFTG 1998). This has been paralleled by an observed reduction in smelt size (length) since 1984 (LEFTG 1998, Dermott *et al.* 1999). As predators on zooplankton, smelt feeding patterns are

Table 1. Summary of selected 1998 nearshore and offshore collection results (range of values presented)

	1998 Nearshore	1998 Offshore
Total Phosphorus (ug/L)	1.9-10.0	2.2-9.3
Soluble Reactive Phosphorus (ug/L)	0.9-1.8	0.6-1.1
Chlorophyll *a* (ug/L)	0.3-3.1	1.2-5.9
Zooplankton biomass (ug/L)	0.1-94.0	0.3-97.6
Secchi disk depth (m)	4.0-8.0	3.5-9.5

closely related to the changing nature of Lake Erie. Although primarily consuming zooplankton, smelt of all age classes also feed opportunistically on emergent benthic species. As dreissenid mussels have been found to increase benthic invertebrate populations through increased habitat complexity (Stewart and Haynes 1994) rainbow smelt may be making greater use of these benthic resources to compensate for decreasing zooplankton production. Smelt diet information will be compared to pre-phosphorus reduction and pre-dreissenid observations of smelt feeding ecology to elucidate changes that could explain reduced smelt size and population declines in past years.

Nearshore zones are generally considered to be more productive than offshore due to direct nutrient inputs. For that reason, zooplankton biomass should also be higher in nearshore areas and thus provide an adequate food resource for young of year fish. Results from 1998 suggest that within our study site neither phosphorus nor zooplankton is more abundant in the nearshore area. Future analyses will consider whether dreissenid mussels are making nearshore and offshore zones more similar in their nutrient and zooplankton profiles and whether this may explain declining recruitment of young of year fish.

FUTURE CONSIDERATIONS

A great deal of discussion has surrounded productivity in Lake Erie, particularly whether reduced phosphorus levels and the invasion of dreissenid mussels have negatively impacted fish stocks. A future direction for this work will include a consideration of population dynamics for piscivorous fish species such as walleye, bass, and lake trout, as they relate to rainbow smelt populations. An assessment of whether these stocks are sustainable in light of declining forage will be made through the use of ecological modeling techniques (Einhouse *et al.* 1999).

A relatively new tool, stable isotope analysis, will be used to assist in the development of an eastern Lake Erie food web model. This technique utilizes unique signatures of the elements carbon and nitrogen to determine where each member of the food web is getting its energy, or in this case, what food resources it is exploiting. We will use this tool as a complement to the direct observations of rainbow smelt diet made through manual identification and identify a possible shift in diet towards a greater benthic component as a result of declining zooplankton resources. Stable isotopes will also be analyzed for muscle tissue from top eastern Lake Erie predators (walleye, bass, and lake trout) to verify their prey selection.

During the basinwide surveys in June, July, and October of 1998 and 1999, a hydroacoustic survey of rainbow smelt was conducted. This survey method involves recording the echoes returned from a sound pulse sent into the water. After analysis, this methods yields abundance and depth distribution of two age groups of smelt (Rudstam *et al.* 1999). Measures of abundance and growth of smelt will be used to calculate smelt production and compare smelt production as a function of zooplankton production since 1993. These ongoing surveys are a multi-agency effort involving the DEC, Ontario Ministry of Natural Resources, and Pennsylvania Fish and Boat Commission (LEFTG 1998).

LITERATURE CITED

Dermott, R., M. Munawar, L. Witzel, and P.A. Ryan. 1999. An assessment of food-web changes in eastern Lake Erie: impact of Dreissena spp. and phosphorus management on rainbow smelt, Osmerus mordax. Pp. 367-385 *in* M. Munawar, T. Edsall, and I.F. Munawar, editor. State of Lake Erie (SOLE) – Past, Present and Future. Backheys Publishers, Leiden, The Netherlands.

Dolan, D.M. 1993. Point source loading of phosphorus to Lake Erie 1986-1990. *J. Great Lakes Res.* 19:212-223.

Einhouse, D.W., M.T. Bur, F.C. Cornelius, R. Kenyon, C.P. Madenjian, P.S. Rand, K.L. Sztramko, and L.D. Witzel. Consumption of rainbow smelt by walleye and salmonine fishes in eastern Lake Erie. Pp. 291-303 *in* M. Munawar, T. Edsall, and I.F. Munawar, editor. State of Lake Erie (SOLE) – Past, Present and Future. Backheys Publishers, Leiden, The Netherlands.

Johannsson, O.E., D.M. Graham, D. Einhouse, and E.L. Mills. 1999. Historical and recent changes in the Lake Erie zooplankton community and their relationship to ecosystem function. Pp. 169-196 *in* M. Munawar, T. Edsall, and I.F. Munawar, editor. State of Lake Erie (SOLE) — Past, Present and Future. Backheys Publishers, Leiden, The Netherlands.

Jude, D.J., F.J. Tesar, S.F. Deboe, and T.J. Miller. 1987. Diet selection of major prey species by Lake Michigan salmonines, 1973-1982. *Trans. Amer. Fish. Soc.* 116:677-691.

Koonce, J.F., W.D.N. Busch, and T. Czapla. 1996. Restoration of Lake Erie: contribution of water quality and natural resource management. *Can. J. Fish. Aquat. Sci.* 53 (Suppl. 1):105-112.

LEFTG (Lake Erie Forage Task Group). 1998. Report of the Lake Erie Forage Task Group. Presented to the Standing Technical Committee, Lake Erie Committee, Great Lakes Fishery Commission. March 1998. 53 pp.

Neilson, M, S. L'Italien, V. Glumac, and D. Williams. 1995. Nutrients: Trends and System Response [online]. SOLEC Working Paper presented at State of the Lakes Ecosystem Conference. EPA 905-R-95-015. http://www.epa.gove/grtlakes/solec/94/nutrient/index.html

Rudstam, L.G., S. Hansson, T. Lindem, and D.W. Einhouse. 1999. Comparison of target strength distributions and fish densities obtain with split and single beam echo sounders. *Fish. Res.* 42:207-214.

Stewart, D.J., J.F. Kitchell, and L.B. Crowder. 1981. Forage fish and their salmonid predators in Lake Michigan. *Trans. Amer. Fish. Soc.* 110:751-763.

Stewart, T.W. and J.M. Haynes. 1994. Benthic macroinvertebrate communities of southwestern Lake Ontario following invasion of *Dreissena. J. Great Lakes Res.* 20(2):479-493.

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The Round Goby (*Neogobius melanostomus*) in Lake Erie

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INTRODUCTION

The North American (Laurentian) Great Lakes have experienced many disturbances to the native aquatic floral and faunal communities since European settlers first arrived in the basin centuries ago (Mills *et al.* 1993). However, the past 100 years mark the period of greatest stress as a result of the dramatic growth in population within the towns and cities located on or near the lakes' shores. Stressors include pollution from industrial and municipal sources, and biological introductions resulting from the removal of geographic barriers (e.g. canal construction) and from increased international shipping activities. Of all five of the Great Lakes, Lake Erie ranks last in total volume, but is likely at or near the top in terms of aquatic nuisance species invasions. Organisms such as the sea lamprey (*Petromyzon marinus*), zebra mussel (*Dreissena polymorpha*), and quagga mussel (*Dreissena bugensis*) are among the most devastating species that have invaded the lake. More recently, an additional nonindigenous organism has invaded the Lake Erie aquatic community; the round goby (*Neogobius melanostomus*) (Fig. 1).

The round goby is a benthic fish native to the Black and Caspian Seas of eastern Europe and western Asia. This species was initially discovered within the Great Lakes basin in the St. Clair River near Sarnia, Ontario, in 1990 (Jude

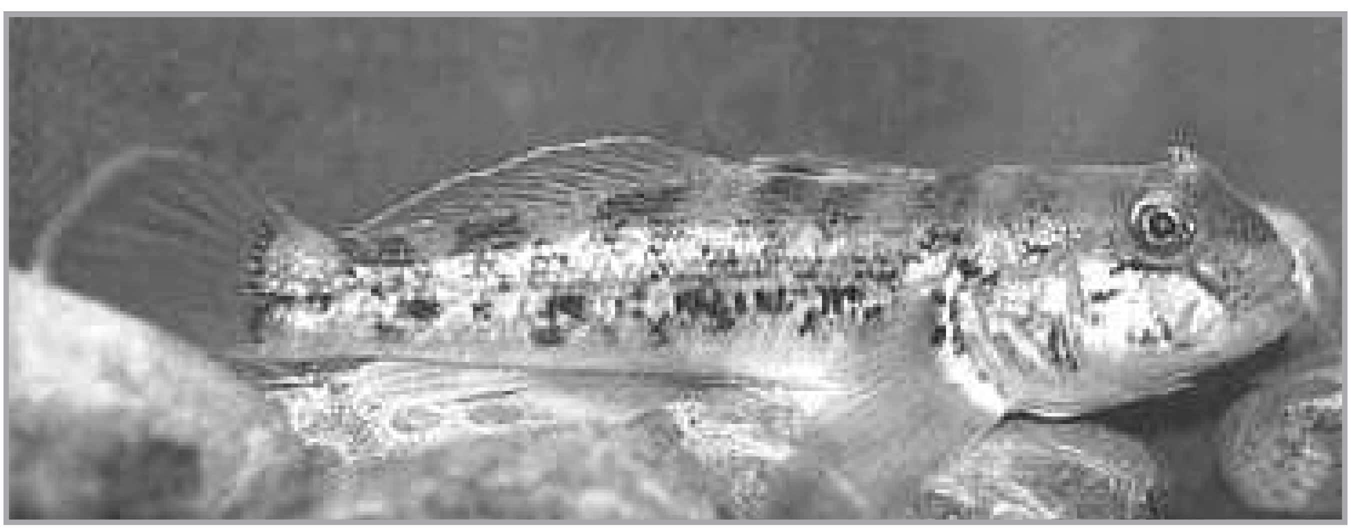

Figure 1. *Round goby, Neogobius melanostomus, (Credit: D. Jude, U. of Michigan)*

et al. 1992) (Crossman *et al.* 1992), and first collected in Lake Erie in 1993, near the confluence of Lake Erie and the Grand River in Ohio (Charlebois *et al.* 1997). Since its introduction, it has been collected in all five of the Great Lakes, with one additional fish collected in the St. Lawrence River near Montreal (USGS 1999). It is believed that the round goby made its way into North American waters in the ballast water of a ship (or ships) departing the Ponto-Caspian region (e.g. Black and Caspian Seas) for Great Lakes ports (Jude *et al.* 1992). In addition, patterns of round goby colonization over the past decade within the basin point to intra- and inter-lake commercial shipping as factors contributing to accelerated range expansions. In the Great Lakes, the likelihood of round goby being found in areas adjacent to industrial harbors and large river channels that experience moderate to heavy shipping activity is high, as indicated by historical round goby sighting data (USGS 1998). High concentrations of round goby are found within, or adjacent to, some of the busiest ports within the Great Lakes. For example, population estimates of round goby along the south shore of Lake Erie indicate high densities near Cleveland, Sandusky, Conneaut, and Ashtabula, (Ohio), all cities experiencing heavy inter-lake and international shipping (Fig. 2). In these locations, round goby densities generally decrease with distance away from the harbor location (USGS 1998). Density-dependant population dynamics may explain, to some degree, the rapid range expansion of this species from introduction sites. Round goby are prolific and can spawn several times per season, establishing high numbers in a relatively brief time frame.

