Volume 5, Number 2 Summer 2001

Great Lakes Research Review

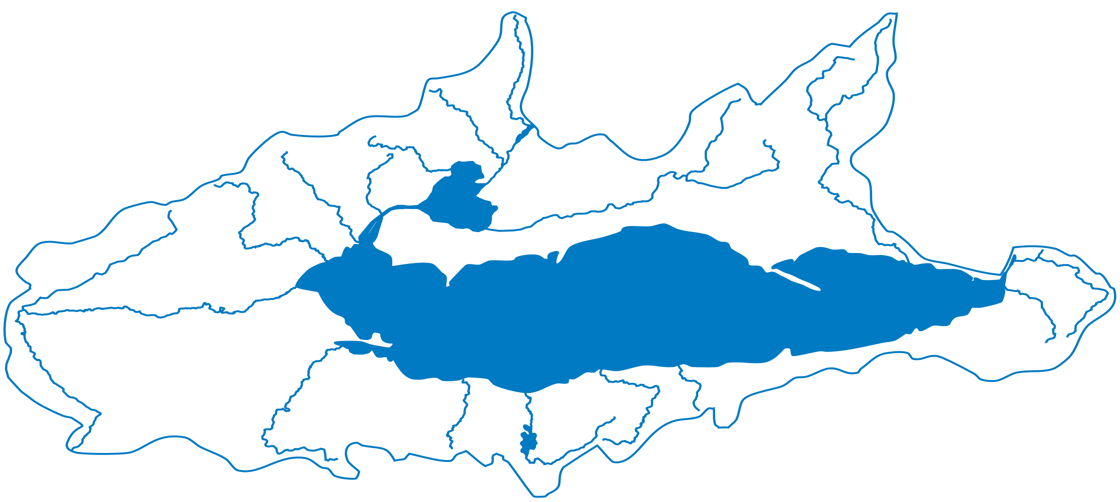
great lakes program

GREAT LAKES RESEARCH CONSORTIUM

Sea Grant New York

Working together for Great Lakes research and education

Lake Erie Ecosystem



In This Issue . . .

Avian Botulism in Lake Erie... Characterization of Eastern Lake Erie Inshore Fish Communities... Did Zebra Mussels Clean Up Lake Erie... Monitoring the Attachment of Zebra Mussels at a Lake Erie Power Gernerating Station... Three-Dimesional Structure of the Water Mass in Eastern Lake Erie as Revealed by Intensive CTD Monitoring and Three-Dimensional Visualization

Great Lakes Research Review

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University of Buffalo
202 Jarvis Hall
Buffalo, NY 14260-4400
Voice: (716) 645-2088
Fax: (716) 645-3667
http://www.buffalo.edu/glp
Director: **Dr. Joseph F. Atkinson**
Associate Director: **Helen M. Domske**
Administrative. Assistant: **Monica S. Moshenko**

Great Lakes Research Consortium

SUNY College of ESF
24 Bray Hall
Syracuse, NY 13210
Voice: (315) 470-6816
Fax: (315) 470-6970
http://www.esf.edu/glrc
Executive Director: **Jack Manno**
Co-Director: **Dr. Richard Smardon**
Research Co-Director: **Dr. Jim Haynes**

Sea Grant
New York

SUNY at Stony Brook
Dutchess Hall
Stony Brook, NY 11794-5001
Voice: (631) 632-6905
Fax: (631) 632-6917
http://www.seagrant.sunysb.edu/
Director: **Dr. Jack Mattice**
Assistant Director: **Ms. Cornelia Schlenk**

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 providing a substantive overview of research being conducted throughout the basin. It is designed to inform researchers, policy-makers, educators, managers and stakeholders about Great Lakes research efforts, particularly but not exclusively being conducted by scientists affilliated with the Consortium and its member institutions.

Each issue has a special theme. Past issues have focused on the fate and transport of toxic substances, the effects of toxics, fisheries issues, and exotic species. The most recent volumes have focused on the Lake Ontario, St. Lawrence River and Lake Erie Ecosystems. The present issue is the second of two describing work related to Lake Erie. We gratefully acknowledge all of the contributing authors who willingly share their research efforts for this publication.

THE UPCOMING ISSUE

The New York Great Lakes Protection Fund was created to provide a perpetual and dependable source of research funds to support regional and state level projects within New York that protect, restore and improve the health of New York's Great Lakes Basin. It has been an important funding source since 1994, but it has had few ways of communicating its results to the public. For this reason, the next volume of the Review will highlight the outcomes of the New York Great Lakes Protection Fund. For more information, contact Jack Manno at *jpmanno@mailbox.syr.edu*.

Volume 5, Number 2 *Summer 2001*

Great Lakes Research Review

Lake Erie Ecosystem

TABLE OF CONTENTS

Editors: *Jack Manno & Michael Connerton* **Layout:** *Michael Connerton & Michelle Bicek*

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SUNY College of Environmental Science and Forestry
Syracuse, NY 13210

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Volume 5, No. 2, Summer 2001

Introduction

Donald E. Zelazny
Great Lakes Programs Coordinator
New York State Department of Environmental Conservation
270 Michigan Avenue
Buffalo, NY 14203-2999

As a new member of New York's Great Lakes "Team," it is my humble pleasure to introduce this issue of the Great Lakes Research Review. Since assuming my duties this past December as Great Lakes Programs Coordinator with New York State's Department of Environmental Conservation (DEC), I have been frantically reviewing past reports, articles, legislation, strategies, and management plans to gain a historical perspective on how far we have come in achieving our mutual vision to restore, enhance, protect, and conserve the water and natural habitat of the Great Lakes basin. I remember all too well my parents preventing me, as a kid, from swimming in Lake Erie because they heard it was "a dead lake filled with toxic brews" and feared for my health; catching walleye in the Niagara River with strange round scars from a mysterious invader; and traveling to Lake Ontario only to find beaches clogged with putrifying alewives by the thousands. Obviously, the condition of the Great Lakes has changed significantly for the better, thanks in part to many of you. But therein lies the challenge ahead of us.

As the scholarly motto goes, "change is constant." The question before us is how to better identify, monitor, anticipate, and respond to the network of changes in the Great Lakes ecosystem. A successful system demands that each component functions in support of the whole. Likewise, we need to share a mutual understanding of the issues and priorities facing the Great Lakes; explore the vastness and complexity of scale associated with the chemical, physical, biological, and temporal forces at work; and together, experiment to find faster, cheaper and more effective means to share our knowledge in order that it may be applied ultimately to the decision-making process to affect positive change. Yes, it is a big job and one with no end in sight. It starts with basic and applied research, communicated concisely and accurately, to develop the fundamental understanding from which we can chart our future course.

This issue of the *Great Lakes Research Review* is the second of two volumes focusing specifically on Lake Erie. In the previous Lake Erie issue (Volume 5, Number 1, Summer 2000), Helen Domske, a Great Lakes Program Associate Director from SUNY Buffalo, provided an excellent introduction to the lake, its changing issues over time, the institutional framework in place, as well as the lakewide management plan (LaMP) designed to guide our research and restoration management priorities. I strongly urge you to review this article, especially if you missed it before, because it succinctly describes how all the parts come together and become coordinated. Other provocative articles in that issue focus on specific issues causing changes within the lake ecosystem and they are worthy of a second read.

From the perspective of a management agency, this research is fundamentally important because it helps to better define an issue, by describing its nature and functionality, which is critical to developing management strategies and action plans. Concurrent with these research efforts, we need to ensure widespread understanding and consensus of the issues from a holistic perspective of the Great Lakes ecosystem, including our economic values and the effects of human interactions. The objective has been, and must continue to be, for DEC and other Great Lakes resource managers to have a process for determining priority information needs in a coordinated manner. To work effectively, the process must continuously be infused with better information and broad community understanding. In this regard, the *Great Lakes Research Review* serves as a critical instrument to the researchers, policy makers, resource users, educators, and the interested public within the Great Lakes community.

The papers presented in this issue of the *Great Lakes Research Review* are an excellent example of this point. Much debate has occurred regarding the detrimental versus beneficial effects of the zebra mussel invasion within Lake Erie. Murray N. Charlton takes a critical look at the zebra mussel and other lake nutrients to help clarify this question from a researcher's and resource manager's perspective. Robert Baier and his research team examine the effectiveness of non-toxic fouling-release coatings in reducing the nature of the zebra/quagga mussel's attachment process which will help lead policy makers and resource users to future management strategies and control technologies. In addition, the articles on the three-dimensional watermass structure, by Dr. Gordon Fraser and his team, and the inshore fish communities, by Jeffrey Diers and others, both characterize important aspects of the eastern Lake Erie ecosystem from which the Great Lakes community can better understand the many complex links within the overall network. Finally, Helen Domske and Eric Obert describe one of the most recent problems affecting the Lake Erie ecosystem, the occurrence of avian botulism that has resulted in extensive mortality of various fish-eating birds (e.g., loons, grebes and gulls) in Lake Erie the past two years. Will we see another outbreak this year? Can the problem spread to Lake Ontario? The article answers some questions while raising still more. We all must be aware of and keep a look-out for future outbreaks.

I am truly inspired to see how the environmental research programs in the Great Lakes basin have matured. From the perspective of implementing an ecosystem management approach, to the growth of numerous partnerships and collaborations, the involvement of community interest organizations, the increasing development of assessment tools and prediction models, and the expanding opportunities and vehicles for systematic information management and dissemination. The challenge that confronts us now is to continue this flowing sea of positive change. But to do so by continuously refining, synthesizing and refocusing the data and information needed to support effective decision making and resource management in light of decreasing funding levels and political influence on Capitol Hill. Success will require us all to continue working together and promoting a shared vision of what we must do to restore and maintain the chemical, physical and biological integrity, as well as the economic and social values of the Great Lakes basin ecosystem.

Great Lakes Research Review
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Avian Botulism in Lake Erie

Helen M. Domske
Extension Specialist, NY Sea Grant
Associate Director, GL Program
University at Buffalo
Buffalo, NY 14260-4400
Erie, PA 16563
hmd4@cornell.edu

Eric C. Obert
Associate Director
Pennsylvania Sea Grant
Penn State Erie
eco1@mail.psu.edu

Avian botulism, a disease caused by *Clostridium botulinum*, has been recognized as a major cause of mortality in migratory birds since the 1900s. Although type C has caused the die-off of thousands of waterfowl (especially ducks) across the western United States, type E has been a threat to fish-eating birds in the Great Lakes region. Other outbreaks of type E have sporadically occurred in Alaska, Florida and California, with periodic outbreaks occurring in Lake Michigan and Lake Huron over a 20-year period beginning in 1964. During 1999 and 2000, a large die-off of waterfowl occurred in Lake Erie which was associated with both type C and type E.

The bacterium is classified into seven types (A-G) by characteristics of the neurotoxins that are produced. The toxins produced by *Clostridium botulinum* are among the most potent biological poisons, warranting human health and safety concerns. These neurotoxins bind to the receptors on nerve endings, affecting neuromuscular function. Infected waterfowl typically show signs of weakness, dizziness, inability to fly, muscular paralysis and respiratory impairment. The necks of impaired birds may become so weak that the animal actually drowns. Often the inner eyelid or nictitating membrane becomes paralyzed, impairing the bird's normal vision.

Although type C and type E avian botulism outbreaks occurred in Lake Erie during the past two years, there are some significant differences between the two types. Type C botulism primarily impacts dabbling ducks and bottom feeding waterfowl, although shorebirds may also fall victim to this type of botulism. In type C botulism, the bacterium does not produce toxin unless it is infected by a specific "phage" or virus. This relationship with a phage is not known to exist with type E. Type E botulism typically impacts fish-eating birds such as loons and grebes. Several species of gulls that are common in the Great Lakes region have been impacted by both type C and type E botulism. Fish carcasses may also contain the type E toxin and feeding on these carcasses or maggots from the carcasses can pass the disease to birds. While live fish can carry spores of type E botulism, it is not known whether they can carry the toxin itself or become sick and die from the toxin. Type E toxin has been found in carcasses of several species of Great Lakes fish, including round gobies. Researchers are studying the role this invader may play, if any, in recent outbreaks of the disease in Lake Erie.

Spores of type C and type E botulism are naturally found in anaerobic habitats such as soils and aquatic sediments, and can also be found in the intestinal tracts of live, healthy animals. The spores can remain in the ecosystem for extended periods of time, even years and are quite resistant to temperature extremes and desiccation. In the absence of oxygen, with a suitable nutrient source, and under favorable temperatures and pH, spores can germinate and vegetative growth of bacterial cells can occur (Brand, et. al 1988). Botulism toxin is only produced during vegetative growth, not when the bacterium is in its spore stage. Decaying animal and insect carcasses provide favorable conditions for botulism toxin production since the decay process uses up oxygen and creates anaerobic conditions (Friend, et al. 1996). Toxin-laden carcasses, or invertebrate scavengers such as maggots that can accumulate the toxin, constitute a major route by which wildlife ingest this powerful neurotoxin.

