

Status and Trends of Key Indicators 2007

Detroit River and Western Lake Erie

Cover photos: Landsat 7 satellite image of western Lake Erie Basin and Detroit River corridor provided by USGS Landsat Project; Upper left: angler with walleye (*Sander vitreus*) by Jim Barta; Middle left: lake sturgeon (*Acipenser fulvescens*) by Glenn Ogilvie; Lower left: *Hexagenia* by Lynda Corkum; Center: lake whitefish (*Coregonus clupeaformis*) by James Boase/U.S. Fish and Wildlife Service; Lower right: juvenile peregrine falcon (*Falco peregrinus*) by Craig Koppie/U.S. Fish and Wildlife Service; Bottom left: bald eagle (*Haliaeetus leucocephalus*) by Steve Maslowski/U.S. Fish and Wildlife Service.



STATE OF THE STRAIT

STATUS AND TRENDS OF KEY INDICATORS

Edited by: John H. Hartig, Michael A. Zarull, Jan J.H. Ciborowski, John E. Gannon,
Emily Wilke, Greg Norwood, and Ashlee Vincent

2007

STATE OF THE STRAIT STATUS AND TRENDS OF KEY INDICATORS

2007

Edited by:

John H. Hartig, U.S. Fish and Wildlife Service
Michael A. Zarull, Environment Canada
Jan J.H. Ciborowski, University of Windsor
John E. Gannon, International Joint Commission
Emily Wilke, Southwest Michigan Land Conservancy
Greg Norwood, U.S. Fish and Wildlife Service
Ashlee Vincent, University of Windsor

Based on the Detroit River-Western Lake Erie Indicator Project, a three-year U.S.-Canada effort to compile and summarize long-term trend data, and the 2006 State of the Strait Conference held in Flat Rock, Michigan

Suggested citation: Hartig, J.H., M.A. Zarull, J.J.H. Ciborowski, J.E. Gannon, E. Wilke, G. Norwood, and A. Vincent, eds. 2007.
State of the Strait: Status and Trends of Key Indicators.
Great Lakes Institute for Environmental Research, Occasional Publication No. 5,
University of Windsor, Ontario, Canada.
ISSN 1715-3980

Report also available at:
www.StateoftheStrait.org
www.epa.gov/med/grosseile_site/indicators/index.html

PREFACE

Preface

Ecosystems change and Lake Erie and the Detroit River are no exception. Some changes are natural, but most are related to past and current human uses and abuses of Lake Erie, the Detroit River, and surrounding lands and waters. Some changes occur on a seasonal basis, while others are observed over a long time frame. During the 1960s, Lake Erie was so polluted that it routinely received national media attention, including an August 20, 1965 article in *Time* magazine which reported that Lake Erie is “dead.”

The media coverage of the pollution of Lake Erie and the public outcry that followed inspired Dr. Seuss to include Lake Erie in the first (1971) edition of *The Lorax*, one of the most well-known children’s books on environmental stewardship. In the 1971 edition of *The Lorax* there was a part where the Humming-Fish no longer could hum because of water pollution and must leave their pond home:

They’ll walk on their fins and get woefully weary
in search of some water that isn’t so smeary.
I hear things are just as bad up in Lake Erie.

Ohio State University graduate students, Marjorie Pless and Claudia Melear, wrote to Dr. Seuss in 1987 and informed him of the substantial environmental improvements that occurred in Lake Erie during the late 1970s and early 1980s because of the public outcry and the subsequent governmental response in implementing pollution control programs. Dr. Seuss thanked the students and promised to revise the text in the next edition since he did not want to perpetuate an inaccurate perception about the lake. Accordingly, the 1992 edition of *The Lorax* dropped that last sentence on Lake Erie.

Today, there is no doubt that the ecosystem state of Lake Erie and the Detroit River is better than the 1960s and early 1970s. However, there are also some indicators from Lake Erie and the Detroit River that show declining conditions once again.

This project was undertaken to translate the science behind these indicator trends and bring greater public clarity to our understanding of the State of the Strait. If Dr. Seuss were alive today, there would be no doubt that he would strongly support this Canada-U.S. Detroit River-Western Lake Erie Indicator Project and champion this report to better educate all of us on our responsibility to care for the place we call home!

State of the Strait Conference Steering Committee

ACKNOWLEDGEMENTS

Acknowledgements

The Detroit River-Western Lake Erie Indicator Project, the December 5, 2006 State of the Strait Conference, and this final report were made possible by financial and in-kind support from many organizations and agencies. We gratefully acknowledge such support from the following sponsors:

- Canadian Consulate
- CDM
- Detroit Water and Sewerage Department
- DTE Energy
- Environment Canada
- Environmental Management Association
- Essex Region Conservation Authority
- Friends of the Detroit River
- Great Lakes Fishery Trust
- International Joint Commission
- International Wildlife Refuge Alliance
- Metropolitan Affairs Coalition
- Michigan Sea Grant
- University of Michigan-Dearborn
- University of Windsor
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

The foundation of this project and report are the indicator trend data and knowledge provided by many partners. Without access to their data, knowledge, and practical management experience, this project and report would not have been possible. We gratefully acknowledge the following partners:

- Ashland University
- Bird Studies Canada
- Central Michigan University
- Community Foundation for Southeast Michigan

- Detroit Audubon Society
- Detroit Water and Sewerage Department
- Downriver Linked Greenways
- Downriver Stream Team
- DTE Energy
- Environment Canada
- Essex Region Conservation Authority
- Fisheries and Oceans Canada
- Great Lakes Fishery Commission
- Habitat Solutions
- Heidelberg College
- Hinshon Environmental Consulting
- Holiday Beach Migration Observatory
- International Association for Great Lakes Research
- International Joint Commission
- Michigan Department of Community Health
- Michigan Department of Environmental Quality
- Michigan Department of Natural Resources
- Michigan Sea Grant
- Metropolitan Affairs Coalition
- Michigan Trails and Greenways Alliance
- Monroe Water Treatment Plant
- National Oceanic and Atmospheric Administration
- Ohio Department of Natural Resources
- Ontario Ministry of the Environment
- Rouge River Bird Observatory
- Southeast Michigan Council of Governments
- Southeastern Michigan Raptor Research
- The Nature Conservancy
- The Ohio State University
- U.S. Coast Guard
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- Union Water Treatment Plant
- University of Michigan
- University of Michigan-Dearborn

- University of Toledo
- University of Windsor
- Utica College
- Wade Trim
- Washtenaw County Conservation District
- Wayne County Department of Environment
- Wayne State University

The project was directed by a State of the Strait Steering Committee made up of the following members:

- Mary Bohling, Michigan Sea Grant
- Jan Ciborowski, University of Windsor
- Melanie Coulter, Detroit River Canadian Cleanup
- Rose Ellison, U.S. Environmental Protection Agency
- John Gannon, International Joint Commission
- Orin Gelderloos, University of Michigan-Dearborn
- John Hartig, U.S. Fish and Wildlife Service
- George Jacobsen, Metropolitan Affairs Coalition
- John Nasarzewski, Southgate Anderson High School
- Greg Norwood, U.S. Fish and Wildlife Service
- Roy Schrameck, Environmental Consulting & Technology, Inc.
- Bruce Szczechowski, Southgate Anderson High School
- Roberta Urbani, DTE Energy
- Ashlee Vincent, University of Windsor
- Emily Wilke, Southwest Michigan Land Conservancy
- Michael Zarull, Environment Canada

We would also like to express our sincere thanks to the university students and interns who helped prepare selected indicator reports: Guadalupe Cummins, Olivia Napierski, Lisa Perschke, and Lena Cicchelli.

Finally, we would like to acknowledge and thank: CDM, and especially Elizabeth Nicol, for their help with design and layout of this report; Karen Koch for help with copy editing; and Kay Morrison of the U.S. Environmental Protection Agency's Large Lakes Research Station for serving as webmaster on this project. Without their contributions, this report and the associated website would not have been possible.

TABLE OF CONTENTS

Preface	i
Acknowledgements	ii
1.0) Executive Summary	1
2.0) Introduction	4
3.0) Comprehensive and Integrative Assessment.....	8
3.1) Pollution Prevention/Control and Evidence of Improved Environmental Quality	8
3.1.1) Oil Pollution.....	13
3.1.2) Municipal Waste	13
3.1.3) Phosphorus and Eutrophication.....	14
3.1.4) Chloride	14
3.1.5) Persistent Toxic Substances.....	14
3.1.6) Contaminated Sediment.....	15
3.2) Ecological Recovery.....	15
3.2.1) Bald Eagles.....	15
3.2.2) Peregrine Falcons	16
3.2.3) Walleye and the Walleye Fishery	16
3.2.4) Lake Sturgeon	16
3.2.5) Lake Whitefish.....	17
3.2.6) Mayflies	17
3.3) Key Environmental and Natural Resource Challenges and Priority Management Actions	17
3.3.1) Population Growth, Transportation Expansion, and Land Use Changes.....	17

3.3.2) Nonpoint Source Pollution	19
3.3.3) Toxic Substances Contamination.....	22
3.3.4) Habitat Loss and Degradation.....	22
3.3.5) Introduction of Exotic Species	24
3.3.6) Greenhouse Gases and Global Warming.....	25
3.4) Priority Research/Monitoring Needs	27
3.4.1) Demonstrate and Quantify Cause-Effect Relationships.....	27
3.4.2) Establish Quantitative Endpoints and Desired Future States	27
3.4.3) Determine Cumulative Impacts and How Indicators Relate.....	28
3.4.4) Further Modeling and Prediction	28
3.4.5) Prioritize Areas for Protection and Restoration	28
3.4.6) Foster Long-Term Monitoring for Adaptive Management	28
3.5) Concluding Thoughts and Recommendations	28
4.0) Literature Cited	31
5.0) Appendix A.....	33
5.1) State of the Strait Conference Program – December 5, 2006.....	34
5.2) State of the Strait Conference Session Summaries	36
Land Use, Transportation, Population and Human Health Session Summary.....	36
Wildlife and Habitat Session Summary.....	38
Fish and Invertebrate Session Summary.....	41
Contaminants Session Summary	43
6.0) Appendix B.....	47
6.1) Pressure Indicators	
Human Population Growth and Distribution in Southeast Michigan.....	52
Land Use Change in Southeast Michigan.....	57
Transportation Trends in Southeast Michigan	63
Phosphorus Loads and Concentrations from the Maumee River	68
Michigan’s Carbon Emissions	75

Oil Pollution of the Detroit and Rouge Rivers	78
Lake Erie Shoreline Hardening in Lucas and Ottawa Counties, Ohio	85
6.2) State Indicators	
Lake Erie Water Levels	92
Water Clarity in Western Lake Erie	99
Lake Erie Ice Cover	102
Phosphorus Concentrations in the Western Basin of Lake Erie	105
Chloride Levels in Western Lake Erie Water Samples Collected from the Monroe Water Intake	111
Dissolved Oxygen Levels in the Rouge River	116
Contaminants in Western Lake Erie Sediments	121
Criteria Air Pollutants in Southeast Michigan	126
Contaminants in Western Lake Erie Fish Community	136
Mercury in Lake St. Clair Walleye	143
Contaminants in Herring Gull Eggs	146
Algal Blooms in Western Lake Erie	151
Plankton Communities	156
Recovery of Wild Celery	160
Reestablishment of Long-Absent Aquatic Macrophytes in Western Lake Erie	163
Detroit River Coastal Wetlands	172
Invasion of the Erie Marsh Preserve by Common Reed (<i>Phragmites australis</i>) Over the Last 20 Years	177
<i>Hexagenia</i> Density and Distribution in the Detroit River	181
Abundance of Burrowing Mayflies in the Western Basin of Lake Erie	189
Chironomid Abundance and Deformities	193
Oligochaete Densities and Distribution	199
Invasion of Zebra Mussels (<i>Dreissena polymorpha</i>) and Quagga Mussels (<i>Dreissena bugensis</i>)	205
Yellow Perch Population	212
Lake Whitefish Spawning	216

Lake Sturgeon Population	221
The Walleye Population of Lake Erie.....	226
Canvasback Population in Lake St. Clair/Detroit River/Western Lake Erie Basin.....	230
Common Tern Reproduction	234
Double-crested Cormorant Population Changes.....	239
Detroit River Christmas Bird Count	243
Rockwood, Michigan Christmas Bird Count – Overwintering Bird Count Fluctuations	247
Fall Raptor Migration at Holiday Beach Conservation Area, Amherstburg, Ontario	253
Fall Raptor Migration over Lake Erie Metropark.....	259
Peregrine Falcon Reproduction in Southeast Michigan	263
Bald Eagle Reproductive Success.....	267
Asthma Hospitalization Rates in Wayne County, Michigan	276
Lead Poisoning in Detroit, Michigan	281
West Nile Virus in Michigan.....	288
6.3) Response Indicators	
Phosphorus Discharges from Detroit Wastewater Treatment Plant.....	294
Combined Sewer Overflow Controls in Southeast Michigan	297
Contaminated Sediment Remediation	305
Land Conservation for Wildlife in the Detroit River International Wildlife Refuge.....	309
Southeast Michigan Greenway Trails	312

1.0 EXECUTIVE SUMMARY

The Detroit River and western Lake Erie are located in the industrial and agricultural heartland of the Great Lakes basin ecosystem. As a result of historical water pollution problems, this region has many long-term, environmental and natural resource data sets. A U.S.-Canada project was initiated in 2005 to assemble as many of these long-term data sets (most with 30 or more years of data) as possible to produce a State of the Strait Report in 2007. Detailed indicator summaries were prepared to examine the trends and interpret and translate the scientific information for policymakers and managers.

On December 5, 2006, a State of the Strait Conference was convened in Flat Rock, Michigan to review available trend data, develop key findings, and discuss possible management actions and research needs. This State of the Strait Conference laid the foundation for a comprehensive and integrative assessment of the state of the Detroit River and western Lake Erie ecosystem. Presented below are the major conclusions and recommendations from this assessment, based on 50 indicator/trend data summaries.

Over 35 years of U.S. and Canadian pollution prevention and control efforts have led to substantial improvements in environmental quality. However, the available information also shows that much remains to be done. Examples of environmental improvements include: reductions in oil, phosphorus, chloride, and untreated waste from combined sewer overflow discharges; declines in contaminants in fish and wildlife; and substantial progress in remediating contaminated sediment.

Improvements in environmental quality have resulted in significant ecological recovery in this region. Trend data document an increase in the populations of bald eagles, peregrine falcons, lake sturgeon, lake whitefish, walleye, and burrowing mayflies to large areas from which they had been extirpated or negatively impacted.

This ecological recovery is remarkable, but many environmental and natural resource challenges remain. Six key environmental and natural resource management challenges include:

- population growth, transportation expansion, and land use changes;
- nonpoint source pollution;
- toxic substances contamination;
- habitat loss and degradation;
- introduction of exotic species; and
- greenhouse gases and global warming.

Research/monitoring must be sustained for effective management. Indeed, without research/monitoring, management is flying blind. Six priority research/monitoring needs based on this comprehensive and integrative assessment include:

- demonstrate and quantify cause-effect relationships;
- establish quantitative endpoints and desired future states;
- determine cumulative impacts and how indicators relate;
- improve modeling and prediction;
- prioritize geographic areas for protection and restoration; and
- foster long-term monitoring for adaptive management.

Clearly, there is a need for comprehensive and integrative assessments of ecosystem health; however, no mechanism currently exists to continue this work. Collectively, millions of dollars are spent annually on research, monitoring, and environmental management in the Detroit River and western Lake Erie. Comparatively, very little is spent on a periodic comprehensive and integrative assessment of ecosystem health. Therefore, it is recommended that

resources be pooled through the Canada-U.S. collaborative monitoring effort under the Binational Executive Committee (BEC) on a regular basis (e.g., at least every five years) to undertake comprehensive and integrative assessments of the health of the Detroit River and western Lake Erie ecosystem. Key coordinating organizations that should be responsible for these assessments include the Remedial Action Plans for Areas of Concern, the Lake Erie Lakewide Management Plan, the Detroit River International Wildlife Refuge, the Lake Erie Committee of the Great Lakes Fishery Commission, watershed and conservation organizations, and land use/transportation planning organizations like the Southeast Michigan Council of Governments.

The assessment presented in this report will serve as a baseline that can be improved upon in the next iteration in the spirit of adaptive management.

Quantitative targets or endpoints do not exist for most indicators. Of the 50 time trend data sets assessed, only 17 have quantitative targets. Only five of the 17 indicators with targets are meeting them. Therefore, it is recommended that

a high priority should be placed on quantifying targets and endpoints for indicators in order to clearly focus management efforts and track progress consistent with adaptive management. The responsibility for quantifying targets and endpoints should rest with the key coordinating organizations such as those identified above.

All trend databases are important to the organizations and agencies collecting the data. However, future iterations of comprehensive and integrative assessments may want to focus on a smaller set of key indicators that best meet the needs of management. In addition, this assessment was heavily weighted on state information – there are 38 state, seven pressure and five response indicators. It is further recommended that

future comprehensive and integrative assessments of the Detroit River and western Lake Erie should include more pressure and response indicators as they become developed, and more economic and social indicators, including indicators of sustainability and human health. Examples of available pressure and response trend data include: air emissions, watershed-specific urban and agricultural nonpoint source loadings, watershed-specific impervious land use, other watershed-specific land-based stressors as summarized by the Great Lakes Environmental Indicator Project (<http://glei.nrrri.umn.edu>), industrial point source loadings, etc.

Finally, some trend data were only available from one side of the international border. Therefore, it is recommended that

binational harmonization be achieved to truly undertake comprehensive and integrative assessment.

2.0 INTRODUCTION

The Detroit River and western Lake Erie are located at the heart of the Great Lakes basin ecosystem (Figure 1). The Detroit River is a channel linking the upper Great Lakes to the lower Great Lakes. It provides 90% of the water flow to Lake Erie. The Detroit River is an important migration corridor for many species of fish and birds. It also provides critical habitat for fish, birds, and benthic organisms, and is an important source of potable water to bordering communities (Upper Great Lakes Connecting Channels Study 1988).

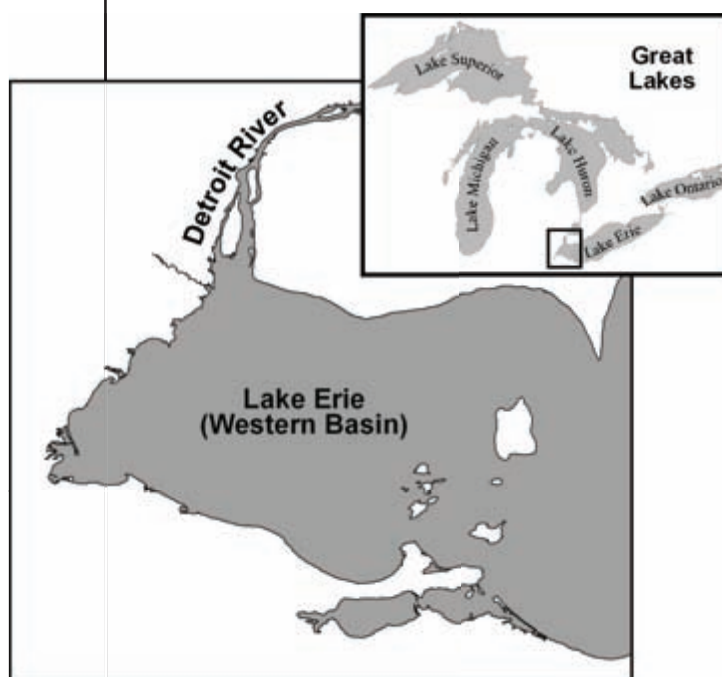


Figure 1. The Detroit River and western Lake Erie.

Lake Erie is the smallest of the Great Lakes (483 km³) by volume and next to the smallest in surface area (25,700 km²). It is also the southernmost Great Lake. The lake is naturally divided into three basins. The western basin is shallow (mean depth = 7 meters), fully mixed, and is separated from the central basin by a ridge running southeast from Point Pelee. About one-third of the total human population of the Great Lakes basin resides within the Lake Erie watershed. Of all the Great Lakes, Lake Erie is exposed to the greatest stress from urbanization, industrialization, and agriculture. Reflecting the fact that the Lake Erie basin supports the largest population, it surpasses all the other Great Lakes in the amount of effluent received

from wastewater treatment plants (Dolan 1993). Intensive agricultural development, particularly in southwest Ontario and northwest Ohio, contributes huge sediment loads to the lake. The Detroit River also delivers sediment from the actively eroding shoreline of southeastern Lake Huron and Lake St. Clair. The western basin is generally the shallowest, most turbid region of the lake, and much of its sediment load eventually moves into the central and eastern basins.

The Detroit River and western Lake Erie have been recognized for their biodiversity in the North American Waterfowl Management Plan, the United Nations Convention on Biological Diversity, and the Western Hemispheric Shorebird Reserve Network, and

as a Biodiversity Investment Area by the U.S. Environmental Protection Agency's and Environment Canada's State of the Lakes Ecosystem Conference.

Because of this region's early European settlement (Detroit was founded in 1701), rapid development into a major metropolitan area (approximately five million people live in the U.S. portion of the Detroit River watershed and over 500,000 live in the Canadian portion), and long history of industrial manufacturing, many long-standing environmental and natural resource problems have existed. As the Detroit metropolitan area developed into an industrial manufacturing center, the automobile capital of the world, and a major steel producer, and as Detroit mobilized to become the "Arsenal of Democracy" during World War II, industrial pollution led to massive winter duck kills due to oil pollution. Indeed, one major oil spill in 1948 resulted in the death of 11,000 ducks and geese in the Detroit River (Hartig and Stafford 2003). The public outcry over this one event is credited with being the catalyst for the industrial pollution control program in Michigan.

During the 1960s, increasing inputs of phosphorus to Lake Erie led to excessive algal growth, oxygen depletion, and fish kills. This pollution of Lake Erie was prominently featured in many national magazines, including *Time* magazine on August 20, 1965 (*Time* 1965). The media coverage that "Lake Erie is dead" and the resultant public awareness became the major catalyst for the 1972 U.S.-Canada Great Lakes Water Quality Agreement that called for a comprehensive phosphorus control program for the Great Lakes.

In 1970 the entire fishery from Lake Huron to Lake Erie, including the Detroit River, had to be closed because of mercury contamination (Hartig 1983). It came to be known as the "Mercury Crisis of 1970" when industrial inputs of mercury from Sarnia, Ontario and Wyandotte, Michigan resulted in widespread mercury contamination. Eventually, chemical plants had to undergo process changes to eliminate mercury from their waste discharges.

The many long-standing environmental and natural resource problems noted above, and the resultant public awareness of the problems in this major urban area, spurred substantial efforts in pollution prevention and control, and resulted in a long history

Monitoring is essential for effective, defensible management.

of Canada-U.S. cooperation in investigating and monitoring the Detroit River-western Lake Erie corridor. Indeed, both the Detroit River Remedial Action Plan and the Lake Erie Lakewide Management Plan have a long 20-year history of identifying actions to restore impaired beneficial uses. The Comprehensive Conservation Plan for the Detroit River International Wildlife

Refuge guides conservation efforts. The Lake Erie Committee of the Great Lakes Fishery Commission oversees fishery management planning, including goals, objectives, and implementation strategies. Each of these planning initiatives calls for monitoring to track changes and measure progress toward goals and objectives. In addition, many nongovernmental organizations and conservation groups practice citizen science through bird and plant surveys. Indeed, it is often said that "if you can't measure it, you cannot manage it." Monitoring is essential for effective, defensible management.

The State of the Strait Conference is a Canada-U.S. conference held every two years that brings together government managers, researchers, students, members of environmental

and conservation organizations, and concerned citizens to assess ecosystem status and provide advice to improve research, monitoring, and management programs for the Detroit River and western Lake Erie. The 2004 Conference focused on monitoring for sound management and recommended that a binational indicator report be prepared to improve accessibility, science translation, and communication of long-term trends (Eedy et al. 2005). In addition, the 2004 Conference recommended that greater emphasis be placed on ensuring that volunteer monitoring data have sufficient quality control, that management agencies sanction these efforts and agree to use the data for management purposes, and that the data become broadly disseminated and used.

An indicator is a measurable feature or features that singly or in combination provides useful information about status, quality, or trends. Indicators can be used to quantify the status for a whole array of factors from the state of the economy to the environment. Indicators should quantify information to make their significance apparent and convey it in a meaningful way to policy- and decision makers. The Binational Executive Committee (BEC) recognized this in creating the State of the Lakes Ecosystem Conference (SOLEC)

An indicator is a measurable feature or features that singly or in combination provide useful information about status, quality, or trends.

to develop and report on indicators of the condition of the Great Lakes as a whole. But many indicators, which have local relevance, greatly complement the general indicators needed to describe basinwide trends.

Most of the detailed summaries presented in this document describe the history and status of important elements of the study area. But they are not indicators, in the strict sense of the term, since quantitative “targets” that represent ideal conditions have not been decided upon. However, the summaries provide

valuable information on status and trends over time, and thus they may eventually serve as the basis for establishing management benchmarks. Those reports are perhaps better called “trend data” rather than indicators per se.

Policymakers and decision makers at all levels need timely, reliable, and relevant information on indicators for management purposes. Indicators can be used to measure progress toward management goals and objectives. From a management perspective, particular emphasis needs to be placed on quantifying targets and endpoints for management programs.

As a result of the recommendation from the 2004 State of the Strait Conference and the need for communication of status and trends of key indicators, the Detroit River-Western Lake Erie Indicator Project was initiated in 2005 (http://www.epa.gov/med/grosseile_site/indicators/index.html). The purpose of this project is to:

- compile and interpret long-term databases for 50 potential indicators from the Detroit River and western Lake Erie;
- translate the information into understandable terms for policymakers and managers; and
- make these data and their time trends readily available via the website above.

On December 5th, the 2006 State of the Strait Conference was convened in Flat Rock, Michigan (Appendix A). Over 300 people participated in reviewing the available trend data, recommending management next steps and research needs, and laying the foundation for a comprehensive and integrative assessment of the state of the Detroit River and western Lake Erie ecosystem. This report represents an initial attempt at preparing a comprehensive and integrative assessment of the state of the Detroit River and western Lake Erie ecosystem based on available environmental trend data and information. The addition of other long-term data sets currently unavailable to this project (e.g., shorebirds, air emissions) and more complete geographic coverage of other data on both sides of the border (e.g., population, land use, transportation) is an ongoing task that will improve our diagnostic capacity. This initial comprehensive and integrative assessment will lay the foundation for future assessments, undertaken within the philosophy of adaptive management, whereby ecosystem status is assessed, management priorities are set, and management actions are implemented in an iterative fashion to foster continuous improvement.