HABITAT

Large expanses of the littoral zone of Lake Erie are ideally suited to round goby colonization based on habitat preferences demonstrated by this species in its native waters. In the Black Sea and Sea of Azov, gobies are found on coarse gravel, shells, and sand in nearshore areas in depths up to 20 meters (Miller 1986), and up to 70 meters in the Caspian Sea (Moskal'kova 1996), where its temperature tolerance is between –1.0° and +30.0° C. In Lake Erie, round goby show seasonal movements, and are typically found from the nearshore to depths of 10 to 20 m from spring through early fall, and are

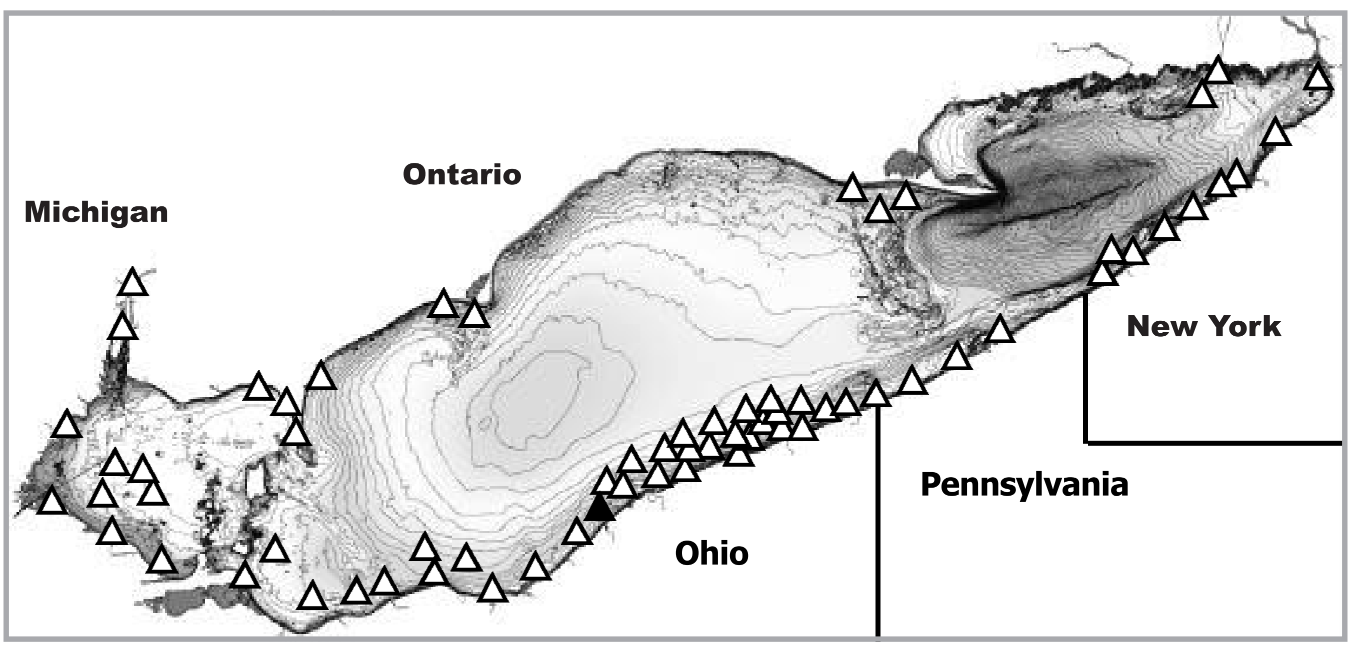

Figure 2. *Reported sightings of round goby in Lake Erie as of January 2000. (data courtesy USGS/Florida Caribbean Science Center)*

believed to move offshore in late fall through winter. Round goby are tolerant of a wide variety of habitat conditions, including low dissolved oxygen and, to some extent, varying salinity. Round goby lack a visible lateral line; however, superficial neuromasts on its body provide it with an increased sensitivity to prey (Jude *et al.* 1995), giving it an advantage in dark or turbid waters.

DIET

Investigations of the diet composition of goby in Lake Erie have demonstrated a reliance on an array of macroinvertebrates, including Hexagenia, chironimids, amphipods, and native sphaerids (fingernail clams), in addition to the consumption of zebra and quagga mussels (Weimer and Sowinski 1999). These diet preferences are shared by other species native to Lake Erie and will likely lead to competetive interactions. For example, bottleneck effects may be experienced by species that rely heavily upon similar macrobenthic taxa for growth during critical developmental stages, or for achieving critical body sizes or lipid levels for successful overwintering. The ability of the round goby to consume zebra and quagga mussels may, however, provide this species with a competitive advantage, as few species in Lake Erie rely on dreissenids as a primary prey item. Diet analysis conducted on round goby collected from Lake Erie indicated that, during various seasons, they feed almost exclusively on dreissenids (Weimer and Sowinski 1999). In laboratory studies, round goby consumed over 100 mussles per day (Ghedotti *et al.* 1995). Similarly, diet studies conducted in Europe have also shown a high reliance upon bivalves, including zebra mussels (Skazkina and Kostyuchenko 1968). Round goby possess strong pharyngeal teeth typical of molluscivores. The invasion and establishment of dreissenids in Lake Erie likely provides an almost inexhaustible prey source for round goby to exploit.

BEHAVIOR

Throughout Lake Erie, several year classes (typically three) are now present. Goby will reach a maximum size of approximately 200 mm (total length), and with an average maximum life span of 3 years. Males grow larger than females, and aggressively guard the nest once eggs have been deposited and fertilized. During the course of this activity, male round goby will turn dark gray to black, and often die shortly after eggs have hatched and fry have dispersed. Studies have suggested that the aggressive behavior exhibited by round goby in acquiring and defending habitat may ultimately lead to a decline in the population numbers of less territorial fish species, such as the mottled sculpin (*Cottus bairdii*) (Dubs and Corkum 1996).

Round goby reproduce several times per year, and are capable of rapidly establishing high population numbers once introduced. This reproductive strategy and aggressive behavior, coupled with the presence of suitable habitat and prey resources, has led to a successful round goby invasion throughout most of Lake Erie's nearshore waters (Fig. 2). As previously mentioned, round goby were first detected in Lake Erie in 1993 in the central basin near the Grand River confluence, approximately 20 miles east of Cleveland. By 1995, populations were detected near Lorain and Ashtabula, Ohio, west and east of the Grand River siting, respectively. Also in 1995, round goby were reported for the first time outside the central basin and in Canadian waters of Lake Erie. Goby were collected at the mouth of the Welland Canal near Port Colborne, Ontario, alerting managers to the potential spread of goby to Lake Ontario. In 1996, round goby were reported for the first time in both the US and Canadian waters of the lake's western basin. Through 1997 and 1998, round goby populations continued to expand, crossing into Pennsylvania waters, with populations detected as far east as Erie, Pennsylvania. In the fall of 1998, a single round goby was detected by the US Fish and Wildlife Service (Service) while conducting bottom trawling in the Buffalo Harbor area. This marked the first documented collection of round goby in New York waters. In 1999, no round goby were captured while trawling the Buffalo Harbor location, although recreational diving conducted in areas adjacent to the trawl sites revealed densities of 5-7 fish/ m^2 at depths of 6-9 meters. The Service, in cooperation with staff from the New York State Department of Environmental Conservation's Lake Erie Fishery Unit (Dunkirk, New York), as well as local bait shop and marina owners, initiated an outreach effort to better document the distribution of round goby in the New York waters of Lake Erie. As sightings were confirmed and recorded, it became apparent that the round goby had successfully invaded most of nearshore community along Lake Erie's southern shoreline. Current maps of reported round goby sightings in North America can be accessed on the internet at a US Geological Survey/Florida Caribbean Science Center website (nas.er.usgs.gov/fishes/images/goby_map.gif).

IMPACTS

Recently, the effects of increasing round goby populations in Lake Erie have been experienced by the lake's shorebound and nearshore anglers. From late spring through fall, round goby are captured by anglers using standard live-bait techniques (jigging, trolling, and still-fishing on bottom), and are typically caught by those targeting yellow perch, walleye, or smallmouth bass. Often, when one goby is caught, many more may follow, as they tend to aggregate into schools. Larger adult fish, typically males, are apparently more vulnerable to capture by anglers, possibly as a result of increased gape-size and heightened aggression. As population densities of round goby in Lake Erie continue to increase, the appeal of angling in locations previously dominated by other native near-shore species may diminish. This scenario has already occurred in other Great Lakes, including the Illinois-Indiana coastline of southern Lake Michigan.

Within Lake Erie, the long-term ecological implications of the introduction of round goby remain to be seen. It is believed that they can compete directly with indigenous nearshore benthivores currently occupying a similar ecological niche within the lake. These native species include the mottled sculpin (*Cottus bairdii*), logperch (*Percina caprodes*), and johnny darter (*Etheostoma nigrum*).

Additional concerns include the possible introduction of sediment-borne contaminants (e.g. PCBs) into progressively higher-level organisms within the lake's aquatic community as a result of the round goby-dreissenid predator-prey linkage (Jentes 1999). If dreissenids display substantial contaminant burdens, effects may be seen at higher trophic levels (e.g. consumers of goby) as a result of biomagnification. Research indicates that round goby are being increasingly utilized by native Lake Erie piscivores, including smallmouth bass, walleye, yellow perch, and burbot. In a diet study conducted by the Ohio Division of Wildlife in 1999, round goby were found in the stomachs of 47% of all smallmouth bass collected in the central and western basins, an increase of almost five-fold since 1996 (C. Knight, personal communication). Contaminant levels within these piscivores must be monitored closely to investigate for changes in tissue levels over time as the use of round goby as a forage base continues to increase.

PREVENTION

The round goby is poised to become an established resident in all portions of Lake Erie's nearshore community. While the total eradication of round goby from Lake Erie is, at this time, highly unlikely, preventing the spread of round goby into waters adjoining the lake is still a possibility, and should be considered a priority. For example, the Erie Canal (New York State Canal System) joins the Niagara River just a few nautical miles downstream from the Buffalo Harbor area, where goby are established. If round goby enter and disperse throughout the canal system, the interior waters of New York State, including the Finger Lakes and, ultimately, the Hudson River basin, would be at a high risk of colonization. Additionally, inland lakes proximal to Lake Erie (e.g. Lake Chautauqua in southwestern New York State) are at risk and should be targeted for intensive prevention efforts. Education programs aimed at boaters, anglers, bait harvesters, and bait dealers are a priority. Various types of media, including brochures, fact sheets, videos, commercials, the Internet, workshops and public forums should be used to advance communication and education efforts.

Other options for preventing the inland expansion of goby might include the construction of actual dispersal barriers, consisting of one or a combination of physical, electrical, acoustical, hydrological (manipulated flow or bubble curtains), or stroboscopic (lighting) methods. Research is currently being conducted to determine effective technologies aimed at repelling round goby movements. Installation of an electrical barrier in the Chicago Sanitary and Ship Canal in Illinois is scheduled for spring 2000, to prevent the movement of round goby and other invasive species out of Lake Michigan and into the Mississippi River drainage via canals comprising this system. The long-term success of this project remains to be seen, and will be closely followed by resource managers with an interest in invasive species control mechanisms.

The invasion of Lake Erie by the round goby represents just one more example of the ongoing process of global ecosystem homogenization that can only be stopped with continued technological and legislative advances in the area of invasive species prevention and control.

Ultimately, we must exercise tighter control over the biota entering the Lake Erie basin, as well as the entire Great Lakes watershed, if we are to ensure the future health and existence of this unique ecosystem.

LITERATURE CITED

Charlebois, P.M., J.E. Marsden, R.G. Goettel, R.K. Wolfe, D.J. Jude, and S. Rudnika. 1997. The round goby, *Neogobius melanostomus* (Pallus), a review of European and North American Literature. Illinois-Indiana Sea Grant Program and Natural History Survey. INHS Special Publication No. 20. 76 pp.

Crossman, E.J., E. Holm, R. Cholmondeley, and K. Tuininga. 1992. First record for Canada of the rudd, *Scardinius erythrophthalmus*, and the round goby, *Neogobius melanostomus*. *Can. Field-Nat.* 106:206-209.

Dubs, D.O.L., and L.D. Corkum. 1996. Behavioral interactions between round gobies (*Neogobius melanostomus*) and mottled sculpins (*Cottus bairdii*). *J. Great Lakes Res.* 22:838-844.

Ghedotti, M.J., J.C. Smihula, and G.R. Smith. 1995. Zebra mussel predation by round gobies in the laboratory. *J. Great Lakes Res.* 21(4):665-669.

Jentes, J. 1999. Zebra Mussels: Key to Contaminant Cycling. Twine Line. Vol. 21. No 4. Ohio Sea Grant Pub.

Jude, D. J., R.H. Reider, and G.R. Smith. 1992. Establishment of Gobiidae in the Great Lakes basin. *Can. J. Fish. Aquat. Sci.* 49:416-421.

Jude, D. J., J. Janssen, and G. Crawford. 1995. Ecology, distribution, and impact of the newly introduced round and tubeneose gobies in the biota of the St. Clair and Detroit Rivers. Pages 447-460 *In* M. Munawar, T. Edsall, and J Leach, eds. The Lake Huron ecosystem: ecology, fisheries, and management. Ecovision World Monograph Series, S.P.B. Academic Publishing, The Netherlands.

Miller, P.J. 1986. Gobiidae. Pages 1019-1095 *in* P.J.P. Whitehead, M.L. Bauchot, J.C. Hureau, J. Nielson, and E. Tortonese, eds. Fishes of the northeast Atlantic and Mediterranean. UNESCO, Paris.