Dead Gull on Lake Erie Beach (Photo by Eric Obert, PA Sea Grant)

It is believed that type C botulism is perpetuated through a carcass-maggot cycle (Figure 1). Birds that have died from type C botulism, decay and become hosts for maggots. The maggots may contain the toxin and if fed upon by other birds, the cycle is continued. In many avian botulism outbreaks, healthy birds are often found in close proximity to sick and dying birds. This close proximity helps to spread

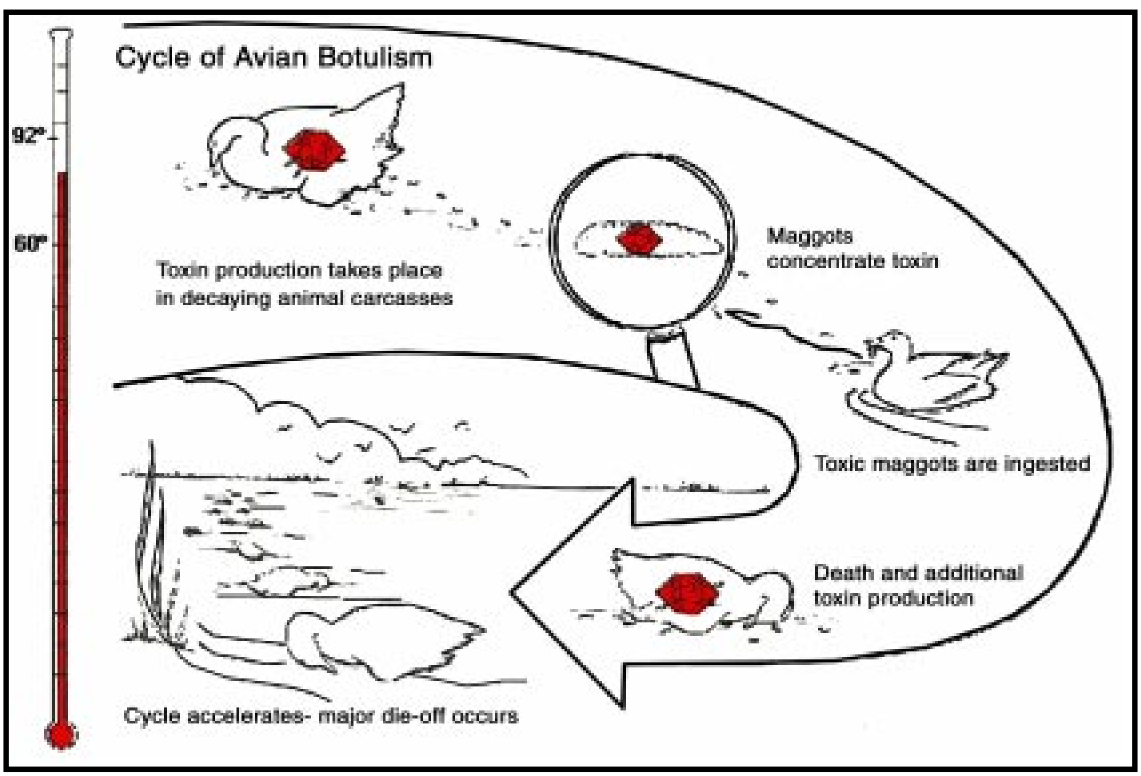

Figure 1. The cycle for Type C Botulism (Illustration from: U.S. Geological Survey, Avian Botulism Factsheet)

the disease among the birds, often causing greater mortality.

RESEARCH WORKSHOP HELD

On January 24-25, 2001, New York and Pennsylvania Sea Grant co-sponsored the first Lake Erie conference on avian botulism. Held in Erie, PA, this conference brought together more than 60 researchers, fishery and wildlife biologists, resource managers and agency representatives. The goal of the workshop was to share findings from both the American and Canadian shores and develop a research and extension agenda. Organizers wanted to determine the extent of the botulism problem based on geography and environmental conditions that existed during the outbreaks, and also look for other factors that may be related to the problem such as exotic species (zebra mussels, round gobies), low water levels, elevated water temperatures, increased water clarity, and changes in algal densities. During the second day of the conference, several breakout sessions were convened to address the research agenda questions that were posed to participants. Although organizers realized that the meeting was premature from a research data standpoint, they wanted to create a functioning network of scientists who could work together on research issues and respond to future outbreaks.

Dr. Christopher Brand of the USGS National Health Center in Madison, Wisconsin, states this about type C and E botulism: "While there are some similarities, there are also major differences in molecular biology, microbiology, and ecology between types C and E which may explain the different epizootiological presentations of these diseases." Dr. Brand indicated that some of the major, but basic, questions regarding type E avian botulism include: the role of various fish species in transferring toxin to birds; whether fish are susceptible to type E toxin or toxin in fish is primarily formed post-mortem in fish carcasses; whether fish-eating birds such as loons scavenge dead fish or mistake them for live fish; the importance of the carcass-maggot cycle during type E outbreaks in the summer; human health risks from sick or dead birds during outbreaks, as well as directly from fish; current prevalence and distribution of type E bacterium in fish and sediments of Lake Erie (as well as other Great Lakes); the impact of Type E botulism on loon populations; and specific ecological conditions required for type E toxin production and transfer to birds. Hopefully, the work and collaborations that began at the workshop will be able to answer some of these important questions.

STATE AND PROVINCIAL FINDINGS

Pennsylvania

According to information from Dr. Mike Campbell and Dr. Larry Gauriloff, from Mercyhurst College, there were a total of 311 dead birds collected at Presque Isle State Park in 1999, including 268 different gulls. Species such as ring-billed, herring, Bonaparte's and greater black-back gulls were included in the mortality. Of that total, 12 common loons, 14 mergansers, 2 grebes and 3 coots were found. In 2000, the number rose to 535 birds, with 374 gulls involved in the die-off. There were 44 coots, 33 common loons and 71 mergansers counted at Presque Isle State Park.

Their research provided these spatial and temporal findings related to bird mortalities:

- Greater overall mortality in 2000 than in 1999.
- Gull mortality is mainly in summer to early fall.
- Loon and merganser die-off mainly in late fall.
- Die-offs seem to occur in episodes following changes in weather.

Bob Wellington with the Erie County Department of Health (Pennsylvania) reported a massive fish die off in Lake Erie in the area in 1999 (millions of alewives and many gizzard shad). The Cladophora problems (a type of filamentous algae) on some local beaches were worse than they had been for several years. He speculated the algae problems and die offs of birds and fish might be related.

New York

During a two-week period in November 2000, a major die-off of loons, mergansers and other fish eating birds occurred along the New York shoreline of Lake Erie. Biologists from New York State Department of Environmental Conservation took the lead on collecting birds and developing mortality surveys based on their findings. Table 1 details the results of that survey.

Ontario, Canada

According to Jeff Robinson of the Canadian Wildlife Service and Dr. Ian Barker of the University at Guelph, an avian botulism outbreak occurred in 1998 and significant outbreaks occurred along the Canadian shoreline of Lake Erie during 1999 and 2000. In October and November 1999, several die-offs took place, including a major event at Rondeau Provincial Park and Pelle National Park that resulted in mortalities estimated at 6000 birds. Type E toxin was confirmed in this outbreak and approximately 90 percent of the birds were mergansers. In 2000, an earlier outbreak of botulism that involved gulls and shorebirds, was followed by an outbreak late in the fall that included mergansers and loons. Greater overall mortality occurred in 2000 than in 1999.

HUMAN HEALTH CONSIDERATIONS

Human botulism is typically caused by eating improperly canned or stored foods and normally involves type A or type B botulism toxin. There have been several fatalities during the 1960s in the Great Lakes basin attributed to type E toxin, but these were caused by eating improperly smoked or cooked fish that contained

Species	Predicted Mortality	Upper Limit 95% Confidence	Lower Limit 95% Confidence
Common Loon	583	816	351
Horned Grebe	109	193	26
Red-breasted Merganser	2479	3097	1862
Bufflehead	91	183	0
Mallard	18	54	0
Great Black-backed Gull	128	230	25
Herring Gull	237	352	122
Ring-billed Gull	1714	2172	1256
Bonaparte's Gull	36	86	0
Common Crow	18	54	0
Black Duck	18	54	0
Total Birds	**5415**	**6519**	**4310**

Table 1. Lake Erie Botulism Mortality Surveys, 100m Transect Survey Results from New York Shore. NYSDEC 11/28, 11/29/00

the toxin. Humans, dogs and cats are generally considered resistant to type C avian botulism (Friend, et al. 1996).

The toxin producing bacteria found in food items will be killed by proper cooking of fish and waterfowl. When canning or smoking fish or waterfowl, methods should be used that incorporate sufficient heat to ensure that the bacteria are killed. Anglers and hunters should avoid harvesting any sick or dying fish or waterfowl, or those demonstrating unusual behavior, in areas where avian botulism has occurred. To avoid risk, people should use gloves or an inverted plastic bag when handling dead birds or fish. If a diseased or dead bird is handled without gloves, hands should be thoroughly washed with hot soapy water or an anti-bacterial cleaner.

In case of a die-off, individuals are urged to contact local agencies responsible for fish and wildlife management to notify them of fish and bird mortalities. It is important to record the location, type of birds or fishes, and number of carcasses found. Individuals should follow agency recommendations in handling dead fish and wildlife. In certain areas, burying of the carcasses is allowed, in other areas incineration may be recommended. If birds are to be collected, they should be placed in heavy plastic bags to avoid the spread of botulism-containing maggots.

CONTACTS

For additional information on the avian botulism outbreaks in Lake Erie, the NY/PA Sea Grant co-sponsored workshop, or to receive a copy of the workshop proceedings, please contact the authors.

REFERENCES

Brand, Christopher J., Stephen M. Schmitt, Ruth M. Duncan and Thomas M. Cooley, An Outbreak of Type E Botulism Among Common Loons (Gavia immer) in Michigan's Upper Peninsula, Journal of Wildlife Diseases, 24(3), 1988, pp. 471-476

Friend, Milton, Louis N. Locke and James J. Kennelly, National Wildlife Health Laboratory, Madison, WI. 1996. Avian Botulism Factsheet: http://www.nwhc.usgs.gov/facts/avian.html

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Characterization of Eastern Lake Erie Inshore Fish Communities

Jeffrey A. Diers
SUNY College at Fredonia
Department of Biology

Current Address:
United States Fish and Wildlife Service
Lower Great Lakes Fishery Resources Office
405 North French Rd Suite 120A
Amherst, New York 14228
jeff_diers@fws.gov

Don Einhouse
New York State Department of Environmental Conservation
Lake Erie Fisheries Unit
Point Drive North
Dunkirk, New York 14048
dweinhou@gw.dec.state.ny.us

David R. Orvos
SUNY College at Fredonia
Department of Biology
Fredonia, New York 14036
orvos@fredonia.edu

INTRODUCTION

Lake Erie has historically had the most productive fishery among the Great Lakes (USFWS, 1995). Some recent changes in the system are not fully understood. Recent data (NYSDEC, 2000) suggest notable declines in populations of walleye (*Stizostedion vitreum*) and yellow perch (*Perca flavescens*). Factors that might account for such changes include continuing recovery from cultural eutrophication, alteration of nutrient and energy dynamics by zebra and quagga mussels (*Dreissena* spp.), and community level effects of other invasive species such as the round goby (*Neogobius melanostomus*) (USFWS, 1995).

Characterizing inshore fish communities is important to understanding the distribution and abundance of exotic, threatened, endangered, and other native juvenile fish species. These data often complement those taken in deeper waters. Prior to 1999, inshore fish communities along the New York State shoreline of Lake Erie had not been described. The NYS Department of Environmental Conservation, Lake Erie Fisheries Unit performs thorough open water studies, but inshore data have been very limited, particularly for juvenile walleye, smallmouth bass (*Micropterus dolomieui*), and yellow perch.

The objectives of this study were to describe inshore fish communities, and to explore temporal, geographic and diel patterns. Although all species sampled were identified and enumerated, our focus was primarily on sport and exotic fish species. Our results should improve understanding of Lake Erie fish populations and fisheries management and provide baseline data for future studies.

DATA COLLECTION

Periodic inshore sampling was conducted from May through October 1999 at five sites from Barcelona Harbor to Sturgeon Point, New York (Figure 1). Three beach seine hauls, constituting one sampling effort, were taken during both day and night at each site. Day and night samples were collected 0700 to 1600 hrs. and 2100 to 0400 hrs., respectively. Sampling during July and August was conducted approximately every two weeks, and comprised the majority of the data. Additional samples were collected in late May, early June, and October at less frequent intervals.

The Barcelona site is located just east of Barcelona harbor, approximately 8 miles (13km) from the Pennsylvania line. Dunkirk 1 is located just east of the public access breakwall of Dunkirk Harbor while Dunkirk 2 is located at Wright Beach, just west of the Dunkirk wastewater facility. Cattaraugus is located just west of the Cattaraugus breakwall. The Sturgeon Point site is located just east of the marina, approximately 15 miles (23km) west of the City of Buffalo. Sites were chosen to be accessible and free from debris and obstructions. Water depths ranged from 0.5 to 2.0 meters.

Samples were collected with a 150-ft beach seine (4-ft tall, 1/4 inch mesh) with a bag, deployed from an 18-ft flat bottom boat and a crew size of four. All fish collected were frozen for future analysis. One very large sample at Cattaraugus (daytime) was sub-sampled in the field. These fish were randomly placed into seven, five-gallon buckets, and only one bucket was retained for analysis. Within each seine haul, total number of fish species (richness) and abundance of each species were recorded. We also determined lengths and maturity of individual specimens. Extremely large samples of individual species were sub-sampled. The 10 most abundant species (>50 of any one species collected) were converted into catch per unit effort (CPUE), which in our study was three seine hauls.