3.0 COMPREHENSIVE AND INTEGRATIVE ASSESSMENT

The Detroit River-Western Lake Erie Indicator Project has compiled considerable useful information on long-term patterns of 50 key trend data sets and indicators (Table 1; Appendix B). Indeed, it is surprising how many long-term databases exist, but are neither accessible nor available. These databases were not integrated, nor comprehensively evaluated and assessed. However, collectively the information and knowledge from these 50 data sets have considerable value to management.

This assessment is comprehensive in that it makes use of all available information. It is integrative in that it identifies emerging trends from suites of indicators that may not be evident from analyzing single indicators. By the same token, all recommendations, as well as the research and monitoring needs, are a result of this integrative assessment.

If one were to look at a small number of these indicators, one might get an incomplete and possibly inaccurate assessment or picture. For a comprehensive assessment of ecosystem health, all indicator databases are important. However, a more limited suite of trend data or indicators may be sufficient for specific resource management needs like fisheries or wildlife. Presented below is an initial comprehensive and integrative assessment that draws on all available databases. This summary and interpretation is heavily weighted on state information – there are 38 state, seven pressure and five response indicators. Although there are important data and knowledge gaps, this initial assessment lays the foundation for continuous improvement in the future in the spirit of adaptive, ecosystem-based management.

3.1 Pollution Prevention/Control and Evidence of Improved Environmental Quality

The Detroit River and western Lake Erie have received considerable local, regional, national, and international media attention over many decades from oil spills, phosphorus pollution, the “Mercury Crisis of 1970,” and more. Growing public awareness and concern over controlling pollution resulted in a number of key regulatory and nonregulatory initiatives being implemented in the early 1970s in both Canada and the United States (e.g., U.S. Clean Water Act, Canada Water Act, U.S. Endangered Species Act, Canada-U.S. Great Lakes Water Quality Agreement, etc.).

These national initiatives and U.S.-Canada agreements, and complementary state, provincial, and local programs, provided the framework and impetus for billions of dollars of pollution prevention and control over the last 35 years. All environmental and natural resource agencies and organizations are interested in results – what has been achieved by pollution prevention and control.

Table 1. A compilation and summary of indicators/trend data for the Detroit River and western Lake Erie.

Indicators/Trend Data	Period of Record	Overall Trend	Quantitative Target	Target Achieved
Human Population Growth and Distribution in Southeast Michigan	1900-2005	Steady increase in population within seven-county region; Detroit's population grew steadily until 1950, then decreased by 50% between 1950 and 2005	No	
Land Use in Southeast Michigan	1900-2006	There has been a substantial increase in the conversion of agricultural land to urban development; there has also been a decrease in housing density	No	
Transportation	1960-2000	88% increase in people driving personal vehicles since 1960; 26,000 fewer people using mass transit since 1980; average travel time to work has increased by three minutes in the last 20 years	No	
Phosphorus in the Maumee River	1975-2006	There has been a general decline in total phosphorus from the mid-1970s through the mid-2000s; dissolved reactive phosphorus declined from the mid-1970s to the mid-1990s and is now increasing through the mid-2000s	No	
Carbon Emissions	1960-2001	Michigan's carbon emissions have increased by 59.7 million metric tons between 1960 and 2001, representing a 46% increase	No	
Oil Pollution of Detroit and Rouge Rivers	1946-2005	Between 1946-1948 and 1961 there was a 97.5% reduction in oil discharges; between 1961 and the 1990s and early 2000s there was another order of magnitude reduction, with the exception of 2002 and 2004 when major oil spills occurred	No	
Shoreline Hardening	1870-1990	The Lake Erie shoreline along two counties in Ohio were almost unaltered until the 1930s; there has been a dramatic increase in shoreline hardening through the 1990s; shoreline hardening in Ottawa and Lucas counties has increased to 78% and 98%, respectively	No	
Lake Erie Water Levels	1918-2005	Water levels vary on both seasonal and long-term scales; high water levels were recorded in Lake Erie in the 1950s and 1980s-1990s, while low water periods have occurred in the 1930s and 1960s; currently, Lake Erie water levels are slightly below the long-term average; water levels are projected to decline 1-2 m over the next 70 years	No	
Water Clarity in Western Lake Erie	1980s-2000s	Water clarity has generally increased since the invasion of zebra mussels in the mid-1980s	No	
Lake Erie Ice Cover	1963-2005	General decreasing trend of ice cover as measured by Annual Maximum Ice Cover between 1963 and 2005	No	
Phosphorus Concentrations in Kingsville Water Intake in Western Lake Erie	1976-2004	High seasonal variability, but there has been a general decline from the 1970s to mid-1990s; there has been an increasing trend from the 1990s to the early 2000s	Yes	No
Chlorides in Western Lake Erie Water	1900-2005	Chloride concentrations increased from 7 to 25 mg/L between 1900 and the 1960s; slight decreasing trend between the late 1960s and mid-1980s; slight increasing trend between mid-1980s and 2005	No	
Dissolved Oxygen in the Rouge River	1973-2006	In the lower Rouge River, the percentage of dissolved oxygen measurements that exceed the 5 mg/L state standard for protection of a warm water fishery has increased from approximately 20% in 1973 to 80% in recent years (early to mid-2000s)	Yes	No (not consistently)

Indicators/Trend Data	Period of Record	Overall Trend	Quantitative Target	Target Achieved
Contaminants in Western Lake Erie Sediments	1971 and 1995	70% decline in mercury in sediment since the 1970s; at least a 50% decline in PCBs and other organochlorine contaminants since the 1970s	Yes	No
Air Quality in Southeast Michigan	Contaminant-specific 1960s-2005	<ul style="list-style-type: none"> • Carbon monoxide: 83% decline between 1979 and 2005 • Lead: 96% decline between 1981 and 2005 • Nitrogen dioxide: 60% decline between 1979 and 2005 • Ozone (8-hour average): no clear trend between 1988 and 2005 • Particulate matter (PM_{2.5}): no clear trend between 1999 and 2005 • Sulfur dioxide: 72% decline between 1979 and 2005 	Yes Yes Yes Yes Yes Yes	Yes Yes Yes No No Yes
Contaminants in Lake Erie Fish	1977-2004	Mercury in walleye (60% decline between the late 1970s and early 1980s; levels have remained steady since); mercury in smelt (an apparent decrease between the late 1970s and the late 1990s; possibly increasing through the early 2000s); DDT in smelt (60% decline between the late 1970s and early 2000s); DDT in walleye (90% decline between the late 1970s and the early 2000s); PCBs in smelt (high year-to-year variability); PCBs in walleye (generally lower in the 1980s and 1990s compared to the 1970s)	No	
Mercury in St. Clair Walleye	1970-2004	Mercury in Lake St. Clair walleye has decreased by 80% since 1970; however, health advisories still remain for certain fish species and sizes	Yes	No (not all species)
Contaminants in Herring Gull Eggs	1974-2004	PCBs (approximately 80% decline); DDE (approximately 90% decline); dioxin (generally lower concentrations in the late 1990s and early 2000s, compared to the mid-1980s to mid-1990s)	No	
Algal Blooms	1960s-present	Algal blooms common in the 1960s and 1970s; no massive algal blooms during the 1980s; algal blooms returned in the 1990s and early and mid-2000s	No	
Plankton Communities in Western Lake Erie	1970-2004	Evidence of plankton degradation was first observed in the mid-twentieth century; during 1995 and 1997 plankton index scores were higher than 1970, reflecting more mesotrophic conditions; during 2000-2003 plankton index scores were below three and similar to the score for 1970, reflecting more eutrophic conditions	No	
Recovery of Wild Celery	1950-1997	Wild celery tuber abundance declined 72% between 1950-1951 and 1984-1985, and then increased 200% between 1984-1985 and 1996-1997	No	
Aquatic Macrophytes	1898-2006	In the Put-in-Bay area of western Lake Erie, there were 40 taxa in 1898, 32 in 1940, 26 in 1949, and 20 in both 1957 and 1967; increased water clarity since 1985 has allowed reestablishment of many long-absent species	No	
Detroit River Coastal Wetlands	1815-present	97% of the coastal wetlands on both sides of the Detroit River have been lost to development since 1815	No	
Erie Marsh Invasion by Common Reed	1984-2003	Vegetation was reported as stable from the early 1900s to the 1970s; common reed was reported at low densities during the 1950s; spatial coverage increased from 5 to 132 ha between 1984 and 2003 (over a 26-fold increase)	No	
Mayfly Abundance in Detroit River	1964-2004	Mayfly densities and distribution have been variable among years; since 1980, they have been more widespread than previously, but little change has been seen since then; sampling is too infrequent to ascribe differences among years to "trends"; mayflies are still rare or absent from much of the lower half of the Detroit River	Yes	No

Indicators/Trend Data	Period of Record	Overall Trend	Quantitative Target	Target Achieved
Mayfly Abundance in Western Lake Erie	1950s-2004	Few mayflies present in western Lake Erie between the 1950s and 1992; mayflies increased between 1997 and 2004 being "good" to "excellent" in the biological reference point since 2002, but generally has shown high variability	Yes	Yes
Chironomid Abundance in Detroit River and Western Lake Erie	1930-2004	In western Lake Erie, density increased fourfold between 1930 and 1961; similar in 1982; densities declined and richness increased by 1993; in Detroit River, densities have risen sevenfold since 1980	No	
Chironomid Deformities	1983-2004	At the mouth of the Detroit River incidence of deformities has declined from two times baseline in 1982 to baseline in 1994	No	
Oligochaete Abundance in Detroit River	1929-2004	1960s-early 1990s had up to 1 million worms/m ² ; densities have since declined by 80-90%, but the numbers suggest some locations (e.g., Trenton Channel) still fall in the "heavily polluted" category	Yes	No
Dreissenids (Zebra and Quagga Mussels)	1987-2004	Zebra and quagga mussels arrived in the mid- to late 1980s; western Lake Erie maximum in early 1990s; declines since then	No	
Yellow Perch Population	1975-2006	The yellow perch population in western Lake Erie increased through the late 1970s; was variable in the 1980s, plummeted in the late 1980s; increased through the 1990s; and then was relatively stable through the 2000s	No	
Lake Whitefish Spawning	1870-2004	Substantial decline in whitefish population between the late 1800s and early 1900s; in 2006 whitefish spawning in the Detroit River was documented for the first time since 1916	No	
Lake Sturgeon Population	1879-2000	Substantial decline in sturgeon population between the late 1800s and early 1900s; no sturgeon spawning recorded from 1970s to 1999; in 2001 sturgeon reproduction was documented for the first time in the Detroit River in 30 years	Yes	No
Walleye Population of Lake Erie	1978-2005	The walleye population in Lake Erie was rated in "crisis" in 1978; it increased through the late 1980s and then declined through the late 1990s; walleye have been increasing since the late 1990s; it now is rated as "high quality"	Yes	Yes
Canvasback Population	1974-2004	High year-to-year variability; however, 12 of the last 20 years were above the long-term average	No	
Common Tern Reproduction	1960-2005	98% decline in common tern nests in the Detroit River between the 1960s-1980s and the mid-2000s; only about 300 nests remain	No	
Double-Crested Cormorants	1979-2005	Dramatic increase in cormorant population in western Lake Erie over the period of record	No	
Detroit River Christmas Bird Count	1978-2005	Bird count trends are species-specific; examples include an increase in Canada geese, mute swan, and waterfowl	No	
Rockwood Christmas Bird Count	1978-2004	Bird count trends are species-specific; examples include decreasing trends for corvids such as American crow; little change in American black duck; Canada goose and mute swan have both increased	No	
Raptor Migration over Holiday Beach, Ontario	1974-2004	Hawk trends are species-specific; decrease in immature red-shouldered hawks since 1993; substantial increase in turkey vultures; increases in peregrine falcons, osprey, and bald eagles; decline in sharp-shinned hawks since 1987	No	

Indicators/Trend Data	Period of Record	Overall Trend	Quantitative Target	Target Achieved
Raptor Migration over Lake Erie Metropark	1992-2004	Hawk trends are species-specific; decrease in immature red-shouldered hawks; increase in turkey vultures; substantial increase of peregrine falcons, osprey, and bald eagles; no change in red-tailed hawk	No	
Peregrine Falcon Reproduction	1986-2005	Falcon population in Michigan decimated in the 1950s; falcons reintroduced in Detroit in 1987; since the early 1990s falcon reproductive success has steadily increased; falcon removed from endangered species list in 1999	Yes	Yes
Bald Eagle Reproductive Success	1961-2006	Population was evenly distributed throughout the region in the early 1900s; almost complete reproductive failure by the mid-1970s; overall eagle production in the region has increased since then and has leveled-off in Ontario and Michigan with Ohio reproduction much greater and continuing to grow; in the vicinity of the Detroit River International Wildlife Refuge there are now at least seven active bald eagle nests producing young after a 25-year absence; the species is now off the federal list of threatened and endangered species in the U.S.	Yes	Yes
Asthma Trends in Wayne County, Michigan	1990-2003	In general, hospitalization rates in Wayne County have not changed since 1990 and remain significantly higher than statewide levels	Yes	No
Lead Poisoning in Detroit	1998-2004	The number and percent of Detroit children with blood lead levels of ten micrograms per deciliter or more have decreased by at least 60% from 1998 to 2004; however, children are still at risk	Yes	No
West Nile Virus	2001-2005	First detected in Michigan in 2001 with 65 West Nile virus-positive birds; first human case detected in 2002; human death due to West Nile virus in Wayne County has been reported in 2002 and 2005	No	
Phosphorus Discharges from Detroit Wastewater Treatment Plant	1966-2003	90% reduction in phosphorus concentration and loading	Yes	Yes
Combined Sewer Overflow (CSO) Controls in Southeast Michigan	1960s-2000s	In the 1970s, CSOs were identified as a major water pollution problem; CSO control programs began in the mid-1980s; approximately \$2 billion was invested in CSO controls during the 1990s and 2000s; additional CSO controls will be required	No	
Contaminated Sediment Remediation	1993-2006	Dramatic increase in volume of sediment remediated and cumulative financial resources expended	Yes	No
Detroit River International Wildlife Refuge Growth	2001-2007	The Detroit River International Wildlife Refuge has grown from approximately 123 hectares (304 acres) in 2001 to over 2,042 hectares (5,047 acres) in 2007	Yes	No
Greenways in Southeast Michigan	1970s-2000s	Limited greenways development during the 1970s and 1980s; regional greenways catalyzed in the 1990s; over \$100 million invested in greenways since the late 1990s	No	

This evaluation of Detroit River and western Lake Erie indicator trends, based on available data, provides concrete evidence of substantial environmental improvement and remarkable ecological recovery. However, the available indicator trends also show that much remains to be done.

This evaluation of Detroit River and western Lake Erie indicator trends...provides concrete evidence of substantial environmental improvement and remarkable ecological recovery.

Presented below are the most compelling trends of pollution prevention/control and evidence of environmental improvement. In most cases, the findings are based on an integrative assessment of several trend data sets.

3.1.1 Oil Pollution

As a result of massive duck kills due to oil pollution (e.g., 11,000 ducks died in 1948), considerable regulatory effort was placed on controlling oil discharges. Michigan's industrial pollution control program brought about a 98% reduction

in oil discharges to the Detroit River between 1946 and 1961. Between 1961 and the early 2000s, there was another order of magnitude reduction in oil discharges, with the exception of major oil spills in 2002 of 378,500 liters (100,000 gallons) and in 2004 of 83,441 liters (22,043 gallons). As a result of these reductions in oil discharges, winter duck kills due to oil pollution have been eliminated.



Figure 2. Combined sewer overflow outfall along the Detroit River (Photo credit: Robert Burns, Detroit Riverkeeper).

3.1.2 Municipal Waste

Since the late 1960s, billions of dollars have been invested in the construction, operation, and continuous improvement of municipal wastewater treatment plants. Consequently, water quality has improved. In addition, nearly \$2.2 billion has been spent in southeast Michigan to eliminate, capture, and treat waste from combined sewer overflows (CSOs; Figure 2). In 1960 none of the 119.2 billion liters per year (31.5 billion gallons per year) of CSO volume was treated. There has been a 65% reduction in untreated CSO volume discharged between 1960 and 2005. It is projected that by 2012, when

all currently designed CSO control projects come online, there will be an 85% reduction in the annual untreated CSO volume discharged from 1960 levels. The treated CSO volume has increased from 9.1 billion liters per year (2.4 billion gallons per year) in 1993 to 22.7 billion liters per year (6 billion gallons per year) in 2005 (150% increase). It is projected that by 2012, when all currently designed CSO control projects come online, there will be a 200% increase in treated CSO volume from 1993 levels.

There has been a 65% reduction in untreated CSO volume discharged between 1960 and 2005.

3.1.3 Phosphorus and Eutrophication

The Detroit Wastewater Treatment Plant (WWTP) is the largest wastewater treatment plant in North America. Since 1966 there has been a 90% reduction in phosphorus concentration and loading from the Detroit WWTP to the Detroit River. Lower ambient phosphorus concentrations were evident in Lake Erie, reversing many of the impacts of cultural eutrophication. However, in recent years, phosphorus concentrations in western Lake Erie have been increasing, algal blooms have returned, and Planktonic Index of Biotic Integrity values have decreased, reflecting a return to more eutrophic conditions. This may be related to some combination of increased nonpoint source loading of phosphorus, unmonitored point discharges (possibly from CSOs), and internal recycling of nutrients.

3.1.4 Chloride

Chloride concentrations in Lake Erie increased from approximately 7 mg/L in the early 1900s to approximately 25 mg/L in the 1960s. Chloride loadings from five chemical industrial facilities decreased from a high of 4,247 tonnes/day (4,681 tons/day) in 1964-1966 to zero in 1986, due to process changes. Chloride concentrations in western Lake Erie dropped from about 25 mg/L in the late 1960s to about 17 mg/L in the mid-1980s. Since then, chloride concentrations have been rising gradually as a result of increasing nonpoint source inputs.

3.1.5 Persistent Toxic Substances

Regulatory controls on persistent toxic substances have increased since the 1960s. The manufacture and use of some chemicals have even been banned as a result of their effects on human health and wildlife. The pesticide DDT was banned in Michigan in 1969, the remainder of the U.S. in 1972, and in Canada in 1985. Since the late 1970s, total DDT concentrations in rainbow smelt and walleye in western Lake Erie have declined by 70% and 90%, respectively. In herring gull eggs from Fighting Island, DDE (a breakdown product of DDT) has declined by 90% since the late 1970s.

In the U.S., cradle-to-grave management of PCBs was enacted through the Toxic Substances Control Act of 1976. Since 1977, Canada has prohibited import, manufacture, sale for reuse, and use of PCBs for purposes other than those stated in Canadian regulations. These strict PCB regulations have resulted in an 85% decline in concentrations of PCBs in herring gull eggs from Fighting Island since the late 1970s. PCB levels in rainbow smelt and walleye from Lake Erie have shown high year-to-year variability since the late 1970s.

As a result of the “Mercury Crisis of 1970,” both the U.S. and Canada imposed regulatory controls on mercury discharges. Mercury cell plants operated by chemical companies in Sarnia, Ontario and Wyandotte, Michigan were shut down to eliminate mercury discharges. Such control measures have contributed to an 85% reduction of mercury in Lake St. Clair walleye since 1970. Mercury levels in western Lake Erie walleye have declined by approximately 50% since the late 1970s.



Figure 3. Ellias Cove (formerly Black Lagoon) remediation project along the Detroit River (Photo credit: Robert Burns, Detroit Riverkeeper).

3.1.6 Contaminated Sediment

Control of contaminants at their source, as well as industrial process changes, have resulted in significant reduction in sediment contaminant levels. For example, PCB levels have declined by approximately 50% and mercury levels have declined by about 70% in Lake Erie sediment since the 1970s.

Despite some signs of improvement, contaminated sediment remains a universal obstacle in restoring beneficial uses in the Detroit River and western Lake Erie (Figure

3). For example, despite a 50-70% reduction in contaminant concentrations in fish, consumption advisories still exist, and contaminated sediment as well as atmospheric inputs continue to impair this beneficial use. Since 1993 over \$154 million has been spent to remediate over 989,000 cubic meters of contaminated sediment in the watershed of the Detroit River and western Lake Erie. However, it is estimated that an additional two million cubic meters of contaminated sediment require remediation to fully restore beneficial uses.

Despite some signs of improvement, contaminated sediment remains a universal obstacle in restoring beneficial uses in the Detroit River and western Lake Erie.

3.2 Ecological Recovery



Figure 4. Bald eagle (*Haliaeetus leucocephalus*) (Photo credit: Dave Menke, USFWS).

Over 35 years of U.S. and Canadian pollution prevention and control programs have led to significant ecological recovery in this region. Trend data document the return of reproducing populations and improving condition of bald eagles, peregrine falcons, walleye, lake sturgeon, lake whitefish, and burrowing mayflies to large areas from which they had been extirpated or negatively impacted. Examples of this ecological recovery are presented below.

3.2.1 Bald Eagles

In the early 1900s, bald eagles were distributed throughout Michigan, but by the 1950s, the bald eagle population had significantly declined due to organochlorine pesticide contamination, loss of habitat, and other species changes (Figure 4). Reproductive impairments in bald eagles reached a crisis point in the mid-1970s when only 38% of Michigan's bald eagles could successfully fledge young. Bald eagle recovery efforts were

catalyzed by the banning of DDT in Michigan in 1969 and the remainder of the U.S. in 1972, and by the passage of the Endangered Species Act in 1973. From 1961 to 1987,

there were no bald eagles fledged in Michigan, likely due to contaminants and the low number of breeding pairs. Since 1991, bald eagle fledging success has steadily increased, particularly in Ohio where over 60 young were fledged in 2006. Fledging success in Michigan and Ontario has also increased since 1990, but to a lesser extent than in Ohio. In the vicinity of the Detroit River International Wildlife Refuge, there are now at least seven active bald eagle nests producing young after an absence of more than 25 years. In 2007, the U.S. Fish and Wildlife Service removed the bald eagle from the federal list of endangered species.

3.2.2 Peregrine Falcons

Peregrine falcons experienced a dramatic decline in the 1950s, mostly due to organochlorine pesticide contamination. DDT caused reproductive problems in peregrine falcons and other species. Again, DDT was banned in Michigan in 1969 and in the remainder of the U.S. in 1972. A peregrine falcon reintroduction program was initiated in Detroit in 1987 when one nesting pair was reintroduced, but no young were produced for the next five years. Then the number of young produced in southeast Michigan gradually increased from zero in 1992 to a peak of ten in 2005. This represents a major success story. In 1999, the U.S. Fish and Wildlife Service removed peregrine falcons from the federal list of endangered species.

3.2.3 Walleye and the Walleye Fishery

In 1978 the walleye population of Lake Erie was considered to be in crisis by fishery



Figure 5. Angler with 13.5-pound walleye caught in the Detroit River in April 2006 (Photo credit: Downriver Walleye Federation).

managers. The cause was overfishing and pollution. The walleye population is much improved following a complete ban on fishing as a result of the “Mercury Crisis of 1970,” and the subsequent implementation of harvest quotas once the ban was lifted. The walleye population of Lake Erie has shown year-to-year variability since the early 1990s, but in 2005 it was four times larger than in 1978. Fishery managers categorize the 2005 population of over 40 million walleye as achieving a high quality population rating. As a result of this exceptional recovery of the walleye fishery, Lake Erie and the Detroit River are now considered the “Walleye Capital of the World” (Figure 5).

3.2.4 Lake Sturgeon

In the 1800s, lake sturgeon were considered a delicacy because of their sought-after smoked flavor and their eggs as caviar. In 1880, Lakes Huron and St. Clair produced over 1.8×10^6 kg (4 million pounds) of lake sturgeon. During the spawning period in June 1890, over 4,000 adult lake sturgeon were caught in Lake St. Clair and the Detroit River on setlines and in pond-nets. Populations plummeted during the early 1900s due to overharvesting, limited reproduction, destruction of spawning habitats, and water pollution. Today, there is no active commercial fishery for lake sturgeon in the Huron-Erie corridor. Sport fishing harvest of lake sturgeon is now restricted in the St. Clair River and Lake St. Clair, and no sturgeon may be possessed by anglers from Michigan or Ontario waters of the Detroit River.

...in 2001, lake sturgeon spawning was documented in the Detroit River near Zug Island for the first time in over 20 years.

From the 1970s to 1999, no lake sturgeon spawning was reported in the Detroit River, which at one time was one of the most productive sturgeon spawning grounds in the United States. However, in 2001, lake sturgeon spawning was documented in the

Detroit River near Zug Island for the first time in over 20 years. Improvements in water quality as a result of pollution prevention and control programs laid the foundation for lake sturgeon to once again spawn in the Detroit River.

3.2.5 Lake Whitefish

During the late nineteenth and early twentieth centuries, large numbers of lake whitefish entered the Detroit River each fall

to spawn. Natural bedrock spawning grounds were destroyed and removed during the construction of the Livingstone Channel in 1907-1916. By the 1960s and 1970s, lake whitefish numbers in Lake Erie were at an all-time low because of overexploitation, predation by and competition with invasive species, degradation of water quality and habitat, and the loss of *Diporeia*, a major nutrient-rich food source. Improvements in water quality due to pollution prevention and control programs during the 1970s-1990s resulted in more favorable conditions for whitefish. In 2005, U.S. Geological Survey and U.S. Fish and Wildlife Service scientists documented natural reproduction of lake whitefish in the lower Detroit River for the first time since 1916.

3.2.6 Mayflies

Burrowing mayfly populations (*Hexagenia* spp.) were extirpated from western Lake Erie in the 1940s and 1950s as a result of water pollution. Burrowing mayfly nymphs first reappeared in sediments of western Lake Erie in 1992-1993 after an absence of 40 years. They returned in response to improved water quality resulting from pollution prevention and control programs, along with changes in trophic status ascribed to zebra mussels. Mayfly nymph densities have increased in recent years to a level considered good for healthy aquatic ecosystems. It is interesting to note that fishery managers have documented an increase in yellow perch abundance in western Lake Erie between the early 1990s and early 2000s, likely due to increased mayfly abundance.

3.3 Key Environmental and Natural Resource Challenges and Priority Management Actions

The return of bald eagles, peregrine falcons, walleye, lake sturgeon, lake whitefish, and mayflies represents a remarkable story of ecological recovery, but many environmental and natural resource challenges remain. Below is a discussion of six key environmental and natural resource challenges. The time trends in these data point to threats to ecosystem integrity. We discuss these challenges and recommend corresponding priority management actions, based on this assessment of all available indicator trends.