Mills, E.L., Dermott, R.M., Roseman, E.F. Dustin, D., Mellina, E., Conn, D.B., and Spidle, A.P. 1993. Colonization, ecology, and population structure of the "quagga" mussel (Bivalvia: Dreissenidae) in the lower Great Lakes. *Can. J. Fish. Aquat. Sci.* 50: 2305-2314.

Moskal'kova, K.I. 1996. Ecological and morphophysiological prerequisites to range extension in the round goby *Neogobius melanostomus*, a species with direct type of development. *J. Ichthyol*. 29:108-122.

Ray, W.J., and L.D. Corkum. 1997. Predation of zebra mussels by round gobies, *Neogobius melanostomus*. *Environmental Biology of Fishes.* 50:267-273.

Skazkina, E.P., and V.A. Kostyuchenko. 1968. Food of *N. melanostomus* in the Azov Sea. Vopr. Ikhtiol. 8:303-311.

US Geological Survey/Florida Caribbean Science Center (website). 1998, 1999. http://www.nas.er.usgs.gov/fishes/images/goby_map.gif

Weimer, M.T. and M. Sowinski. 1999. Diet of the round goby (*Neogobius melanostomus*) in Lake Erie. *Dreissena!* (Digest of the ANS Clearinghouse). Vol. 10. Number 1.

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Excitement Along the Shores of Lake Erie – *Hexagenia* – Echoes from the Past

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ABSTRACT

Mayflies are again an integral part of the Lake Erie ecosystem. *Hexagenia*, the largest mayfly of North America, has resurfaced. Several factors including substrate type, oxygen concentration in the sediment and a permanent body of water are important to the distribution of *Hexagenia* nymphs. The location of nymphs in the eastern basin has not been determined. The anoxic conditions of Lake Erie apparent in the 1950s provided an inhospitable environment for nymphs. However, recent improvements in water quality have led to the resurgence of *Hexagenia*. During the summer of 1999, clouds of *Hexagenia* were observed on Doppler Radar. The appearance of the *Hexagenia* mayflies along the shores of Lake Erie indicates that oxygen is available for growth and survival of the mayfly nymphs. This should provide a renewed source of forage for Lake Erie fish.

INTRODUCTION

Mayflies have been considered a nuisance by some and revered by others. Ken Kreiger, director of Ohio's Mayfly Watch Program, conveys some problems associated with mayfly emergence. " The insects don't bite, but swarms are generally considered a nuisance. They are attracted to and congregate under bright lights, and the decomposing piles of insects smell fishy and serve as breeding grounds for flies. Swarms of *Hexagenia* can also pose as a traffic hazard. Thousands of mayflies resting on the pavement in the glow of streetlights get flattened by car tires, making the roads dangerously slick." In addition, mayflies have created power outages by shorting out transformers in Detroit in June 1995 and Toledo in 1996. A headline in a Great Lakes United publication (1996) reads, "The mayfly, an ecosystem canary, recovers." The return of *Hexagenia* signaled considerable water quality improvement. Lynda Corkum (IJC 1996) wrote, "Fishflies (Canadian Sailor or Soldier) are a seasonal delicacy for many species of fish." This abundant food source for Lake Erie fish could mean a dramatic change again in the angler's catch.

The mayfly belongs to the order Ephemeroptera, meaning "live for a day," and at least 16 species are thriving in Lake Erie. These species include:

BAETIDAE — *Callibaetis flucuans* (Walsh),

BAETISCIDAE — *Baetisca lacustris* McDunnough,

CAENIDAE — *Caenis amica* Hagan, *Caenis latipennis* Banks,

EPHEMERELLIDAE — *Ephemerella dorothea* Needham,

EPHEMERIDAE *Ephemera simulans* Walker, *Hexag*enia *atrocaudata* McDunnough, *Hexagenia bilineata* (Say), *Hexagenia limbata* (Serville), *Hexagenia rigida* McDunnough,

HEPTAGENIIDAE — *Heptagenia flavescens* (Walsh), *Stenacron interpunctatum* (Say), *Stenonema femoratum* (Say), *Stenonema mexicanum integrum* (McDunnough), *Stenonema pulchellum* (Walsh),

POLYMITARCYIDAE — *Ephoron album* (Say). (Randolph & McCafferty, 1998; McCafferty, 1975)

One genus, *Hexagenia,* has attracted attention over the years in part because it is the largest mayfly in North America (Figure 1 a, b). It suddenly disappeared from Lake Erie in 1953 and was virtually absent for almost 40 years until it made a dramatic reappearance in the 1990s (Figure 2). Its numbers in 1997-1999 approached former historical densities of the late 1940s and early 1950s. Of the seven species of *Hexagenia,* four have been found in Lake Erie: *H. limbata* (Serville), *H. rigida* McDunnough, *H. atrocaudata* McDunnough, and *H. bilineata* (Say). Two species, *limbata* and *rigida* (Wood 1973; Chandler, 1963) were common from 1929-1952 with *H. limbata* predominating. Chandler (1963) found that in the 1940s the ratio was 75% *H. limbata* to 25% *H. rigida.* J. Hageman (personal comm. in Krieger *et al.*1996) reported that for 1993 *H. limbata* was 80% to 20% *H. rigida* and in 1994 79%-21%. Current collections in the Pennsylvania region of Lake Erie are predominately *H. rigida*.

The preferable habitat for *Hexagenia* nymphs is rich marl in the mud/clay bottoms of well oxygenated cold lakes. Lyman (1943) reported that *Hexagenia* nymphs were found in soft organic muds of deeper-water areas contiguous to the shallower sandy or rocky littoral region. He states, "Although specimens may be found on a sandy bottom or on a bottom of fine sand and mud intermixed, by far the greater numbers occur on bottoms of distinctly soft, muddy character."

Mayflies are important to the aquatic food chain, but researchers are concerned that they may have detrimental effects on the ecosystem due to their ability to uptake contaminants. Ciborowski & Corkum (1988) found significant concentrations of pentachlorobenzene (QCB), hexachlorobenzene (HCB), octachlorostyrene (OCS), and 16 poychlorinated biphenyl (PCB) congeners in most animals collected at eight Canadian sites adjacent to the St. Clair and Detroit rivers. Annual mobilization of contaminants (total PCBs) from sediments to *Hexagenia* nympal tissues in Lake St. Clair approximated the annual input from aerial loading (Corkum *et al.* 1995). Researchers are concerned that fish consumption advisories will increase due to migration of contaminants from lower trophic levels to game fish populations.

Since 1994, *Hexagenia* immatures have been appearing with increasing numbers in the stomachs of walleye and yellow perch (Lake Erie Mayfly Research Group, 1998). The return of the *Hexagenia* mayfly may be associated with the reappearance of the sturgeon, whitefish, lake herring and silver chub. Interestingly, when *Hexagenia* spp. mayflies disappeared, so

Figure 1 (a). *Hexagenia spp. female imago*

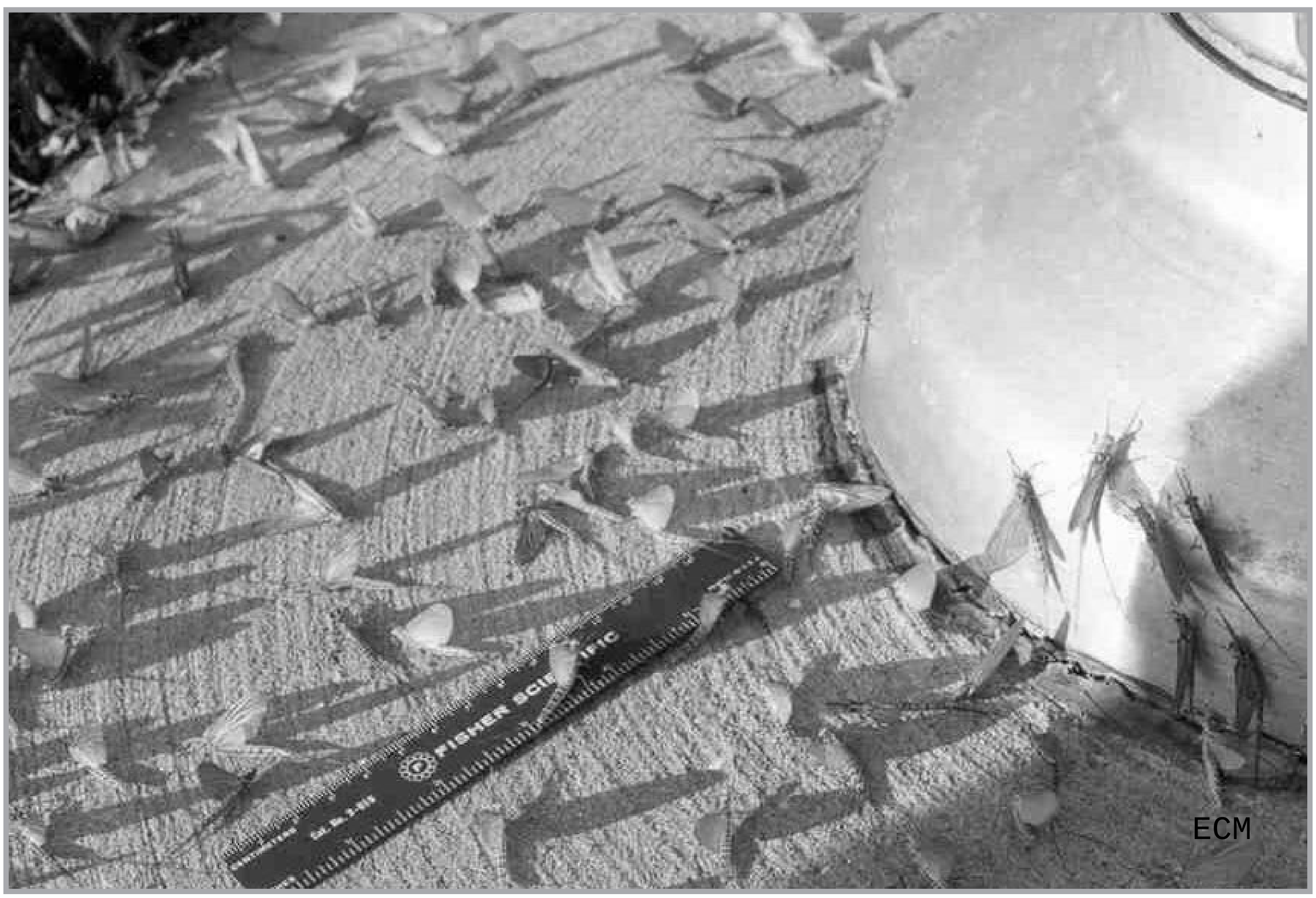

Figure 1 (b). *A group of subimagos at the base of a light pole with a ruler for size comparison.*