INSHORE FISH COMMUNITIES

During July and August there were 40,102 fish collected at the five sites, in 100 beach seine hauls. Of the 100 hauls, 30 comprised catches of > 100 fish/net (the majority being shiners). The largest single seine haul was collected at Cattaraugus in August during the day and totaled 21,972 fish (19,380 shiners). Due to difficulty identifying large number of shiners to species, all shiners were placed into one category, *Notropis spp*. Of the 40,102 fish, 33,972 were Notropis (85% of the total). Qualitatively, emerald and spottail shiners dominated approximately 90% of the Notropis spp. (at least 10 different species).

In addition to *Notropis spp*., we collected 22 native and 7 non-native species. Thus 24% of the species encountered were non-indigenous. Exclusive of *Notropis*, 91% of individuals were native fish and 9% were non-native.

Species defined as abundant are listed in Table 1, while infrequent species are listed in Table

Common Names	***Scientific Names***
Alewife	*Alosa pseudoharengus*
Gizzard shad	*Dorosoma cepedianum*
Shiners	*Notropis spp.*
Quillback	*Carpiodes cyprinus*
Shorthead redhorse	*Moxostoma macrolepidotum*
Smallmouth bass	*Micropterus dolomieu*
Trout perch	*Percopsis omiscomaycus*
White bass	*Morone chrysops*
White perch	*Morone americana*
Yellow perch	*Perca flavescens*

Table 1. *Common and scientific names of abundant fish species in near shore samples. Data for July and August of 1999.*

ID #	Common Names	Scientific Names
1	Banded killifish	*Fundulus diaphanus*
2	Black crappie	*Pomoxis nigromaculatus*
3	Bluegill	*Lepomis macrochirus*
4	Brook silverside	*Labidesthes sicculus*
5	Common carp	*Cyprinus carpio*
6	Channel cat	*Ictalurus punctatus*
7	Fresh water drum	*Aplodinotus grunniens*
8	Goldfish	*Carassius auratus*
9	Johnny Darter	*Etheostoma nigrum*
10	Largemouth bass	*Micropterus salmoides*
11	Log perch	*Percina caprodes*
12	Northern hogsucker	*Hypentelium nigricans*
13	Pumpkinseed	*Lepomis gibbosus*
14	Rainbow trout	*Oncorhynchus mykiss*
15	Rockbass	*Ambloplites rupestra*
16	Round goby	*Neogobius melanostomus*
17	Rudd	*Scardinius erythrophthalmus*
18	Stone cat	*Noturus flavus*
19	Walleye	*Stizostedion vitreum*
20	White sucker	*Catostomus commersoni*

***Table 2**. Common and scientific names of less abundant fish species in near shore samples. Data for July and August of 1999.*

2. Geographic distribution of the abundant species can be observed in Figure 1, while occurrence of uncommon species may be viewed in Table 3. Dunkirk 1 and Barcelona had the highest species richness among all sites, 25 and 21, respectively. Species richness was generally similar between day and night samples, with the exception of Dunkirk 1, which had notably higher richness at night (Figure 1 and Table 3).

Among the target sport species collected, smallmouth bass and yellow perch were abundant, although the vast majority of yellow perch were collected in one seine haul at the Cattaraugus site in August (daytime). Walleye and rainbow trout were less frequently collected. Young of the year dominated day samples of smallmouth bass, yellow perch and walleye, while adults were more prevalent in night samples (Figure 2).

Most fish did not appear to have any obvious trends in diel occurrence, except for smallmouth bass and gizzard shad. Smallmouth tended to be collected during the daytime, while gizzard shad tended to be collected at night (Figure 1).

As with any field study of aquatic communities, gear limitations should be considered when planning research and interpreting results. Some species occupying the inshore area may not have been recruited to the mesh size employed (1/4 inch) or may have avoided the sampling gear. However, smaller mesh sizes easily clog with filamentous algae making sampling difficult or impossible in some cases. Also, benthic fish such as darters and the exotic round goby tend to reside in rocky habitats, and are probably not effectively sampled by seines.

Offshore fish assessments may not provide complete measures of the fish community. Inshore habitats are not only vital to juvenile fish, but some exotic, endangered, and threatened spe-

	Barcelona	Dunkirk1	Dunkirk2	Cattaraugus	Sturgeon Pt.
Day	4,6,10,11,12, 15,16,19	1,4,10,11,15	4,10,15	10,11,15,19	4
Night	5,6,7,12,14, 15,19,20	1,2,3,4,5,6, 7,8,9,10,12, 13,15,17,18	4,6,10,12,13, 19,20	2,4,12,14,15, 19,20	No Samples

***Table 3**. Day vs. night and geographic distribution of less abundant species. Data for July and August of 1999.*

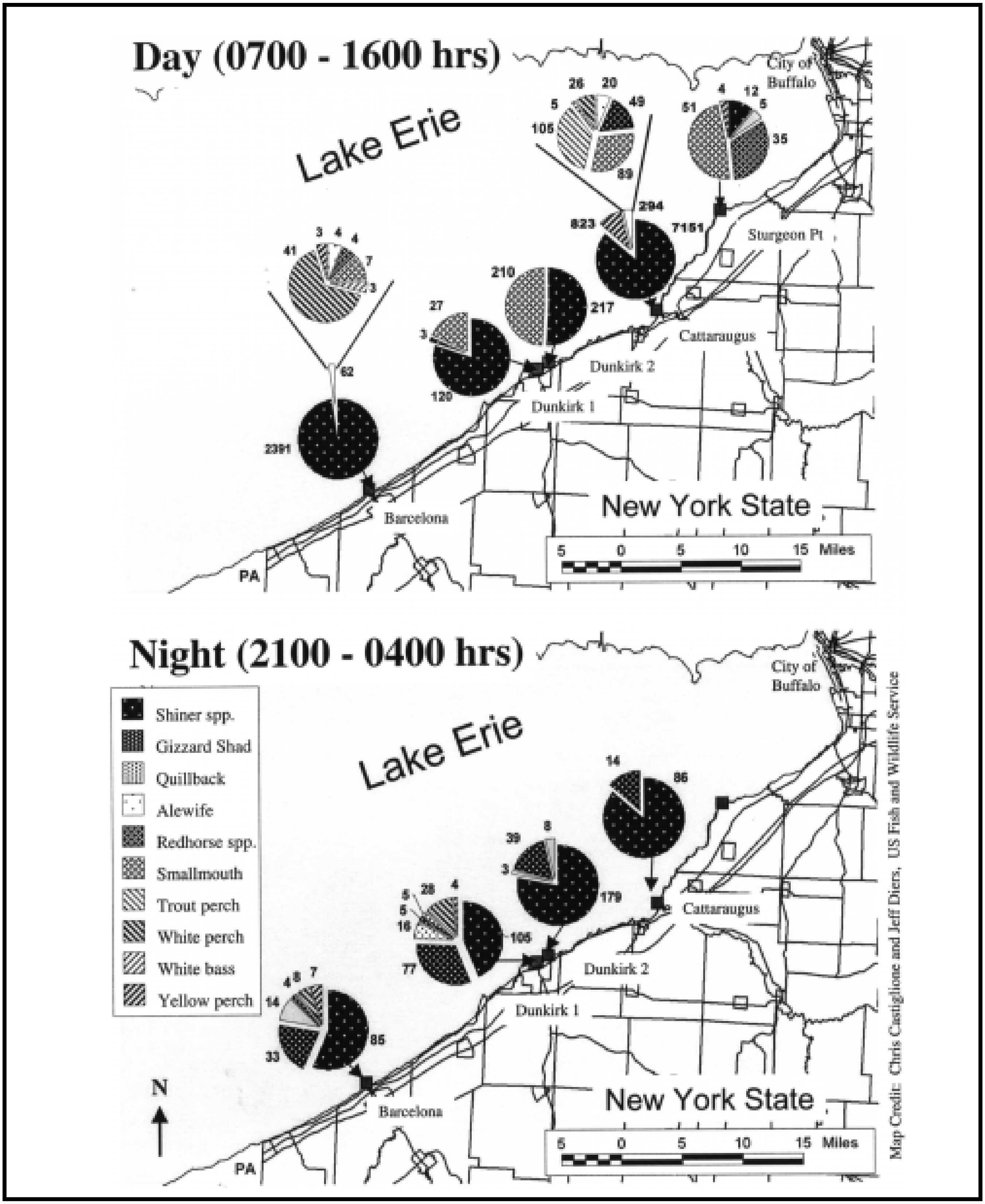

Figure 1. Distribution of 10 abundant species in day and night samples at the five eastern Lake Erie inshore sites. Values adjacent to pie slices for each species are catch per unit effort (CPUE – fish/3 seine hauls). Data for July and August of 1999. Exotic species = E, Native = N.

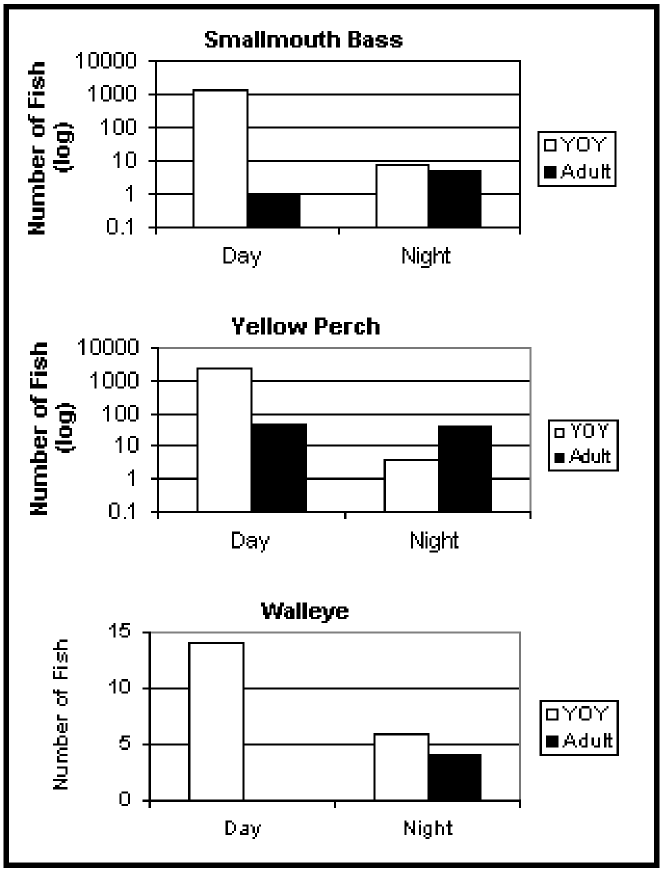

***Figure 2**. Abundance of young of the year (YOY) and adults of game species in day and night near shore samples, pooled among five geographic sites (see Figure 1.). Data for July and August of 1999.*

cies, may be primarily found in these areas (eg, see Jude, 2001). Future inshore studies may provide more information on differential utilization of lake zones by native and non-native fish species.

The results presented for July and August 1999, represent the beginning of an information base for this important lake zone, and may contribute to improved fisheries management. Inshore fish community studies may provide information that may be used by lake managers to determine seasonal and yearly variations of native and non-native fish populations. One study, however, is only the beginning of the assessment of these fish communities. It will be important to have several years of data and results from other seasons to fully understand the value of inshore habitats to the fishery of Lake Erie.

ACKNOWLEDGMENTS

Financial support was provided by a Great Lakes Research Consortium- Alcan Corporation Undergraduate Fellowship to Jeffrey Diers, and by SUNY College at Fredonia. The Fredonia Biology Department and NYS Department of Environmental Conservation Lake Erie Fisheries Unit provided assistance with facilities and equipment for the project. We would like to thank Jack Diers and Chris Bauer for extensive help with fish sorting and identification. The United States Fish and Wildlife Service Lower Great Lakes Fishery Resources Office, provided additional support including GIS services.

REFERENCES

Culligan, W.J, F.C. Cornelius, D.W. Einhouse, D.J. Zeller, R.C. Zimar, B. Beckwith. 2000. 2000 Annual Report to the Lake Erie Committee. New York Department of Environmental Conservation, Albany. 12201.

Jude, D.J,. 2001. Round and Tubenose Gobies: 10 years with the Latest Great Lakes Phantom Menace. *Dreissena* vol.11, number 4.

United States Fish and Wildlife Service, Department of the Interior. 1995. Great Lakes Fishery Resources Restoration Study, Report to Congress. Washington, D.C. 20240.

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Did Zebra Mussels Clean up Lake Erie?

Murray N. Charlton
National Water Research Institute
Environment Canada
Burlington Ontario

INTRODUCTION

Since the zebra mussel invasion of Lake Erie in the late 1980s there has been much speculation about the effects of the mussels in the lake ecosystem. Industry was quickly affected as the accumulating mussels clogged and sometimes closed water intake systems. Within a few years, though, industry and municipal water users learned ways to both prevent and to clean out mussel accumulations. At one time there was speculation that fundamental deleterious effects on fisheries would occur. Today, however, there are still fisheries in the lake although the ultimate cumulative effect of introduced species is of much concern. Although alien species have been introduced at the rate of more than one per year during the 1990s, zebra mussels and their cousins, the quagga mussel, have received the majority of the attention. The reasons for the attention is the high biomass the mussels developed due to a lack of competition for space and the availability of food. The mussels filter algae and other particles out of the water. Thus, they tend to clarify the water and remove algae from the base of the food chain. Where the water is shallow the mussels can make a visible impact on water clarity. Most people see the lake from the shore or close to shore and yet statements are often made to the effect that "zebra mussels have cleaned up the whole lake". At about the same time as the mussels arrived, however, the nutrient loading reduction targets called for under the Great Lakes Water Quality Agreement were achieved and this was also expected to increase clarity. This article seeks to briefly examine whole lake data to find out if mussels have actually had such a dramatic effect on all of Lake Erie.