3.3.1 Population Growth, Transportation Expansion, and Land Use Changes

3.3.1.1 Challenge

Southeast Michigan's population growth rate and pattern of development are similar to that experienced in many major metropolitan areas in North America. Between 1900 and

1950, Detroit's population steadily increased to nearly two million people. Between 1950 and 2004, Detroit's population decreased by 50% as people moved to the suburbs. The seven-county region of southeast Michigan grew from about 600,000 residents in 1900 to nearly five million in 2005. While Detroit experienced a 50% decline in population between 1950 and 2004, the seven-county region experienced an increase in population of over 50%.

Movement out of the city of Detroit in the 1950s was helped by the ease of owning an automobile and the creation of an expanding, heavily subsidized transportation network. This movement to surrounding areas has, in general, increased distance and travel time to work, and nearly doubled the use of personal vehicles between 1960 and 2000. This phenomenon, often referred to as urban sprawl, causes nonpoint source pollution and creates loss, degradation, and fragmentation of habitats, among other impacts.

Initially, developed land was centered in the city of Detroit. Outlying areas, once forested, were first converted into farmland and more recently have been transformed for residential and related uses. As more area in southeastern Michigan was converted into urban and suburban development as a result of sprawl, the amount of impervious surface grew significantly, and urban nonpoint source pollution increased correspondingly.

There is also concern for loss of biodiversity and potentially more infectious diseases as a result of urbanization. The Michigan Department of Community Health reported that 70% of newly emerging infectious diseases, like West Nile virus, are due to landscape changes. One hypothesis is that landscape fragmentation caused by urbanization reduces biodiversity, which increases susceptibility to biological invasions and removes natural ecosystem population controls.

3.3.1.2 Recommended Priority Management Actions

Transportation, land use, environmental, and natural resource planning have traditionally been treated as separate initiatives and not effectively integrated. Furthermore, plans, regulations and enforcement are limited by hierarchical political boundaries, whereas stresses to the ecosystem follow watersheds and other natural boundaries. The ability of different agencies and organizations to collaborate on integrated planning and management strategies has been limited due to narrowly-focused and uncoordinated legislation and regulations, governmental fragmentation, and relatively short planning and budgeting horizons.

Transportation and land use planning must become better integrated to accommodate sustainable environmental and natural resource conditions on a watershed scale.

Transportation and land use planning must become better integrated to accommodate sustainable environmental and natural resource conditions on a watershed scale. The goal should be to streamline and better coordinate the process of making land use and transportation planning decisions. All phases – from plan development to plan approval – should consider issues on a watershed basis.

Historically, transportation planning has been skewed by the promises of short-term economic gain espoused by land developers and highway department personnel who have a narrow perspective, as well as federal and state policies and funding that encourage the construction of infrastructure as a means of economic stimulus. In a major way, land

conversion and urban sprawl are currently driving, and being driven by, transportation development.

There are no simple solutions to the problem of urban sprawl and its concomitant transportation needs. Alternatives to existing transportation modes and practices are needed, as well as better planning to design improved transportation systems. For example, alternatives to automobiles include a balanced intermodal mix of walking/biking (over \$200 million has been invested in building greenways in southeast Michigan in the last five years), public transit, aviation, and trucks/freight. Other important solutions will use technological advances, transportation demand management, transportation supply management, good land use planning, legislation, and education.

In southeast Michigan, the Southeast Michigan Council of Governments has developed a regional analysis of the impact of planned transportation projects on the environment and a series of guidelines for mitigating impacts (www.semco.org/TranPlan/Environment/) and the Metropolitan Affairs Coalition has championed SpeedLink as a network of rapid transit that can serve the greatest number of people in the least amount of time for the lowest cost (<http://www.mac-web.org/Accomplishments/Speedlink.htm>).

Ultimately, progress in developing a more balanced and environmentally-friendly transportation system – particularly one that offers better public transit options – will require political will driven by public demand. Escalating gasoline prices, an aging population that is increasingly in need of such options, and the public's growing concern about climate change provide some cause for optimism that this transformation can happen in metropolitan Detroit.

3.3.2 Nonpoint Source Pollution

3.3.2.1 Challenge

The relative contribution of nonpoint source pollutants has increased as point source pollution has been regulated through effective control programs. There is recent evidence that nonpoint source pollution problems (particularly for water) may be increasing because of increasing trends in population growth, transportation expansion, and continued land use development for suburbanization. As impervious surface increases through urban sprawl, more wetlands are lost and more nonpoint source pollution occurs. This further increases runoff, compounding nonpoint source pollution.

Bottom-dwelling invertebrate indicators for the Detroit River continue to show impacts from urban pollution. Several other key indicators suggest increasing nonpoint source problems. For example, chloride levels in water samples from the Monroe Water Intake in Michigan have been monitored since the late 1960s. Between 1968 and 1985, there was a slight decreasing chloride trend due to reduced industrial discharges. However, between the late 1980s and early 2000s, there has been a steady increase in chloride concentration due to nonpoint source inputs.

Dissolved reactive phosphorus is the form that is most available for algal and other plant growth. In the last ten years, there has been a sharp increase in dissolved reactive phosphorus concentrations in the Maumee River. Although the precise cause of this increasing trend is not clear at this time, changes in agricultural practices have been implicated.

The Union Water Intake draws water from western Lake Erie in Kingsville, Ontario. Total phosphorus levels in water samples from the Kingsville Water Intake decreased from the early 1980s to the mid-1990s as a result of the phosphorus control program. However, total phosphorus levels have nearly doubled between 1994 and 2004. The underlying cause is unknown, but food web changes resulting from introductions of exotic species like zebra mussels have been implicated in altering the phosphorus cycle and possibly increasing total phosphorus concentrations. Increasing nonpoint source inputs may be another contributing factor.

It is noteworthy that there is concurrence among recent increases in chloride concentration at the Monroe Water Intake in Michigan with increases in dissolved reactive phosphorus concentrations in the Maumee River in Ohio and increases in total phosphorus concentrations at the Kingsville Water Intake in Ontario. These recent increases have occurred in three geographically removed regions within the western basin of Lake Erie. Although the causes are not fully understood, increases from nonpoint sources could help explain these three increasing trends.

In comparison, the Rouge River watershed (48 communities and 1.5 million people), which in the past had major nonpoint source pollution problems, has achieved a significant improvement in lower river dissolved oxygen levels over the past 25 years. This has been accomplished through the development and implementation of a comprehensive watershed-wide nonpoint source control plan at a cost exceeding \$600 million. This serves as a model for others and demonstrates that watershed-based efforts can be effective.

Two other important observations should be made relative to nonpoint source pollution. Urban and suburban development in southeast Michigan has been accompanied by more and more wetland loss. To date, 97% of the original coastal wetlands along the Detroit River have been lost to development. Loss of wetlands translates into a loss of natural filtering capacity and more urban runoff. Air pollution is another form of nonpoint source pollution. Asthma continues to be a major public health problem, particularly in Wayne County. Outdoor air quality factors known to affect asthma include ozone and particulate matter (PM). Detroit ranks sixth among the 25 U.S. cities most polluted with particulate matter. Since 1999, the Detroit area has met the new PM standard only once, in 2004. Currently, the Detroit area is not considered in compliance with the National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter. On average, rates of hospitalization due to asthma in Wayne County are over 75% higher than in the state of Michigan as a whole. In addition, rates of asthma hospitalization in Wayne County show no appreciable change since 1990, while the asthma rates of hospitalization statewide show a significant overall decline since 1990.

3.3.2.2 Recommended Priority Management Actions

Some nonpoint source pollution problems can be addressed through management strategies and/or technological practices. However, the problem is also rooted in basic aspects of North American society, including dominant patterns of low-density suburban development. Therefore, political, as well as technical, solutions are required. Science can help propose solutions to both kinds of problems.

Controlling nonpoint source pollution must be approached in a holistic and comprehensive manner.

Controlling nonpoint source pollution must be approached in a holistic and comprehensive manner. In addition, the priority management actions to reduce nonpoint source pollution must be made visible and understandable to a broad range of stakeholders and partners. An essential step in the process is to adopt the watershed as the primary unit for planning and management. Watershed management attempts to take a comprehensive view of the physical, chemical, and biological components necessary to achieve locally-based water use goals. Site-specific goals and uses are established based on watershed characteristics and public, scientific, and regulatory input.

Watershed management brings federal, state and local partners together to address water quality issues and to identify mechanisms to solve them. Watershed management plans lay the groundwork for implementation of actions, including but not limited to:

- developing ordinances that protect current beneficial land uses, including wetland preservation, storm water controls, soil erosion controls, and waterfront setbacks;
- implementing structural and vegetative practices that control erosion and reduce pollutants;
- implementing diagnostic management practices, such as collecting and analyzing soil samples to determine how much phosphorus needs to be applied to a lawn, farm field, or golf course;
- implementing conservation easements that permanently protect river corridors, floodplains, shorelines and wetlands; and
- implementing information and education strategies to make people aware of nonpoint source pollution and what they can do to protect and improve our water.

The Rouge River Remedial Action Plan (RAP) and the Rouge River National Wet Weather Demonstration Project are excellent examples of federal, state, and local governments, and environmental and natural resource management agencies, aligning programs to address nonpoint source pollution on a watershed basis. Experience has shown that best management practices must be comprehensively implemented to achieve desired results. Also, strong partnerships are necessary to ensure the communication, coordination, and cooperation to achieve these desired results. Much greater use of economic and technical assistance incentives is required.

The importance of atmospheric nonpoint source pollution must not be overlooked. The specific atmospheric sources of persistent toxic substances must be identified, loadings must be quantified, reduction targets established, and control measures implemented to achieve the long-term goal of their virtual elimination. One example of a practical, initial management action for conventional air pollutants might be to adopt “the bubble concept” for air quality regulations as a cost-effective means for achieving target load reductions (Ryding 1992). In this system, transferable pollution rights encourage those having the best knowledge and practical means of reducing pollution sources to do so, trading this savings in mass emissions for profit to those with lesser technology or means.

3.3.3 Toxic Substances Contamination

3.3.3.1 Challenge

Both humans and wildlife continue to be exposed to low-level toxic substance contamination and continue to be at risk.

Although contaminant levels in fish, herring gull eggs, and sediment have declined, health advisories remain in effect on the consumption of many species of fish. Both humans and wildlife continue to be exposed to low-level toxic substance contamination and continue to be at risk. Concern has also been raised over the potential effects of environmental endocrine disruptors on avian populations and humans. Contaminated sediment in polluted areas like the Trenton Channel of the Detroit River, the lower Rouge River, the lower River Raisin and the lower Maumee River continues to contribute to beneficial use impairments.

3.3.3.2 Recommended Priority Management Actions

Control of contaminants at their source remains the primary imperative for action. Experience has shown that pollution prevention is much more ecologically sound and cost-effective than environmental remediation. Clearly, the old adage that an ounce of prevention is worth a pound of cure holds true. Examples of important programs to prevent toxic substance problems include:

- Design for Environment;
- ISO 14000;
- Life Cycle Assessment and Management; and
- Full Cost Accounting.

These initiatives proactively identify and prevent toxic substance problems before they become manifest in the environment. Management experience has shown that quantifying annual toxic substance loading estimates by source, making these loading data publicly accessible, and reaching agreement on toxic substance loading reduction targets are essential for measuring and sustaining progress and achieving the long-term goal of virtual elimination of persistent toxic substances.

Remediation of contaminated sediment hot spots will be essential to fully restore impaired beneficial uses like fish consumption advisories. Although nearly one million cubic meters of contaminated sediment have been remediated at a cost of \$154 million in the last 13 years, approximately two million cubic meters of contaminated sediment require remediation to fully restore beneficial uses. Priority hot spots include the lower Rouge River, the Trenton Channel of the Detroit River, the lower River Raisin, and the lower Maumee River.

3.3.4 Habitat Loss and Degradation

3.3.4.1 Challenge

There is considerable concern over the continuous and incremental loss and degradation of habitat in southeast Michigan, northwest Ohio, and southwest Ontario. Increasingly, conversion of natural and agricultural land for residential uses and transportation

expansion has resulted in considerable loss and degradation of natural habitat. Coastal wetland loss is the most dramatic. Since the early 1800s, most of the Detroit River's coastal wetlands have been lost to shoreline developments and channel modifications, especially encroachment into the river and hardening of the shoreline by installing steel

There is considerable concern over the continuous and incremental loss and degradation of habitat in southeast Michigan, northwest Ohio, and southwest Ontario.

sheet piling, building concrete breakwalls, and adding fill material to address erosion and flood control. By 1982 only 26 hectares (64 acres) of coastal wetlands on the U.S. side remained of the 2,768 hectares (6,840 acres) that were present in 1815 – a loss of 99%. Shoreline armoring increased from < 5% in the 1930s to 78% in Ottawa County and 98% in Lucas County, Ohio in the 1990s. Shore protection structures like this provide limited or no shoreline habitat value and alter coastal ecological processes and biological life cycles in the lake itself.

3.3.4.2 Recommended Priority Management Actions

The protection and restoration of habitat, like land use planning and nonpoint source pollution with which it is so closely interlinked, should be addressed on a watershed scale. It is often said that habitat has no home (i.e., physical habitat is often overlooked and does not receive adequate attention in traditionally separate water quality management and fish and wildlife management programs). This is particularly true in urban areas. Consequently, there must be a concerted effort to ensure that habitat is an integral part of community master plans. Effective communication and strong partnerships are essential to achieve this. Critical components of a process to ensure that habitat is incorporated into community master plans include (U.S. Environmental Protection Agency and Environment Canada 1995):

- compiling habitat inventory;
- developing public participation;
- forming an intergovernmental coordinating committee; and
- developing a public/governmental partnership in plan development.

From a strategic perspective, greater emphasis needs to be placed on incorporating habitat protection and rehabilitation with other local and regional planning and development initiatives (i.e., communities should ensure that habitat gets incorporated into master plans). Although a systematic and comprehensive process of habitat conservation, rehabilitation, and restoration will be a long-term endeavor, considerable opportunities exist to move forward with short-term actions that will benefit habitat and other issues (e.g., land use, economy, agriculture, recreation). Some examples of practical actions include (U.S. Environmental Protection Agency and Environment Canada 1995):

- incorporating habitat protection into master, land use, and watershed plans, zoning ordinances, etc.;
- seeking permanent protection for ecologically significant habitats by purchasing land, establishing easements, etc.;

- ensuring that individuals with fish and wildlife expertise get involved early in project planning for waterfront redevelopment, shoreline modification, sediment remediation, navigational structures, etc., to adequately address fish and wildlife enhancement opportunities and ensure adequate assessment and monitoring;
- ensuring that agencies like state and local transportation departments, departments of public works, parks and recreation departments, and others incorporate ecologically sound techniques that enhance fish and wildlife (e.g., bioengineering, incidental habitat enhancement of physical structures, willow posts, setbacks) into operating manuals and day-to-day operations; and
- establishing citizen stewardship programs to help inventory habitat and work with landowners and agency personnel to enhance habitat.

Management of the Detroit River International Wildlife Refuge is guided by a Comprehensive Conservation Plan (CCP). In total, the Detroit River International Wildlife Refuge has grown from approximately 123 hectares (304 acres) in 2001 to 2,042 hectares (5,047 acres) in 2007. The CCP for the Detroit River International Wildlife Refuge has set a U.S. land conservation target of 4,856 hectares (12,000 acres; i.e., the U.S. Fish and Wildlife Service has identified 4,856 hectares of marshes, wetlands, islands, shoals, and uplands that could potentially be conserved through acquisitions, easements, and cooperative agreements). Canadian targets have not been established. Land conservation must continue to be a priority while opportunities exist.

3.3.5 Introduction of Exotic Species

3.3.5.1 Challenge

Invasive exotic species are organisms that are not native to the regional ecosystem and often cause substantial ecological harm and economic impact. Exotic species are a major problem in the Huron-Erie corridor. The zebra mussel was first introduced into Lake St. Clair in 1988 and the quagga mussel in 1989. The goby was introduced into the St. Clair River in 1990. The spiny amphipod was first found in the Detroit River in 1994. The emerald ash borer was first discovered in southeast Michigan in 2002. Viral hemorrhagic septicemia (VHS) was introduced into Lake St. Clair in 2002 or 2003.

Key indicator trends for the Detroit River and western Lake Erie have shown that zebra and quagga mussels are well established and have had major negative economic impacts on municipal water intakes and power plant intakes. They may have affected the ecosystem itself by altering food web dynamics and biodiversity. Fishery managers have found that the zebra/quagga mussel invasion has generally increased water clarity in nearshore parts of western Lake Erie, which in turn has led to resurgence of submerged aquatic plants and plant-loving sunfishes (centrarchid fishes like pumpkinseeds and bluegills). West Nile virus was first discovered in birds in southeast Michigan in 2001, and has impacted both birds and humans. The first human case of West Nile virus was found in Wayne County in 2002 and has since resulted in 15 human deaths. The Rockwood Christmas Bird Count has documented a decline in the American crow population as a result of West Nile virus. In the 897-hectare (2,217-acre) Erie Marsh, common reed (*Phragmites australis*) has dramatically increased in coverage from 5 hectares (12 acres) in 1984 to 132 hectares (326 acres) in 2003.

Nearly \$100 billion in U.S. economic losses have occurred over an 85-year period from just 79 exotic species (U.S. Congress-Office of Technology Assessment 1993). Pimentel et al. (2000) estimated losses to the United States economy of at least \$137 billion per year associated with the effects of exotic species on native ecosystems, agriculture, and natural resources, including the costs for control efforts. In addition to economic and human health costs, exotic species are believed to be the leading cause of biodiversity change in the Great Lakes and extinctions in North American freshwater ecosystems (International Association for Great Lakes Research 2002).

The governments...must stop the introduction of exotic species into the Great Lakes.

3.3.5.2 Recommended Priority Management Actions

The governments of the United States and Canada, the eight Great Lakes states and the provinces of Ontario and Quebec, must stop the introduction of exotic species into the Great Lakes. Every year of delay results in substantial ecological harm and economic impacts.

3.3.6 Greenhouse Gases and Global Warming

3.3.6.1 Challenge

There is new and strong evidence that most of the warming over the last 50 years is attributable to human activities. Human activities have altered the chemical composition of the atmosphere through the buildup of greenhouse gases – primarily carbon dioxide, methane, and nitrous oxide. The heat-trapping property of these gases is undisputed, although uncertainties exist about exactly how Earth's climate responds to them.

According to the U.S. Environmental Protection Agency (2006), atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15% since the beginning of the Industrial Revolution. These increases have enhanced the heat-trapping capability of the Earth's atmosphere.

Between 1960 and 2001, Michigan's carbon emissions from fossil fuel combustion increased from 129.4 million metric tons per year (142.6 million tons per year) to 189.1 million metric tons per year (208.4 million tons per year) – an increase of 59.7 million metric tons (65.8 million tons). This represents a 46% increase over four decades.

Evidence of potential effects of global warming on Lake Erie is being compiled. Maximum winter ice cover on Lake Erie has shown a general decline since the late 1970s. Extremely mild winters have been recorded in 1983, 1991, 1998, 2002, and 2006, resulting in low winter ice cover.

Lake Erie water levels fluctuate on short-term and long-term scales. Currently, Lake Erie water levels are slightly below the long-term average and are coming down from historic highs seen in the 1980s. Even though there is considerable uncertainty as to the effects of global warming on Lake Erie water levels over the next several decades, projections are that there will be a decline. For example, it has been predicted that global warming will result in a 1-2 meter decline in water levels over the next 70 years (Lofgren et al. 2002; Mortsch and Quinn 1996). A 1.5 meter drop in Lake Erie water levels is expected to result in a 4% reduction in surface area of the western basin and a 20% reduction in

volume of the western basin. The shoreline would move lakeward by distances of less than 1 km to as much as 6 km (Lee et al. 1996). It should also be noted that less ice cover on Lake Erie increases evapotranspiration that can result in further reductions in water levels.

There is growing concern over potential effects of global warming on birds and other wildlife. To date, no concrete evidence exists about global warming impacts on birds in the watersheds of the Detroit River and western Lake Erie. However, it is interesting to note that hawk monitoring programs at both Holiday Beach and Lake Erie Metropark have shown increasing trends of turkey vultures. Kiff (2000) suggests that the northern range expansion of turkey vultures may be due to global warming.

Price (2006) has reviewed the scientific literature on songbirds in Michigan and has identified many possible bird changes that might occur as a result of global warming. Some examples include:

- some species might disappear as summer residents in the Lower Peninsula (e.g., alder flycatcher, least flycatcher, tree swallow, yellow-throated vireo, bobolink);
- some species might have their climatic ranges contract (e.g., black-capped chickadee, house wren, yellow warbler, Baltimore oriole, house finch); and
- some species might include Michigan in their future climatic summer ranges (e.g., Carolina chickadee, Kentucky warbler, Bell's vireo).

Monitoring is essential to document changes.

It should also be noted that there are potential effects of global warming on illness and death related to West Nile virus. Environmental Entrepreneurs (2005) have reported that higher temperatures in Michigan could increase heat-related deaths and illnesses from insect-borne diseases like West Nile virus. Over 200 human cases of West Nile virus were reported in Wayne County in 2002, resulting in 15 deaths.

3.3.6.2 Recommended Priority Management Actions

There is growing public concern about global warming and growing public demand for actions to address it consistent with the Precautionary Principle.

There is growing public concern about global warming and growing public demand for actions to address it consistent with the Precautionary Principle (i.e., if an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relationships are not fully established scientifically). Indeed, the 2007 report of the United Nations Intergovernmental Panel on Climate Change calls for speedy and decisive international action on climate change (<http://unfccc.int/2860.php>).

Clearly, international cooperation will be needed to stop global warming. However, action can and should be taken at the national, state/provincial, local, and individual levels. Examples of recommended priority actions include:

- ensuring public disclosure of annual inventories of greenhouse gas emissions;
- establishing short- and long-term greenhouse gas reduction targets;

- accelerating research on global warming and environmentally sustainable technologies;
- supporting international cooperation on solutions to global warming;
- supporting business leadership on global warming (e.g., Business Environmental Leadership Council - www.pewclimate.org);
- supporting market-based solutions to reduce greenhouse gas emissions;
- scheduling a global warming speaker at a community event;
- using environmentally sound products (e.g., replacing incandescent light bulbs with compact fluorescent bulbs);
- signing up for electricity from renewable energy sources;
- planting native trees (that take in carbon) in communities;
- when replacing appliances, choosing ones with the Energy Star label;
- carpooling to work, using mass transportation, driving a hybrid, or riding a bicycle; and
- calculating and offsetting one's carbon dioxide footprint at www.carboncounter.org.

3.4 Priority Research/Monitoring Needs

Specific research and monitoring needs are identified in each indicator write-up. Presented below are six priority research/monitoring needs based on this comprehensive and integrative assessment.

3.4.1 Demonstrate and Quantify Cause-Effect Relationships

Research is needed to achieve a better understanding of cause-and-effect relationships. For example, we must better quantify biological effects of contaminated sediment in order to properly target sediment remediation. Such cause-and-effect relationships must be quantified and incorporated into models to predict outcomes and guide management actions. Such quantitative understanding will, in the long run, not only better focus management actions, but will potentially save money.

3.4.2 Establish Quantitative Endpoints and Desired Future States

Of the 50 indicators presented in this report, only 34% have quantitative targets...only five are achieving them.

There is a need to identify scientifically defensible quantitative endpoints and desired future states for management agencies. Of the 50 indicators presented in this report, only 34% have quantitative targets (17 out of 50 indicators; Table 1). Of the 17 indicators with quantitative targets, only five are achieving them. Quantitative endpoints and desired states should be tied to beneficial use impairment criteria for the Detroit River, Rouge River, River Raisin, and Maumee River RAPs, Lake Erie Lakewide Management Plan objectives and those of the Comprehensive Conservation Plan for the Detroit River International Wildlife Refuge.

3.4.3 Determine Cumulative Impacts and How Indicators Relate

Research is needed to better understand the cumulative impacts of multiple pressure indicators or stressors. In addition, research is needed to determine how indicators relate to one another. It is necessary to know which pressures affect what state indicators, to what degree, and what is the appropriate type and level of response necessary to provide the desired result/state.

3.4.4 Further Modeling and Prediction

Modeling is needed to better understand and quantify the controlling factors and the relationships among indicators. Contaminant-food web modeling is needed to identify and prioritize remaining source reduction strategies and contaminated sediment remediation projects. Both scientists and managers need to recognize the changing nature of the system and anticipate and predict future scenarios. For example, water level changes in Lake Erie are projected to result in substantial changes to the shoreline. Modeling is needed to better predict these changes, especially in wetlands, in order to make better waterfront planning and conservation decisions.

3.4.5 Prioritize Areas for Protection and Restoration

Research is needed to help establish protection and restoration priorities in order to most effectively reach the quantitative targets of state indicators. Greater emphasis must be placed on establishing and maintaining the link between scientific information and management actions (science-policy linkage).

3.4.6 Foster Long-Term Monitoring for Adaptive Management

Without a commitment to long-term monitoring, management is flying blind.

Long-term monitoring is essential to practice adaptive management, in which assessment is undertaken, management priorities are established, and management actions are taken in an iterative fashion for continuous improvement. Without a commitment to long-term monitoring, management is flying blind.

3.5 Concluding Thoughts and Recommendations

Clearly, there is a need for comprehensive and integrative assessments of ecosystem health based on the evaluation of long-term trend data from a variety of indicators. As part of these comprehensive and integrative assessments, there is a need to identify priority management actions and research/monitoring needs. Trend data must be compiled, interpreted, translated, and made accessible to all stakeholders. Experience throughout the Great Lakes has shown that public reporting on scientific trends and simultaneous public discussion of necessary remedial and preventive actions, as well as research and monitoring needs, strengthens the science-policy linkage and accelerates prevention, remediation, and restoration actions.

There is much to be gained by the integration of monitoring/assessment and management activities of the RAPs, the Lake Erie Lakewide Management Plan, the Comprehensive Conservation Plan for the Detroit River International Wildlife Refuge, the Lake Erie Committee of the Great Lakes Fishery Commission, watershed and

conservation organizations, and land use/transportation planning organizations like the Southeast Michigan Council of Governments. Indeed, the Detroit River and Lake Erie cannot be managed without such integration.

Comprehensive and integrative assessments are a way to bring key organizations and initiatives together to practice adaptive management.

Current policies associated with human population growth, land use planning and transportation are uncoupled from the science and management of the ecosystem. That must change. Comprehensive and integrative assessments are a way to bring key organizations and initiatives together to practice adaptive management.