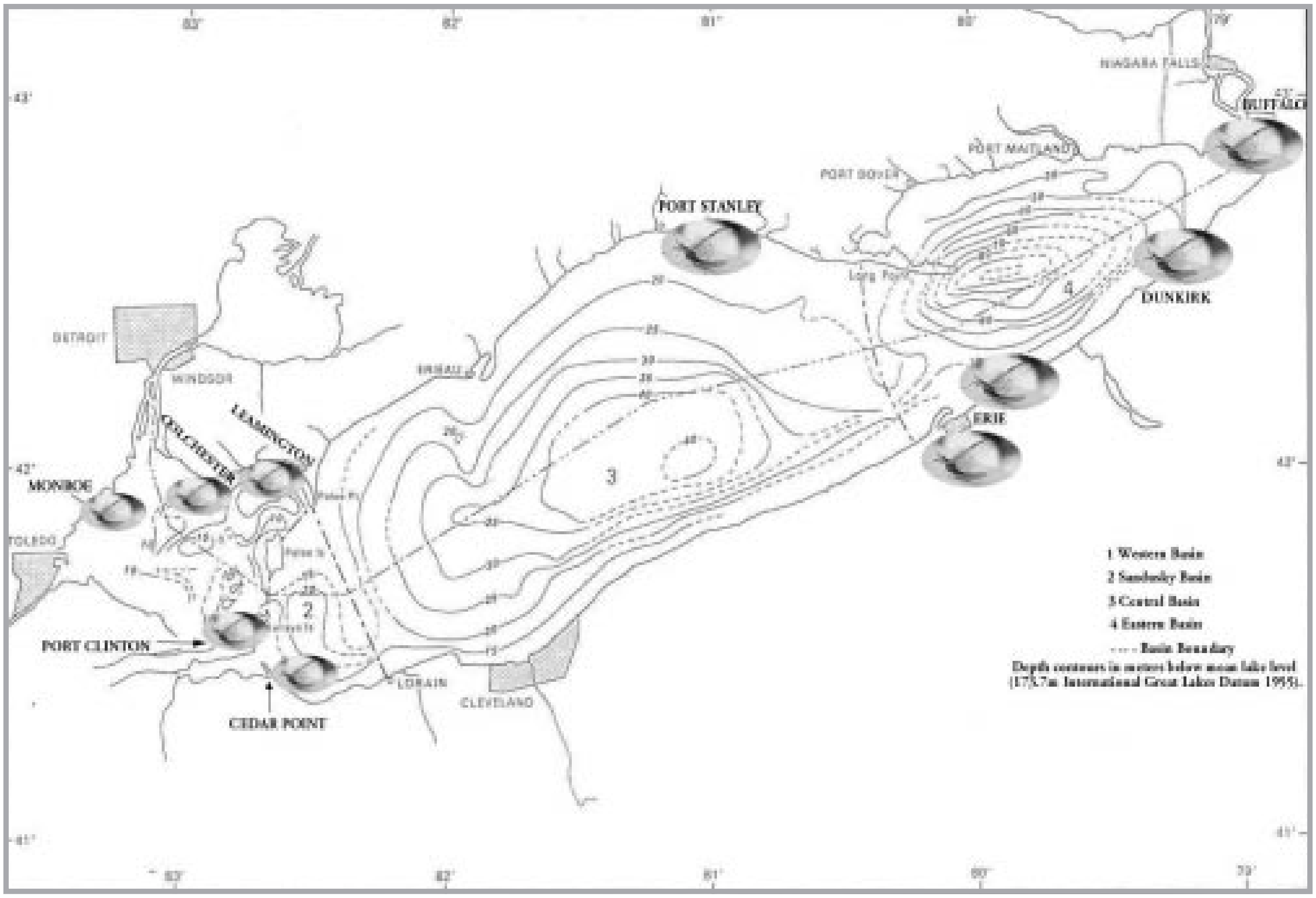

Figure 2. *Lake Erie topography map of Pleistocene deposits (adapted from IJC 1969) with the mayflies (photo courtesy K. Krieger) indicating areas of significant Hexagenia populations coming onshore in 1999.*

did the blue pike (*Stizospedion vitreum glaucum* Hubbs). Rasmussen (1988) reported that *Hexagenia* nymphs are among the largest benthic animals from littoral and sublittoral zones of lakes. Numerous references were made to the high selectivity in consumption of these nymphs by perch, walleye, whitefish, drum, white crappie, and other epilimnetic fish.

SEDIMENT CHARACTERISTICS AND *HEXAGENIA* NYMPHS OF LAKE ERIE

Lake Erie is the oldest of the five Great Lakes (12-13,000 years) and the shallowest, with a volume of 484 km^3, and a surface area of 25,657 km^2 (NOAA, 1989). It ranks as one of the largest freshwater lakes in the world, ninth in area and fifteenth in volume. Glacial deposits are widely exposed on the lake bed adjacent to the shore zone in water depths up to 20 meters.

Approximately 58% of the lake bottom is covered with a silty clay or clay mud deposit. Mud accumulation is limited to the deeper parts of the basins. Based on bathymetry, Lake Erie naturally forms three different types of basins, western, central and eastern (Figure 3). The maximum mud thickness in the three basins was reported to be 5 m west basin, 20 m central basin and 40 m in the east basin (IJC 1969).

The western basin has a mean depth of 7.4 m, a maximum depth of 18.9 m, and tends not to stratify. It was formerly well oxygenated at all depths. The bottom sediment is comprised of muck and gravel-rubble deposit or shoals with exposed limestone bedrock strata (Kenyon

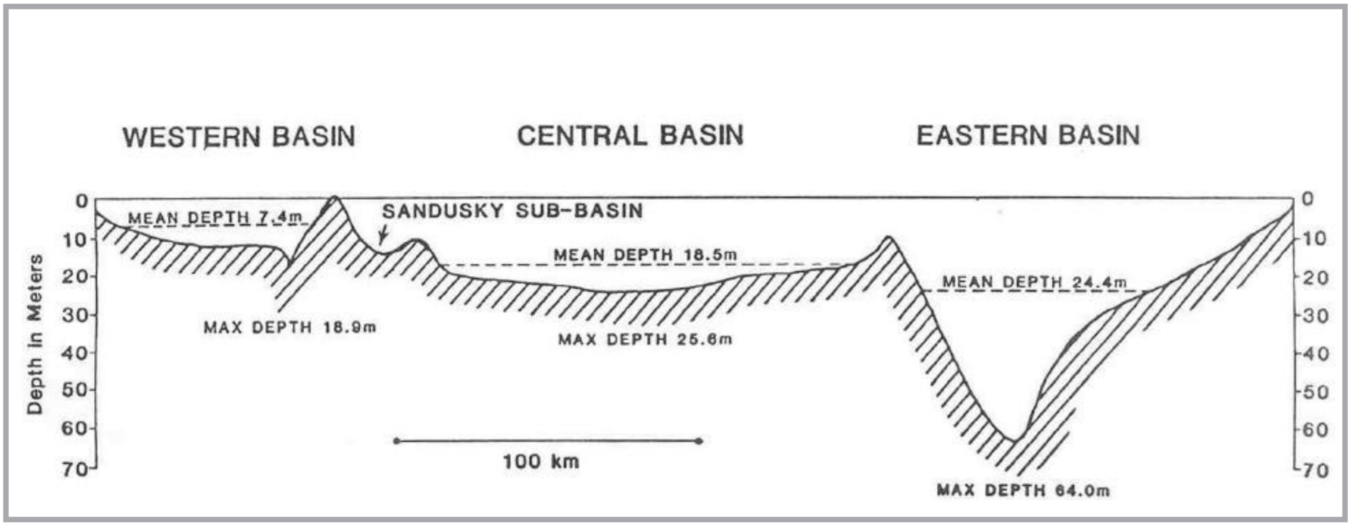

Figure 3. *Bathymetric cross-section of the Lake Erie Basin (from NOAA, 1989) indicating the different depth patterns of each basin.*

1972) and all of the islands and most shoals are surrounded by limestone or dolomite outcrops. Historically, the thermocline formation in the western basin was irregular since temperature did not vary more than 2° C from surface to bottom and oxygen did not vary over 2 ppm from surface to bottom (Chandler 1940).

The central basin, with a mean depth of 18.5 m, a maximum depth of 25.6 m, has no shoals or irregularities on its flat plain-like substrate of clay and mud. Reynoldson and Hamilton (1993) documented the presence of *Hexagenia* from tusks found in sediment core samples collected in the central basin in 1988. Sediment core samples from 50-year time intervals identified *Hexagenia* tusks on both the north and south shores of the central basin in less than 20 meters of water. This publication provides information on the potential distribution of *Hexagenia* in the central basin. They noted that populations fluctuated only slightly from an estimated date of 1740 to the late 1890s.

The eastern basin is the deepest with a maximum depth of 64 m and a mean depth of 24.4 m. The sloping floor extends towards the deepest point several miles east of Long Point, Ontario, where it stratifies regularly (Kenyon 1972). The bottom substrates are composed of sand, mud, gravel and shale bedrock or mixtures of clay, sand and gravel. A large submerged sandbar divides the central and eastern basins. Long Point projects 40 km eastward into the deepest part of the eastern basin. Materials transported eastward along the south shore of the spit are dumped into the eastern basin. The spit is advancing over the post-glacial mud of this basin at a rate of 7 m per year (IJC 1969). In the eastern half of the lake, the glacial deposits are derived from gray carbonate and black shale rock.

HABITAT CHANGES

Several factors, including substrate type, oxygen concentrations and a permanent body of water (large river or lake) are important in influencing the distribution of *Hexagenia* nymphs. Lyman (1943) showed that the character of the bottom is among the most important factors influencing distribution of *Hexagenia* nymphs. In Douglas Lake, Michigan, the greatest depth of *Hexagenia* nymphs was correlated with dissolved oxygen relationships within the thermocline.

Reynoldson *et al.* (1993) used sediment tusk profiles to report the disappearance of mayflies in the western basin. The populations of *Hexagenia* in the early 1930s and 1940s were extremely large. However, a period of population decline and instability followed in the late 1940s. Reynoldson *et al.* (1989) also showed the *Hexagenia* populations between 1925 and 1955 had two dramatic declines, one in 1937 and another in 1944. These changes in population density seem to be correlated with the anoxic conditions that occurred in Lake Erie. Herdendorf (1984) documented the anoxic areas of the central basin from 1930-1982 (Figure 4). The

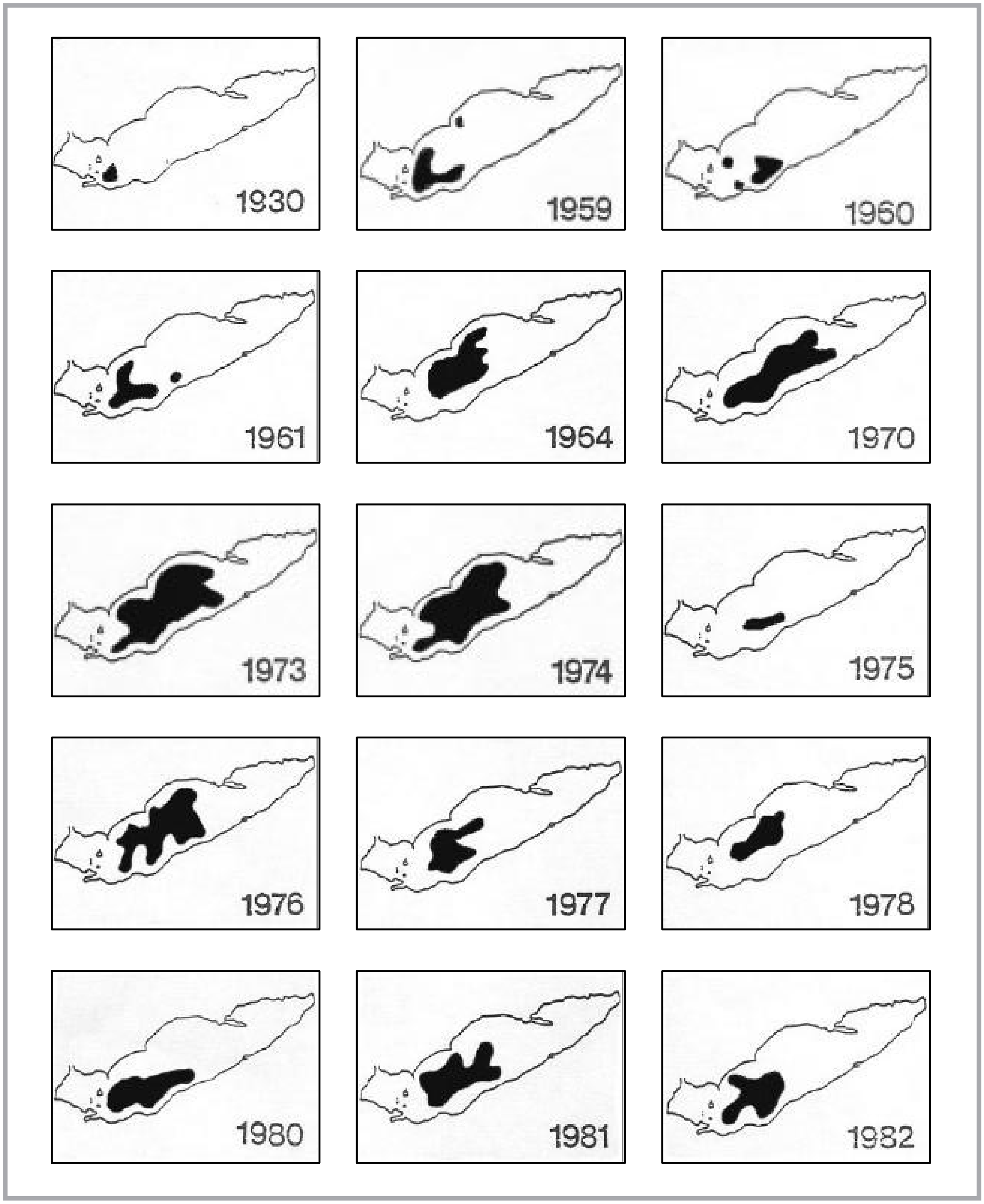

Figure 4. *Summer anoxic area in the hypolimnion of Lake Erie (1930-1982). Redrawn, used by permission (Herdendorf, 1984).*

mayfly populations were devastated in 1953 when unusually calm weather prevailed in late summer. As a result, the hypolimnion became almost anoxic with oxygen concentrations as low as 0.7 ppm. This condition lasted for a period of 13 days (Britt 1955) and occurred again in 1955. Arnold (1971) documented low levels of oxygen in the central basin of less than 1 ppm. Mayflies would have had difficulty surviving these conditions. Recent oxygen levels in Lake Erie have been relatively stable, yet Pennsylvania Fish and Boat Commission biologist Roger Kenyon reported oxygen levels of 3ppm in the hypolimnion in 1999.