DATA COLLECTION

From the late 1960s Environment Canada has conducted periodic surveys for research and monitoring purposes. Up to 57 stations spread over each basin have been visited in roughly one week periods on and off for more than 30 years. These data can be used to see the effects of the nutrient reductions and the zebra mussels. Following from Charlton et al. (1999) samples were collected from stations in the lake deeper than 15M and during the months of June, July, and August.

DATA TRENDS

The most damage due to nutrient loads occurred in the west end of the lake and that is where the largest change in nutrient concentrations occurred. It is generally thought that phosphorus concentrations declined from about 41 ug/L to about 20 ug/L during the period of nutrient reductions in the west basin (Lesht et al, 1991 and Williams et al., 1998). After the mussel invasion, the phosphorus concentration declined to about 18 ug/L although there is much variability (Charlton et al., 1999).

The changes in phosphorus in the main body of the lake, the central and the east basin, can be represented by central basin data in Figure 1.

Phosphorus declined by about 3 ug/L during nutrient controls up to 1988 and there was a similar decline coincident with the mussel invasion followed by a slight increase after the mid 1990s. The perturbation resulting in a phosphorus low period in 1995 may have been caused by grazing of mussel larvae but there does not seem to be direct evidence of this. The cause of the subsequent recovery of phosphorus is unknown.

Algal populations were most affected by nutrient reductions. One way of monitoring algal populations is by measuring the amount of chlorophyll pigment they contain. Algae are expected to decline both due to nutrient reductions and due to filtering by the mussels. Figure 2 (central basin) shows that there was a decline of about 2 ug/L up to the mid 1980s and little change after the mussel invasion. Chlorophyll concentrations measured recently were also occurring before the mussels arrived.

Perhaps the most interesting measure of the effects of the nutrient reductions is the change in water clarity. The depth to which a white Secchi disk can be seen is used world wide as a measure of water clarity. Algae and suspended sediment both cause turbidity that will reduce visibility. Both nutrient reductions and zebra mussels can reduce turbidity and increase clarity/visibility.

Although chlorophyll was reduced the most in the west basin, consistent with nutrient loads, the effect on Secchi depth was minimal (Fig. 3). Once the mussels were established, however, a fundamental change to clearer water occurred. This is thought to be due to the mussels' ability to filter suspended sediments as well as algae.

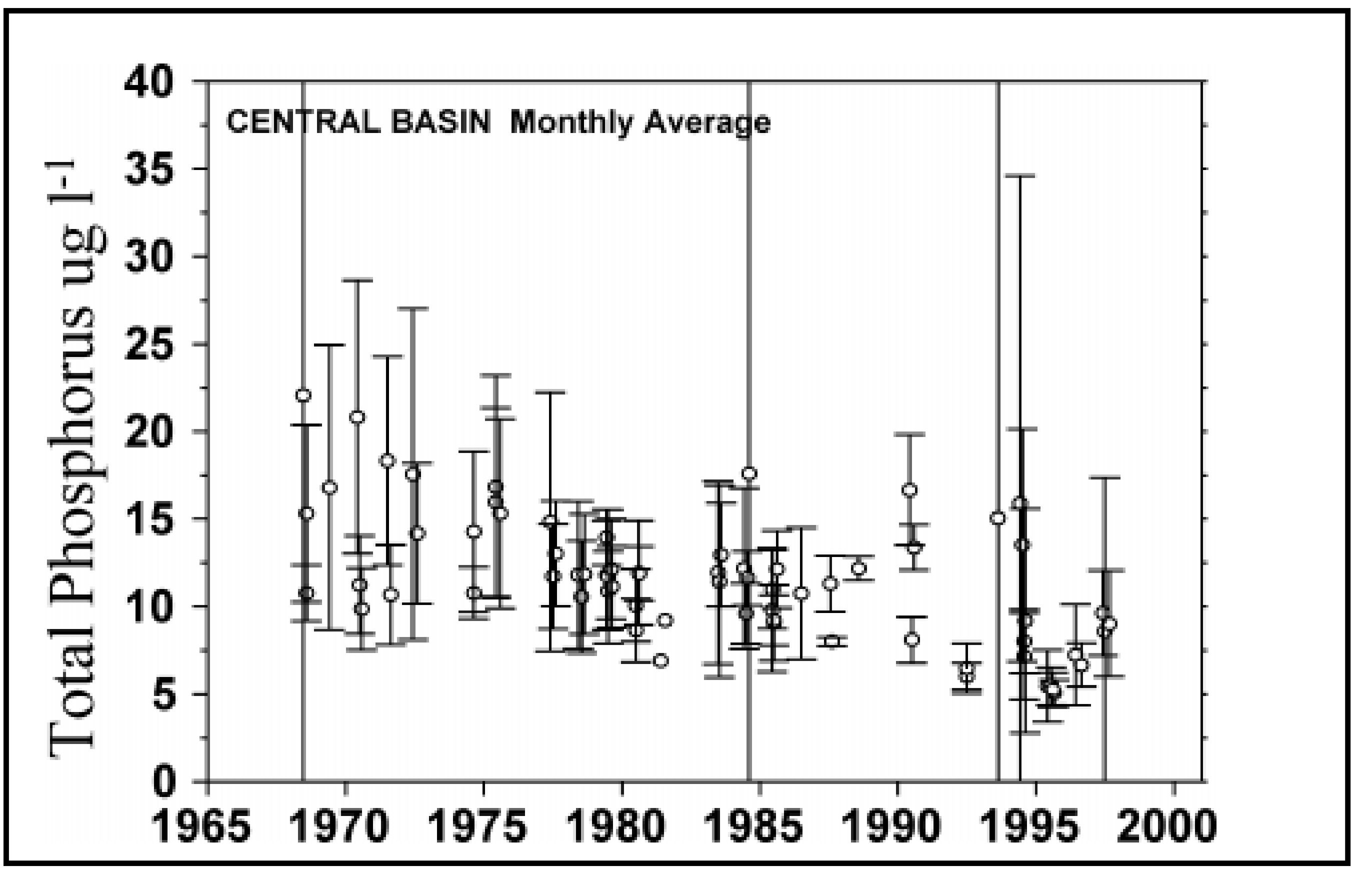

Figure 1. *Total phosphorus trend in the central basin*

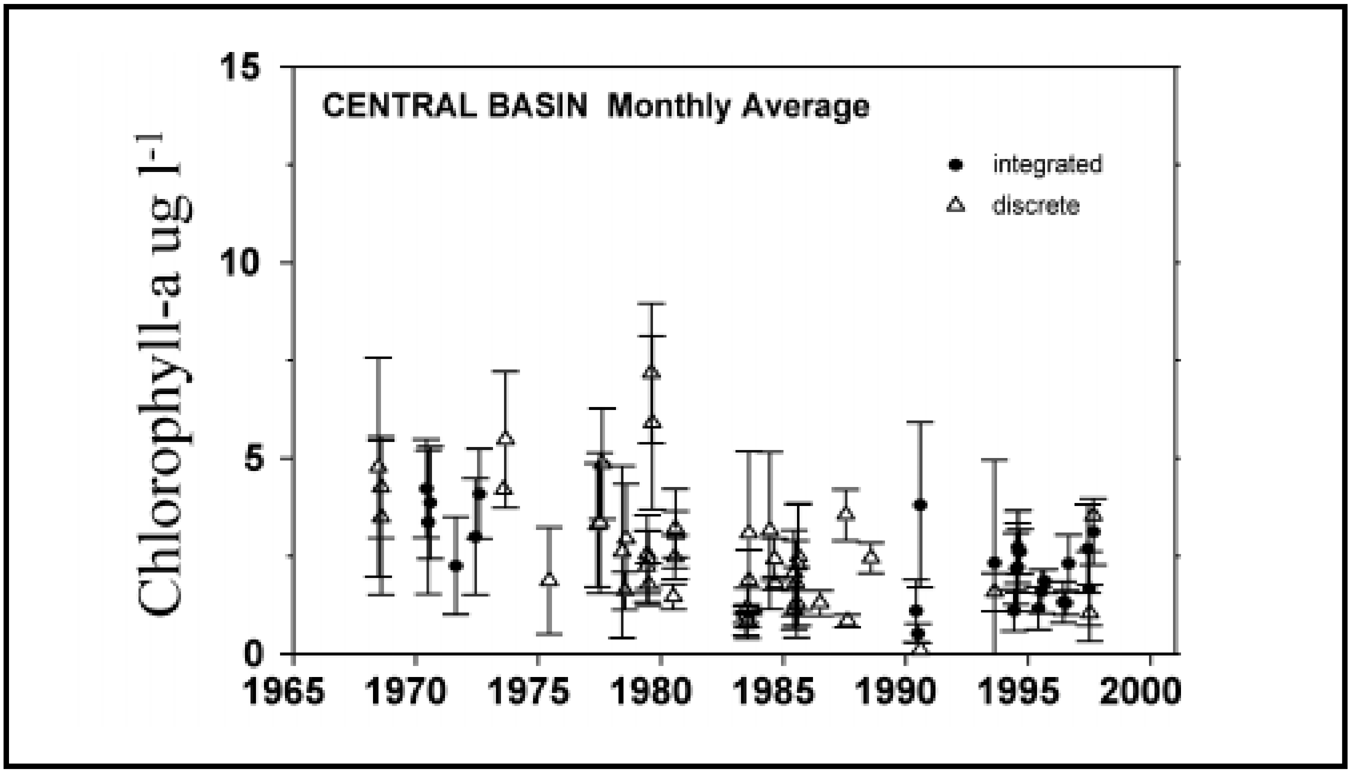

Figure 2. *Chlorophyll trend in the central basin*

In addition, the west basin is the most shallow of the three basins so the mussels would be expected to have the most effect there.

The nutrient reductions caused an increase in Secchi depth of 2 to 2.4 M in the east and central basins (Charlton et al. 1999). After the mussels arrived, however, changes in Secchi depth were not distinguishable statistically in the offshore area. Secchi depth means of over 6 metres on surveys with some readings much higher indicate relatively good water quality and attractive aesthetics offshore.

DISCUSSION

Changes in the lake during nutrient reductions and after the mussel invasion are summarized as percentages in Table 1. Although those interested in the lake often discuss phosphorus, chlorophyll, and Secchi depth even larger changes occurred in nitrogen concentrations. Nitrogen as Nitrate and Nitrite has increased steadily in the lake due to a combination of atmospheric, non-point runoff, fertilizers, and mostly unabated loading from sewage. Although concentrations are not a danger yet there are increasing reports of blue green algae blooms. One of the first recent blooms was observed by the author in the west basin in August 1994. Since then, the blooms have reoccurred and toxin production has been confirmed (Brittain et al. 2000). It is thought the blue green algae may be a result of changing nitrogen to phosphorus ratios and unpalatability to the mussels.

The data from the offshore area lend little support to the notion that the mussels have cleaned up the whole lake. In shallow near shore areas and the in the west basin which is about 10M deep the mussels have had a large effect. In the majority of the lake, the central and east basins with depths of 20 and 60 M respectively, the mussels appear to have little effect on the sur-

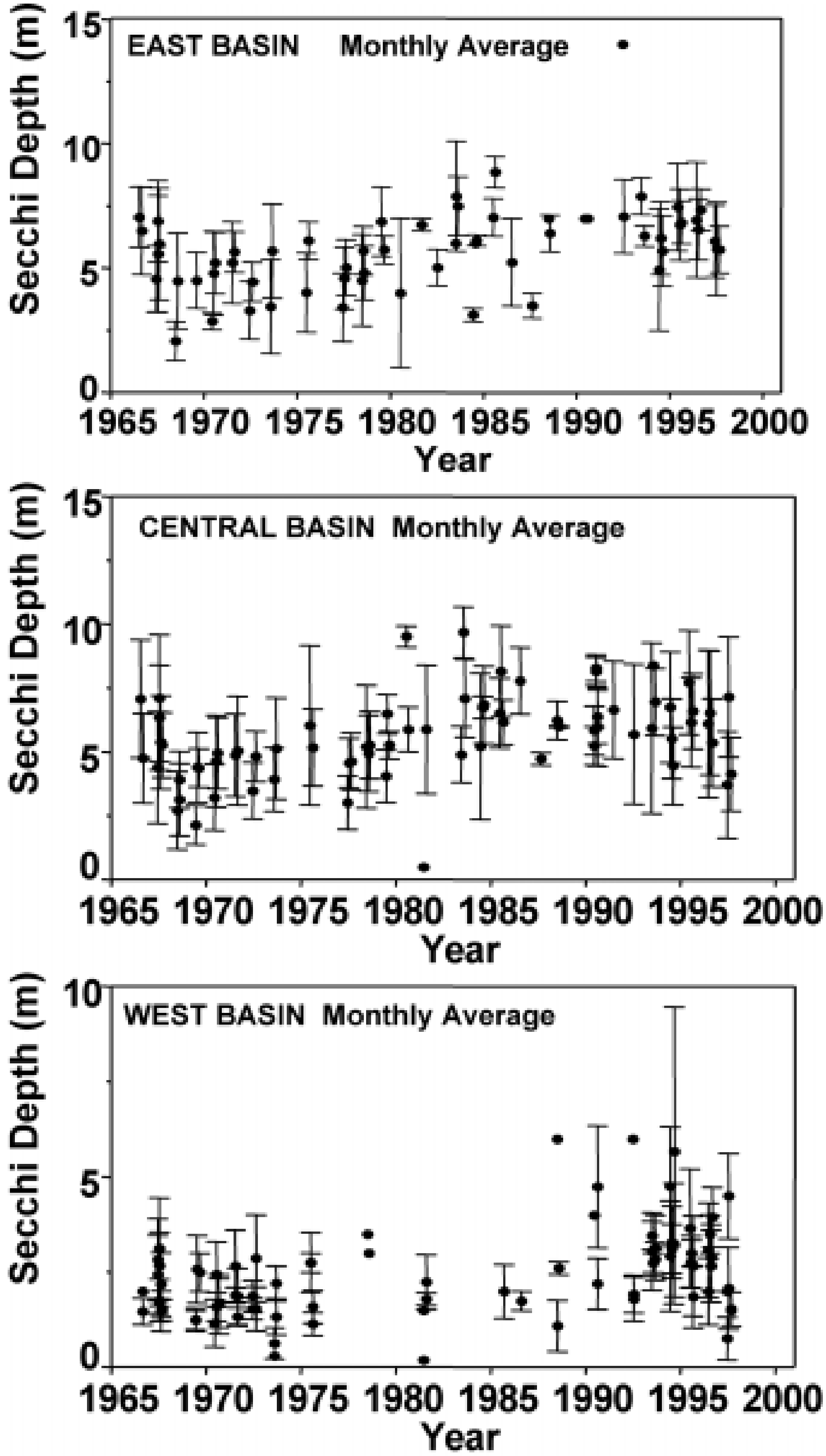

Figure 3*. Secchi depth trends in Lake Erie*

	1968 to 1988				1988 to 1994/95/96			
Basin	P	N	Chla	Secchi	P	N	Chla	Secchi
East	-19	+325	-43	+48	-33	+53	-25*	+8*
Central	-23	+340	-54	+59	-23	+5*	-17	-5*