Currently, there is no mechanism to continue comprehensive and integrative assessment work. Collectively, millions of dollars are spent annually on research, monitoring, and environmental management in the Detroit River and western Lake Erie. Comparatively, very little is spent on periodically performing comprehensive and integrative assessments of ecosystem health. Therefore, it is recommended that

resources be pooled through the Canada-U.S. collaborative monitoring effort under the Binational Executive Committee (BEC) on a regular basis (e.g., at least every five years) to undertake comprehensive and integrative assessments of the health of the Detroit River and western Lake Erie ecosystem. Key coordinating organizations that should be responsible for these assessments should include the RAPs, Lake Erie Lakewide Management Plan, the Detroit River International Wildlife Refuge, the Lake Erie Committee of the Great Lakes Fishery Commission, watershed and conservation organizations, and land use/transportation planning organizations like the Southeast Michigan Council of Governments.

The assessment presented in this report will serve as a baseline that can be improved upon in the next iteration in the spirit of adaptive management.

Quantitative targets or endpoints do not exist for most indicators. Of the 50 time trend data sets assessed, only 17 have quantitative targets (Table 1). Only five of the 17 indicators with targets are meeting them. Therefore, it is recommended that

a high priority should be placed on quantifying targets and endpoints for indicators in order to clearly focus management efforts and track progress consistent with adaptive management. The responsibility for quantifying targets and endpoints should rest with the key coordinating organizations such as those identified above.

All time trend databases are important to the organizations and agencies collecting the data. However, future iterations of comprehensive and integrative assessments may want to focus on a smaller set of key indicators that best meet the needs of management. In addition, this assessment was heavily weighted on state information – there are 38 state, seven pressure and five response indicators. It is further recommended that

future comprehensive and integrative assessments of the Detroit River and western Lake Erie should include more pressure and response indicators as they become developed, and more economic and social indicators, including indicators of sustainability and human health. Examples of available pressure and response trend data include: air emissions, watershed-specific urban and agricultural nonpoint

source loadings, watershed-specific impervious land use, other watershed-specific land-based stressors as summarized by the Great Lakes Environmental Indicator Project (<http://glei.nrri.umn.edu>), industrial point source loadings, etc.

Finally, some trend data were only available from one side of the international border. Therefore, it is recommended that

binational harmonization be achieved to truly undertake comprehensive and integrative assessment.

4.0 LITERATURE CITED

- Dolan, D.M. 1993. Point source loadings of phosphorus to Lake Erie: 1986-1990. *Journal of Great Lakes Research* 19(2):212-223.
- Eedy, R., J. Hartig, C. Bristol, M. Coulter, T. Mabee, and J. Ciborowski (eds.). 2005. *State of the Strait: Monitoring for Sound Management*. Great Lakes Institute for Environmental Research, Occasional Publication No. 4. University of Windsor, Ontario, Canada.
- Environmental Entrepreneurs. 2005. Effects of global warming on the state of Michigan. April Issue Brief. http://www.e2.org/ext/doc/e2_michigan.pdf
- Hartig, J.H. 1983. Lake St. Clair: Since the "Mercury Crisis." *Water Spectrum* 15:18-25.
- Hartig, J.H., and T. Stafford. 2003. The public outcry over oil pollution of the Detroit River. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 69-78. Bloomfield Hills, MI: Cranbrook Institute of Science.
- International Association for Great Lakes Research. 2002. Research and management priorities for aquatic invasive species in the Great Lakes. International Association for Great Lakes Research. <http://www.iaglr.org/scipolicy/ais/index.php>
- Kiff, L.F. 2000. The current status of North American vultures. In *Raptors at Risk*, eds. R.D. Chancellor, and B.U. Meyburg, pp. 175-189. World Working Group on Birds of Prey and Owls. Surrey, British Columbia, Canada: Hancock House.
- Lee, D.H., R. Moulton, and B.A. Hibner. 1996. *Climate change impacts on western Lake Erie, Detroit River, and Lake St. Clair water levels*. Great Lakes-St. Lawrence Basin Project Report. Environment Canada and NOAA, GLERL Contribution #985. Ann Arbor, MI.
- Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel, A.J. Eberhardt, and C.L. Luukkonen. 2002. Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCMs. *Journal of Great Lakes Research* 28:537-554.
- Mortsch, L.D., and F.H. Quinn. 1996. Climate change scenarios for Great Lakes Basin ecosystem studies. *Limnology and Oceanography* 401:903-911.
- Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50:53-65.
- Price, J. 2006. Global warming and songbirds in Michigan. American Bird Conservancy. <http://www.abcbirds.org/climatechange/Michigan.pdf>
- Ryding, S. 1992. *Environmental Management Handbook*. Boca Raton, FL: Lewis Publishers.

Time. 1965. Time for transfusion. August 20. <http://www.time.com/time/magazine/article/0,9171,841998-1,00.html>

Upper Great Lakes Connecting Channels Study. 1988. Volume II. U.S. Environmental Protection Agency, Environment Canada, Michigan Department of Natural Resources, Ontario Ministry of the Environment.

U.S. Congress-Office of Technology Assessment. 1993. Harmful nonindigenous species in the United States. OTA-F-565. Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency and Environment Canada. 1995. Practical steps to implement an ecosystem approach in Great Lakes management. <http://www.ijc.org/php/publications/html/toc.html>

U.S. Environmental Protection Agency. 2006. Climate. <http://yosemite.epa.gov/oar/globalwarming.nsf/content/climate.html>

5.0 APPENDIX A

STATE OF THE STRAIT CONFERENCE PROGRAM AND SESSION SUMMARIES

5.1 State of the Strait Conference Program

STATE OF THE STRAIT CONFERENCE PROGRAM

December 5, 2006

Flat Rock Community Center, Flat Rock, Michigan

8:00-8:30	Registration and Breakfast
8:30-8:35	Welcome – Canadian Consulate General Robert Noble and Flat Rock Mayor Richard Jones
8:35-8:45	History of State of the Strait and Overview of Detroit River-Western Lake Erie Indicator Project – Ms. Emily Wilke and Dr. John Hartig, U.S. Fish and Wildlife Service-Detroit River International Wildlife Refuge
8:45-10:00	Land Use and Transportation/Population/Human Health Indicators Session <i>Session Convenor</i> - Mr. John Nasarzewski, Southgate Anderson High School and Downriver Stream Team <i>Panelists</i> Mr. Matthew Child, Essex Region Conservation Authority Mr. Eric Foster, Michigan Department of Community Health Mr. Jim Rogers, Southeast Michigan Council of Governments
10:00-10:15	Coffee Break
10:15-11:30	Fish/Invertebrate Indicators Session <i>Session Convenor</i> - Dr. John Gannon, International Joint Commission <i>Panelists</i> Dr. Lynda Corkum, University of Windsor Mr. Bob Haas, Michigan Department of Natural Resources Fisheries Division Dr. Bruce Manny, U.S. Geological Survey-Great Lakes Science Center Mr. Stewart Thornley, Ontario Ministry of Environment
11:30-1:00	Lunch and Poster Session
1:00-2:15	Wildlife and Habitat Indicators Session <i>Session Convenor</i> - Mr. Bruce Szczechowski, Southgate Anderson High School and Downriver Stream Team

Panelists

Ms. Julie Craves, Rouge River Bird Observatory
Mr. Paul Cypher, Southeastern Michigan Raptor Research
Mr. Dan Lebedyk, Essex Region Conservation Authority
Mr. Phil Roberts, Essex County Field Naturalists
Dr. Chip Weseloh, Canadian Wildlife Service

2:15-3:30

Contaminant Indicators Session

Session Convenor - Ms. Melanie Coulter, Detroit River Canadian Cleanup

Panelists

Mr. Mike Alexander, Michigan Department of Environmental Quality
Mr. Charlie Bristol, Bristol Technical Services
Dr. Ken Drouillard, University of Windsor-Great Lakes Institute for Environmental Research
Dr. Chris Marvin, Environment Canada

3:30-3:45

Coffee Break

3:45-4:10

Summary Talk on State of the Strait

Dr. Jan Ciborowski, University of Windsor; Dr. John Hartig, U.S. Fish and Wildlife Service; and Dr. Michael Zarull, Environment Canada

4:10-4:55

Facilitated Panel Discussions on “Where do we go from here?”

Mr. Ted Briggs, Ontario Ministry of Environment
Ms. Rose Ellison, U.S. Environmental Protection Agency
Ms. Sandra George, Environment Canada
Dr. Russ Kreis, U.S. Environmental Protection Agency
Dr. Don Scavia, Michigan Sea Grant

4:55-5:00

Concluding Remarks

Dr. John Hartig, U.S. Fish and Wildlife Service
Dr. Michael Zarull, Environment Canada

5.2 State of the Strait Conference Session Summaries

On December 5, 2006, a State of the Strait Conference was convened in Flat Rock, Michigan to review available trend data, develop key findings, and discuss possible management actions and research needs. This State of the Strait Conference laid the foundation for a comprehensive and integrative assessment of the state of the Detroit River and western Lake Erie ecosystem. Presented below are the summaries from the individual conference sessions.

Land Use, Transportation, Population and Human Health Session Summary (prepared by John Nasarzewski)

There is a wide range of indicators being developed by the Detroit River-Western Lake Erie Indicator Project. It is important to understand the effects of land use changes, transportation patterns, and population trends on the ecosystem. Further, it is important to recognize that humans are a part of the ecosystem and that human health trends are an important part of assessing the state of the strait.

Once known as the “Paris of the Midwest,” Detroit initially experienced dramatic population growth, followed by urban sprawl and associated disinvestment in the inner city. The growth of Detroit from 1910 to 1930 is similar to the growth of Las Vegas, Nevada today, a city growing rapidly in population and investment. What makes it more dramatic is that the same amount of growth in Detroit was achieved when the population of the United States was just over 100 million versus 300 million today! Even when the rapid growth slowed during the Great Depression, Detroit was still one of the fastest growing cities in the United States. Detroit’s population was just under two million residents in 1950 and there are approximately 900,000 today.

What was not envisioned at that time was the enormous changes that were about to transform the well-functioning, centralized urban center of Detroit. It suffered from rapid suburban growth and subsequent urban decline. Even today, that trend continues; the Southeast Michigan Council of Governments estimates that southeast Michigan’s population will grow by 10%, but consume 30% more land over the next 25 years. Furthermore, two-thirds of the region’s growth will take place in 32 communities in the outer suburbs, consuming 250,000 acres of rural land instead of reclaiming land near existing city centers.

These changes impact the quality of life for everyone who lives in the region. It is clear that human population growth and, more importantly, urban sprawl can:

- increase impervious surface and lead to storm water runoff problems;
- decrease wildlife habitat;
- increase susceptibility to biological invasions;
- increase water and air pollution;
- increase herbicide and pesticide use; and
- adversely affect human health.

This growth itself is encouraged by the transportation management policies at the state and federal levels. Instead of discouraging new road construction into green space and encouraging reclamation of existing areas in established communities, policies favor green space consumption. Such sprawl then further reduces the likelihood of improvements in a mass transportation system, which is much needed for the daily commutes of residents. In cities such as Chicago and Boston, mass transit is a more efficient option for all residents, thanks to higher population density and farsighted policies. Instead, since the 1950s, fewer and fewer people in southeast Michigan are using mass transportation and more individuals are driving greater distances to work.

Urban sprawl and its subsequent increase in vehicle use is one source of the region's air pollution. The Detroit metropolitan area is not considered in compliance with the National Ambient Air Quality Standards for both ozone and particulates, and these two pollutants are most closely linked to triggering symptoms of asthma. Even as the pollution per kilometer or mile driven has decreased from our vehicles, more cars and trucks on the road and more kilometers driven has contributed to the continued problems with air quality in southeast Michigan. Rates for hospitalization due to asthma in Wayne County average over 75% higher than in the state of Michigan as a whole and have remained this high since 1990. This may be an underreported figure because in the United States, the number of individuals without health care has increased and individuals who suffer breathing problems may be going untreated or at least unreported.

Along with the air quality problems most commonly associated with urban sprawl, there is also an increase in electric power usage associated with the increase in average size and number of housing units. Data from the National Association of Home Builders show that the average home built in 1970 (with larger families) was 1,400 square feet in comparison with 2,330 square feet in 2004. These new homes are often positioned on the lot without consideration for the natural cycles of the sun, wind and vegetative cover to allow nature to help heat and cool the home. Rather, they are built to be either heated or air-conditioned using traditional energy resources. Both of these factors create increased demand for electrical power, which then contributes to the air pollution problem. Most residents in northeastern North America and the Great Lakes region remember the August 2003 blackout when 100 coal-fired plants were shut down. What is not widely known is that a study by a University of Maryland research team revealed how large a role our need for electrical power has in these emissions problems. The Maryland team sent up two light aircraft over the affected areas the day after the blackout started. The data were then compared to similar tests from the previous year that had the same atmospheric condition. The day after the blackout, sulfur dioxide dropped by 92% and ozone by more than 50%, along with other air pollutant reductions.

In summary, southeast Michigan faces some enormous challenges that directly impact the quality of life of all residents. The indicators of changing land use and transportation are linked to adverse effects on the ecosystem. Other models and examples of community development exist that encourage green space preservation and redevelopment in city-center space. Once urban sprawl is decreased and population density increased, mass transit becomes more viable. This, in turn, reduces traffic congestion, reduces pollution, reduces human health effects and increases our quality of life. While such changes do not happen overnight, many other communities have shown that it can be done.

Wildlife and Habitat Session Summary (prepared by Bruce Szczechowski)

Conserving and restoring habitat is the best way to protect and increase biodiversity in the Detroit River and western Lake Erie. From an inauspicious start of 123 hectares (304 acres) in 2001, the Detroit River International Wildlife Refuge has grown to 2,042 hectares (5,047 acres) in just six years, with a targeted goal of 4,856 hectares (12,000) acres of marshes, wetlands, islands, shoals and upland habitats in the Detroit River-western Lake Erie corridor.

In order to support diverse ecological communities in this region, it is imperative that wetlands along the Detroit River be protected and restored. Two hundred years ago, coastal wetlands were extensive along the Detroit River. Today, only 3% of the original wetlands remain along the Detroit River, resulting in the loss of many fish spawning and nursery grounds, and wildlife nesting, foraging and shelter habitats. Communities must be encouraged to protect and restore wetlands for fish and wildlife habitat, and for improvement of water quality and flood control. Wetland protection laws must be enforced, and volunteer restoration efforts and soft engineering projects must be encouraged and supported in areas with high likelihood of success (e.g., Grosse Ile's Gibraltar Bay project).

Reestablishment of suspended/submersed aquatic macrophytes in western Lake Erie is important, since increasing plant diversity will lead to more diverse and stable ecosystems. In 1898, a western Lake Erie survey recorded 40 species of aquatic macrophytes. By 1967, 50% of the aquatic macrophytes had disappeared as a result of algal blooms and subsequent reduced light availability. As light availability improved, macrophyte diversity began to rebound between 1968 and 1995. In recent years, two more pondweed species (*Potamogeton nodosus* and *P. zosteriformis*) have reestablished themselves and are flourishing. In addition, *P. illinoensis* may possibly become a reproducing component in the flora of Put-in-Bay and recolonization by other species is not unexpected. However, further research is needed to determine the effects of resurgent *Cladophora* – a green, filamentous alga. It is imperative that monitoring for new invasive organisms be rigorously pursued. Policy changes must be made at the state and national levels to prevent ongoing introductions of invasive species into the Great Lakes.

Wild celery (*Vallisneria spiralis*) is an aquatic macrophyte of particular importance as a food source for diving ducks. Wild celery growth is also a water quality indicator, as it is sensitive to chemical contaminants. Prior to the 1900s, Detroit River wetlands were up to 1.6 km (1 mile) wide along both Canadian and U.S. coastlines, providing abundant areas for wild celery growth. From 1950 to 1985, oil pollution and filling of wetlands resulted in marked decreases in wild celery beds at several locations. Around the mid-1980s, colonization by zebra mussels brought about changes in water clarity which, along with improved water quality, resulted in increased wild celery abundance. Implementation of pollution abatement programs to improve water quality and clarity, which encourages the continued recovery of wild celery beds, should be a priority, along with preservation of remaining coastal wetland habitats and the rehabilitation of degraded ones to support wildlife populations.

Canvasbacks (*Aythya valisineria*) and other waterfowl use the Detroit River as stopover habitat during spring and fall migrations. The canvasback requires large amounts of food such as wild celery, as well as pondweeds, sedges and other aquatic plants during

migration to and from its central Canadian breeding grounds. The population of canvasbacks declined drastically from 100 years ago to the mid-1970s as a result of droughts, market hunting, development, industrial/sewage discharges adversely impacting wild celery beds and agricultural conversion of wetland breeding areas. In 1974, the migrating canvasback population in the Detroit River was only 125. The population increased dramatically with effective conservation efforts, rainfall in breeding areas, and the aforementioned recovery of wild celery beds, peaking in 1999 at 79,300. Since 1999, however, there has been a precipitous drop in canvasback numbers surveyed. One reason for the declining trend may be due to delayed migration, resulting in more canvasbacks migrating later in the fall after the November 5th flyover survey. It is also possible that canvasbacks may be undergoing a population shift to other locales in the Great Lakes during their cross-continental migrations. Since southeast Michigan and connecting waters have been one of the most important flyways for migrating canvasbacks, as well as other waterfowl, wetland stopovers in the Lake St. Clair-Lake Erie corridor must be protected and rehabilitated.

The Christmas Bird Count (CBC) in the Detroit River-western Lake Erie region includes the more northerly Detroit River Christmas Bird Count, as well as the more southerly Rockwood Christmas Bird Count. These counts circumscribe areas of 24.1 km (15 miles) in diameter and include parts of the U.S. and Canada. In the Detroit River CBC, 35 species have been observed over the past 27 years, including the Canada goose. Since reintroductions in the 1920s-1930s, the Canada goose population has grown 14% annually. There has also been a steadily increasing trend for mute swans from 1986 to 2004. The mute swan, a nonnative, aggressive, invasive species from north-central Asia and Europe, has been spreading throughout the U.S. since the 1920s, displacing native waterfowl by taking over preferred nesting habitat and damaging beds of submersed vegetation, such as wild celery.

In the Rockwood CBC, low numbers of American crows (average 1975-2001 = 636; 2002-2004 = 35) in recent years likely reflect mortality due to West Nile virus. The ratio of American black duck to mallard now is 1:17, with one reason being that mallards are much more adaptable to urbanization than American black ducks. For future CBCs, use of GPS for more accurate recording of observation locations will help to ensure consistency of areas covered. There is a need for consistency in count hours and efforts by volunteers. Additionally, more attention should be paid to weather conditions, as average weather conditions for the weeks and month preceding the count day may affect waterfowl counts.

Though the double-crested cormorant (*Phalacrocorax auritus*) is not believed to have established a presence in the Great Lakes until the early 1900s, it has undergone a population explosion in recent years throughout the Great Lakes, including western Lake Erie and the Detroit River. The cormorant is a colonial-nesting waterbird that feeds on small fish, mainly forage fish such as alewife and gizzard shad, but they also consume sport fish. The cormorant population slowly increased until the mid-1950s (to approximately 1,000 pairs), at which time a sharp decline in reproductive success ensued, caused by adverse reproductive effects of DDT and its metabolite, DDE, as well as PCBs. Banning or limiting use of these persistent toxic substances in the 1970s and 1980s was followed by an exponential growth of the cormorant population in the Great Lakes in the 1980s and early 1990s. Today, with populations at an all-time high (in excess of 30,000 pairs), concerns

are mounting over the cormorant's potential impact on fisheries, degradation of native Carolinian forest vegetation from its fecal waste, and its displacement of co-occurring species from nesting habitat, such as egrets and herons. Monitoring and research are needed on the double-crested cormorant and its effects on fish, wildlife and vegetation in western Lake Erie and the Detroit River.

Another colonial-nesting waterbird is the common tern (*Sterna hirundo*), which is fast-disappearing from Michigan waters everywhere, particularly the Detroit River, where populations plummeted from over 4,000 pairs in the 1960s to less than 300 pairs today. Reasons for the decline are thought to include sensitivity to contaminants, vegetative overgrowth of habitat, human development on islands formerly used for nesting, and competition for nesting sites with ring-billed gulls. After extensive observations during the past four years of common terns nesting on man-made bridge structures in the Trenton Channel (Grosse Ile Free and Toll Bridges), it has become apparent that this state-threatened species is being impacted by black-crowned night heron predation. It is imperative that predator control structures be erected at current nesting sites, as well as restoring more nesting areas for common terns with predator controls installed at the outset. The latest habitat restoration effort took place at the DTE Energy River Rouge Power Plant in the fall of 2006, with Southgate Anderson High School students helping to move 73 meters (80 yards) of sand and gravel onto abandoned mooring cells. The site was retrofitted with a predator control structure in the spring of 2007. Other potential sites for nesting habitat include BASF's Hennepin Point property, Mud Island, Humbug Marsh, inside Pointe Mouillee's banana dike and possibly Belle Isle.

Another avian species decimated by toxic chemicals is the national symbol of the United States, the bald eagle (*Haliaeetus leucocephalus*). At the top of the food web, eagles nesting near Great Lakes shorelines have historically been more adversely affected by toxic contaminants in the Great Lakes food web than eagles nesting further inland. Coincident with reduction of toxic chemicals, such as DDT and PCBs, the population of bald eagles in the western Lake Erie and Detroit River region has seen an upward trend from the early to mid-1980s to the present time, with Ohio bird populations faring much better than populations in Michigan and Ontario. The bald eagle was recently removed from the federal endangered species list. Though it is apparent that the bald eagle is recolonizing former Great Lakes habitats, including western Lake Erie and the Detroit River, they remain extremely vulnerable to human disturbance, contaminants and habitat loss. Therefore, continued monitoring is essential for gauging the contaminant levels and reproductive status of the bald eagle.

The peregrine falcon (*Falco peregrinus*) is globally rare and another raptor residing at the top of the food web that has been hit especially hard by toxic contaminants, such as DDT. After the population crashed in the 1950s, the peregrine falcon was listed as endangered in 1970; no birds were observed east of the Mississippi River at that time. Reintroduction efforts began in 1982, including urban areas. Reintroductions in Michigan began in 1991, with the raising and release of 139 peregrine falcons. The number of nesting pairs and sites has been slowly increasing in southeast Michigan. Currently there are six nesting pairs of peregrine falcons in the Detroit River corridor with the goal of at least ten nesting pairs. The peregrine falcon was removed from the endangered list in 1999, but there is a need in the Detroit River corridor to continue protecting and enhancing habitat and monitoring its reproductive success and population recovery.

Fish and Invertebrate Session Summary (prepared by John Gannon)

A newspaper reporter once called me a “physician of lakes” because I was assessing the ecological health of inland lakes in the northern Lower Peninsula of Michigan. So, just as a medical doctor uses certain tests (e.g., blood sample, blood pressure, pulse, etc.) as indicators of your health, aquatic ecologists use indicators of the ecological health of rivers and lakes. In the Detroit River and western Lake Erie, as in water bodies elsewhere, invertebrates (plankton and benthos) and fish make particularly good indicators because of their importance in the food web. Many species of plankton (i.e., free-floating or free-swimming organisms) and benthos (i.e., bottom-dwelling organisms) form the base of the food web that supports the fish community. Fish, of course, are important in river and lake ecology, and provide economically valuable fisheries.

Studies of Detroit River and western Lake Erie phytoplankton (i.e., microscopic plants or algae) and zooplankton (i.e., microscopic animals) communities date back to the late nineteenth and early twentieth centuries, but they have been sporadic. Therefore, it is often difficult to determine status and trends over time using the available data. In some cases, observational information is useful in the absence of data collected consistently over time using comparable methods (an essential requirement of a good indicator). For example, a “picture is worth a thousand words” when observing high concentrations called “blooms” of blue-green algae (cyanobacteria) on or near the water surface and heavy growths of the macro-alga, *Cladophora*, smothering nearshore habitats and forming stinking, rotting mats on beaches. Both blue-green blooms and extensive *Cladophora* growths, once prominent in the 1960s and 1970s, became much less prevalent in the 1980s in response to water quality improvements, especially reductions in phosphorus. In the 1990s, blue-green algal blooms reappeared and are continuing into the 2000s while nuisance growths of *Cladophora* reoccurred in the 2000s. These are possible indicators of declining water quality in recent years, but factors involved with infestations of zebra and quagga mussels may be at least partially responsible also. In any case, the resurgence of algal blooms and excessive *Cladophora* growths is a concern and monitoring and research need to be continued on these likely indicators of declining ecosystem quality.

Sometimes, individual species of plankton can be used as an indicator, but more often, attributes of the entire plankton community can indicate ecological health. One such plankton community indicator, the Planktonic Index of Biological Integrity (P-IBI), has recently been developed to describe the offshore waters of Lake Erie. It is based on five measures of the abundance and kinds of phytoplankton and zooplankton. The index is especially designed to indicate the response of the plankton community to nutrient pollution, especially phosphorus. The P-IBI values are lower for the 2000s in comparison with the mid-1990s, indicating a possible decline in water quality in recent years.

Perhaps the best benthic indicator in the Detroit River and western Lake Erie is the burrowing mayfly, *Hexagenia*. It is a sensitive indicator of water and bottom sediment (mud) quality, and many fish species feed on *Hexagenia*. It was formerly abundant, but was extirpated in the early 1950s because of pollution. Ecologists heralded the reappearance of *Hexagenia* in the early 1990s as an indicator of improved water and sediment quality in the Detroit River and western Lake Erie.

The density of oligochaetes (worms) and chironomids (midge larvae) in bottom sediments is also a useful indicator of pollution and ecosystem health. Excessively high densities are

often an indicator of nutrient pollution, and excessively low densities an indicator of toxic pollution. In addition, deformities of teeth in the head capsule of chironomids are used as an indicator of pollution. The distribution and density of oligochaetes and chironomids in the Detroit River corridor is a function of sediment type, as well as pollution. In general, pollution, as indicated by these benthic communities, is historically worse in the Trenton Channel and continues today.

Observations have been made of lake whitefish spawning and increases have occurred in the lake sturgeon population in the Detroit River and walleye and yellow perch populations in western Lake Erie. In general, these indicators collectively represent a “good news” story of improving ecosystem quality and sound fishery management. During the late nineteenth and early twentieth centuries, lake whitefish entered the Detroit River from Lake Erie in spectacularly large fall spawning runs. These spawning runs practically disappeared in the early 1900s due to habitat loss (especially the loss of spawning habitat due to construction of the Livingstone Channel), habitat degradation, overfishing, and pollution. Lake whitefish numbers were at an all-time low in the 1960s and 1970s in Lake Erie, started a modest recovery in the 1980s, and the recovery has continued into the 1990s and 2000s. The first confirmed spawning and successful reproduction of lake whitefish in the Detroit River since 1916 was documented in 2006.