A decrease in oxygen levels can result from an excess of organic nutrients and can accelerate the eutrophication of a lake or other body of water. Beeton (1965) documented many chemical changes that caused accelerated eutrophication of Lake Erie over a 30-year period. In 1972, Kenyon wrote, "A century of intensive agriculture and increased urbanization in the Western Lake Erie watershed was responsible for the deposition of excessive amounts of sediments, organic deposits and solids as well as the nutritive elements – the phosphates and nitrates." All of these factors were prime examples of features that lead to eutrophication. In 1970, a large region of the central basin had anoxic conditions that remained through 1974.

LIFE HISTORY

Adult mayflies appear on Lake Erie as early as the first week of June and emerge sporadically until September. Langlois (1951) reported that the period of emergence from Lake Erie was controlled by water temperature. After mating, the adult female mayfly deposits as many as 8,000 eggs directly on or in the water. The eggs then sink to the bottom of the lake and after several days to several months, depending on water temperature, hatch into the nymphal stage.

The nymphs live in the lake sediment and feed on particulate matter. They construct a U-shaped burrow or tunnel by digging with their front legs and undulating their abdominal gills to keep the burrow oxygenated (Figure 5). Burrows may be 10-15 cm. deep. The nymph stage lasts one or two years depending on species, or cohort, and temperature conditions. There may be two cohorts, one with a 14-month life cycle and another with a 22-month life cycle (Corkum *et al.* 1997).

Nymphs usually mature in two years in colder climates. As the nymphs continue to grow, they go through a molting process (ecdysis), during which they shed their exoskeleton and form a new one. Nymphs may undergo as many as 20 to 30 molts before emerging as adults. When the nymph is ready for emergence, it leaves the burrow at dusk and swims to the surface. At the surface, the nymph's exoskeleton splits and the fully-winged subimago (sub-adult) emerges. The subimago then flies to a hard surface for its final molt to adulthood. This transformation to the adult stage may occur in a few minutes or take the entire night. Subimagos which are sexually immature and incapable of mating, are often mistaken for an adult. They are, however, easy to tell apart by their color. Subimagos are a dark smoke color, while adults are white or straw colored. Wings of subimagos are dark, while wings of imagos (adults) are clear and glistening. Adult mayflies have a single purpose: reproduction. Neither subadults nor adults feed since they have incomplete mouthparts. Interestingly, the mayfly digestive tract is filled with air which may be an aid to flight. Mayflies mate at dusk at which time the males congregate in huge swarms to attract females. After mating, the females deposit their eggs on the lake surface and then die. The life span of the adult mayfly is variable depending on temperature and humidity, but may be up to 72 hours. Data from light traps shows that inland migration may be as far as 24 km. Freisen & Flannagan (1976) reported parthenogenesis in *H. rigida*, however, it remains to be determined if parthenogenesis is taking place with the Lake Erie population.

Figure 5. *A Hexagenia nymph in artificial substrate. Photograph by Calvin Fremling (from Fremling and Schoening 1973) used by permission.*

RADAR DETECTION

("Live and in concert with nature, a crystal ball of the future and perhaps echoes of the past" from an article by Don Hopey Pittsburgh Post-Gazette July 26, 1999.)

During the summer of 1999, clouds of *Hexagenia* spp. mayflies were observed on Doppler Radar at a local television station, WJET- TV 24 (Figure 6). Radar observations of mayflies were first reported by Krieger *et al*. (1996) on June 22, 1994, from the radar of the ship R/V Muskie II. This 8 km cloud was located 3 km east of South Bass Island in Lake Erie. Doppler radar can measure the movement toward or away from the transmitter, which makes it possible to determine the height of a cloud. The Channel 24 Doppler Radar is located 12 km from the Lake Erie shorelines in Erie, Pennsylvania. In order to see the mayfly movement, the radar transmitter was moved to an angle slightly above the lake surface. The first observation of the mayfly emergence was on June 26, 1999 by meteorologist Dave Call of the WJET-TV Channel 24 weather staff. The emerging mayflies appear on radar as what appear to be precipitation bands. The clouds vary in color of blue to green depending on the intensity of the radar echoes. In this case, the intensities represented the abundance of the target-mayflies. At times, the clouds were 3-6 km wide and 16-24 km long. Mayflies were observed on 14 nights through July 20th. Mayflies typically started emerging around 9:30 p.m. Movement

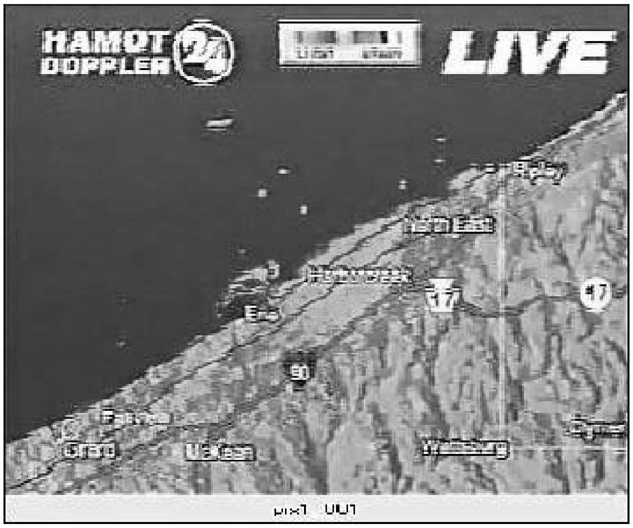

Image 1

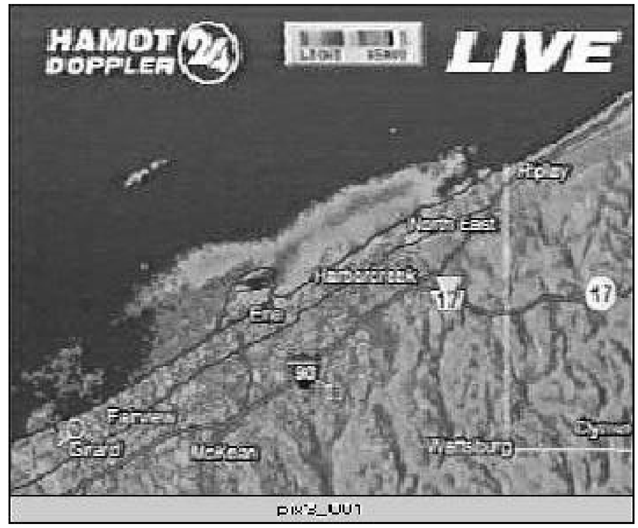

Image 2

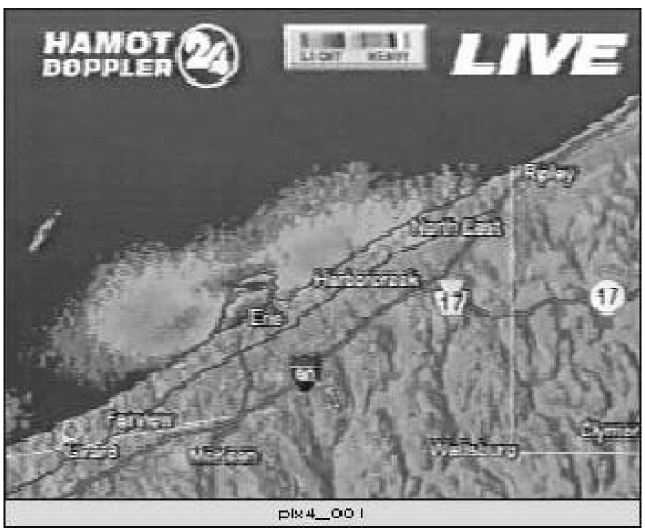

Image 3

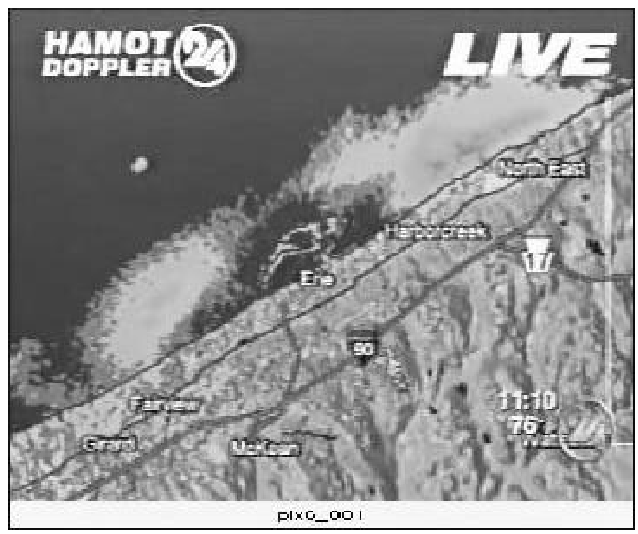

Image 4

Figure 6. *Radar images from three different dates in 1999. For reference, the distance from Fairview to North East is 37 km. Image 1 and 2 June 26, 1999, approximately 20 minutes apart. Image 3 July 11, 1999 and Image 4 July 15, 1999.*

to the shore took from 20-60 minutes, where emergence was confirmed by onshore ground collections. Surprisingly, on July 11th, a large migration was observed moving back to the lake over a 72-minute period. This movement is thought to be female mayflies returning to the lake to deposit their eggs.

The following weather data were recorded at the time of collections: air temperature, wind speed and direction, relative humidity and barometric pressure. On the nights of peak emergence, wind speed was always less then 15 km per hour and on only two occasions was the wind out of the west or north. The most prevalent wind direction was SSE or SSW which is from the land to the water. From our observations it appears that mayflies are moving onshore by flying and are not being carried by the wind. The dominant mayfly species was *Hexagenia rigida*. Also present in these collections was *Ephemera simulans*.

For color renditions of the radar scans of mayfly migration on- and off-shore, visit the Pennsylvania Sea Grant website at http://www.pserie.psu.edu/seagrant

STATUS AND PREDICTIONS FOR 2000

Initial sampling in Erie, Pennsylvania started in 1996 and peak emergence was on July 9th, with both *H. limbata* and *H. rigida* present. Collecting began in earnest in 1997 when the peak was July 16th with close to 2000 individuals collected of which *E. simulans* was well represented. The Ohio Mayfly Watch program showed increasing numbers from 1997 through 1999. In 1998, Pennsylvania collections were in low numbers and a peak was observed on July 6th. Then the explosive year of 1999 showered us with over 8000 individuals, entirely *H. rigida* and a sizable *E. simulans* collection from all collection sites from June through August. Peak emergence for 1999 was on the 8th and 15th of July (Figure 7).

Chandler (1963) noted cyclical trends of low emergence in 1941-1942 and high numbers in 1940 and 1943. Reynoldson (1989) describes cyclical trends for nymphs between 1925-1955. There appears to be some cyclical tendencies in the Pennsylvania *Hexagenia* populations from 1996-1999.

It appears that oxygen must be present in the benthos of deep water since exuvial skins were sighted by C. Murray, (pers. comm.) 14.5 km from shore where water depths approached 27 m. During the summer of 1999, *Hexagenia* nymphs were collected near Cleveland (reported by the Easterly Wastewater Treatment personnel on July 5, 1999) at a depth of 13.7 m.