* Change is not statistically significant

***Table 1**. Percentage change in phosphorus (P), nitrate (N), chlorophyll (Chla), and Secchi depth (Secchi) in the east and central basins of Lake Erie during the period of nutrient reductions (1968 to 1988) and after the mussel invasion (1988 to 1994/95/96).*

face water quality offshore. Possibly, the effects of mussels will increase as they colonize more and more of the soft sediment areas. Also, the effect of the mussels alone may not be so apparent when so many alien species have been introduced lately. Compensatory reactions in the ecosystem can include species composition shifts in the algae that may mask the effects of the mussels. At the same time predacious zooplankton species Bythotrephes and Cercopagis also have the ability to alter the planktonic food chain. We do not have a good explanation of why phosphorus concentrations declined in the mid 90s and then increased again. These temporary fluctuations may have been caused by the mussels or other species. Those who study the lake be they scientists or fishers are concerned that the mussels can affect food availability for fish fry that spend their early lives in shallow areas. Thus, it is not the author's intention to minimize the effects of the mussels. Rather, it is important to maintain long term sampling and data gathering efforts so that the data themselves can show what is happening in the lake.

REFERENCES

Brittain, S.M., Wamg, J., Babcock-Jackson, L., Carmichael, W.W., Rinehart, K.L., and Culver,D.A. 2000. Isolation and characterization of Microcystins, cyclic hepatapeptide hepatotoxins from a Lake Erie strain of Microsystis aeruginosa. J. Great Lakes Res. 26(3):241-249.

Charlton, M.N., LeSage, R., and Milne, J.E. 1999. Lake Erie in transition: the 1990s. State of Lake Erie (SOLE) - Past Present and Future, pp 97 - 123. Editetd by M. Munawar, T. Edsall, and I.F. Munawar. Ecovision World Monograph Series. Backhuys Publishers, Leiden, the Netherlands.

Lesht, B.M., Fontaine III, T.D., and Dolan, D. 1991. Great Lakes total phosphorus model: post audit and regionalized sensitivity analysis. J. Great Lakes Res. 17:3-17.

Williams, D.J., Kuntz, KW., L'Italien, S., and, Richardson, V. 1998. Lake Erie surveillance program: spatial and temporal trends of selected parameters, with emphasis on 1994 - 1995 results. Environment Canada Report No: EHD/

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Monitoring the Attachment of Zebra Mussels *at a Lake Erie Power Generating Station: 1991-1997*

Robert Baier
Industry/University Center for Biosurfaces
University at Buffalo
Buffalo, NY 14214

Anne Meyer
Industry/University Center for Biosurfaces
University at Buffalo
Buffalo, NY 14214

Alan Wells
Lawler, Matusky & Skelly Engineers LLP
Pearl River, NY 10965

John Matousek
Lawler, Matusky & Skelly Engineers LLP
Pearl River, NY 10965

Edward Neuhauser
Niagara Mohawk Power Corporation

PREFACE

The results reported here are only a portion of those developed during a project for "Evaluation of Nontoxic Fouling-Release Coatings as a Means of Reducing the Attachment of Zebra Mussels (*Dreissena polymorpha*) at Great Lakes Generating Stations." The project developed quantitative methodology and field monitoring results in a joint effort by Lawler, Matusky & Skelly Engineers, LLP (LMS) and the Industry/University Center for Biosurfaces (IUCB) at University at Buffalo, at facilities made available by Niagara Mohawk Power Corporation.

LMS personnel designed and conducted the field investigation phase of the project, summarized the field observations, and performed the statistical analyses used to determine nontoxic coatings' effectiveness at limiting zebra mussel settlement. IUCB personnel selected the nontoxic coatings for evaluation, and conducted extensive field and laboratory investigations on the surface properties of the respective coatings. Field observation information and the results of the surface property investigations were incorporated in the statistical evaluation of the coatings.

BACKGROUND

Lake Erie was the earliest large U.S. lake to become infested with the exotic bioinvader called the "zebra mussel." Significant shore structure accumulations were noted as early as 1990 at numerous Lake Erie sites. With the introduction of the surface-dwelling zebra mussel (*Dreissena polymorpha*) and, later, the nearly identical quagga mussel (*D. bugensis*) into the freshwaters of North America, critical services such as public drinking water supplies, plant cooling water intake systems, and industrial process water systems were jeopardized by structural biofouling. One way of mitigating this threat is through the use of nontoxic fouling-release coatings. Such coatings appreciably reduce the strength of mussel adhesion and do not release potentially harmful compounds into the surrounding waters. Such coatings can also be durable, easy to apply, easy to clean, and economical.

Beginning in 1991, Niagara Mohawk Power Corporation (NMPC) sponsored a multi-year study designed to evaluate the surface properties and effectiveness of a number of nontoxic coatings as a means of limiting zebra mussel settlement at cooling water intakes. The study was conducted by Lawler, Matusky & Skelly Engineers LLP (LMS) and the Industry/University Cooperative Research Center for Biosurfaces (IUCB) located at the University of Buffalo. Since separate steel and concrete uncoated panels were included as controls in all the test racks, an excellent "natural history" of zebra mussel infestation of Lake Erie's southern shore also was obtained.

EVALUATION PROCEDURES

The main set of evaluation studies was conducted at the cooling water intake of the NMPC electric generating station located at Dunkirk [Dunkirk Steam Station (DSS)] on Lake Erie. Nontoxic fouling-release coatings were evaluated on 20 cm x 25 cm steel and concrete test panels. The steel panels were made of 3.2 mm thick cold-rolled steel, while the concrete panels were made of 19.0 mm thick reinforced concrete.

Test panels were mounted on test frames constructed of PVC pipe. Each frame was designed to hold up to ten test panels. Generally, five randomly arranged coated and uncoated steel panels were placed in the top row of each frame and five coated and uncoated concrete test panels in the bottom row. Of the five panels in each row, one always was an uncoated control panel. Eight support frames were deployed at the generating station. Frames and panels were replicated within the same test site.

Eighteen coatings, of both commercial and non-commercial origin and/or application, were initially selected for testing (Meyer and Baier, 1992). Project goals, project duration, and the number of panels and coupons required were explained to all selected coating providers before obtaining their agreement to participate. Identical uncoated steel and concrete panels were supplied to all providers for coating according to each industry-preferred protocol.

After a preliminary series of site inspections and zebra mussel harvesting experiments in 1991, to confirm zebra mussel location and abundance, deployment of the panels took place during January 1992. Monitoring occurred bimonthly in the first year and quarterly thereafter. At each inspection, after removing the test frames from the water, racks and panels were photographed (Figure 1) and then each rack was rinsed for 3-5 minutes (20-30 seconds per panel) with freshwater at 25 psi. After rinsing, each panel was photographed again and the extent of mussel infestation was determined using a 4x4 grid overlay. Settlement in each of the 16 grid squares was scored as: 0 = none, 1 = light, 2 = moderate, and 3 = heavy. At each observation period, the 32 scores for each coating/substratum combination (e.g. 2 coated steel panels, 16 grid squares per panel) were averaged to give a "Zebra Mussel Infestation Index" for that coating during that observation period (Figures 2 and 3). After the post-rinsing evaluation, the frames were returned to the water.

Two indices of effectiveness were developed. The "Integrated Index" was obtained by summing the mean mussel settlement score over all observation periods and then dividing by the sum of the mean score for the control panel. This index produced a value of 0% for no mussel settlement to 100% for settlement equal to the control panel. A value greater than 100% was reported when the test panel infestation was greater than that of the control panel. A second index, "Ending Index", used only the

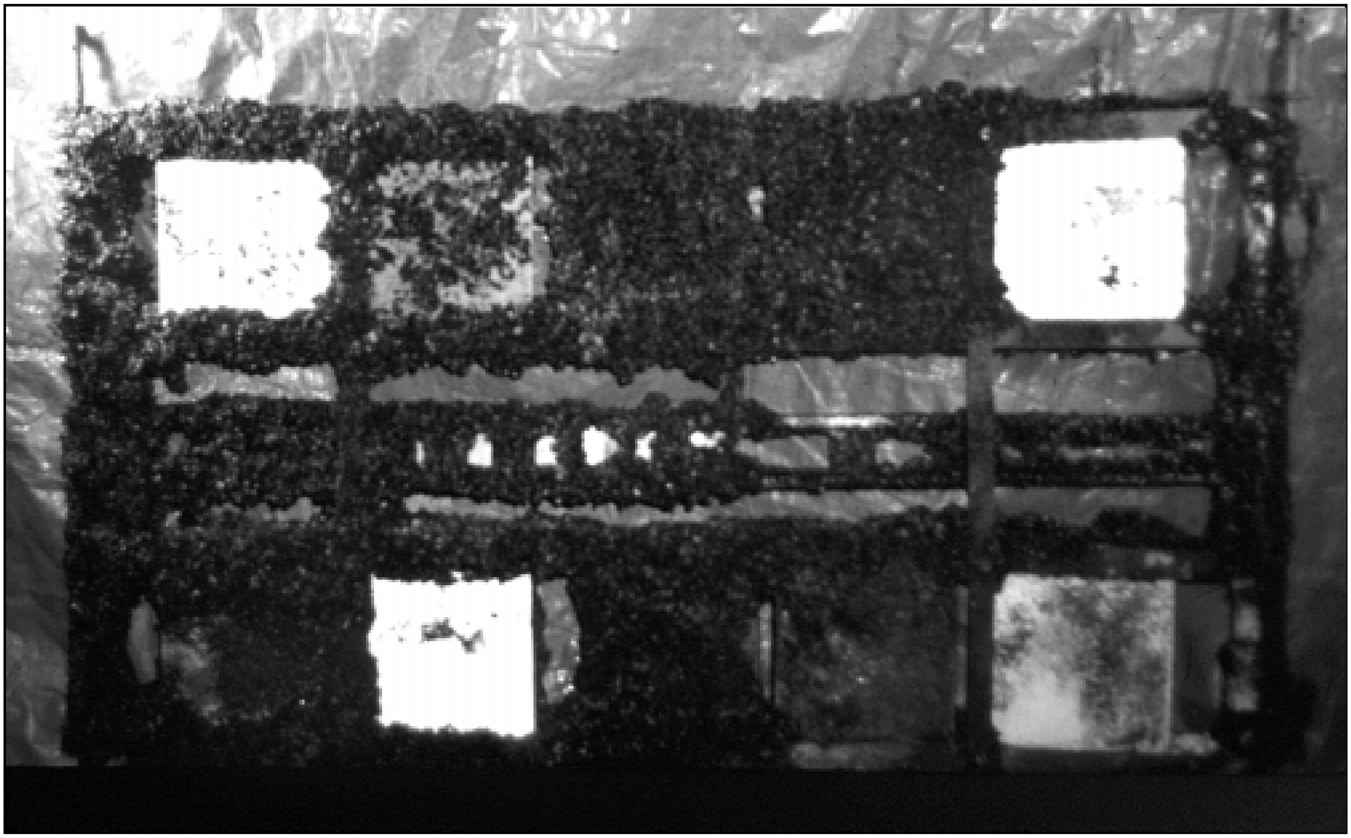

Figure 1 *- Photo of one of the Test Racks from the NMPC Dunkirk Station Intake Tunnel, 20 Months After Initial Immersion (January 1992 to September 1993)*

last observation. Chi-square (C^2) analysis was used to test for significant differences between coated test panels and non-coated control panels.