The lake sturgeon story in the Detroit River closely parallels that of the lake whitefish. The lake sturgeon population was abundant in Lake Erie and the Detroit River in the 1800s and the Detroit River was one of the most productive sturgeon spawning grounds in North America. The population declined from a combination of the above-mentioned factors in the early 1900s and remained at extremely low numbers throughout most of the twentieth century. In the 1990s, lake sturgeon began a modest recovery and the first reported sturgeon spawning in the Detroit River in over three decades occurred in 2001.

Walleye live and breed in Lake Erie and the Detroit River. As adults, walleye are top predators in Lake Erie and Detroit River food webs and this position makes them good indicators of ecosystem health. Walleye populations generally declined through the mid-twentieth century, and in 1970 a legal walleye harvest was prohibited due to mercury contamination coming from the St. Clair and Detroit rivers. The industrial source of mercury contamination was eliminated and a limited legal harvest was renewed in 1972. Through a combination of harvest quota management and improving water quality, the walleye population increased in the 1980s and developed into a fishery of enormous economic importance. However, in the late 1980s a decline in the walleye population occurred. The last five years has seen variability, yet an increase to a rating of “high quality” in 2005. Fishery managers are adjusting harvest quotas and monitoring walleye populations and their food base in an effort to maintain and sustain the walleye population for commercial and recreational use and its keystone position as Lake Erie’s and the Detroit River’s top predator fish.

The yellow perch is lower in the food web than walleye, and its population normally fluctuates more widely than walleye in Lake Erie and the Detroit River. It is highly prized as a sport and commercial fish and on the dinner table. The catch peaked in the late 1880s and decreased substantially thereafter, reaching a population low in the early 1990s, possibly due to the invasion of zebra and quagga mussels. Since the late 1990s, yellow perch populations are once again increasing, coinciding with the return of *Hexagenia*, an important food source.

In summary, the public has long held the perception that the Detroit River and western Lake Erie are polluted. Although there is need for further improvement, the fish and invertebrate indicators show overall improvement in ecosystem quality over recent decades in response to water quality and habitat improvements and sound fishery management. Some indicators are showing recent (past 5-10 years) declines in ecosystem quality. This emphasizes the importance of continuing the monitoring of fish and invertebrate indicators to assist with science-based resource management and policy decisions in the Detroit River and western Lake Erie.

Contaminants Session Summary (prepared by Melanie Coulter)

Over the past century, contaminants of various sorts have caused a variety of problems in the Detroit River and western Lake Erie. These range from DDT (which causes bald eagle eggshell thinning and mortality) to oil spills (which cause large bird die-offs) to mercury (which continues to give rise to fish consumption advisories). Contaminants enter the river and lake in several ways, including point source discharges from industry and sewage treatment plants, nonpoint source runoff from urban and agricultural areas, airborne deposition, and from upstream sources which travel through the Detroit-St. Clair corridor. Some of the contaminants in the river are not from current sources, but are the residue of historical contaminants that have settled into the river bottom sediments. They can be released from those sediments during storm events or dredging activities, or they may be ingested by bottom-dwelling organisms.

It is difficult to give a clear answer as to whether the indicators demonstrate an overall improvement or deterioration in the contaminant situation. Some of the indicators show an improvement, while others do not. An accurate assessment would be to characterize the results as mixed, with generally improving trends.

Discharges of liquid and solid waste from agricultural and domestic sources have introduced toxic substances into the waters of western Lake Erie. Over the years, these contaminants have accumulated in successive layers at the bottom of the lake, providing a historical record of natural and anthropogenic events. The ongoing goal is to see a reduction in the levels of contamination in these sediments, and research demonstrates that levels are decreasing. Research on Lake Erie in 1971 found that the highest total mercury and DDT concentrations occurred in the western basin near the mouth of the Detroit River, while the highest PCB concentrations were found along the southern shore of Lake Erie, particularly the western half. Fifty of the original 259 sites were revisited by Environment Canada in 1995. On that occasion, researchers found that the levels of PCBs and organochlorides in sediments had decreased considerably, although they were still highest in the western basin of Lake Erie. Further research in 1997 found that although the levels of contaminants in western Lake Erie sediments were decreasing, they still exceed Canadian Threshold Effect Level guidelines and U.S. Threshold Effect Concentrations. In addition, levels of mercury, PCBs, dioxins, and furans still exceed the Ontario Lowest Effect Level.

All of the Areas of Concern around Lake Erie have some areas of contaminated sediment, which have been an obstacle to the full restoration of beneficial uses. However, efforts have been made in the Detroit River to clean up some of these contaminated sites. Between 1993 and 2006, almost one million cubic meters of sediment have been remediated at twelve project sites at a cost of \$154 million. Some of these sites include

Elizabeth Park Marina, Conners Creek, and Ellias Cove (formerly Black Lagoon). Unfortunately, these projects only represent 33% of the total contaminated sediments in the basin. The Michigan Department of Environmental Quality estimates that approximately 2.3 million cubic meters of contaminated sediments remain, particularly in the Trenton Channel, Rouge River, and River Raisin.

In the 1970s, phosphorus was identified as the primary nutrient limiting algal growth in the Great Lakes. As a result, the Ontario Ministry of the Environment began analyzing untreated water samples taken from the Union Water Treatment Plant intakes at Kingsville, Ontario on a weekly basis. During the years since the program began, there have been three detectable periods of trends. An increase was noted in the years from 1976 to 1983, and a decrease from 1983 to 1994. Since 1994, the mean total phosphorus has again been increasing, but the pattern is not consistent with loadings from point or nonpoint sources. Additional research is required to determine the causes of this increase, as well as to what degree these nearshore intake samples are representative of the western basin of Lake Erie as a whole.

The Detroit Wastewater Treatment Plant (WWTP) was constructed in 1940, and treats the waste of over three million people (over 2.6 billion liters or 700 million gallons of wastewater) every day. For years, the plant had the dubious distinction of being the largest single phosphorus contributor to Lake Erie. However, between 1966 and 2003, there was a reduction of more than 90% in phosphorus concentrations and loadings from the Detroit WWTP to the river. Although the plant is still a major point source contributor to Lake Erie, nonpoint phosphorus sources are now a major factor as well. Ongoing management to continue to reduce levels is required, as well as better estimates of phosphorus loadings to Lake Erie to accurately assess the current situation.

Chlorides (in small amounts) are required for normal cell functions in plants and animals. However, at high concentrations, chloride is toxic to aquatic biota. Lake Erie has a chloride concentration at least three times that of Lake Huron because of its shallowness and relatively small water volume, and because of significant urban and industrial inputs of chloride. Chloride levels have been monitored in western Lake Erie for the past century, and during that time there have been three detectable trend periods. Although there is seasonal and year-to-year variability, there was an increase noted from the early 1900s through the 1960s, followed by a decreasing trend from 1968 to 1985 which can be attributed to reduced point source loadings to the Detroit River when industries ceased operations. From the late 1980s to the present, there appears to be an increase in chloride concentrations. That rise may be attributable to increases in nonpoint sources, such as agricultural runoff, highway deicing, and streambank erosion.

The Detroit River is an essential resting and feeding ground for migrating waterfowl, and is generally a good habitat for waterbirds. However, when oil spills occur, they can be devastating to wildlife. External oil causes loss of buoyancy, elimination of the insulation properties of feathers, and reduced swimming ability. Oil contamination of eggs will decrease their hatchability, and the ingestion of oil by birds causes sickness and mortality. Unfortunately, between 17% and 40% of all reported oil spills in Michigan occur in the Detroit and Rouge rivers. A major spill in 1948 resulted in the death of 11,000 ducks in the Detroit River. However, there was a 97.5% reduction in oil discharges between the late 1940s and the early 1960s, and an additional 80% decrease in discharges between 1963

and 1976. Spills such as the one in 1948 have not occurred since that time. However, there are still years in which the volume of oil spilled is comparable to 1961 values, including a 378,540 liter (100,000 gallon) spill in the Rouge River in 2002, which resulted in a \$7.5 million cleanup of 43 kilometers (27 miles) of shoreline and the death of at least ten waterfowl. In addition to these reported spills, there are many unreported spills and releases through combined sewer overflows that are not counted.

In 1977, the Canada Department of Fisheries and Oceans began monitoring the contaminant burdens of representative top predator and forage fish species from western Lake Erie to measure the success of remedial actions. Unfortunately, it is difficult to draw many conclusions from the results because invasive species are exerting pressure and causing changes in chemical cycling and energy flows, although the overall results seem to be demonstrating a downward trend. In rainbow smelt, concentrations of mercury were variable, while concentrations of PCBs and DDT declined over the period. However, levels of all three contaminants show a spike in 2002 which could not be explained. In walleye over the same time frame, there was more variation among contaminants. Mercury showed a rapid decline from 1977 to 1983, a leveling off, and then increases in 1999, 2003, and 2004 (although with less variability than levels in smelt). Total PCB levels were lower in the 1980s and 1990s compared to the late 1970s, although concentrations have fluctuated (as they have for smelt). DDT levels have declined by an order of magnitude since 1977, with the 2003 concentration being the lowest measured since the program began. The key element in the reduction of these contaminants in fish is to control the contaminants at their source.

Herring gulls (*Larus argentatus*) are an ideal species with which to track contaminants because they are year-round residents of the Great Lakes, easy to study and locate, tend to return to the same nest sites, and are a top food web predator. Environment Canada's Canadian Wildlife Service has monitored herring gull eggs for decades, and this study provides a good, ongoing dataset with which to assess trends. Herring gulls in western Lake Erie and the Detroit River have been studied on Middle Island and Fighting Island. There was a significant decrease in levels of PCBs from the mid- to late 1970s to the early 1990s, followed by a nonsignificant decreasing trend from the early 1990s to the early 2000s. This represents an 83% decline on Fighting Island, and a 75% decline on Middle Island during the study period. For dioxin, there is a general pattern of lower concentrations in the late 1990s and early 2000s when compared to the period from the mid-1980s to the mid-1990s, with the exception of an elevated dioxin concentration on Fighting Island in 2003. Other positive indications are that, in addition to reductions in levels of persistent toxic contaminants, reproductive success has improved and visual abnormalities are now seldom seen.

In its elemental form, mercury is not regarded as a major contaminant in water because it is almost completely insoluble. However, in sediments, it can be transformed by microorganisms into a more soluble and toxic form. There are currently fish consumption advisories in western Lake Erie and the Detroit River due to elevated mercury levels. Mercury problems reached their peak during the Mercury Crisis of 1970 when elevated mercury levels forced the closure of the fisheries from southern Lake Huron to Lake Erie. However, research has demonstrated that the mercury content in Lake St. Clair walleye has decreased by more than 80% during the period from 1970 to 2004; a similar reduction is also evident in other fish species. Currently, the primary sources of mercury

are contaminated sediments from historic discharges and airborne deposition. In addition to other steps required to remediate sediments contaminated with mercury, the control of mercury emissions at their sources remains an imperative.

At the State of the Strait Conference, two key steps were identified as necessary to adequately deal with issues related to contaminants. First, better loading and ecosystem models and monitoring are needed to help assess where the contaminants originate and how they are influencing species and ecosystem health. Secondly, funding is required to address known problems, including the remediation of contaminated sediments, elimination of point sources, and prevention of nonpoint source loadings. Contaminant loadings and contaminated sediment are long-standing issues in the Detroit River that will take a cooperative effort by governments, industries, and surrounding communities to resolve. However, it is clear that such efforts are already underway and seem to be making a difference in some of the indicators.

INDICATOR REPORTS

6.0 APPENDIX B - CONTENTS

Pressure Indicators

Human Population Growth and Distribution in Southeast Michigan	52
Land Use Change in Southeast Michigan	57
Transportation Trends in Southeast Michigan	63
Phosphorus Loads and Concentrations from the Maumee River	68
Michigan's Carbon Emissions	75
Oil Pollution of the Detroit and Rouge Rivers	78
Lake Erie Shoreline Hardening in Lucas and Ottawa Counties, Ohio	85

State Indicators

Lake Erie Water Levels	92
Water Clarity in Western Lake Erie	99
Lake Erie Ice Cover	102
Phosphorus Concentrations in the Western Basin of Lake Erie	105
Chloride Levels in Western Lake Erie Water Samples Collected from the Monroe Water Intake	111
Dissolved Oxygen Levels in the Rouge River	116
Contaminants in Western Lake Erie Sediments	121
Criteria Air Pollutants in Southeast Michigan	126
Contaminants in Western Lake Erie Fish Community	136
Mercury in Lake St. Clair Walleye	143
Contaminants in Herring Gull Eggs	146
Algal Blooms in Western Lake Erie	151
Plankton Communities	156
Recovery of Wild Celery	160

Reestablishment of Long-Absent Aquatic Macrophytes in Western Lake Erie	163
Detroit River Coastal Wetlands	172
Invasion of the Erie Marsh Preserve by Common Reed (<i>Phragmites australis</i>) Over the Last 20 Years	177
<i>Hexagenia</i> Density and Distribution in the Detroit River	181
Abundance of Burrowing Mayflies in the Western Basin of Lake Erie	189
Chironomid Abundance and Deformities	193
Oligochaete Densities and Distribution	199
Invasion of Zebra Mussels (<i>Dreissena polymorpha</i>) and Quagga Mussels (<i>Dreissena bugensis</i>).....	205
Yellow Perch Population	212
Lake Whitefish Spawning	216
Lake Sturgeon Population	221
The Walleye Population of Lake Erie	226
Canvasback Population in Lake St. Clair/Detroit River/Western Lake Erie Basin	230
Common Tern Reproduction	234
Double-crested Cormorant Population Changes	239
Detroit River Christmas Bird Count	243
Rockwood, Michigan Christmas Bird Count – Overwintering Bird Count Fluctuations	247
Fall Raptor Migration at Holiday Beach Conservation Area, Amherstburg, Ontario	253
Fall Raptor Migration over Lake Erie Metropark	259
Peregrine Falcon Reproduction in Southeast Michigan	263
Bald Eagle Reproductive Success	267
Asthma Hospitalization Rates in Wayne County, Michigan	276
Lead Poisoning in Detroit, Michigan	281
West Nile Virus in Michigan	288

Response Indicators

Phosphorus Discharges from Detroit Wastewater Treatment Plant	294
---	-----

Combined Sewer Overflow Controls in Southeast Michigan	297
Contaminated Sediment Remediation	305
Land Conservation for Wildlife in the Detroit River International Wildlife Refuge	309
Southeast Michigan Greenway Trails	312

6.0 APPENDIX B

PRESSURE INDICATORS

INDICATOR: HUMAN POPULATION GROWTH AND DISTRIBUTION IN SOUTHEAST MICHIGAN

Background

During the nineteenth and first half of the twentieth centuries, immigrants and farmers moved to big cities for the opportunity of higher income jobs in industry. By the middle of the twentieth century, with the greater accessibility of the automobile, big city residents were moving away from urban centers, seeking suburban areas with more space and within driving distances of their workplace. Suburbanization and the postwar baby boom generation filled in what are now the inner-ring suburbs. By the end of the century, decentralization of population continued farther from the traditional core cities (SEMCOG 2002).

Southeast Michigan's population growth rate and pattern of expansion has followed a similar pattern experienced in many major metropolitan areas around the country (SEMCOG 2001). All of the counties in southeast Michigan have experienced population increases. Farmland has been bought for subdivisions and woodlots are being cleared for developments throughout southeast Michigan. People that moved farther away from the urban centers to enjoy the rural and suburban life are now finding that the city is moving to them. The places that were once rural are not staying that way; urban areas are continuing to push outward.

The population growth and distribution in southeast Michigan is an indicator of pressure humans place on the ecosystem. Uncontrolled growth of urban areas poses serious threats to the natural environment, agricultural and energy resources, and to human health and quality of life. Human population growth and expansion can:

- increase impervious surface and lead to storm water runoff problems;
- decrease wildlife habitat;
- increase water and air pollution;
- increase herbicide and pesticide use; and/or
- introduce nonnative invasive species.

However, growth could be managed in ways that protect significant natural areas, conserve natural resources, protect essential ecological processes (e.g., groundwater recharge, stream flows), and prevent pollution (especially smog and hazardous wastes).

Status and Trends

The City of Detroit's population increased more than sixfold during the first half of the twentieth century, due largely to a massive influx of Eastern European and southern migrants who came to the area for the burgeoning automobile industry. In 2004, Detroit

was the United States' 11th most populous city, with slightly over 900,000 residents. This is half the population the city boasted at its peak in the 1950s (Figure 1). Detroit's population decline has been one of the largest in the nation.

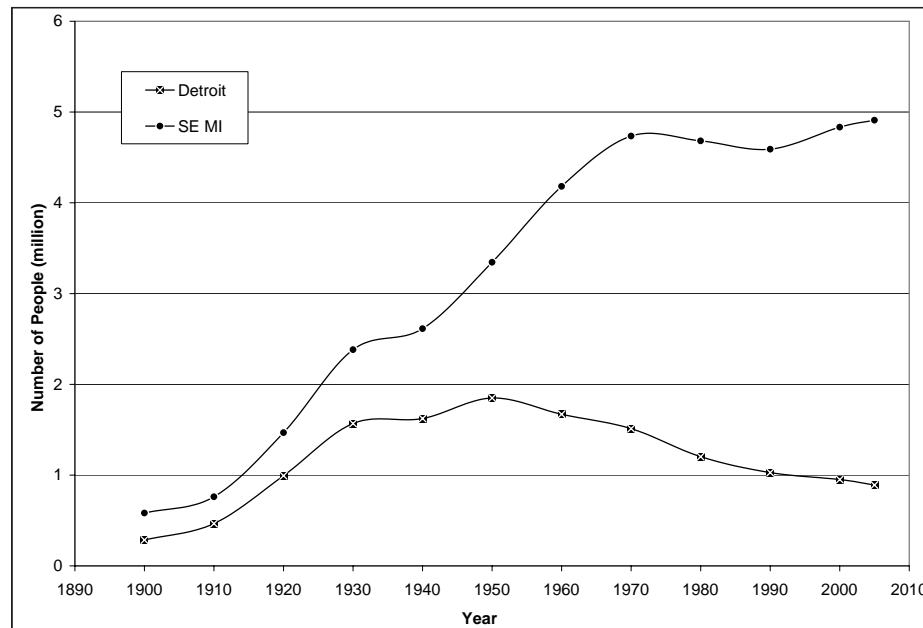


Figure 1. Population growth in Detroit and southeast Michigan from 1900 to 2005 (data collected by Southeast Michigan Council of Governments).

In 1900, the total population of southeast Michigan, a region including Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne counties, was nearly 600,000 (Figure 1). A century later, in 2000, southeast Michigan's population was just over 4.8 million (SEMCOG 2002). With the exception of a couple of population dips in 1980 and 1990, southeast Michigan has experienced steady growth.

The population distribution has changed substantially in southeast Michigan between 1900 and 2005. Wayne County's dramatic population growth occurred between 1900 and 1950, while Oakland, Macomb, and Washtenaw counties experienced steady growth from 1950 to 2005 (Figure 2). This pattern indicates people moving out of Detroit to surrounding areas. Oakland County has experienced the most growth, with just the northern townships increasing 40% since 1990. As of 2005, the fastest growing areas in the region are southern and western Wayne County, the Ann Arbor area in Washtenaw County, much of Livingston County, western and northern Oakland County, and central Macomb County (SEMCOG 2001).

The region added 4.3 million people between 1900 and 2000. In 1900, the region contained 10 cities, 133 townships, and 46 villages, and in 2000 the number of cities increased to 89 cities, 115 townships, and 27 villages (SEMCOG 2002). At the beginning of the twentieth century, Wayne County was the only urbanized population center. By 2000, Oakland and Macomb counties had joined Wayne County in becoming urbanized population centers (Figure 3). This reflected the overall shift from agrarian to urban living over the past 100 years (SEMCOG 2002).

The Southeast Michigan Council of Governments estimates that, in the next 25 years, southeast Michigan's population will grow by 10 percent – but that extra percent will

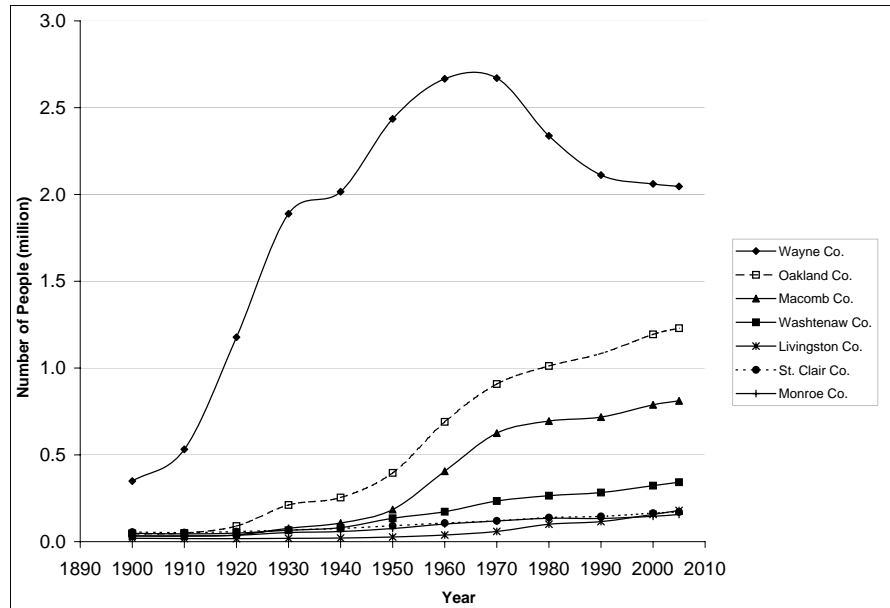


Figure 2. Population fluctuations in southeast Michigan by county, 1900-2005 (data collected by Southeast Michigan Council of Governments).

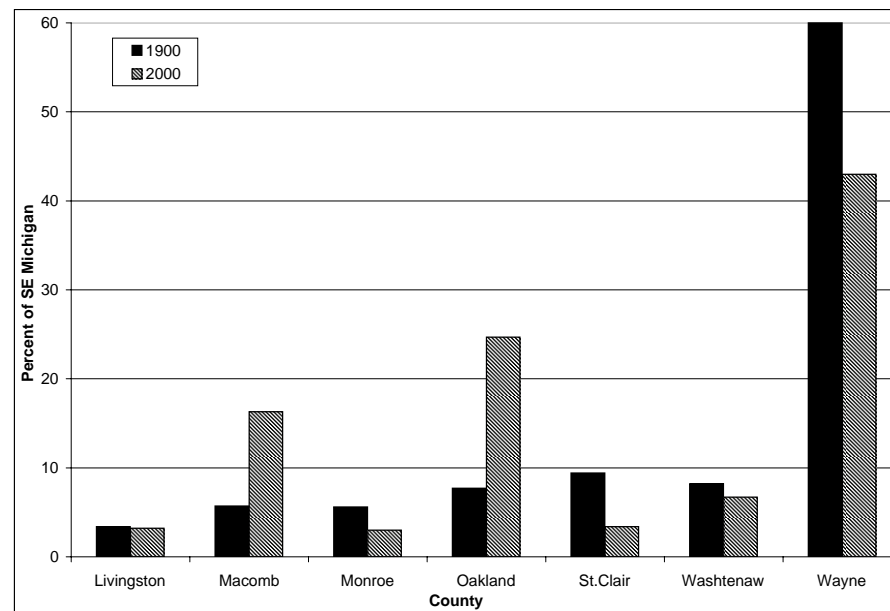


Figure 3. Percent of the population of southeast Michigan in each county in 1900 and 2000 (data collected by Southeast Michigan Council of Governments).

consume at least 30 percent more land. Two-thirds of the region's growth will take place in 32 communities in the outer suburbs, converting 101,172 hectares (250,000 acres) from rural to suburban uses (Hackney 2005).

Management Next Steps

Population growth can lead to dramatic changes in communities and the landscape. As new dwellings, businesses, and industries are built or expanded, land is converted from one use to another to accommodate that change. As development expands across suburbs and once rural landscapes, traffic congestion, unattractive commercial strips, and the

destruction of a more pastoral landscape push people who seek open space even farther into the countryside. They are aided by a fast and efficient road network and relatively low land prices.

As people seek the “good life” further and further out from the urban core, land, energy, natural resources, and open space disappear. The land use pattern that results is costly to service and, over time, results in a loss of the very qualities sought by those who moved there. As the transportation system expands into previously undeveloped or minimally developed areas, water and air pollution can increase and wildlife habitat can be fragmented or lost.

The southeast Michigan region and its communities need to utilize growth management techniques that systematically guide the type, rate, location, timing, public cost of, and quality and character of land development in support of growth, yet preserves quality of life. Promising techniques include:

- purchase of development rights;
- transfer of development rights;
- concurrency (pay as you go);
- urban and general services districts;
- development agreements;
- regional impact coordination; and
- interjurisdictional growth management.

Further, special efforts should be expended to integrate land use and transportation planning in southeast Michigan to better manage growth through regional efforts.

This could include:

- reaching agreement on a regional sustainability vision (i.e., economic, societal, and environmental) and signing a partnership agreement to generate cooperation amongst communities and businesses;
- empowering Southeast Michigan Council of Governments to expand its capability to map, inventory, and predict changes in population, land use, and transportation trends (e.g., 2035 Regional Development Forecast; SEMCOG 2001);
- identifying constraint areas from an environmental and servicing perspective in order to indicate where development is and is not appropriate;
- developing regional sustainability policies to preserve key ecosystem features and quality of life (e.g., public transportation, minimizing nonpoint source pollution, stopping floodplain encroachment, limiting impervious surface area development, etc.); and
- proactively working with communities to implement policies and undertaking state of the environment/economy/society reporting every three to five years.

Continued priority should be given to educating the public about the environmental and natural resource consequences of population growth, population density, land use, and transportation practices. Developers and land use and transportation planners need more education on sustainable design.

Research/Monitoring Needs

Southeast Michigan Council of Governments must continue to track population trends and predict future growth and distribution patterns. Also, more research is needed that integrates population trends with land use and transportation planning on a regional scale. Innovative best management practices must be identified that preserve quality of life and sustain our communities, economies, and environments. A combination of incentives and regulatory tools need to be used to better manage growth and ensure sustainability.

References

Hackney, S. 2005. Red Hot and Rural. *Detroit Free Press*. <http://www.freep.com> (May 2005).

[SEMCOG] Southeast Michigan Council of Governments. October 2001. *2030 Regional Development Forecast for Southeast Michigan: Population, Households, and Jobs, for Cities, Villages, and Townships 1990-2030*.

[SEMCOG] Southeast Michigan Council of Governments. June 2002. Historic Populations and Employment by Minor Civil Division, Southeast Michigan: Population, 1900-2000; Employment, 1970-2000.