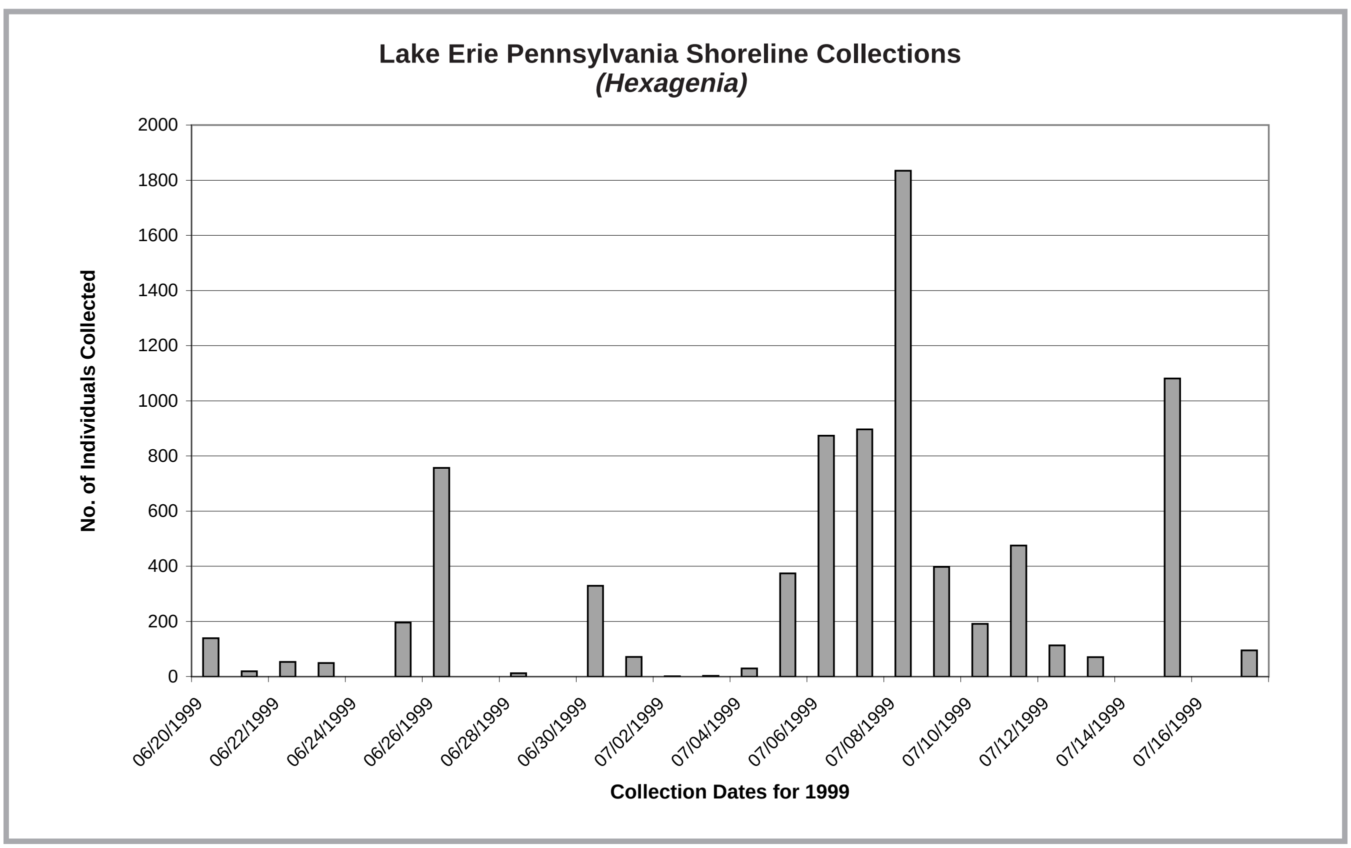

Figure 7. *Collection numbers for 1999 along the shore at Erie, PA.*

Rawson (1930) has reported that *Hexagenia* occurred at depths of greater than 33 m in Lake Simcoe.

Bottom sediment type and the presence of oxygen must be important for *Hexagenia* nymphs. Nymphs have often been observed in the western basin and have been collected in the central basin. To our knowledge, nymphs have not been collected in the eastern basin, but we believe they are present. It is our objective to determine where the nymphs are located in the eastern basin. Our success may depend on finding sediment similar to that of the western basin. At Erie, Pennsylvania, the mass emergence of mayflies in 1999 all appear to be *H. rigida* that is similar to reports from Buffalo, New York (Wayne Gall, pers. comm.). Is *Hexagenia rigida* the deep water inhabitant of the eastern basin of Lake Erie? It is hoped that future studies will help answer this question.

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REFERENCES

Arnold, D. 1971. Lake Erie Alive but changing. The Conservationist of New York. 23-30, 36.

Beeton, A., Kempe, L. Daniels, S. Billy, T. 1965. Field Application of Methods for Recovery of the Selective Lampricide, 3-Trifluoromethyl-4-Nitrophenol. Proceedings 8th Conf. Great Lakes Research.

Britt, N. W. 1955. Stratification in western Lake Erie in summer of 1953: Effects on the *Hexagenia* (Ephemeroptera) Population. *Ecology* 36(2): 239-244.

Charbonneau, P., and L. Hare. 1998. Burrowing behavior and biogenic structures of mud-dwelling insects. *J. North American Benthological Society.* 17(2):239-249.

Ciborowski, J., and L. Corkum. 1988. Organic contaminants in adult aquatic insects of the St. Clair and Detroit Rivers, Ontario, Canada. *J. Great Lakes Res.* 14 (2): 148-156.

Corkum, L. D., J. J. H. Ciborowski, and Z.E. Kovats. 1995. Aquatic insects as biomonitors of ecosystem health in the Great Lakes areas of concern. *In*: Biomonitors and Biomarkers as Indicators of Environmental Change. Ed. Butterworth, F. M., L. D. Corkum & J. Guzman. Plenum Press. NY. 31-44 pp.

Corkum, L., 1996. Commentary. Focus. International Joint Commission. Nov./Dec. 1996. p 11.

Corkum, L. D., J.J. H. Ciborowski and R. Lazar. 1997. The distribution and contaminant burdens of adults of the burrowing mayfly, *Hexagenia,* in Lake Erie. *J. Great Lakes Res.* 23 (4):383-390.

Fremling, C. R., and G. L. Schoening. 1973. Artificial substrates for *Hexagenia* mayfly nymphs. Proceedings First International Conference on Ephemeroptera. 209-211.

Friesen, M. K., and J. F. Flannagan. 1976. Parthenogenesis in the burrowing mayfly *Hexagenia rigida* Ephemeroptera. *Canadian Entomologist*. 108: 1295.

Great Lakes United. 1996. The mayfly, an ecosystem canary, recovers. Vol.10 (4):8. Buffalo State College. Buffalo, NY.

Herdendorf, C. A., and K. A. Krieger. 1989. Overview of Lake Erie and its estuaries with the Great Lakes Ecosystem. 1-34 pp. NOAA Dept. Commerce.

Herdendorf, C. A. 1984. Lake Erie Water Quality 1970-1982: Management Assessement US EPA. Chicago, IL. EPA-905/4-84-007. 144 pp.

International Joint Commission. 1969. Pollution of Lake Erie. Vol. 2 International Lake Erie Water Pollution Board. 316 pp.

Kenyon, R. 1972-73. Lake Erie Changing but not dying. Pennsylvania Angler. Part I-III. September 1972, 6-9; November 1972, 8-11,32; January 1973, 10-13.

Krieger, K. A., D. Schloesser, B. Manny, C. Trisler, S. Heady, J.J.H. Ciborowski & K. Muth. 1996. Evidence of the recovery of burrowing mayflies (Ephemeroptera: Ephemeridae: *Hexagenia*) in western Lake Erie. *J. Great Lakes Res.* 22:254-263.

Krieger, K. 1998. Mayflies and Lake Erie, A sign of the times. Ohio Sea Grant FS-069. 4 pp.

Lake Erie Mayfly Research Group. 1998. Hexagenia mayfly populations in western Lake Erie: status and research needs. Unpubl. Summary document & discussion paper prepared by J.J.H. Ciborowski and D.W. Schloesser.

Langolis, T. H. 1951. The mayfly crop of 1951. Ohio Conservation Bulletin. 15:15,32.

Lyman, F. E. 1944. Notes on emergence, swarming, and mating of *Hexagenia* Ephemeroptera. *Entomological News* LV(8):207-210.

Manny, B. A. 1991. Burrowing mayfly nymphs in western Lake Erie, 1942-1944. *J. Great Lakes Research.* 17:517-521.

McCafferty, W. P. 1975. Burrowing mayflies of the United States. Transactions of American Entomological Society. 101:447-504.

Murray, C. 1999. Pers. Communication. Pennsylvania Fish and Boat Commission. Fairview Fish Culture Station.

NOAA. 1989. Lake Erie Estuarine Systems: Issues, Resources, Status, and Management. Estuary-of-the-Month. Seminar Series No. 14. US Dept. Commerce. National Oceanic and Atmospheric Administration. April 1989.

Randolph, R. P. & W. P. McCafferty. 1998. Diversity and distribution of the mayflies (Ephemeroptera) of Illinois, Indiana, Kentucky, Michigan, Ohio, and Wisconsin. Ohio Biological Survey Bulletin New Series 13(1): vii+ 188 pp.

Rathke, David E. 1984. Lake Erie Intensive Study 1978-1979. Great Lakes National Program Office, U.S. EPA, Region V. NTIS Springfield, VA. 484 pp.

Rasmussen, J. B. 1988. Habitat requirements of burrowing mayflies (Ephemeridae:*Hexagenia*) in lakes, with special reference to the effects of eutrophication. *J. North American Benthological Society.* 7(1):51-64.

Rawson, D. S. 1930. The bottom fauna of Lake Simcoe and its role in the ecology of the lake. Univ. Toronto Studies, Biol. Ser. No. 34. Publ. Ontario Fisheries Res. Lab. 40:1-38.

Reynoldson, T. B., D. W. Scholesser, & B. A. Manny. 1989. Development of a benthic invertebrate objective for mesotrophic Great Lakes waters. *J. Great Lakes Research.* 15:669-686.

Reynoldson, T. B., and A. L. Hamilton. 1993. Historic changes in populations of burrowing mayflies (*Hexagenia limbata*) from Lake Erie based on sediment tusk profiles. *J. Great Lakes Res.* 19(2): 250-257.

Wood, K. G. 1973. Decline of *Hexagenia* (Ephemeroptera) nymphs in Western Lake Erie. Proceedings of First International Conference on Ephemeroptera. 26-32 pp.

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The Aquatic Macrophyte Community at Put-in-Bay, Ohio

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ABSTRACT

During most of the last century the aquatic macrophyte community at Put-in-Bay, Ohio, (Figure 1) evidenced a decrease in species diversity. Through 1971, the submersed marcophytes evidenced a 61% loss. The last decade has seen a remarkable reversal of those tends. Reduced nutrient and suspended sediments along with increased light availability due in large part to the invasion and spread of *Dreisen*a spp., have facilitated the return and dominance by species favored by increased light availability.

INTRODUCTION

The marshes, shorelines, and shallow waters of western Lake Erie provide a unique site for the assessment of long-term changes in the aquatic macrophyte flora. Floristically, this area represents the confluence and richness of aquatic macrophyte species with respect to the previous glaciation and subsequent migration of species with eastern, western, northern, and southern geographic distributions as well as endemics (Stuckey 1993). The first large scale, systematic survey of aquatic macrophytes in

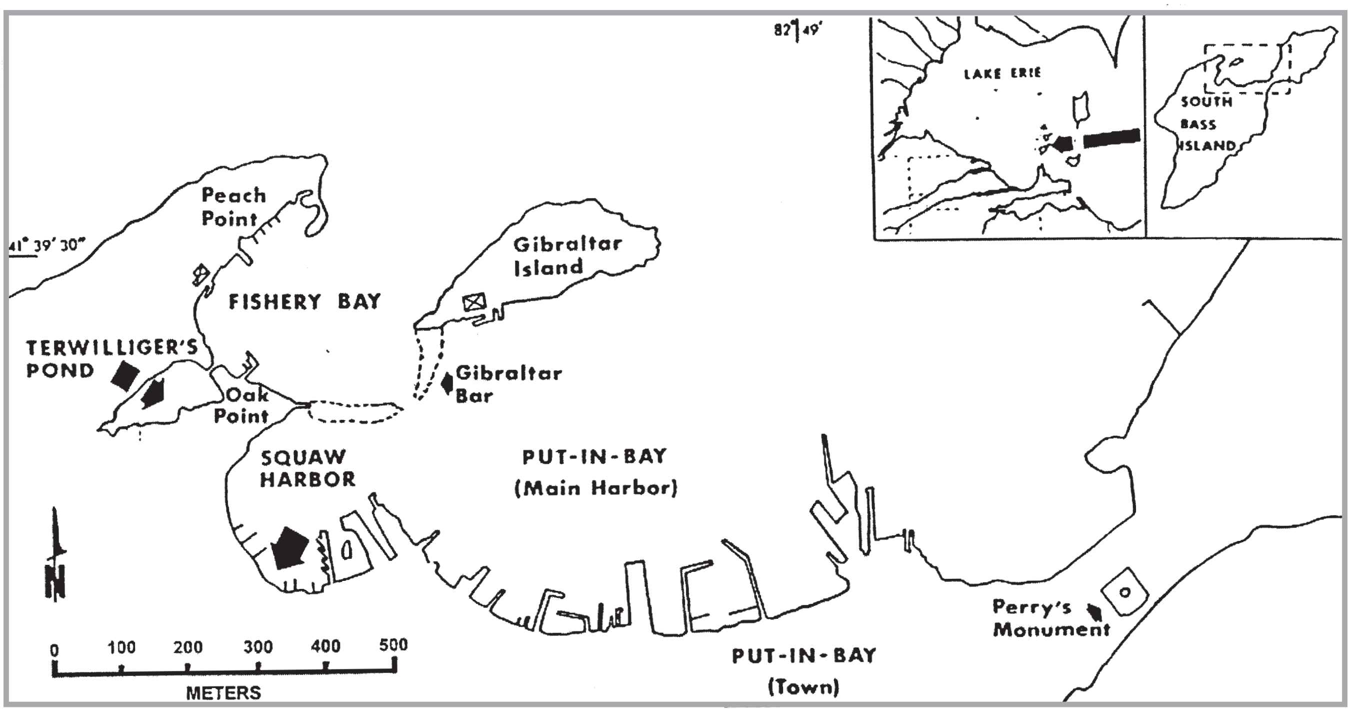

Figure 1. *Location of study sites (Stuckey and Moore 1995).*

the United States was made by Adrian J. Pieters in 1898, (Pieters 1901) and included the islands and marshes of western Lake Erie. He had done a much smaller study the previous year on Lake St. Clair. Pieters' work provides a community description which allows us, with additional researchers' observations, records, and collections, to glimpse the aquatic macrophyte communities through a century of change, and allows an assessment of the shifts in that community structure.