In addition to the coated test panels, identically coated steel coupons (3.2x25x76 mm) also were deployed. These small strips were mounted in a separate rack located in the center of each frame. Six coupons of each coating were initially deployed. Coupons were removed periodically throughout the study and used for determination of surface properties.

Surface properties of all coatings were analyzed using the following tests (Baier and Meyer, 1992): Comprehensive contact angle analysis: This evaluation procedure measured the surface energy properties of each coating. A graph of the contact angle cosine for various diagnostic liquids was plotted to form the "Zisman plot" (Zisman 1964). Using inert (nonsolvating and nonswelling) test liquids, the intercept of the plot defined the "critical surface tension" (gamma-c) for each coating material.

Internal reflection infrared (IR) spectroscopy: IR-measurement provided a direct, non destructive technique for identifying the chemical composition of coatings and their transferable residues, such as oily additives (Harrick 1967). For fouling-release coatings, the amount of silicone (or other materials) transferred via pressure-contact was an indicator of the presence of releasable components from the sample. The measured "infrared absorbance units" were directly proportional to the amount (mass).

Brush Shear Tests: One special brush shear test was developed to quantitatively evaluate the ease of fouling removal from exposed coated coupons. This laboratory test focused on the

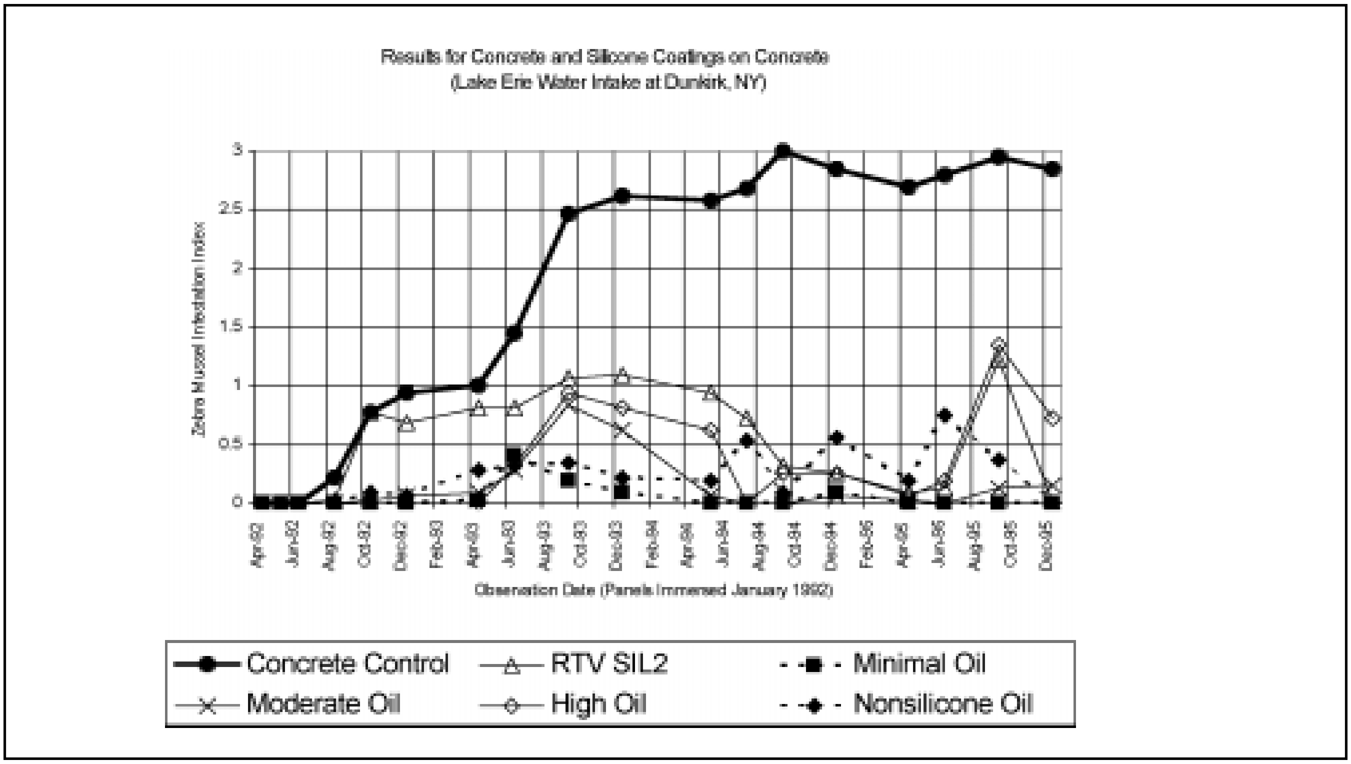

Figure 2. *Zebra Mussel Infestation Index Results for Concrete and Silicone Coatings on Concrete (Lake Erie Water Intake at Dunkirk, NY)*

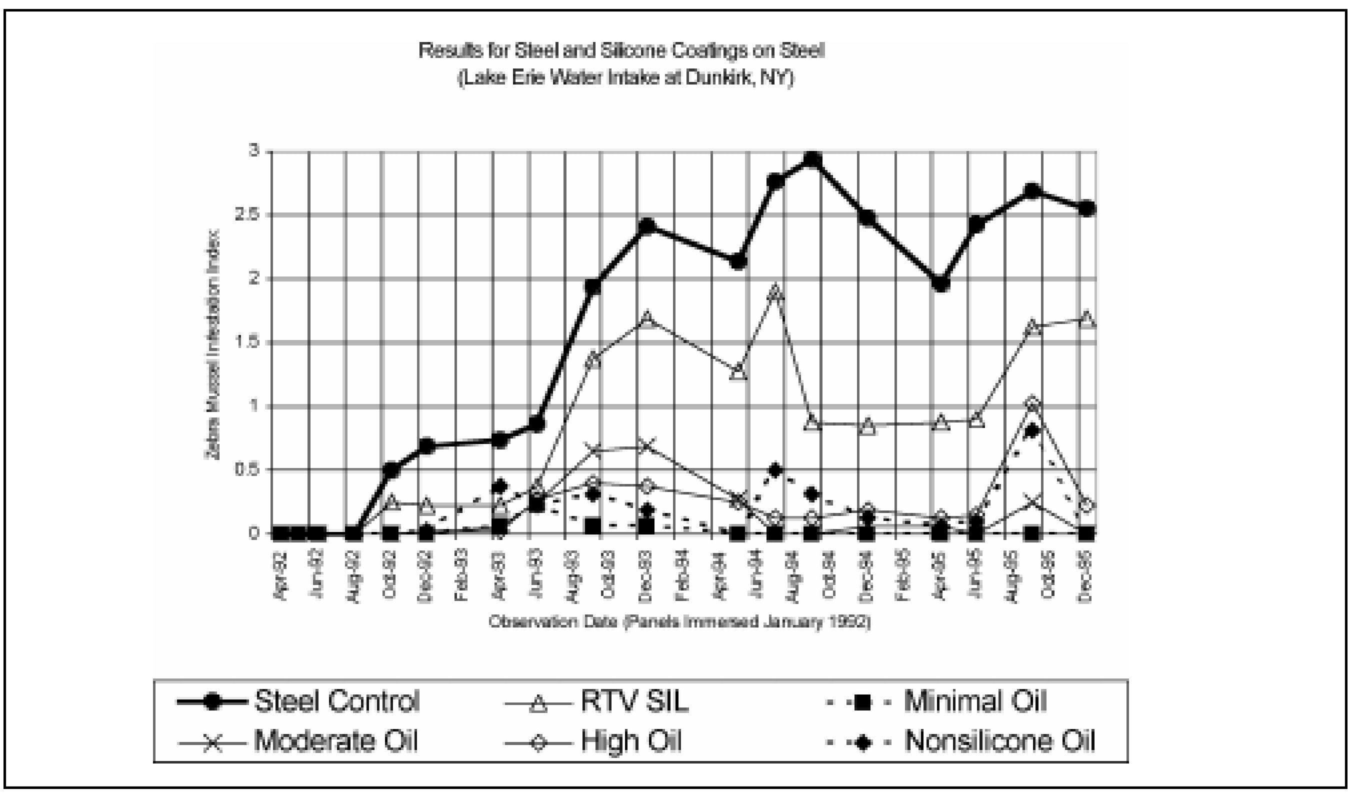

Figure 3. *Zebra Mussel Infestation Index Results for Steel and Silicone Coatings on Steel (Lake Erie Water Intake at Dunkirk, NY)*

removal of all visible fouling, including algae and slimes. A standard-weight wetted was drawn five times down the length of the fouled (wet) test plate and observations made as to amounts of fouling removed. The process was repeated with increasing brush weights until all visible fouling had been removed. A "high limit" value was assigned for samples that were not clean by the end of the test. Tests were conducted at intervals throughout the study period on post-exposure coupons taken from racks where identical coatings remained continuously under test for more than 5 years.

Near the end of the field testing period, a second brush shear test procedure, using a powered rotating two-brush unit, allowed observations of each coating's prospects for ease of repetitive cleaning while retaining foul-release qualities (Baier, et al., 1997).

Abrasion Testing: In addition to the laboratory tests of coating "wetting" properties, laboratory abrasion testing was conducted on initial-condition coated steel coupons. Tests of abrasion resistance of pre-exposure test coatings were conducted using ASTM Method D968-81 and, also, another customized rotating brush test. The laboratory rotating brush test was used in addition to the ASTM test to better document the susceptibility of elastomeric coatings to mechanical damage. In the rotating brush test, the average depth of wear was determined for coatings abraded by standard-weight nylon brushes in increments up to 145,000 brush strokes (simulating the abrasive wear expected from more than 20 brush cleanings of the coatings in the field) (Meyer, et al., 1995). Maintenance of coatings' easy-release surface qualities was monitored at the end of each test cycle, to estimate likely field longevity of coating effectiveness and compare with the actual field performance.

EVALUATION PROGRAM RESULTS

From our tests, it was clear that no product (or products) clearly excelled in every evaluation criterion important to use in power plant intakes. In order to judge overall performance, we constructed a composite index (CI) from the average effectiveness scores, IR spectroscopy test, rotating brush test, and brush shear test. The first step was to rank each coating by its numerical score on each test and assign each coating its rank value. Tie scores were assigned the average rank value for the tied coatings. Next, relative importance weights were assigned. Effectiveness in reducing biofouling by retained zebra mussels was the most important characteristic of the four measures. To reflect this, the average effectiveness ranks were multiplied by four. Durability was the next most important characteristic, so the rotating brush rankings were multiplied by three. Ease of cleaning was the next most important so brush shear ranks were multiplied by two. The potential for elutable material to contaminate the environment was not given any additional weighting factor in the rankings, although it would be of considerably greater importance for coatings used in potable water systems. Final scores were based on the sum of the four scores for each coating, with lower sums indicating better overall performance (Wells, et al., 1997).

At the DSS Lake Erie site, average uncoated control panel scores were 31% and 23% for concrete and steel, respectively, at the end of the first year (January - December 1992). Summaries of test results are provided below:

Controls: In spite of already present, heavy zebra mussel attachments (estimated 20,000-100,000 individuals per square meter) to nearby infrastructural walls, both new steel and concrete (uncoated) test panels showed little evidence of infestation until 10 months after first installation. Thereafter, infestation rates increased more or less steadily throughout the test period, all control panels becoming about 90-100% covered with zebra mussels, often with multiple thicknesses of layered shells.

Zebra Mussel Attachment to Commercial Easy-Release Coatings: One main coating subcategory included silicone-based resins with nonsilicone surface oils. Settlement was significantly less than on the control panels ($P < 0.01$); typically, only very small mussels (1-2 mm) were present. One commercially available multi-layered silicone-topped coating, originally developed primarily for marine environments, also demonstrated statistically lower ($P < 0.01$) infestation rates compared to the controls and was the second most effective coating for reducing biofouling in the field trials. Another silicone-based coating, compared to both the steel and concrete control panels, also demonstrated significant reductions in infestation ($P < 0.01$), but the coating appeared to be somewhat more effective on concrete. The discrepancy was most apparent at the end of the trial and was due to failure of the anticorrosion layer and physical damage to the steel panels.

A commercial multi-layer silicone-based product, with surface oil, that had the highest amount of transferable residue recorded in the study also displayed significantly lower infestation rates than the uncoated control panels. Only a few small (1-3 mm) mussels were found on the test panels. Abrasion resistance was poor, however.

Silicone-based coatings without significant amounts of surface oil showed somewhat better wear-resistance characteristics and lower infestation rates on both steel and concrete coated panels ($P < 0.01$) than for the control test panels. Therefore, it is an important result of these monitoring studies that migratable surface oils do not have to be present to minimize zebra mussel retention.

Another commercially available multi-layer silicone product, also originally developed for use in marine environments, contained no significant amounts of surface oil. Coated test panels again showed significantly less infestation than the control panels ($P < 0.01$). This coating was, in fact, the most effective of those tested in resisting biofouling. Panels displayed little growth of any kind throughout the entire test period.

Pre-commercialization coatings: One experimental coating based on methylsilicone and having no significant amount of surface oil, despite relatively poor effectiveness scores, had an infestation rate still significantly less than for the uncoated controls.

Another noncommercial silicone-based coating that lacked significant amounts of surface oil, for both coated steel and concrete test panels, displayed statistically less infestation than the controls ($P < 0.01$). Overall, Integrated Index scores were intermediate for both steel and concrete. Zebra mussel infestation rates were relatively high during the early stages of the study, peaking at the end of the second year, and the infestation rates decreased more-or-less steadily thereafter.