Links for More Information

Southeast Michigan Council of Governments: www.semCog.org

Sprawl City, Detroit: <http://www.sprawlcity.org/detroit.html>

Mackinac Center for Public Policy, "Urban Sprawl" and the Michigan Landscape: A Market-Oriented Approach: <http://www.mackinac.org/article.asp?ID=763>

Western Resource Advocates, Urban Sprawl: <http://www.westernresourceadvocates.org/media/pdf/SWChapter4.pdf>

Contact Information

Xuan Liu
SEMCOG, Data Center Coordinator
E-mail Address: liu@semCog.org

Jim Rogers
SEMCOG, Data Center Manager
E-mail Address: rogers@semCog.org

INDICATOR: LAND USE CHANGE IN SOUTHEAST MICHIGAN

Background

The history of land use in southeast Michigan begins along the Detroit River. In the early 1700s, Antoine de la Mothe Cadillac established a military post along the waterway to advance French control of the fur trade. The land was seen as a secondary asset compared to the river which allowed military activities and easier transport of trade goods. The expansion of urban development began in earnest in the early 1800s when significant changes occurred in transportation methods. At that time, the waterfront was becoming lined with many docks to support the steamboats and ships containing goods of all kinds as Detroit became a center of commerce. The 1860s marked a decrease in water transport as an extensive network of railways were built. Recognized as a geographic center for population and business, Detroit was linked to the electric interurban railway system in the late nineteenth and early twentieth centuries. Since 1950, the region has experienced increases in urban area development and decreases in density due to the automobile.

Southeast Michigan is a major urban area with nearly five million people. Like many major urban areas throughout the United States, people in southeast Michigan began moving away from Detroit beginning in the 1950s seeking suburban areas with more space and within driving distance to their workplace as the suburbs developed. Personal automobiles and cheap fuel made this possible. In addition, federal tax subsidies for home mortgage interest and property taxes, as well as infrastructure financing policies, all supported new growth outside existing cities (SEMCOG 2003).

Different beliefs in private property rights and the role of government have emerged due to the rapid, new development outside the cities. Anti-sprawl or “Smart Growth” proponents are now advocating for denser, more walkable neighborhoods with a diversity of home designs and mass transit. Others see regulations on growth as infringing on private property rights and a challenge to economic consumer demand. The 2001 Detroit Area Study found that 70% of respondents to a survey preferred the suburban auto-oriented neighborhood instead of one that was more walkable and transit-oriented (SEMCOG 2003). The effects of current sprawl are realized in increased housing prices, decreased water quality, need for additional infrastructure and transportation, loss of open space and natural habitat, and decreasing tax revenues in older communities.

The Southeast Michigan Council of Governments (SEMCOG) has identified four factors contributing to current land use trends:

- Population
- Households
- Employment
- Income

Population has continually increased in southeast Michigan and this affects how land is used. Recently, there has been an increase of 67,000 people between 2000 and 2006 which contributes to an increase in demand for housing and business infrastructure (SEMCOG 2006a). However, it is not only the increase in population that controls land development. More importantly, it is the increasing number and size of houses. This means that about the same number of people are occupying more houses, and every additional house is consuming more land. The demand for larger homes on more land is made possible because more jobs have been created, thus increasing average income. Fewer people on average are living in each house and this is primarily due to the decrease in the number of children being born. The number of people in each house decreased with an average of 2.66 people per house in 1990 decreasing to 2.58 in 2000 (SEMCOG 2003).

Status and Trends

Very early land use changes started at the riverfront in the early 1800s as large docking structures for holding ferries and steamboats were constructed. By the late 1800s, docks lined five miles of riverfront (Kerr et al. 2003).

By the 1890s, Detroit's role changed from a commercial city with an even diversity of wholesale trading and retailing to one of heavy industrial manufacturing. At this time, convenient transportation was available with new electric horsecar lines, steam railroads, and steam-powered boats. This resulted in dense urban development that grew up around public transport.

A very significant change in land development occurred in the first half of the twentieth century (Figure 1). A new transportation revolution began about 1920 as the number of people owning automobiles increased dramatically. There were 54,366 registered motor vehicles in 1913 and 989,010 in 1925 in the state of Michigan (U.S. Census Bureau 1926). Development was no longer focused around rail lines as paved roads were built throughout the region. The urbanized area increased from 1.5% in 1890 to 9% in 1950 (SEMCOG 2001). Freeways and more affordable automobiles made transportation cheap and encouraged urban growth.

Agriculture in southeast Michigan peaked between 1880 and 1900 and has decreased since 1910 (USGS 2003). More recent land use changes in southeast Michigan are evident in our rapid transformation of agricultural areas and open space to low density residential, commercial, and business developments (Norris et al. 2002). The rate of residential land development continues to increase because of a greater demand for new, lower density housing.

Each house is consuming more land. Between 1990 and 2000, the amount of land used for homes increased by 19%, while the number of households only grew by 9% (SEMCOG 2001 and 2003). Prior to 1990, there were 2.84 housing units per acre, but this has decreased to an average of 1.26 after 1990 (SEMCOG 2003). This increase in the amount of land used for each house is significant because it accounts for 43% more land developed than would have been with the higher-density construction before 1990.

The demand for housing development is not the only reason for the decrease in agricultural land. Some land previously farmed is no longer used since farming is

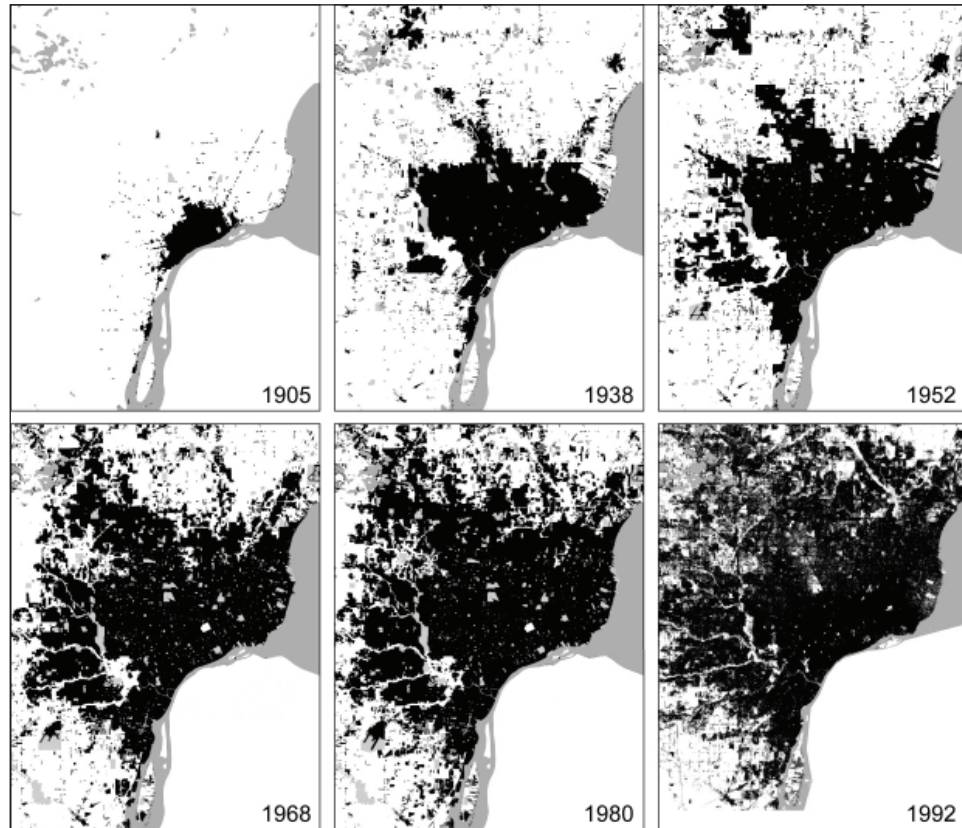


Figure 1. The history of developed land in southeast Michigan, 1905-1992 (USGS 2003). This image shows the general rate of urban land growth in southeast Michigan through the twentieth century where the shaded areas represent area covered by “urban or built up land” according to Anderson et al. (1976).

generally becoming less profitable, especially for small farms where operating costs are high compared with revenue. The overall decrease has been a loss of 13% or 56,980 hectares (140,800 acres) of agricultural land between 1990 and 2000 (SEMCOG 2003).

Not only have the total number of households and residential space increased in southeast Michigan, but the pattern of development has changed substantially with out-migration from Detroit to suburbs. This pattern of out-migration has generally led to less investment in established infrastructure that has resulted in lower property values, further encouraging people to leave. Today, Detroit’s population is about half of what it boasted during its peak in the 1950s. Detroit has experienced a 7% decrease in population between 1990 and 2000, creating more vacant land (SEMCOG 2003). It is estimated that 12% of the suburban housing development in southeast Michigan is due to households relocating from Detroit (SEMCOG 2003).

Changes in other types of land use, including industrial, extractive, and roadways were not as significant in the last few decades compared to residential development. Industrial land development over the last decade has increased by 4,218 hectares (10,423 acres) (SEMCOG 2004). This represented a 15% increase from 1990 to 2000. Between 1996 and 2005, general nonresidential development showed a peak between the years 1998 and 2002. An average of 250,838 square meters (2.7 million square feet) of development occurred during those five years compared with an average of 16 million for 1996, 1997, 2003, 2004, and completed projects in 2005 (SEMCOG 2006b).

In 1990, there were 936,700 acres of developed land and two million acres of undeveloped land. In 2000, there were 1.1 million acres of developed land and 1.8 million acres of undeveloped land (SEMCOG 2003).

Management Next Steps

Future land use planning must balance the need for environmental protection, economic progress, and human development. There is a need for well-defined roles and responsibilities in land use planning at all government levels under a common future vision (Norris et al. 2002). This can be done by establishing concrete regional goals, specific responsibilities for each level of government, and empowering local governments with the best available information (Michigan Land Use Leadership Council 2003). To carry out their responsibilities, local land use decision makers have a number of training resources available to them. The Planning and Zoning Center at Michigan State University, the Michigan Association of Planning (MAP), and Michigan State University Extension offer training sessions for planning officials. The Michigan Municipal League (MML) and the Michigan Townships Association (MTA) provide advice to elected officials. In addition, the Michigan Land Use Leadership Council (2003) has constructed nine recommended actions that serve to guide future decisions in the state. In summary, these recommendations include preserving farmland and open space by incorporating new incentives for landowners, encouraging partnerships with universities, foundations, and private and public entities, and clearly defining the allocation of funds in possible use of state bonds. More emphasis needs to be placed on developing model ordinances for sustainable land use practices. These model ordinances should be broadly disseminated throughout southeast Michigan.

Regional land use trends and programs need to be systematically evaluated and benefits assessed to help communities directly connect cost-efficiency and land use decisions (American Forests 2006). The Urban Dynamics Research Program was created by the U.S. Geological Survey to aid community decision makers in managing urban sprawl. Its focus is modeling land use change with respect to population growth. The National Science Foundation sponsors a Biocomplexity and Environment Program, one project being Project SLUCE (Spatial Land Use Change and Ecological Effects). From 2001 to 2006, researchers based at the University of Michigan investigated land use change at the urban-rural fringe and the environmental interactions and impacts using models. Their research focused on southeast Michigan and, ultimately, they want to be able to use their models to evaluate the potential for specific government interventions in creating better land use choices. An important first step for many communities is to implement a master or comprehensive plan.

Research/Monitoring Needs

Agricultural land and open space is currently changing most rapidly. The value of agricultural land in maintaining biodiversity across the landscape is well established. Therefore, research must focus on alternatives to the current rate of development because it is unsustainable. Land is being transformed from rural to urban faster than the population is growing and the negative impacts on the environment are real. Future research needs include inventorying land use models and assessing their accuracy at predicting what actually will occur on the land. Others include understanding ecosystem

response to current development patterns. There is also a growing need to evaluate the ecosystem response of different land use practices and its impact on climate (U.S. Climate Change Science Program 2003). Continued research is needed in sustainable, best management practices for urban areas. In addition, research in cover crops, those that improve soil quality and farming sustainability, will better equip farmers with tools for managing their farms for profit and sustainability. Finally, emphasis must be placed on quantifying economic, environmental, and societal benefits of best management practices in land use planning and management. Such benefits assessment can be compelling rationale for sound land use decision making.

References

- American Forests. May 2006. Urban ecosystem analysis, SE Michigan and City of Detroit: Calculating the value of nature. http://www.americanforests.org/downloads/rea/AF_Detroit.pdf (December 2006).
- Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. Washington, DC: United States Government Printing Office.
- Kerr, J.K., W.S. Olinek, and J.H. Hartig. 2003. The Detroit River as an artery of trade and commerce. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 35-47. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Michigan Land Use Leadership Council. 2003. *Michigan's Land, Michigan's Future: Final Report of the Michigan Land Use Leadership Council*. <http://www.michiganlanduse.org/finalreport.htm> (March 2007).
- Norris, P.E., J. Soule, C. Weissert, S. Gage, and D. Skole. 2002. Michigan's Opportunities and Challenges: MSU Faculty Perspectives. <http://web1.msue.msu.edu/iac/transition/papers/ManLandUse.pdf>
- [SEMCOG] Southeast Michigan Council of Governments. 2001. 2030 Regional development forecast for southeast Michigan: Population, households, and jobs, for cities, villages, and townships, 1990-2030.
- [SEMCOG] Southeast Michigan Council of Governments. 2003. Land use change in southeast Michigan: Causes and consequences.
- [SEMCOG] Southeast Michigan Council of Governments. 2004. *Land Use in Southeast Michigan, Regional Summary, 1990-2000*.
- [SEMCOG] Southeast Michigan Council of Governments. 2006a. Population and household estimates for southeast Michigan.
- [SEMCOG] Southeast Michigan Council of Governments. 2006b. Nonresidential development in southeast Michigan, Summary 2005.
- United States Climate Change Science Program. July 2003. *Strategic Plan for the Climate Change Science Program Final Report*. <http://www.climatechange.gov/Library/stratplan2003/final/ccspstratplan2003-chap6.htm> (December 2006).

United States Census Bureau. 1926. Statistical Abstract of the United States 1925. Forty Eighth Number. Government Printing Office.

[USGS] United States Geological Survey. 2003. Detroit River corridor, preliminary assessment of land use change. Lora Richards. Urban Dynamics Research Program.

Links for More Information

Michigan Land Use Institute: <http://www.mlui.org>

Michigan Land Use Leadership Council: <http://www.michiganlanduse.org/>

Michigan State University Extension – Home page for Kurt Schindler’s land use page: http://www.msue.msu.edu/portal/default.cfm?pageset_id=160691

People and Land: <http://www.peopleandland.org/>

Project SLUCE Biocomplexity Program: <http://www.cscs.umich.edu/research/projects/sluce/>

Southeast Michigan Council of Governments: <http://www.semcog.org/>

Contact Information

Xuan Liu
SEMCOG, Data Center Coordinator
E-mail Address: liu@semcog.org

Jim Rogers
SEMCOG, Data Center Manager
E-mail Address: rogers@semcog.org

INDICATOR: TRANSPORTATION TRENDS IN SOUTHEAST MICHIGAN

Background

In the 1950s, people began moving out of the city of Detroit with the ease of owning an automobile. This pattern of people moving out of the city to the surrounding suburbs created a longer commute. The greater number of people driving to work every morning creates an environmental stressor with additional road construction, air pollution, and the overuse of natural resources, such as petroleum (Figure 1). Before the 1950s many people in Detroit walked or rode the bus to work. In 2004 the southeast Michigan transportation system had a total of:



Figure 1. I-75 photo taken from the bridge on Ferry Street in Detroit, MI (Photo credit: Southeast Michigan Council of Governments).

- 4 million registered vehicles;
- 36,693 kilometers (22,800 miles) of public, state and county roads;
- 164,900 automobile accidents;
- 1,156 kilometers (718 miles) of pedestrian and bicycle pathways;
- six marine ports;
- 30 airports;
- 1,473 kilometers (915 miles) of active rail; and
- 3,560 bridges (SEMCOG 2004).

Status and Trends

In general, travel time to work and the distance to work have increased, and personal vehicle use (instead of mass transit) has increased for southeast Michigan. The population trends from this area, viewed in the Human Population Trends and Distribution in Southeast Michigan

indicator report, should be taken into account when viewing these travel transportation data. As the suburban population increases, commuter time will also increase. From 1980 to 2000, residents of southeast Michigan continued to make longer commutes to get to their workplace and the distance traveled to work increased (Figure 2).

The number of people driving personal vehicles (i.e., cars, trucks, and vans) to work has nearly doubled between 1960 and 2000 (Figure 3). Not only is it taking more time to drive to the workplace, residents are more often driving alone. In 1980, approximately 1.7 million people drove to work alone. Ten years later, over 1.9 million people drove to work alone (U.S. Census Bureau). This means that in 10 years, approximately 200,000 more people were driving to work alone in southeast Michigan, increasing air pollution and traffic congestion.

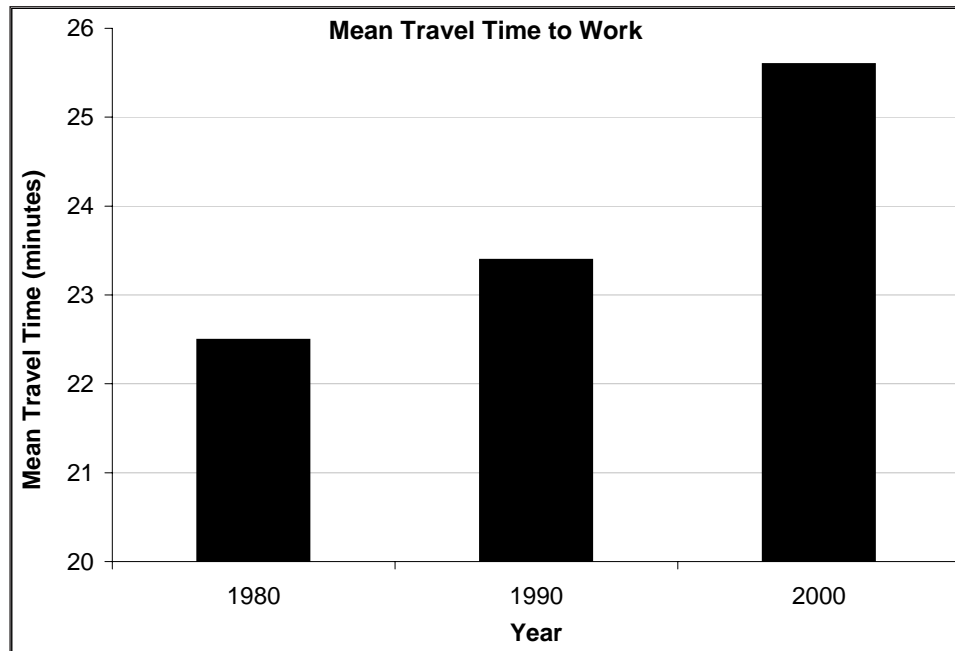


Figure 2. Mean travel time to work in southeast Michigan, 1980-2000, U.S. Census Bureau.

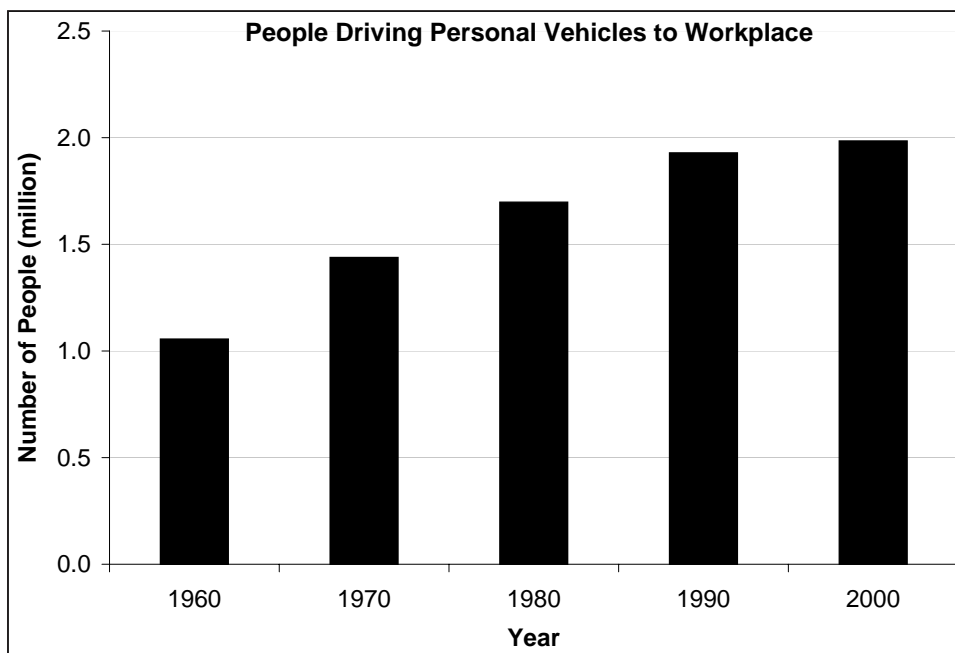


Figure 3. Number of people driving personal vehicles to work in southeast Michigan, 1960-2000, U.S. Census Bureau.

In contrast, the use of mass transit has greatly decreased (Figure 4). This trend is likely due to economics and limited availability and reliability of a mass transit system. In the greater Detroit area there is currently no widespread, easy-to-use, and reliable mass transit system.

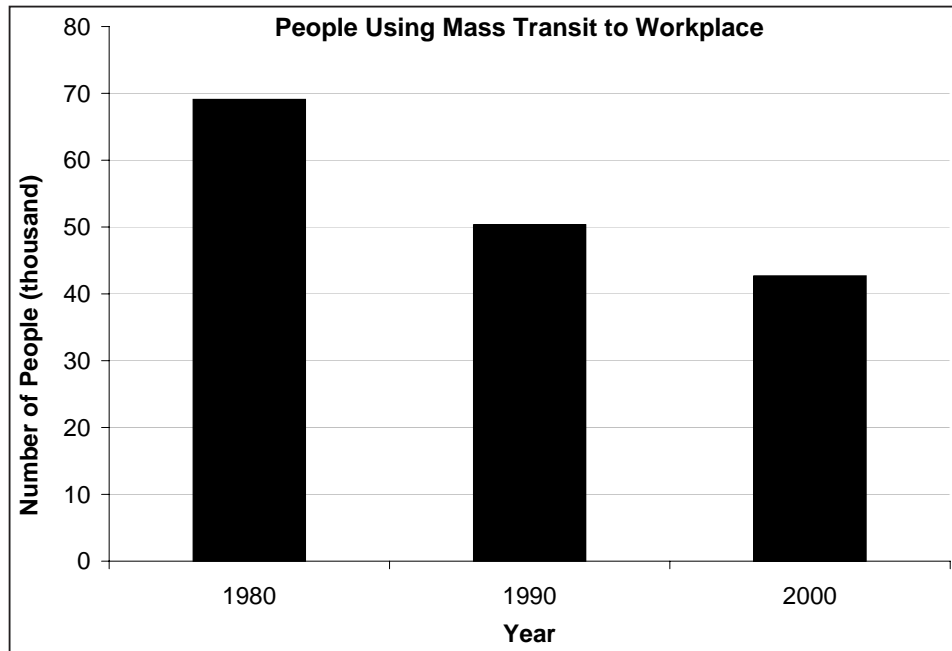


Figure 4. Number of people who use mass transit to get to work in southeast Michigan, 1980-2000, U.S. Census Bureau.

Management Next Steps

Southeast Michigan Council of Governments (SEMCOG 2004) forecasts that by 2030, there will be a 12% increase in population, 21% increase in households, and 16% increase in jobs. Roads and bridges throughout southeast Michigan are going to continue to age and deteriorate. In response, the region needs to continue to improve its regional transit system, emphasize the use of greenways, and increase carpooling (e.g., using the RideShare program organized by SEMCOG) to and from work throughout the region. Sharing a ride:

- cuts commuting costs;
- alleviates congestion by removing cars from the road;
- reduces stress; and
- improves air quality (SEMCOG 2005).

Forecasting models, such as the regional Travel Demand Forecasting Model (TDFM) implemented by SEMCOG, quantify the amount of travel expected to take place on the region's transportation system. Such models should be used by agencies and corporations to improve planning and management of our future transportation needs.

Greater emphasis needs to be placed on providing an effective mass transit system that is reliable, safe, accessible, and cost-effective. More people need to be encouraged to take public transit, or walk or bike to work. Mass transit systems should be increased, especially between cities such as Ann Arbor and Detroit, and other lines coming into Detroit from the north and south. Improved mass transit will:

- help keep the region economically competitive;

- provide a higher quality of life;
- help alleviate road congestion;
- help lessen air pollution and improve air quality; and
- serve those who cannot or choose not to drive (SEMCOG 2004).

Distinct transportation policies and initiatives designed to guide further progress toward stated goals and objectives, and ultimately enhance our regional transportation system, are set out in the *2030 Regional Transportation Plan (RTP) for Southeast Michigan* (SEMCOG 2004). The policies, initiatives, and projects outlined in the 2030 RTP comprise an aggressive, long-range vision for the region. A regional traffic operations committee should be established to oversee all activities designed to increase efficiency of the road network. No single agency can be responsible for implementing this vision; it requires coordination among many agencies, government units, special interest groups, and the general public (SEMCOG 2004). SEMCOG is responsible for bringing these parties together and making sure the RTP is implemented. The public should be kept informed about the progress of the RTP, which should be reviewed and updated in response to changing priorities.

Research/Monitoring Needs

Studies should be conducted on the environmental effects of southeast Michigan travel trends such as:

- monitoring changes in air pollution;
- monitoring noise pollution;
- fossil fuel consumption;
- habitat fragmentation; and
- road construction.

SEMCOG should continue to expand research on home-to-work commutes in southeast Michigan. Current data should be used to improve models, such as the TDFM, to make them more efficient in predicting estimated passengers on new routes, riders on new rapid transit lines, or responses to certain travel demand management policies (i.e., imposing higher parking fees). There should be additional research on the environmental effects of different modes of transportation.

References

[SEMCOG] Southeast Michigan Council of Governments. 2004. *2030 Regional Transportation Plan for Southeast Michigan*. <http://www.semco.org/TranPlan/RTP/index.htm>

[SEMCOG] Southeast Michigan Council of Governments. 2005. Conserve energy... RideShare. SEMscope.