Factors operative in these shifts include both natural and anthropogenic forces. Fluctuations in precipitation and lake levels would naturally shift marshes and shallow water communities laterally with respect to the shoreline, following substrate gradients. Unfortunately, much of the the lake plain became valuable farmland with ditching and draining, and prime real-estate for private and commercial development. This and shoreline modification for docks, wharfs, and houses virtually eliminated much of the emersed aquatic macrophyte habitat. In addition, the increased sediment and nutrient loading which reduced available light in the water column and favored periodic algal blooms, effectively eliminated much of the submersed macrophyte species diversity except for the few turbidity tolerant species.

Another factor was the introduction of nonindigenous aquatic macrophyte species. One in particular, *Lythrum salicaria* L. (Purple Loosestrife) has proven so aggressive that it ecologically displaces any other marsh or wetland species (Stuckey 1981). The native *Phragmites australis* (Cav.) Steud. (Reed Grass) has been facilitated in it spread via highways and other corridors and out competes most other aquatic macrophyte species especially in disturbed habitats.

As a graduate student, I surveyed the diversity of aquatic macrophyte flora at East Harbor State Park, Ottawa County, Ohio (Moore 1976). That study assessed the changes in aquatic macrophyte community composition, 81 years after Pieters' survey. Of the 89 species originally reported by Pieters (1901) and Mosely (1899), 25% had disappeared. If those species formerly abundant, but which had become rare were included, the loss was about 42%. Stuckey (1971) had documented a loss of 50% of the aquatic macrophyte species at Put-in-Bay, Ohio. If one considered only the submersed macrophyte community, the loss was 61%. Those trends were characteristic of the sites studied in western Lake Erie (Stuckey 1971). When I returned to The Ohio State University's F. T. Stone Laboratory in 1985, there were obvious differences in the submersed macrophyte communities. The reduction of phosphate loading had resulted in less intense and frequent summer algal blooms, and the filtering activities of *Dreissena* spp. after 1988, had reduced the suspended sediment and nutrient load and greatly increased the photic zone. When I returned to Stone Lab to teach Aquatic Plants on a regular basis, I began a study of the submersed macrophyte community with two foci: first, the interactions between *Dressena polymorpha* Pall., introduced into western Lake Erie in 1988, and their postveliger recruitment of submersed macrophytes; second, the long-term changes in community structure and composition of the submersed macrophyte community at Put-in-Bay.

MACROPHYTE RECRUITMENT BY DREISSENIDS

In the summer, 1994, four transects (Figure 2) were established from which to quantitatively sample submersed macrophytes for the degree and pattern of recruitment by *Dreissena* postveliger stages. Submersed macrophytes were harvested and 100 g samples examined for dreissenid recruitment (Moore 1995). Results suggested that recruitment began at the lakeward margins of the submersed macrophyte beds by the second week in August and peaked by the end of August, though new

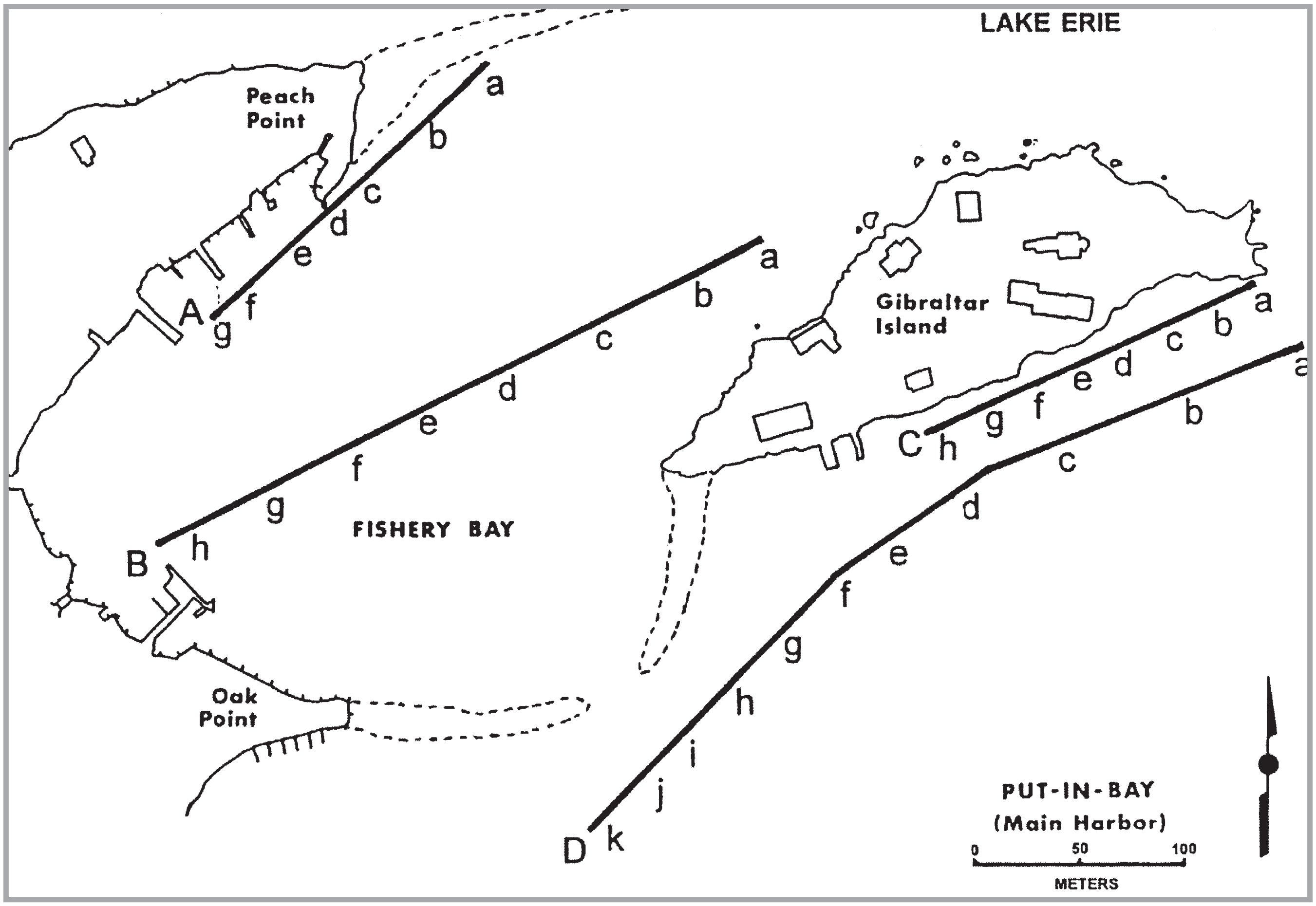

Figure 2. *Transects at Put-in-Bay, Ohio (Stuckey and Moore 1995).*

recruits were evident through mid-September. The recruitment numbers decreased toward the denser middle portions of the macrophyte beds and appeared to be dependent more on species distribution than species specificity. Settlement densities were highest in water of 2-3.5 m depth. Analysis of the sediments suggests fewer than 1% the adult dreissenids survive after the annual disintegration of the macrophyte beds in late October and November. The upper 5 cm sediment of Fishery Bay ranges from 4% pulverized dreissenid valves at 1.5 m water depth to 80% at 2.5 m (Moore 1995).

LONG-TERM CHANGES IN SUBMERSED MACROPHYTE COMMUNITIES

Surveys of the submersed macrophyte communities of Put-in-Bay were begun in summer, 1993, utilizing snorkel and scuba, and continue. A complete vegetational map (Figure 3) of the Put-in-Bay Harbor area was constructed and provides a reference by which to assess ongoing changes in submersed macrophyte community structure and composition. The increase in light availability between 1982 and 1994 (from an annual mean secchi depth of 0.8 m to 3.02 m) favored the spread and dominance by *Vallisneria americana* Michx. and reduction of the more turbidity tolerant species such as *Heteranthera dubia* (Jacq.) MacM., *Myriophyllum spicatum* L., and *Potamogeton crispus L.* (Stuckey and Moore 1995).

The improved water quality and light availability has favored the return of species which had disappeared during the first half of the 20th century: *Najas guadalupensis* (Spreng.) Magnus, *Najas flexilis* (Willd.) Rostk. & Schmidt,

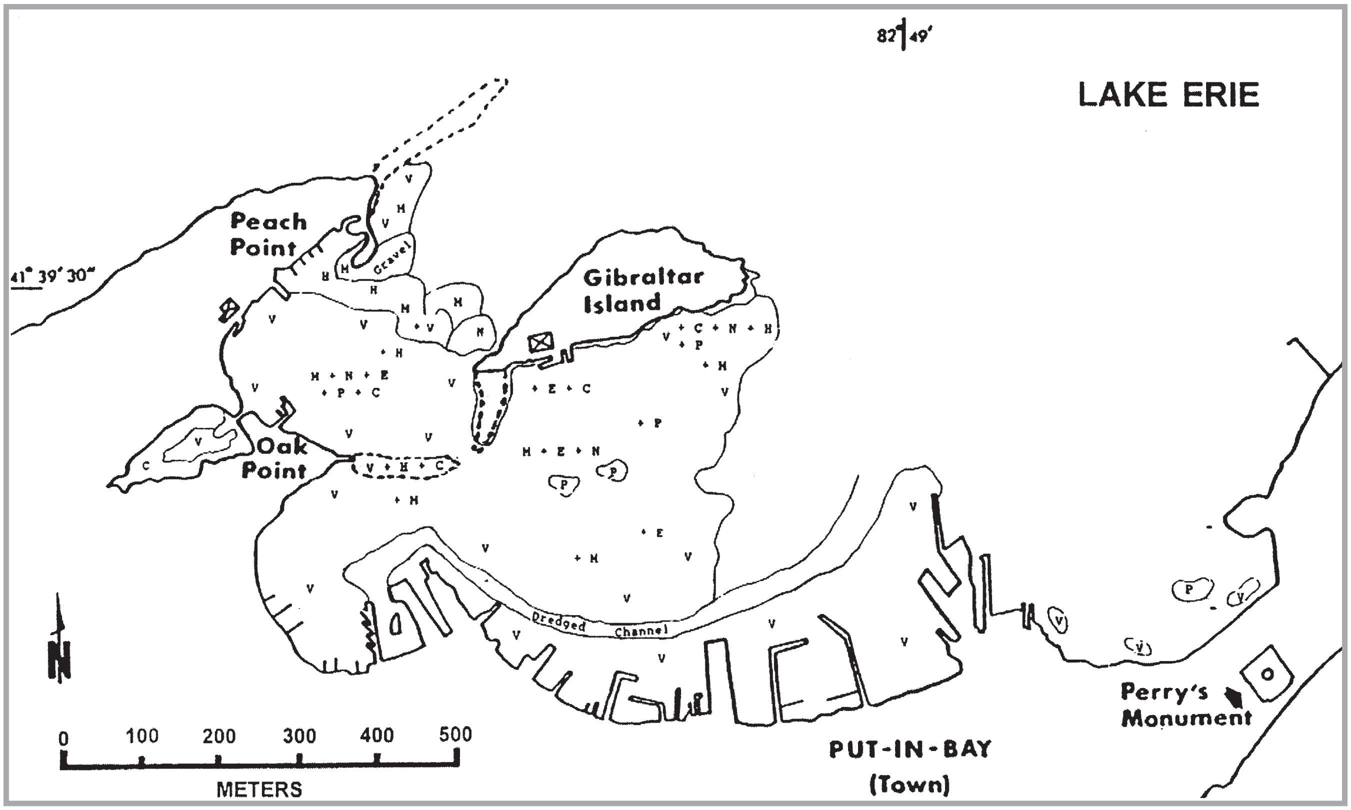

Figure 3. *Map of submersed macrophyte vegetation in 1994 (Stuckey and Moore 1995).*

Potamogeton pusillus var. *pusillus* L., *P. foliosus* Raf., and *Elodea canadensis* Michx. *Najas minor* All., an European species, was first reported in 1994. Floating leaved macrophytes have also returned: *Nelumbo lutea* (Willd.) Pers. and *Nuphar advena* Ait. (Stuckey and Moore 1995).