For comparison, laboratory standard polydimethylsiloxane, previously demonstrated to be effective in preventing biofouling of medical devices (Baier, 1982) on steel and concrete, also showed infestations significantly lower ($P < 0.01$) than for the controls. Addition-cured elastomeric silicone (polyvinylsilicone without significant oil), tested only on steel test panels, also displayed significantly less ($P < 0.01$) mussel infestation than the control. In contrast, an unpigmented polydimethylsiloxane (silicone) with a long history of use in manufacturing, coated only on steel panels, showed significantly less ($P < 0.01$) infestation than the uncoated controls, but the overall effectiveness was relatively low.

Corrosion-resistant Coatings: Silicone-epoxy coatings, originally applied without anticorrosion undercoats, for both coated steel and concrete panels, showed heavy mussel settlement. The coated concrete test panel was not statistically different from the uncoated control ($P>0.05$). Rotating brush cleaning of the silicone-epoxy panels in the field was able to remove most of the attached fouling quite readily, however. Similar field "brush cleaning" of the controls was entirely ineffective. A commercially available, nonsilicone (reportedly an amine/epoxy) product, originally developed for purposes other than foul-release, showed no evidence of effectiveness or easy cleanability on either steel or concrete panels.

A nonsilicone fluoroepoxy coating, originally developed for coating the inside of military fuel storage tanks and known to foul badly in marine environments, became heavily fouled (both steel and concrete panels) by the end of the first year. The Integrated Index for fluoropolymer-coated steel and concrete panels were 113.9% and 113.5%, respectively, indicating a greater degree of biofouling than the uncoated controls. Polytetrafluoroethylene (PTFE, Teflon,) solid polymer film, even more highly fluorinated than the fluoroepoxy coating, also showed poor performance at the Lake Erie test site.

LESSONS LEARNED

Zebra mussel infestations at the Lake Erie shoreline were controllable using nontoxic fouling-release coatings with these attributes: they effectively reduced the level of biofouling; were economical to apply and to maintain (easy to clean); and durable enough that re-applications were unnecessary. Further, it was found that effective coatings need not release contaminants into the surrounding environment, and that — if brush cleaning is anticipated — silicone/epoxy coatings with intrinsic corrosion resistance and wear resistance can be useful.

Nevertheless, unalloyed methylsilicone coatings were the most effective in significantly limiting the amount of biofouling. Of the silicones, those with releasable surface oil were generally more "spontaneously" (without rinsing or brushing) effective than those without extra oil. The notable exception was a commercial coating that was the most effective product in reducing fouling and was without significant surface oil before immersion.

Previous investigators also evaluated silicone-based nontoxic fouling-release coatings and generally concluded that these soft coatings are very susceptible to mechanical damage (EPRI 1989, Leitch and Puzzuoli 1992, Race and Kelly 1996). Their use, therefore, has not been recommended for exposed structures or high volume intakes. The fact that most of the silicone-based test panels in our program were still effective after more than four years of immersion in a Lake Erie power plant intake should moderate this prior conclusion. Gross (1996) reported it took as little as two years for a return on investment from nontoxic coatings (based on reduced cleaning costs alone). Based on more than four years of successful field testing in this program, fouling-release coatings should prove to be economical in a coordinated abatement program for zebra mussels and quagga mussels in the Great Lakes

ECONOMICAL CONSIDERATIONS

EPRI (1989) and Gross (1996) concluded that the complete cost of easy-release silicone-based coating systems' material and labor was approximately $10 per square foot. For several of the more successful coatings in our test, each manufacturer's sales representative was asked to supply cost and product system (including surface sealant, tiecoat, and topcoats) information for the following scenario: to coat 10,000 square feet of good condition concrete in a dewatered lake intake tunnel. Labor costs were not included. The material cost estimates per square foot ranged from $2.99 to $4.00 in 1996.

Our monitoring program also revealed differences in durability among fouling-release coatings. Generally, the most wear-resistant coatings were the less effective non-silicone and silicone-epoxy coatings. But even among the more effective silicone coatings there was considerable variability.

Coatings that were easily cleaned should be more economical due to reduced maintenance labor costs. Again, there was considerable variation among products. Overall, coatings with critical surface tension values between 20 and 25 mN/m were the best performers while coatings with values less than 20 or greater than 30 mN/m had the poorest field performance and predicted lowest cost-effectiveness.

ENVIRONMENTAL IMPLICATIONS

The principal reason for using nontoxic coatings for zebra and quagga mussel control in the Great Lakes is to reduce the amount of harmful chemicals released into the Great Lakes environment. Chlorination, other oxidizing chemical injections, and durable toxic coatings are available for protecting "shoreline" facilities, but toxic components in these materials typically diffuse or eventually leach into surrounding waters and biota, and can cause unintended environmental damage. Nontoxic coatings eliminate this problem. Not all currently available nontoxic coatings are free of elutable products, however. Silicone and mineral oils, while not directly toxic, are undesirable, especially in public water supplies. The IR spectroscopy results of this reported monitoring program indicated a wide range of variability among, otherwise, effective coatings in the amounts of potentially transferable residue. Generally, the nonsilicone coatings had the lowest "exportable" residues, while silicones with added oils had the highest.

POSTSCRIPT

Beginning in 1996, there was a major "downshift" in mussel fouling pressure at the Lake Erie water intake at Dunkirk. The test racks were transferred to a secondary site in Oak Orchard Creek, in the tailrace of a NMPC hydroelectric generating station in Medina, NY, where the reported patterns of zebra mussel fouling were maintained through 1998. The test panels and attached mussels have since been "harvested" and retained for further examination and speciation.

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REFERENCES

Baier RE (1982) Conditioning Surfaces to Suit the Biomedical Environment: Recent Progress. Journal of Biomechanical Engineering, 104:257-271.

Baier RE and Meyer AE (1992) Surface Analysis of Fouling-Resistant Marine Coatings. Biofouling, 6:165-180.

Baier RE, Meyer AE, and Forsberg RL (1997) Certification of Properties of Nontoxic Foul-Release Coatings Exposed to Abrasion and Long-Term Immersion. Naval Research Reviews, XLIX(4):60-65.

Electric Power Research Institute [EPRI] (1989) Nontoxic Foul-Release Coatings, Final project Report. EPRI Report No. GS-6566, Project 1689-9. Report prepared by Stone & Webster Engineering Corporation (SWEC). Palo Alto, CA. October 1989.

Gross AC (1996) Long Term Experience with Non-fouling Coatins and Other Means to Control Macrofouling. in Abstracts, Sixth International Zebra Mussel & Other Aquatic Nuisance Species Conference, Michigan Sea Grant College Program, Dearborn, MI, March 5-7, 1996, page 83.

Harrick NJ (1967) Internal Reflection Spectroscopy. Interscience Publishers, New York.

Leitch EG and Puzzuoli FV (1992) Evaluation of Coatings to Control Zebra Mussel Colonization: Preliminary Results 1990-1991. Journal of Protective Coatings & Linings, 9(7):28-41.

Meyer AE and Baier RE (1992) Nontoxic Control of Zebra Mussels: Surface Chemistry/Physics of Biological Adhesion. in Proceedings, Zebra Mussel Control Technology Conference, October 1991, Electric Power Research Institute, pp 2.45-2.58.

Meyer AE, Baier RE, and Forsberg RL (1995) Degradation of Nontoxic Fouling-Release Coatings as a Result of Abrasion and Long-term Exposure. in Proceedings, Fifth International Zebra Mussel & Other Aquatic Nuisance Organisms Conference 1995, February 14-21, 1995, Toronto, Canada, pp 337-342.

Race TD and Kelly MA (1996) Controlling Zebra Mussels with Coatings. Journal of Protective Coatings & Linings, 13(12):60-71.

Wells AW, Meyer AE, Matousek JA, Baier RE, and Neuhauser EF (1997) Nontoxic Foul-Release Coatings for Zebra Mussel Control. in Waterpower '97: Proceedings of the International Conference on Hydropower, August 1997, American Society of Civil Engineers, Vol. I, pp 451-460.

Zisman WA (1964) Relation of the equilibrium contact angle to liquid and solid constitution. in Contact Angle: Wettability and Adhesion, Advances in Chemistry Series, Vol. 43, American Chemical Society, Washington, DC, pp 1-51.
ECB-OR/98-05/1.

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Three-Dimensional Structure of the Watermass in Eastern Lake Erie as Revealed by Intensive CTD Monitoring and Three-Dimensional Visualization

Gordon Fraser
Great Lakes Center
Buffalo State College
Buffalo, NY 14222
frasergs@buffalostate.edu

John Freidhoff
Great Lakes Center
Buffalo State College
Buffalo, NY 14222

Michael Goehle
Great Lakes Center
Buffalo State College
Buffalo, NY 14222
goehle@glc.snybuf.edu

Jacob Napieralski
Great Lakes Center
Buffalo State College
Buffalo, NY 14222

INTRODUCTION

Marine scientists for a long time faced a recurring problem in gathering sufficient data to describe the variability occurring in large water bodies. Until the introduction of automatic logging instruments, only small amounts of data could be gathered, and that at great expense. Water masses were visualized as laterally homogeneous over large areas because of the limited ability to gather spatially distributed data that would scale with potential spatial variability. Even the ability to gather data with sufficiently dense vertical spacing was difficult because of the time required to sample and analyze samples. Where details of the vertical structure of the water column were developed, however, scientists could see that a much more comprehensive understanding of the diversity of physical, chemical, and biological processes was needed. To some degree, use of remote sensing techniques addressed the problem by allowing investigators to gather information over large areas quickly and relatively inexpensively. But remote sensing data are only indirect mea-

Figure 1. *Seabird CTD datalogger being deployed from the stern of the RV Aquarius of the Great Lakes Center at Buffalo State College*

Conductivity	Acceleration	Surface Irradiance (SPAR)
Temperature	Average Sound Velocity	ORP (redox)
Potential Temperature	Descent Rate	Density
Potential Temperature Anomaly	# Bottles Fired	Sound Velocity
Depth	# Bytes Processed	Specific Conductance
Pressure (dB)	# Scans Averaged	Specific Volume Anomaly
Pressure Temperature	pH	Thermosteric Anomaly
Dissolved Oxygen	Turbidity	Time (seconds, hours, days)
Oxygen Current	Salinity	Flourometer - Chloryphyll-A
Oxygen Temperature	Transmissivity	Altimeter
Oxygen Saturation	Irradiance (PAR)	Backscatterence

Table 1. *Parameters that can be measured with the Seabirds CTD datalogger.*

sures of properties, and need to be groundtruthed and calibrated to be applied with confidence. In addition, their ability to infer deep structure within large water bodies is limited by the array of assumptions that are required for application.

Automated electronic data loggers were eventually developed that could be deployed and retrieved rapidly, accumulate data at discreet intervals in a matter of seconds, and store it for downloading. One such automated instrument, the Seabird CTD data logger, was developed that offered substantial advantage over previous instruments in that it could analyze various water quality parameters at a speed of one to two orders of magnitude faster (fig. 1) than the others that are commonly used.

The CTD data logger is capable of analyzing for a variety of parameters (Table 1) and can even be used to trigger autosamplers that can be deployed with the datalogger. The rapidity with which the sensors can refresh themselves is an advantage over other automated samplers in that the logger can be deployed and retrieved quickly at data gathering stations so that many more stations can be occupied and data can be collected almost continuously during both upcasts and downcasts. This capability vastly increases the amount of data that can be gathered during the course of a cruise, with a commensurate increase in spatial data density, both vertically and laterally.

The CTD data logger provides only part of the answer to the problem of interpreting the internal structure of large water bodies. Each sampling location is still only a single discrete point that is a miniscule representation of the various parameters that characterize a water mass the size, say, of Lake Erie. Even with many such points, the variation is still difficult to visualize in three dimensions, in part because the data return may be too large to assimilate and visualize easily. Three-dimensional visualization software, therefore, is the other part of the solution. It allows us to enter the data into 3-dimensional space and to correlate among data points so that the parameter variability within the total volume of the watermass can be modeled. We use EVS-PRO three-dimensional visualization software to perform this essential function. This software combines state-of-the-art analysis and visualization tools into an extremely powerful system that can be integrated with modular analysis and graphics routines for customized visualization applications. EVS-

PRO can accept digital data from the Seabird logger and process it for display as fully bounded and color-mapped 3D isovolumes and 3D colored isolines, exploded layers of selected value intervals, interactively positioned horizontal and vertical slice planes, configurable 3D labeled axes, and rectilinear or offset convex hull-bounded griddings. All views are capable of rotation and translation in real-time in order to achieve optimum viewing perspectives.

APPLICATIONS

We have combined these technologies in two projects. In one, we attempted to determine the 3-dimensional structure of the physico-chemical parameters in eastern Lake Erie, and in the other we are attempting to track the plume of the Buffalo River as it enters Lake Erie and the Niagara River in an effort to determine the transport paths of associated contaminants into these receiving waters.