Links for More Information

Southeast Michigan Council of Governments: www.semcog.org

Planes and Trains, Part II: <http://www.mlui.org/growthmanagement/fullarticle.asp?fileid=17015>

Detroit Regional Chamber, Transportation Central: <http://www.detroitchamber.com/centrals/index.asp?id=139>

Michigan Department of Transportation: <http://www.michigan.gov/mdot/>

SEMSCOPE, One day in southeast Michigan: <http://www.semcog.org/Products/pdfs/SEMScopeSpring2006.pdf>

A citizens' guide to transportation planning in southeast Michigan: <http://www.semcog.org/Products/pdfs/citizensguide2005.pdf>

SEMCOG, RideShare Program: <http://www.semcog.org/Services/CommuterPrograms/RideShare/index.htm>

A Summary of the 2030 Regional Transportation Plan for Southeast Michigan: http://www.semcog.org/TranPlan/RTP/assets/2030RTP_summary.pdf

Contact Information

Jennifer Evans
SEMCOG, Transportation Coordinator
E-mail Address: evans@semcog.org

INDICATOR: PHOSPHORUS LOADS AND CONCENTRATIONS FROM THE MAUMEE RIVER

Background

Lake Erie has a long history of accelerated cultural eutrophication. During the 1960s, algal blooms induced by excess nutrients led to oxygen depletion of deeper waters and caused fish kills. Phosphorus was judged to be the most readily controllable nutrient required for algal growth. Consequently, the U.S. and Canadian governments worked through the Great Lakes Water Quality Agreement to set an annual phosphorus target load of 11,000 metric tons to control water quality problems associated with phosphorus enrichment. This phosphorus control program called for controlling phosphorus from municipal wastewater treatment plants, agricultural and urban runoff, and cleaning agents and laundry detergents. The target load was met for the first time in 1981. Since then, the target has been met in most years. Nonpoint source loads, especially those from agriculture, vary greatly from year to year due to differences in weather (Figure 1).



Figure 1. Sediment loading from the Maumee River originating from agricultural nonpoint source inputs (Photo credit: NASA Landsat Program).

The Maumee River is the largest tributary to Lake Erie. Its watershed of more than 16,835 square kilometers (6,500 square miles) is located mostly in northwest Ohio, with smaller portions in eastern Indiana and southern Michigan. Water from the Maumee River enters Lake Erie's western basin at Toledo. The Maumee River is also the single largest source of phosphorus loading to Lake Erie, with the majority of the load coming from agriculture. More than 80% of the watershed is devoted to agricultural land uses. For more information about the Maumee River watershed, see Richards et al. (2002a).

The National Center for Water Quality Research (NCWQR) at Heidelberg College in Tiffin, Ohio has been monitoring water

quality in the Maumee River since 1975. The sampling station is located at the Bowling Green drinking water intake, near the USGS gaging station at Waterville, Ohio. Three samples per day are collected by an automatic sampler. The samples are collected weekly and returned to the Center's Water Quality Laboratory for analysis. During periods of low flow, one sample per day is analyzed; at other times, all three samples are analyzed. This program produces about 425 samples per year and provides the most detailed data for nutrient load determination available anywhere in the Great Lakes (www.heidelberg.edu/wql). Previous studies of water quality trends in the Maumee River are included in Richards (2006), Richards et al. (2002b), and Richards and Baker (2002).

Status and Trends

Annual loads of total phosphorus (TP) from the Maumee River are shown in Figure 2. There is a gap in the graph because of a lack of funding during 1979-1981. While weather-related annual variation in these loads is great and renders suspect any apparent short-term trends, there does appear to be a downward trend over the entire period of record, as indicated by the trendline. This trend does not achieve statistical significance ($p=0.065$), but it suggests a decrease in the annual loads of about 33% over the 30-year period of record. On average during this time, the Maumee River annual load to Lake Erie is about 19% of the estimated total annual load from all sources.

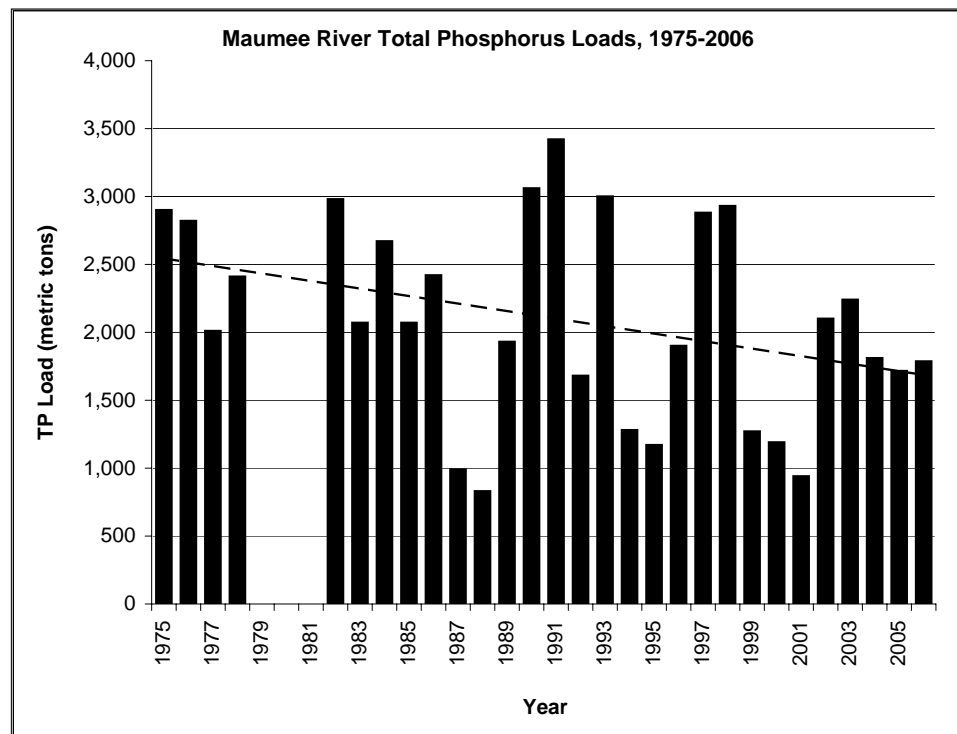


Figure 2. Total phosphorus loads in the Maumee River at Waterville, 1975-2006. The downward trend of about 33% is not statistically significant.

Dissolved reactive phosphorus (DRP) is that portion of total phosphorus that is readily available for algal and other plant growth. Typically about 10-30% of TP in the Maumee is DRP. DRP in the Maumee River has decreased approximately 10% over the period of record, but this trend is not statistically significant (Figure 3).

Although annual TP loads are the measure by which we evaluate success in managing inputs to Lake Erie, important information can also be obtained by examining trends in flow-weighted mean concentrations (FWMCs) of total phosphorus and of other forms of phosphorus. The FWMC is the load divided by the discharge. FWMC plots are prepared to make long-term trends more apparent.

The plot of TP FWMCs shows a 42% decrease over the period of record (Figure 4), similar to the plot of TP loads. However, this trend is statistically significant. The plot of DRP FWMCs (Figure 5) shows a 57% decrease between the early 1970s and early 1990s, and then an approximate 90% increase between the early 1990s and 2006.

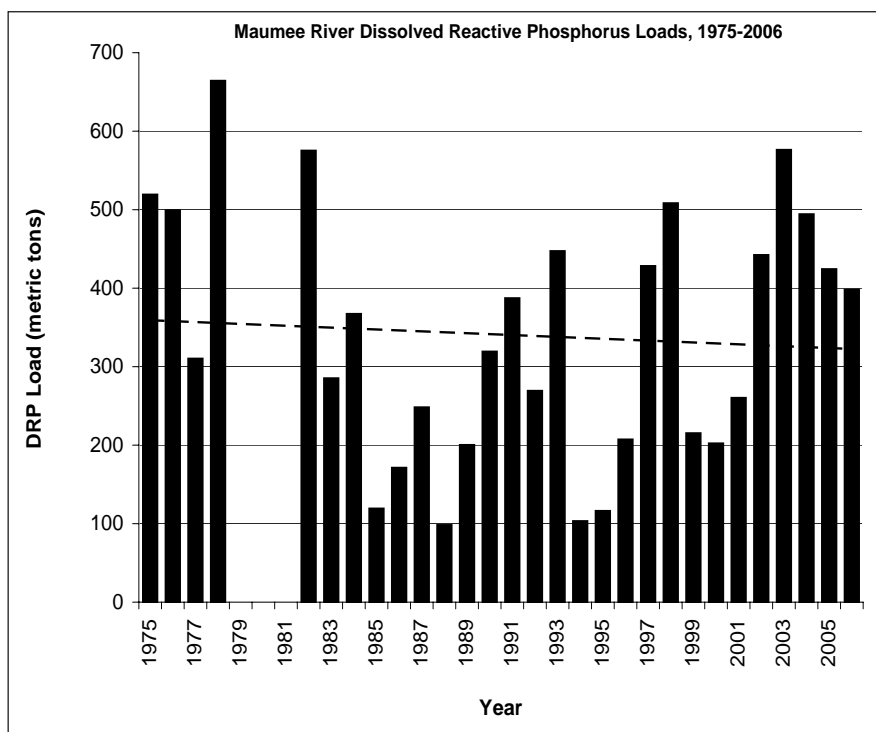


Figure 3. Dissolved reactive phosphorus loads in the Maumee River at Waterville, 1975-2006. The downward trend of about 10% is not statistically significant.

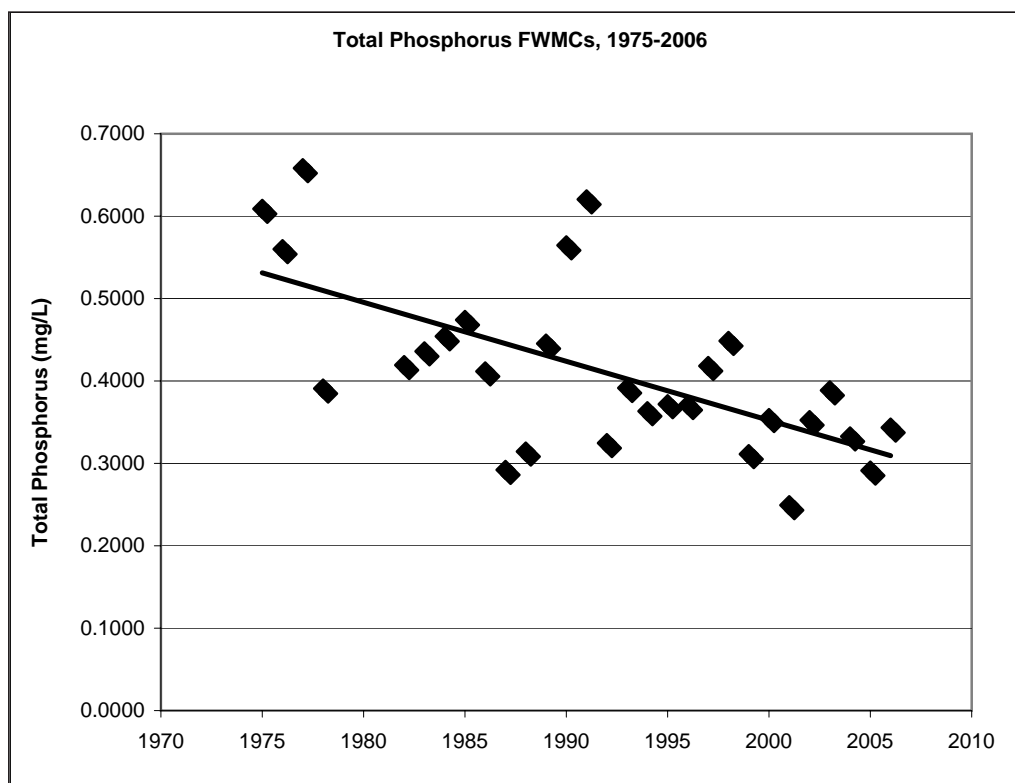


Figure 4. Total phosphorus annual flow-weighted mean concentrations for the Maumee River at Waterville, 1975-2006. The downward trend is highly significant and is a 42% decrease.

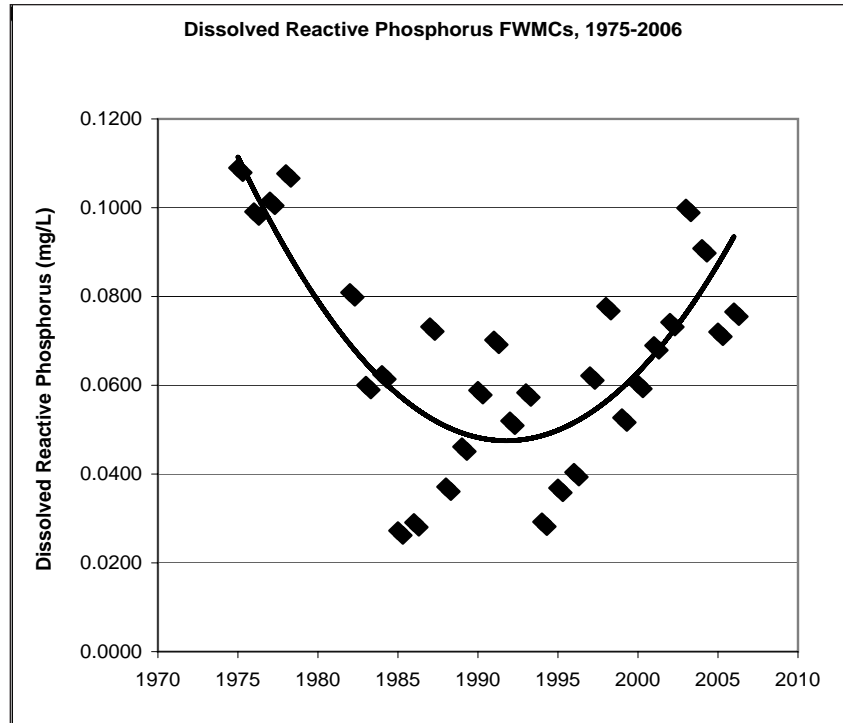


Figure 5. Dissolved reactive phosphorus annual flow-weighted mean concentrations for the Maumee River at Waterville, 1975-2006. The parabolic trend is highly significant and represents a decrease of 57% followed by an increase from the minimum of 94%.

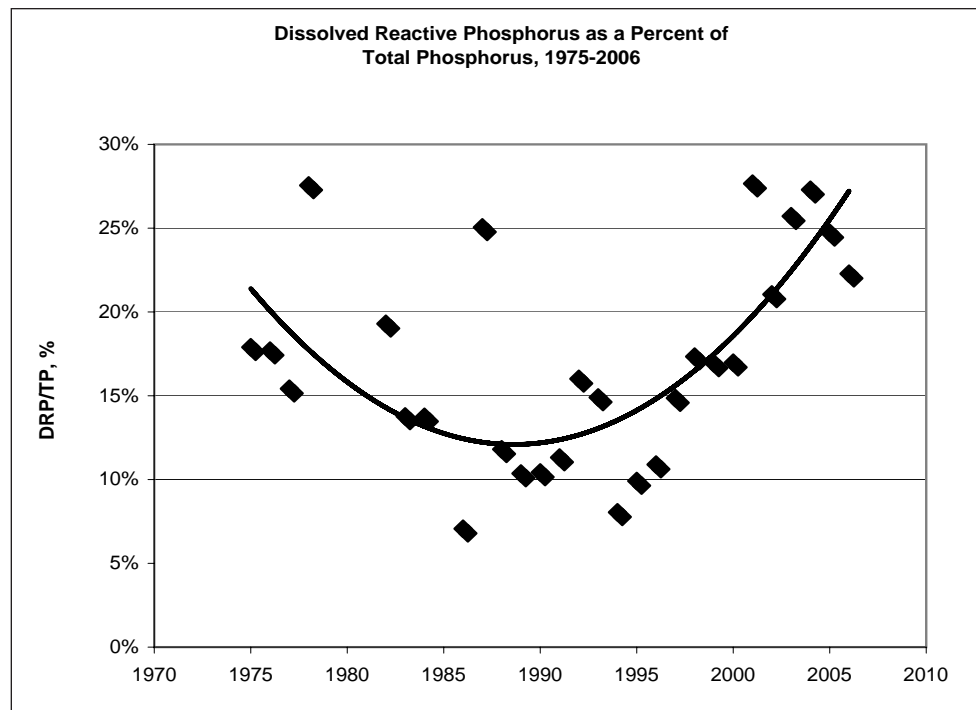


Figure 6. Dissolved reactive phosphorus as a percent of total phosphorus, annual values for the Maumee River at Waterville, 1975-2006. The parabolic trend is highly significant and represents a decrease of 57% followed by an increase from the minimum of 125%.

Figure 6 shows DRP as a percent of TP. The percentage of DRP in TP decreased from about 21% in the early 1970s to about 12% in 1989, then increased to 27% in recent years.

Finally, Figure 7 provides a plot of the difference between TP and DRP (TP-DRP). This estimates the portion of the TP that is attached to or contained in sediment particles, called particulate phosphorus (PP). PP is bound phosphorus that is only partly available to plant growth. Like TP, PP shows a statistically significant decrease of 45% over the period of record.

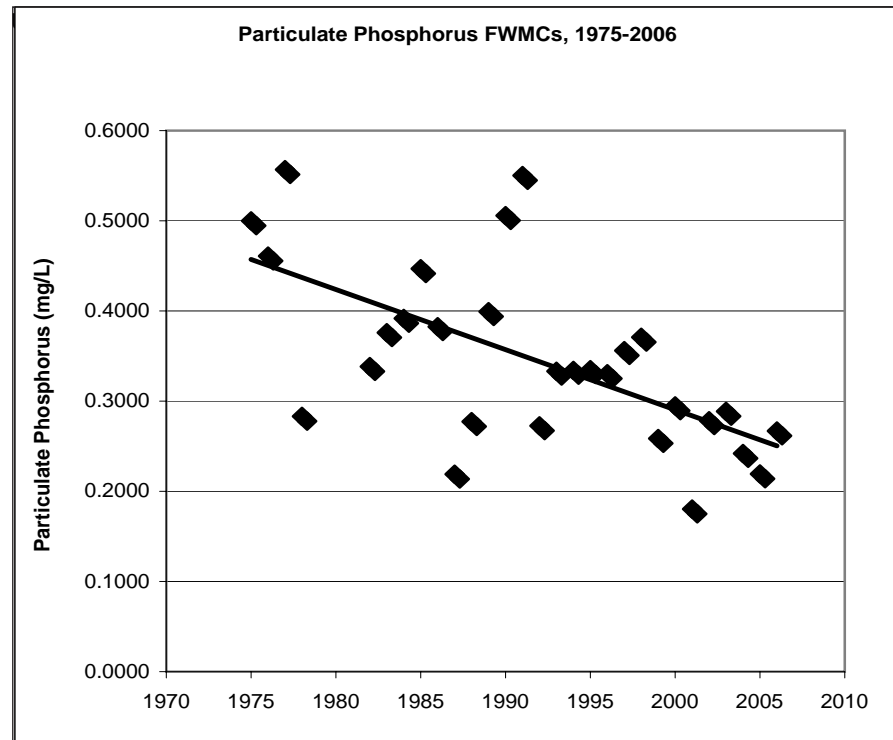


Figure 7. Particulate phosphorus annual flow-weighted mean concentrations for the Maumee River at Waterville, 1975-2006. The downward trend is highly significant and is a 45% decrease.

Decreases in phosphorus loads and concentrations are generally considered desirable, although some Lake Erie fisheries managers have expressed concern that overly large reductions might lead to reduced fish production. The downward trends seen in these data document the success of management efforts over the last three decades to control export of phosphorus into Lake Erie. The sharp increases in DRP in the last decade or so are troublesome, and reasons for these increases are unclear. Similar increases are seen in several other Lake Erie tributaries. Lake Erie has been showing signs of nutrient stress in the last decade, including increasing in-lake phosphorus concentrations in the spring, increased hypoxia in the central basin in the summer, and increased abundance of nuisance algae such as *Cladophora* and noxious cyanobacteria such as *Microcystis*. While some researchers have pointed to zebra mussels and their impact on lake ecosystems as the cause of these problems, increased DRP loadings from the tributaries must also be considered.

Management Next Steps

Efforts are needed to reverse the trend toward increasing dissolved reactive phosphorus. The cause or causes of the increasing trend are not clear at this time, but a number of management actions could be taken that will contribute to reductions in DRP. These include:

- improved fertilizer/manure management, especially with no-till agriculture, to minimize enrichment of phosphorus in the surface layer of the soil;
- improvements in the regulation and management of liquid manures from concentrated animal operations;
- use of cover crops in the winter to tie up nutrients and protect the soil;
- reductions in fall fertilization and spreading of manure in fall and winter, especially in the absence of cover crops;
- incorporation of fertilizer/manure into the soil rather than surface application;
- continued reductions in sewage treatment plant effluent concentrations to counter human population growth in the basin;
- reduction or elimination of combined sewer overflows and sewage bypasses;
- improvements in the functioning of home septic systems and small-scale treatment systems;
- elimination of direct connections of rural home septic systems into agricultural drain tiles and ditches;
- improved management of urban nonpoint runoff; and
- reduction or elimination of phosphorus from lawn fertilizers.

The causes of major changes in nutrient status that have occurred in Lake Erie in recent years are poorly understood, but it is clear that management programs, research, and monitoring must be sustained and closely coupled in order to achieve management goals for the Detroit River and Lake Erie.

Research/Monitoring Needs

Major budgetary cuts have occurred in monitoring and research for the Lake Erie tributaries. The collection and interpretation of water quality data, on which we base our current knowledge of phosphorus in the Maumee River and Lake Erie, is a program of the National Center for Water Quality Research. While this program continues without reductions, it is in constant jeopardy of being cut or eliminated. Without it, estimates of total annual phosphorus loads for Lake Erie, the basic yardstick by which we assess success in managing Lake Erie, will not be possible (Dave Dolan, Natural and Applied Sciences at University of Wisconsin-Green Bay, personal communication 2004). This critical program needs to be continued, and should be funded on a permanent basis.

Research is needed to determine the cause or causes of increased dissolved reactive phosphorus in the Lake Erie tributaries, and to determine the importance of these increases as a possible cause of renewed problems in Lake Erie itself.

Research is also needed to better understand the linkages between the tributaries and the lake. How are tributary phosphorus loads modified by their passage through embayments and the nearshore zone? Are loadings in certain seasons more important to Lake Erie than those in other seasons?

And finally, research is needed to better understand the relationships between total phosphorus and dissolved reactive phosphorus, and the reasons that this relationship has changed over time (at least in the tributaries). How much of the total phosphorus that enters the lake from the tributaries is taken up by algae and other primary producers, and over what time scale? Would we understand the lake better if we built our concepts and models around dissolved reactive phosphorus rather than total phosphorus?

References

Richards, R.P. 2006. Section 10.10. Trends in sediment and nutrients in major Lake Erie tributaries, 1975-2004. In *Lake Erie Lakewide Management Plan 2006 Update*. www.epa.gov/glnpo/lakeerie/2006update/index.html

Richards, R.P., F.G. Calhoun, and G. Matisoff. 2002a. The Lake Erie Agricultural Systems for Environmental Quality project: An introduction. *Journal of Environmental Quality* 31:6-16.

Richards, R.P., D.B. Baker, and D.J. Eckert. 2002b. Trends in agriculture in the LEASEQ watersheds, 1975-1995. *Journal of Environmental Quality* 31:17-24.

Richards, R.P., and D.B. Baker. 2002. Trends in water quality in LEASEQ rivers and streams, 1975-1995. *Journal of Environmental Quality* 31:90-96.

Links for More Information

National Center for Water Quality Research: <http://www.heidelberg.edu/WQL>

Contact Information

R. Peter Richards
Senior Research Scientist
Heidelberg College
National Center for Water Quality Research
E-mail Address: prichard@heidelberg.edu

INDICATOR: MICHIGAN'S CARBON EMISSIONS

Background

Water vapor, carbon dioxide, and other gases in the Earth's atmosphere trap some of the sun's heat close to the surface, creating a natural "greenhouse" that permits life to flourish. Without these gases the Earth would be too cold for life to survive. In the last 50 years, however, human activities have increased the concentration of these greenhouse gases in the atmosphere, trapping more of the sun's heat close to the Earth's surface. The heat-trapping properties of carbon dioxide, methane, nitrous oxide, water vapor and other greenhouse gases in the Earth's atmosphere is undeniable, but uncertainty remains as to precisely how the Earth's climate will respond to increased levels of greenhouse gases.

Evidence continues to build that accelerated warming of the Earth's surface temperature has occurred during the past two decades and that this warming is attributed to human activities that have increased the levels of greenhouse gases. These human activities include the burning of fossil fuels to run cars and trucks, heat homes and businesses, power factories, and to run equipment for agriculture, logging, and mining. Since pre-industrial times, atmospheric concentrations of carbon dioxide have increased by 35%, atmospheric levels of methane have increased by 150%, and atmospheric levels of nitrous oxide have increased by 18% (EPA 2006). These increases in greenhouse gases have enhanced the heat-trapping capability of the Earth's atmosphere.

Status and Trends

Human activities over the last century (primarily the burning of fossil fuels) have changed the composition of the atmosphere in ways that threaten to dramatically alter the climate in years to come. The U.S. is the largest worldwide contributor of carbon dioxide – the primary greenhouse gas. The U.S. Public Interest Research Group (U.S. PIRG) Education Fund (2006) has recently reported on carbon emission trends over four decades spanning 1960 to 2001 (data were compiled by the Oak Ridge National Laboratory). Key findings from the U.S. PIRG (2006) study include:

- between 1960 and 2001, U.S. emissions of carbon dioxide doubled, jumping from 2.9 billion metric tons of carbon dioxide in 1960 to almost 5.7 billion metric tons in 2001, an increase of 95%;
- in the 1990s, carbon dioxide emissions grew more quickly than in the 1970s and 1980s, increasing steadily at an average rate of 1.5% per year; and
- among the states, Michigan ranked ninth in 2001, releasing 189.1 million metric tons of carbon dioxide.

Between 1960 and 2001, Michigan's carbon emissions from fossil fuel combustion increased by 59.7 million metric tons (Table 1). This represented a 46% increase over four decades.

A dramatic increase in greenhouse gas emissions from the transportation sector and energy sector (primarily coal combustion) fueled the national increase in carbon emissions between 1960 and 2001 (U.S. PIRG 2006). For example, carbon dioxide emissions from oil combustion jumped 1.1 billion metric tons between 1960 and 2001, accounting for 40% of the total increase in U.S. carbon emissions. The transportation sector primarily drove this increase. Carbon dioxide emissions from coal also climbed 1.1 billion metric tons between 1960 and 2001, accounting for another 40% of the total increase in U.S. carbon emissions. Increased electricity generation from coal-fired power plants primarily fueled this rapid growth.

Table 1. Trends in Michigan's carbon dioxide emissions (million metric tons per year) from fossil fuel combustion, 1960-2001 (U.S. PIRG 2006).

Year	1960	1970	1980	1990	2001
Michigan's CO ₂ Emissions (million metric tons per year)	129.4	185.9	179.4	180.1	189.1

Management Next Steps

Action is occurring at every level to reduce, avoid, and better understand the risks associated with climate change. Many cities and states across the country have prepared greenhouse gas inventories; and many are actively pursuing programs and policies that will result in greenhouse gas emission reductions.