Potamogeton richardsonii (Benn.) Rydb. was a rare species before the 1993 survey. Since then, I have been documenting the appearance and expansion of its colonies within the harbor. It is now common in portions of the harbor with some colonies greater than 400 m^2 in the sandy substrates. Since fruiting is common, it is likely that recolonization by seed is occurring. However, it is unclear if contribution by the seed bank is occurring for this or other species of submersed macrophytes in the harbor. A seed bank analysis has not been completed for this area. Since the seeds of many aquatic species respond to light cues in germination, most of the harbor's sediments to a depth of 4-4.5 m have light available and seed bank germination is possible if the seeds are still viable. From the surveys in 1993-94, it was evident that several of the pollution intolerant species which had disappeared from the harbor in the years between Pieter's 1894, and Stuckey's 1971 study were reestablished in the harbor and increasing in abundance. The dominant turbidity tolerant species in the submersed macrophyte community such as *M. spicatum, Heteranthera dubia*, and *Potamogeton pectinatus* L. had in much of the harbor been replaced by species favored by higher light levels such as *Vallisneria americana*, *Elodea canadensis*, *Najas flexilis*, and *Potamogeton richardsonsii*. In comparison with Stuckey's (1971) assessment of species loss at 61% the reappearance of some of those species suggests a dramatic reversal of trends. Given the increased light availability and the potential for propagule immigration or seed bank contribution, it is reasonable to expect that additional species may return or new species may be added to the submersed macrophyte community.

MORPHOECOLOGICAL CONSIDERATIONS IN COMMUNITY COMPOSITION

Myriophyllum spicatum is considered an invasive, weedy species in many portions of the United States, including Ohio. However, at Put-in-Bay, *Vallisneria americana* out competes it and assumes the status of "weediness." Prior to the 1990s, *V. americana* was a relatively rare species in western Lake Erie, but with improved water quality and increased light availability, several of its physiological, morphological, and perennation attributes appear to have favored its spread and dominance at Put-in-Bay (Moore 1998). The long, tape-like leaves are capable of greater photosynthetic capability than the finely-dissected, sediment-coated leaves of *M. spicatum* with low irridiation (Jana and Choudhuri 1979), although the branching canopy nature of *M. spicatum* provides an advantage nearer the water surface. The greater potential for lateral colonization and regrowth of *V. americana* in the spring and summer favors its spread. Effective nutrient acquisition may also be a factor. With the greater potential for lateral expansion by *V. americana*, the absorption of nutrients from the sediments (biogenic reduction) may deplete available phosphorus and exchangeable nitrogen (Barko, *et al.* 1991) and provide a competitive advantage when nutrients are not as available from the water column. The higher "sand" content of much of the sediments of Fishery Bay and much of Put-in-Bay Harbor, due to the abundance of pulverized dreisseneid valves, may also be providing a competitive advantage for *V. americana*, since *M. spicatum* grows more poorly on sandy substrates in controlled experiments (Aiken and Picard 1980).

CURRENT RESEARCH

Although the changes in macrophyte community structure and composition have been documented through historical time, we do not have a good understanding of pre-historical macrophyte communities. Sediment cores collected during the 1998-99 season and are being analyzed for aquatic macrophyte pollens present. An understanding of the community structure over time as determined from pollen frequencies may provide a more complete understanding of the dynamics of the macrophyte communities at Put-in Bay.

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REFERENCES

Aiken, S. G. and R. R. Picard. 1980. The influence of substrate on the growth and morphology of *Myriophyllum exalbescens* and *Myriophyllum spicatum*.

Barko, J. W., R. M. Smart, D. G. McFarland. 1991. Interactive effects of environmental conditions on the growth of submersed aquatic macrophytes. *J. Freshwater Ecol.* 6:199-207.

Jana, S. and M. A. Choudhuri. 1979. Photosynthetic, photorespiratory and respiratory behavior of three submersed aquatic angiosperms. *Aquatic Bot.* 7:13-19.

Moore, D. L. 1976. Changes in the marsh and aquatic flora of East Harbor State Park, Ottawa County, Ohio, since 1895. *Ohio J. Sci.* 76(2): 78-86.

Moore, D. L. 1995. *Dreissena polymorpha* Pall. postveligers in submersed macrophyte beds of Put-in-Bay, Ohio, as related to rate and density of settlement, macrophyte preference, water depth, and position within beds. Proceedings of the Fifth International Zebra Mussel and Other Aquatic Nuisance Organisms Conference. pp. 343-369.

Moore, D. L. 1998. Interspecific competition between *Myriophyllum exalbescens* Fern., *Myriophyllum spicatum* L., and *Vallisneria americana* Michx. at Put-in-Bay, Ohio: a morphoecological perspective. Proceedings of the Eighth International Zebra Mussel and Aquatic Nuisance Species Conference.

Mosely, E. L. 1899. Sandusky Flora. A catalogue of the flowering plants and ferns growing without cultivation in Erie County, Ohio, and the peninsula and islands of Ottawa County, Ohio. Ohio Academy Sci. Special Papers No. 1, 167 pp.

Pieters, A. J. 1901. The plants of western Lake Erie, with observations on their distribution. Bulletin U.S. Fish Comm. 21:57-79.

Stuckey, R. L. 1971. Changes of vascular aquatic flowering plants during 70 years in Put-in-Bay, Lake Erie, Ohio. *Ohio J. Sci.* 71:321-342.

Stuckey, R. L. 1981. Distributional history of *Lythrum salicaria* (Purple Loosestrife) in North America. *Bartonia* 47:3-20.

Stuckey, R. L. 1993 Phytogeographical outline of aquatic and wetland angiosperms in continental eastern North America. *Aquatic Bot.* 44:259-301.

Stuckey, R. L. and D. L. Moore. 1995. Return and increase in abundance of aquatic Flowering plants in Put-in-Bay Harbor, Lake Erie, Ohio. *Ohio J. Sci.* 95(3):261-266

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The Lake Erie Millennium Plan

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OVERVIEW

The Lake Erie Millennium Plan (LEMP) was initiated in 1998 by scientists at the University of Windsor, National Water Research Institute — Burlington, Ohio Sea Grant/F.T. Stone Lab of Ohio State University, and US-EPA Large Lakes Lab at Grosse Ile, Michigan, to foster and coordinate research that will identify and solve basic ecological questions relevant to the Lake Erie Ecosystem through a binational, collaborative network.

To be relevant to regional and binational groups responsible for Lake Erie's health, the research must address lakewide management needs as well as further basic knowledge of the ecosystem. To this end, the active sponsorship of agencies and organizations whose mandate concerns Lake Erie was solicited. Twelve binational, national, regional, state, and provincial organizations have contributed funds to sponsor LEMP activities. Additionally, 13 collaborating organizations have been active participants in the planning, information transfer or research aspects of the LEMP, providing in-kind/and or technical support that further Plan activities. Goals of the LEMP are:

1) To collectively document the research and management needs of users and agencies;

2) To summarize the current status of Lake Erie from process and ecosystem function perspectives; and,

3) To develop a framework for a binational research network to ensure coordinated collection and dissemination of data that addresses the research and management needs.

These goals are being achieved through a five-step process:

1) Identify needs and issues of the public and government; achieved at a Prevailing Issues Workshop (1998);

2) Take stock of what is and is not known about Lake Erie; achieved through Lake Erie at the Millennium binational conference (April 1999);

3) Summarize 'what are the questions?' — determined through a post-conference workshop (April 1999);

4) Resolve how to answer the questions; addressed at a series of Research Definition workshops (1999/2000);

5) Undertake a binational effort to secure joint funding for a 4-5 year research goal-oriented plan to get answers (2001-2006).

ACTIVITIES

Prevailing Issues Workshop

In November 1998, a "Prevailing Issues Workshop" held at the University of Windsor brought together Lake Erie managers, researchers, and other interested parties to discuss the major questions and management issues facing Lake Erie. The workshop participants reviewed and distilled over 90 issues that had been identified as management concerns in response to a broader request for issues. The panel identified 48 separate topics, which they organized into 7 subject areas. Participants then evaluated the ecological, economic, human health and societal importance of each issue, the perceived understanding of the issue, and the priority that each issue was receiving from agencies. A working draft of the proceedings of this workshop is complete. The subject areas identified became focal directions for the LEMP binational conference (below), and a modelling summit held in June 1999 at IAGLR in Cleveland, Ohio.

Lake Erie at the Millennium Binational Conference

In April 1999, the LEMP convened a binational conference at the University of Windsor to compile current knowledge of Lake Erie processes, forecast trends for the next 3-5 years, and identify critical research gaps. Over 170 individuals attended the 4-day event. The 48 invited speakers were additionally asked to cast their special expertise in the context of the previously identified management and data needs. The conference culminated in a "Research Needs" workshop that summarized consensus on the 7 themes. The conference program and major findings and recommendations of the workshop are summarized at the LEMP web site, which is maintained through collaboration with the IJC's Council of Great Lakes Research Managers (URL: http://www.ijc.org/boards/cglr/erie2000).

Lake Erie at the Millennium Monograph and Journal Issue

Invited presenters' peer-reviewed manuscripts will appear as a monograph summarizing Lake Erie's present status, possible future states, and unresolved ecological issues. Seven subject editors' summary chapters integrate and focus the conclusions and research needs of groups of related chapters. Contributed presentations are being compiled to appear as a special issue of the *Journal of Great Lakes Research*. Both publications should appear in 2001.

Research Needs Workshops and Research Network Formation

The binational conference and workshops have defined and refined researchers' and managers' needs into several suites of ecological problems. Each suite will be the focus of a 2-3 day Research Definition workshop. The first meeting, held in October 1999 at USEPA-Grosse Ile, Michigan, addressed the processes regulating energy flux at the base of the food chain. Subsequent workshops will deal with issues of contaminants (2000), habitat, fish community dynamics, exotic species invasions, and human health.

Each workshop will produce a statement of our current understanding of issues, and a proposal to develop suites of key studies that will resolve each of the most pressing research issues. The resulting coordinated 4-5 year research programs will concurrently generate the data needed to resolve uncertainties in the fundamental management issues (monitoring). Results of our first research workshop will generate a white paper and research proposal entitled *Limits on Energy Transfer in the Lake Erie Ecosystem — Critical Tests of Hypotheses.*

Linked Canadian and U.S. research proposals will be generated from each workshop meeting for submission to granting agencies. NSERC Collaborative research programs will be asked to fund the proposals of the Canadian participants. U.S. participants will submit parallel requests to major U.S. granting agencies. Explicit in the goals of this research network is the need for secure, longer-term commitment to the collection, compilation, interpretation and application of data that will be made available to the entire Great Lakes community. These research efforts will advance our basic understanding of large-lake processes. Equally important, the work will complement ongoing systematic efforts of programs such as the Lakewide Area Management Plan to guide resource use and protect ecosystem integrity.

How to Participate

The LEMP has succeeded to date through the good will and cooperative activities of concerned citizens, advocacy and stewardship groups, agencies from all levels of government, and scientists. We have attempted to attract as broad a base of interest in this effort as possible. We believe the plan will succeed precisely because of the focus on inclusiveness. We invite all organizations and individuals to participate as their interest and resources dictate.

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Lake Erie Ecosystem

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