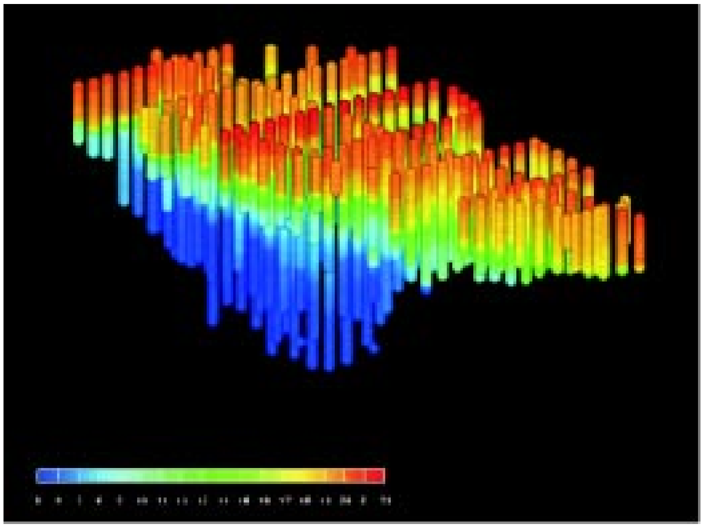
3-DIMENSIONAL STRUCTURE OF THE WATERMASS IN EASTERN LAKE ERIE

The key to developing a model of the 3-dimensional structure of a water body like Lake Erie is to complete the monitoring during a period when weather conditions do not vary appreciably. Wind direction and speed, especially, can alter the distribution of temperatures, and temperature-linked parameters by altering the direction of surface currents and changing the pattern upwelling and downwelling in the lake. We occupied 46 stations in a grid pattern extending from the mouth of the Buffalo River in the east, to a N-S line extending from Long Point, Ontario to Erie, Pennsylvania. X, y locations were established using differentially-corrected GPS positioning, and z locations were taken from the CTD logger. The data were reduced by averaging analyses over 0.5 meter intervals giving us over 7,500 data points for our analysis. This density of data was required for the krigging that the EVS-PRO software would perform in developing the model. Indicator krigging and heterogeneous parameter modeling were used to correlate between discrete data locations to view three-dimensional spatial variability.

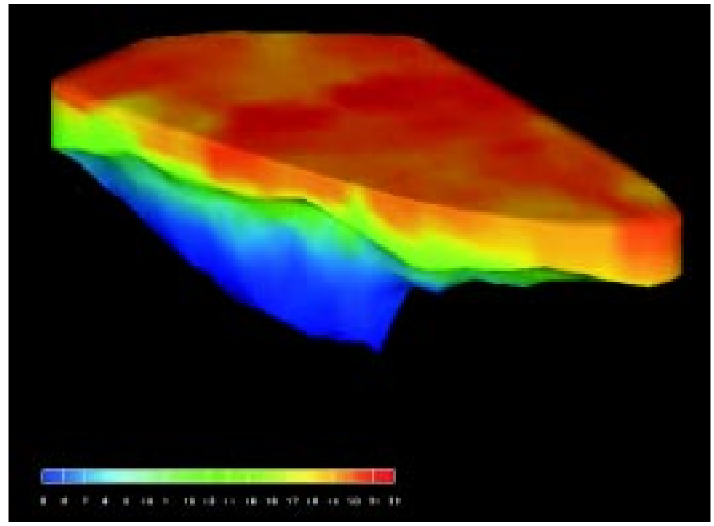
As an example of the technique we can show the model that was developed for temperature in three-dimensional space. Sampling stations are represented by columns instead of points (fig. 2A), with each column representing the total depth to which the CTD logger performed analyses, and the correct lateral spatial relationships among individual stations. The temperature on the bar is color-ramped and the values in ^{o}C are shown on the bar at the bottom of the view. The thermocline, shown in yellow, is the boundary between the warm waters near the surface and the colder waters at depth, and represents the depth at which the rate of downward cooling is most rapid.

After indicator krigging was performed on the data, a 3-dimensional model of temperature distribution in the watermass in eastern Lake Erie was created. The model shows the solid volume and temperature variation of the watermass (fig. 2B). Note the subtle variations in water temperature at the surface and the vertical irregularity in the boundaries between temperature categories as seen along the south side of the watermass.

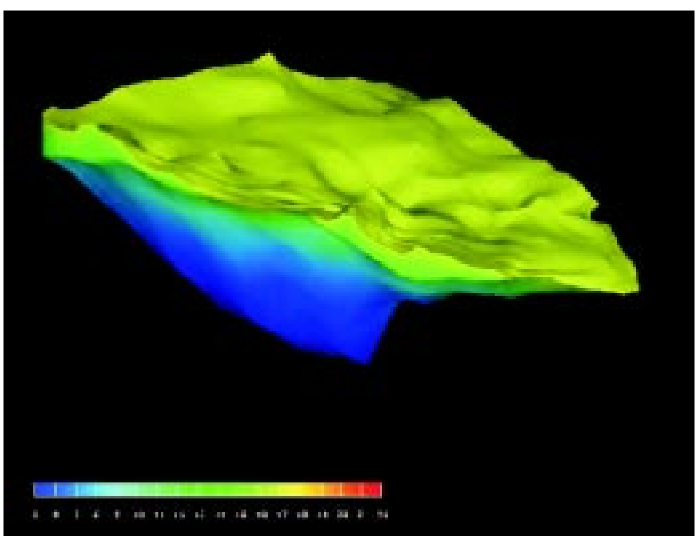
Such a view of the exterior of the watermass is no real improvement over simple cross-sections, however, but with EVS-PRO, we are able to strip away all the warmer waters above the thermocline to show the character of its surface (fig. 2C). Previous models of the thermocline envisioned it to be a broadly undulating surface but this concept was actually an artifact of the sampling density. The much greater density, allowed by use of the CTD logger resulted in a model that shows the surface with abundant, small-scale irregularities. This variation can possibly be attributed to inflowing streams, or



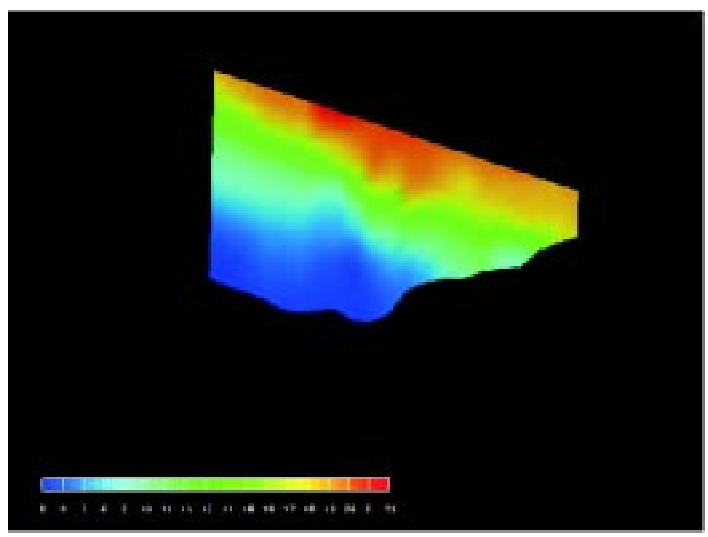
A. Three-dimensional view of the disribution of temperature data collected with the CTD datalogger in the eastern part of Lake Erie



B. Three-dimensional view of the watermass in the eastern part of Lake Erie showing the temperatures at the air-water and substrate-water interfaces



C. Three-dimentional view of the watermass shown in Figure 2C showing the upper water layers stripped down to the surface of the thermocline



D. East-west slice taken through the watermass showing the internal 2-dimensional distribution of temperatures

Figure 2.

to along-shore variations in the intensity of downwelling at the southern shore caused by the southerly prevailing winds during the sampling period.

An infinite series of cross-sections can be viewed at any place and with any orientation through the watermass once the data has been spatially correlated within the EVS-PRO software. This typical cross-section is oriented vertically and in an E-W direction (fig. 2D). Again, note the vertical irregularity in the boundaries between temperature categories. We should note here, as well, that once a particular view has been constructed, it can be rotated to any orientation in real-time for viewing from different perspectives.

TRACKING THE PLUME OF THE BUFFALO RIVER

The Buffalo River leaves its mouth as a thermally buoyant plume in the spring and early summer, and in the fall when lake waters are cold. However, there may be little difference in thermal character between river and basin waters in the late summer as the lake warms, and the outfall from the river may enter the lake as an interflow at the thermocline, or as an underflow if the thermocline is very deep. Little is known about the thermal structure of the flow in winter, but it is likely that river water is significantly warmer than basin waters.

Two Seabird SBE Sealogger profilers were used to collect the large amounts of data needed to parameterize the sampling area in order to intercept the suspected scale of variability in the watermasses. A total of 85 stations were occupied; 14 within the Black Rock Canal, 20 within the Buffalo River, and 51 within the Niagara River. Parameters measured included conductivity, depth, temperature, dissolved oxygen, and turbidity, although turbidity was found to be the most useful of these in establishing the shape and movement of the plume. X,y positioning was done with Magellan GPS units, and z locations were established by pressure transducers on the profilers supplemented by depth recorders on the winch cables. Two research vessels were used from the Great Lakes Center to deploy the loggers. Sampling events were to include four runs for each of three storms and one run for each of 2 baseflow periods. Baseflow events followed at least 72 hours of negligible precipitation.

The sample sites were labeled and separate files of tab-delimited data of each site number and event were created and identified according to UTM position for import into EVS-PRO. Preliminary results with EVS-PRO indicated a significant problem in the way the krigging process analyzed the data. The breakwall dividing the Niagara River from the Black Rock Canal is very narrow and could not be recognized by EVS-PRO due to the short transverse (cross-stream) spacing versus the long longitudinal (downstream) spacing of sample sites in the Niagara River and the Black Rock Canal. The result was that the models developed did not treat the breakwall as a boundary, but as a shallow water-covered area. Values for the various parameters in the river and canal, therefore, were averaged together during the krigging rather than as separate water bodies, so that data from the Niagara River influenced that in the Black Rock Canal and vice versa.

Attempts to overcome the difficulty were made by altering the krigging parameters, such as points per node and resolution, in order to create more calculated values in the sampling area or to refine the filter to resolve the breakwall as a land area. Various combinations were tried, and while some progress was made toward resolving the breakwall as a boundary, serious problems were created in other parts of the project area. Efforts also were made to grid the data in ArcView Spatial Analyst prior to kriging. A successful bathymetric model of the basin was created, but again, in order to resolve the breakwall, the grid size had to be set so small that the digital datafile of the gridded area was too large to be accepted by EVS-PRO. Extensive time has been spent attempting to overcome this obstacle, with mixed results, and the remaining option is modeling the canal and river independently.

For preliminary display, characteristic transects were selected and all data graphed for each event and each run to show lateral and vertical variability (figure 3). The water temperature of Lake Erie and the Buffalo River were virtually identical during the time the data for figure 3 was collected. Therefore, the plume from the river entered the lake as an underflow, clearly seen in the graph, due to the suspended sediment load that was being carried by the flow at its base. Another method used was to average all vertical and horizontal data from each transect and analyze the temporal and spatial results. A third approach graphically compared individual sites during particular events. All three methods demonstrated trends that EVS-PRO will be able to show in greater detail.

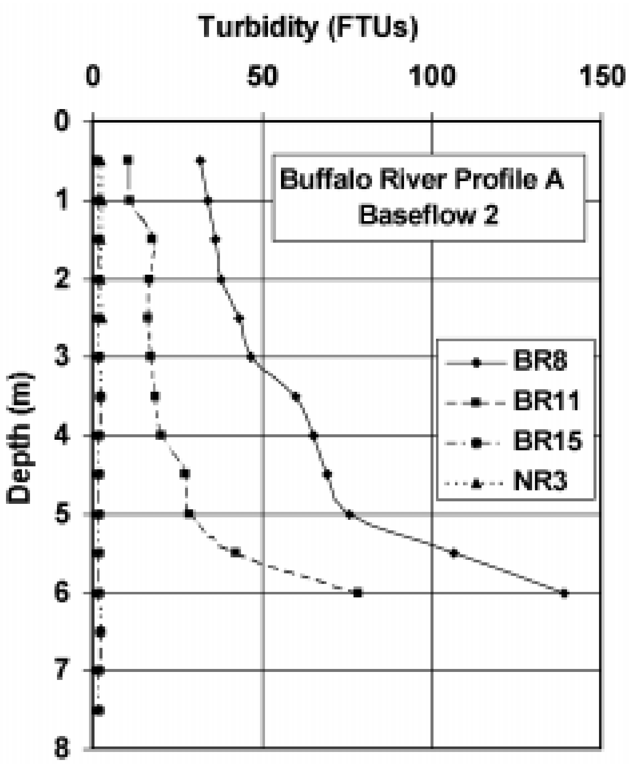


Figure 3. Graph showing the vertical distribution of turbidity levels as measured by a CTD datalogger at four sampling stations extending from the mouth of the Buffalo River (BR8) northwest into Lake Erie near the head of the Niagara River (Nr3).

FUTURE WORK

We hope to develop a cooperative project with other research organizations to monitor Lake Erie several times during the summer during 2-day periods. Three or four boats, each deploying a CTD logger could provide coverage over the whole lake in the same time period we used in our initial effort. Each monitoring event, therefore, would be a "snapshot" of the condition of the entire lake. We also have tested the viability of using hydroacoustic sensors to map the location of schools of fish in the lake and incorporate the data into EVS-PRO as discreet point data. Towed hydroacoustic equipment returns a continuous stream of data that can be processed to give information about fish size, species, and density along the travel path of the boat. We stopped at sampling points to gather hydroacoustic returns and data on the physicochemical and biotic parameters (chlorophyl-a) with the objective of correlating distribution of game fish and prey fish with respect to important controlling factors in the watermass. If done over a period of time, this would allow us to track movement of fish through the summer with respect to changes in the structure of the characteristics of the watermass.