At the national level, the U.S. Global Change Research Program (www.usgcrp.gov) coordinates the world's most extensive research effort on climate change. Federal agencies are actively engaging the private sector, states, and localities in partnerships based on a win-win philosophy aimed at addressing the challenge of global warming while, at the same time, strengthening the economy. For more information, see the U.S. Climate Action Report (<http://www.gcric.org/CAR2002/>).

At the global level, countries around the world have expressed a firm commitment to strengthening international responses to the risks of climate change. The U.S. is working to strengthen international action and broaden participation under the auspices of the United Nations Framework Convention on Climate Change (<http://unfccc.int/2860.php>).

Key elements of a carbon emission reduction action plan identified by U.S. PIRG (2006) include:

- establishing targets for reduction of carbon dioxide and other greenhouse gases; and
- reducing U.S. dependence on fossil fuels by making homes and businesses more energy efficient, making cars and sport utility vehicles (SUVs) go farther on a gallon of gasoline, and generating more electricity from renewable energy sources.

Research/Monitoring Needs

Research should be conducted to address the following:

- improve computer modeling to give scientists more confidence about their projections of the global warming impacts on a large scale (e.g., global temperature, precipitation changes, ecosystem impacts) and small scale (e.g., local temperature, precipitation changes, ecosystem impacts);
- determine if global warming could lead to more frequent and intense storm events; and
- investigate the link between El Niño events (the periodic warming of the equatorial Pacific Ocean) and global warming.

References

[U.S. PIRG] U.S. Public Interest Research Group Education Fund. 2006. *The Carbon Boom: National and State Trends in Carbon Dioxide Emissions since 1960*. Washington, DC.

[EPA] Environmental Protection Agency. 2006. Climate Change – Science. Atmosphere Changes. <http://www.epa.gov/climatechange/science/recentac.html>

Links for More Information

U.S. Environmental Protection Agency's – Global Warming: <http://epa.gov/climatechange/index.html>

Union of Concerned Scientists – Global Warming: http://www.ucsusa.org/global_warming/

Contact Information

Audrie Washington
Energy Star Program Manager
U.S. Environmental Protection Agency
E-mail Address: washington.audrie@epa.gov

INDICATOR: OIL POLLUTION OF THE DETROIT AND ROUGE RIVERS

Background

Industrial pollution of the Detroit and Rouge rivers dates back to the end of the nineteenth century. However, the problem did not become a priority until the late 1940s when oil pollution resulted in massive winter duck kills (Hartig and Stafford 2003). Historically, the lower half of the Detroit River froze from bank-to-bank during the winter. The southward spread of industry resulted in effluent along the western banks of the river which caused it to warm in pockets, leaving small patches of open water by the mid-1930s (Miller and Whitlock 1948). The lower half of the river is distinct from the upper half in that it is divided and separated with shoals and islands, which provide an increased abundance of food for waterfowl (Hartig and Stafford 2003). The combination of open water and food availability soon provided resting and feeding grounds for migrant waterfowl, which began to spend most or all of winter in these areas. However, given their proximity to the industries, the open patches of water also contained high concentrations of oil. The result was waterfowl mortality which occurred in varying degrees beginning in the mid-1930s. Oil spills continue to occur, including the largest oil spill in the Great Lakes in the last twelve years that occurred in 2002 (Figure 1).



Figure 1. Oil spill on the Rouge River in 2002
(Photo credit: U.S. Coast Guard, Sector Detroit).

Waterfowl are affected by oil in a number of ways. External feather oiling causes loss of buoyancy which can result in drowning (Michigan Department of Natural Resources 2005). In addition, feather insulating properties are lost when feathers become matted (Figure 2), which can result in death due to exposure of the skin to cold water (Hartig and Stafford 2003). Reduced swimming or flying mobility may result in starvation. Ingestion of oil can result in internal pathological changes, causing sickness and/or mortality. If eggs are contaminated, the result is decreased hatchability and increased embryonic mortality (Michigan Department of Natural Resources 2005).



Figure 2. Oil-soaked ducks from the lower Detroit River brought to the Michigan Capitol to protest oil pollution in 1948 (Photo credit: State Archives of Michigan).

In years of heavy ice cover, the impact of oil on waterfowl was magnified due to limited availability of open water (Hartig and Stafford 2003). In 1948 the situation climaxed when approximately 11,000 ducks were killed due to oil pollution in the Detroit River (Table 1). Sportsmen were outraged and collected the oil-soaked waterfowl and put them on the lawn of the State Capitol building in Lansing, in hopes that policymakers would address the overlooked issue (Cowles 1975). This event marked the commencement of industrial pollution control programs in Michigan.

Table 1. Waterfowl mortality in the Detroit River due primarily to oil pollution (Hartig and Stifler 1979; U.S. Department of Health, Education, and Welfare 1962).

Year	Estimated Waterfowl Mortality
1948	11,000
1949	76
1950	871
1951	250
1952	1,000
1953	345
1954	238
1955	2,600
1956	191
1960	12,000
1967	5,400

Status and Trends

A series of relevant legislative events followed the massive 1948 winter duck kill. In 1949, the Michigan legislature amended the water pollution control statute to establish the Michigan Water Resources Commission (Cowles 1975). In addition, the definition of pollution was broadened and state approval was required for all new uses of state waters. However, oil slicks were still reported on the Detroit River approximately one-third of the time during winter and spring between 1950 and 1955 by the U.S. Department of Health, Education, and Welfare (1962).

Other sources of oil pollution in the Detroit River not associated with industrial activities were soon recognized. Some of these include municipal wastewater treatment plants, government installations, combined sewer overflows, and shipping (International Joint Commission 1968). As these sources were identified, pollution control efforts became increasingly effective. According to the U.S. Department of Health, Education, and Welfare (1962), there was a 97.5% reduction in oil discharges to the Detroit River between the late 1940s and early 1960s (Figure 3). The Michigan Department of Natural Resources (1977) reported that there was an additional 80% decrease in point source discharges of oil between 1963 and 1976. As would be predicted, winter duck kills associated with oil pollution also decreased dramatically.

Nevertheless, recent data collected by the U.S. Coast Guard National Response Center (2005) indicate that there are still years in which total volume of oil and other petroleum products spilled in the Detroit and Rouge rivers is comparable to estimated oil releases in 1961 (Figure 4). In April 2002, a 378,541 liter (100,000 gallon) oil spill occurred in the

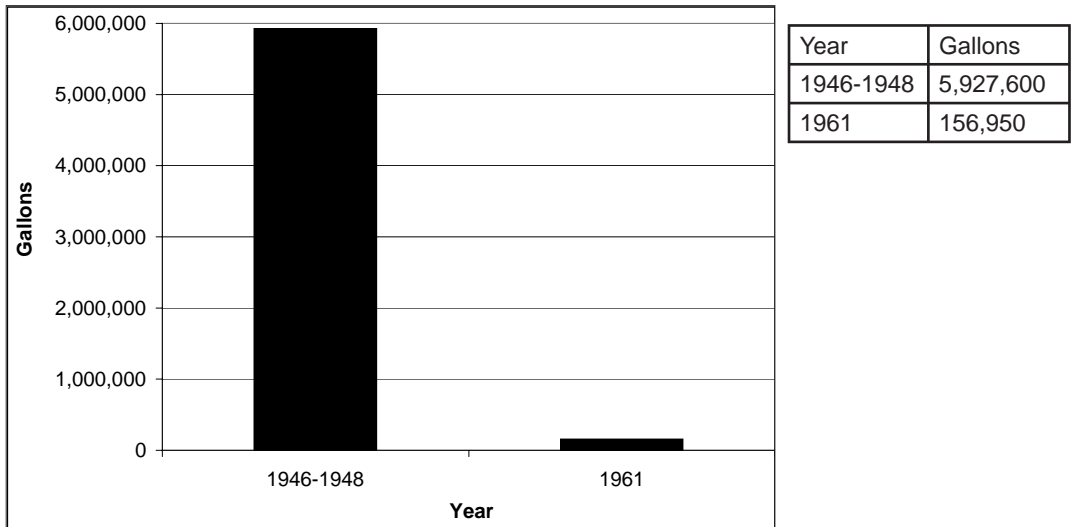


Figure 3. Total volume of oil/other petroleum products spilled in the Detroit River in gallons per year (1946-1948 and 1961). Note: One gallon = 3.79 liters.

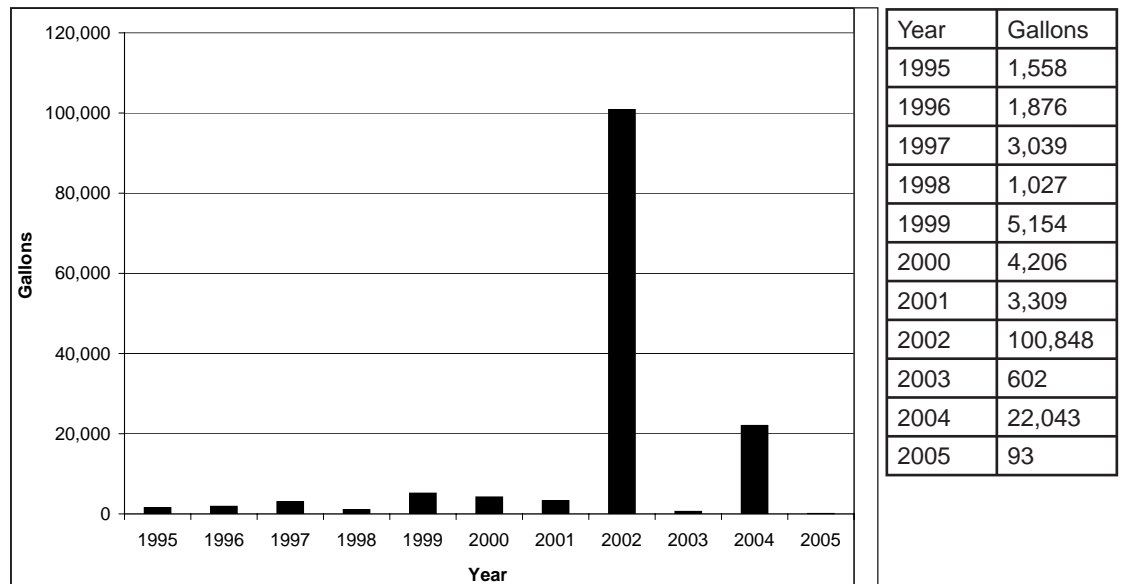


Figure 4. Total volume of oil/other petroleum products spilled in the Detroit River in gallons per year (1995-2005). Note: One gallon = 3.79 liters.

Rouge River. The U.S. Coast Guard and other governmental and industrial partners undertook a \$7.5 million cleanup on 27 miles of the lower Rouge River and U.S. and Canadian sides of the Detroit River (Hartig and Stafford 2003). Ten ducks and geese died as a result of the oil pollution. While this number may seem insignificant to years past, it reminds us that oil pollution continues to be a threat to waterfowl and other wildlife.

It is important to note that the data presented in Figure 4 merely reflect reported incidents. In addition, there are undoubtedly many unreported spills and releases through combined sewer overflow events that are not accounted for in these data. These figures are therefore conservative. Figure 5 shows that 16-41 spills of unknown volume have occurred each year since 1995. Although these spills are probably small in volume,

they are still a concern because of their frequency. Figure 6 demonstrates that more sheens were reported in some years than were total spills reported with volume, further documenting the ongoing release of oil of unknown volume into the Rouge and Detroit rivers.

Oil pollution continues to be an important issue because of combined sewer overflow events and industrial releases. Figure 7 shows that since 1995, 17-40% of all the reported oil spills in Michigan occurred in the Detroit and Rouge rivers.

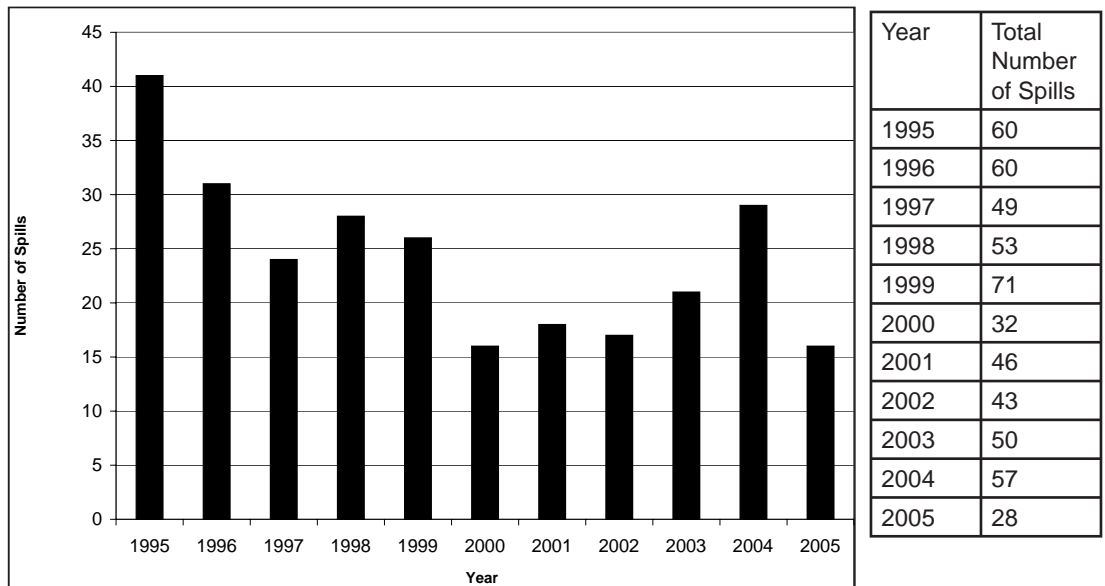


Figure 5. Number of spills with an unknown volume (1995-2005).

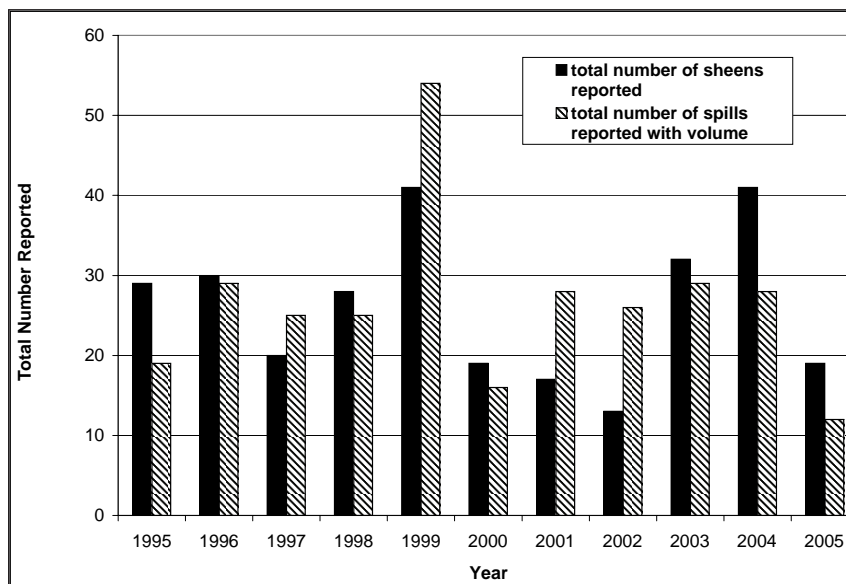


Figure 6. A comparison of total number of spills reported with volume to total number of sheens reported (1995-2005).

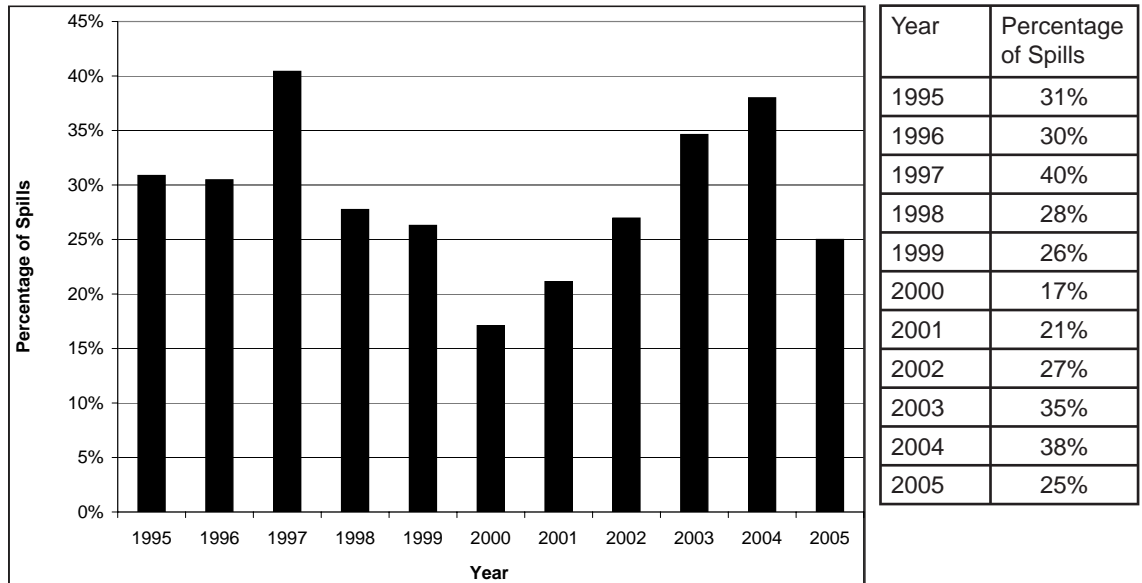


Figure 7. Percentage of Michigan oil spills that occurred in the Detroit and Rouge rivers (1995-2005).

Management Next Steps

Even with state and federal enforcement programs, there are still frequent occurrences of small oil spills and even occasional large ones. Greater emphasis must be placed on prevention. Key management recommendations follow:

- Lower the allowable limits of oil and other contaminants from industrial contributors to Detroit and other municipal wastewater treatment plants;
- Identify high priority outfalls that empty into the Rouge and Detroit rivers and target them for implementing early warning systems;
- Heighten Michigan Department of Environmental Quality and U.S. Environmental Protection Agency enforcement of industrial pretreatment programs;
- Educate the business community that it shares the responsibility of preventing the problem and becoming a part of the solution to oil pollution;
- Encourage industrial companies pursuing the voluntary ISO 14000 certification to identify oil as a “significant environmental aspect” in order to prevent accidental release of oil; and
- Increase public awareness of the need to prevent pollution, notice changes in water quality, and report problems immediately.

Research/Monitoring Needs

An early warning system is essential to protecting the Detroit and Rouge rivers from oil pollution and the wildlife that depends on these river ecosystems. It is recommended that governments pursue funding to expand implementation of early warning systems and monitoring devices for water systems.

References

- Cowles, G. 1975. Return of the river. *Michigan Natural Resources Magazine*. January-February, Lansing, Michigan.
- Hartig, J.H., and T. Stafford. 2003. The public outcry over oil pollution of the Detroit River. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 69-78. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Hartig, J.H., and M.E. Stifler. 1979. Water quality and pollution control in Michigan. Michigan Department of Natural Resources. Publication Number 4833-9803. Lansing, Michigan.
- International Joint Commission. 1968. Pollution of the Detroit, St. Clair, and St. Mary rivers. Washington, DC and Ottawa.
- Michigan Department of Natural Resources. 1977. *The Detroit River: 1966-1976: A Progress Report*. Publication Number 4833-9438. Lansing, Michigan.
- Michigan Department of Natural Resources. 2005. Oil intoxication. http://www.michigan.gov/dnr/0,1607,7-153-10370_12150_12220-27243-,00.html
- Miller, H.J., and S.C. Whitlock. 1948. Detroit River ducks suffer heavy losses. *Michigan Conservation* 17(4):11-15.
- U.S. Coast Guard National Response Center. 2005. Emergency Response Notification System (Data collected from 1982-2005). <http://www.nrc.uscg.mil/foia.html>
- U.S. Department of Health, Education, and Welfare. 1962. Pollution of the navigable water of the Detroit River, Lake Erie and their tributaries within the State of Michigan. Detroit, Michigan.

Links for More Information

U.S. Coast Guard National Response Center: <http://www.nrc.uscg.mil/foia.html>

U.S. Environmental Protection Agency: <http://www.epa.gov/oilspill/>

Pollution Emergency Alerting System: <http://www.michigan.gov/deq/0,1607,%207-135-3304-9820-,00.html>

Contact Information

John H. Hartig, Refuge Manager
Detroit River International Wildlife Refuge
E-mail Address: John_Hartig@fws.gov

Rosanne Ellison, Environmental Scientist
U.S. Environmental Protection Agency
Great Lakes National Program Office
E-mail Address: ellison.rosanne@epa.gov

Commander Sean Moon
U.S. Coast Guard, Sector Detroit
E-mail Address: smoon@msodetroit.uscg.mil

Olivia Napierski, Refuge Volunteer
Detroit River International Wildlife Refuge
E-mail Address: liv570@hotmail.com

INDICATOR: LAKE ERIE SHORELINE HARDENING IN LUCAS AND OTTAWA COUNTIES, OHIO

Background

The Ohio shoreline of Lake Erie is one of the most developed and structurally protected in the Great Lakes. As described by Fuller and Gerke (2005), “structural protection began in the early 1800s with the development of harbors, which were designed as aids to waterborne navigation. Although the harbor protection structures allowed river mouths to stay open by reducing littoral sediment transport into the river mouths, the adjacent, downdrift shoreline was deprived of sand. Since sand beaches provide protection from shoreline erosion, the loss of littoral sediment has accelerated shoreline erosion in these areas.”

As the Lake Erie Commission (2004a) explains, “to combat this erosion, lakeshore property owners began armoring (i.e., hardening with stone, concrete, or steel) the shoreline. Examples of hardening or armoring include: dikes, revetments, breakwalls,

seawalls, jetties, piers, retaining walls, boat docks, groins, gabions, etc. (Figure 1). However, because each artificial structure can create erosion downdrift of the structure, the affected shoreline, in turn, requires armoring to mitigate the ravages of wave energy directly breaking on the shoreline and bluff as opposed to dissipating along the beach. This ‘domino effect’ of erosion and shoreline armoring continues to this day.”



Figure 1. Lake Erie shoreline hardening with steel sheet piling (Photo credit: Greg Norwood).

In addition, many shore protection structures have limited natural habitat value and alter the coastal processes and hydrologic connections that support critical ecological processes and biological

life cycles in nearshore areas. This is particularly significant in that Ohio’s Lake Erie sport fishery alone is valued at \$1 billion annually.

Status and Trends

Changes in the density of shoreline hardening or armoring along Ohio’s western Lake Erie coast have been documented by the Ohio Department of Natural Resources since the 1870s (Fuller and Gerke 2005). In particular, there is a significant increase in the proportion of densely hardened or armored shoreline in both Ottawa and Lucas counties along Ohio’s portion of western Lake Erie (Figure 2). For Lucas County, the western

Lake Erie shoreline is now 98% hardened and armored. Much of this shoreline is protected by armored flood control dikes to prevent flooding of adjacent upland areas during periods of elevated Lake Erie water levels and/or short-term storm events.

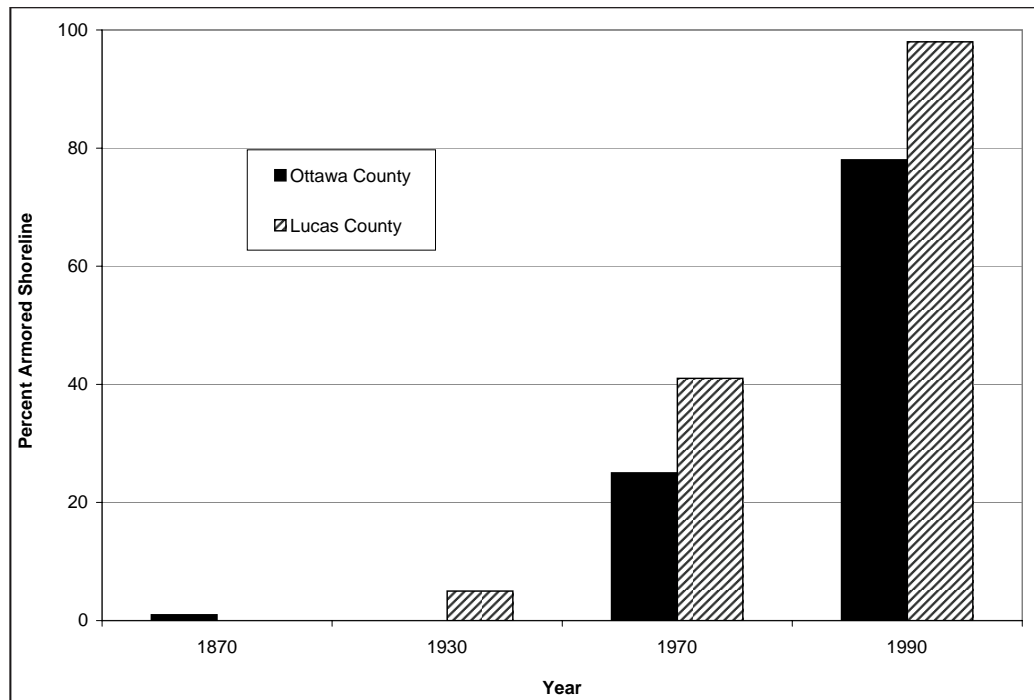
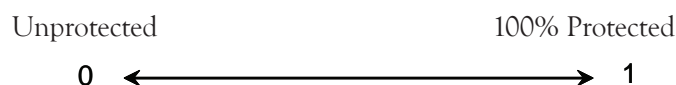


Figure 2. The percentage of armored shoreline along Ohio's Lake Erie western basin coastline has increased dramatically since the mid-1930s in response to development and higher Lake Erie water levels.

The shore structures were also analyzed for biological compatibility with critical nearshore environments. The trends for the mainland shore of western Lake Erie indicate that the majority of the shore protection structures were in the "poor" category, where the structure is nonfavorable to the nearshore biological community in both structure type and structure composition (Fuller and Gerke 2005).

These data indicate that the present shoreline protection along Ohio's western Lake Erie shoreline is generally effective with respect to erosion and flood control, but is not biologically-friendly. The 2004 *State of the Lake Report* for Lake Erie suggested that a shoreline hardening indicator should be characterized not only by the number and extent of erosion control structures, but by the biological compatibility of those structures as well. We propose that the ratio of protected to unprotected shoreline be used as a measure of shoreline modification. In other words, a value of zero (0) would represent an unmodified natural shoreline and a value of one (1) would represent a highly modified or 100% engineered shoreline.



High Biological Compatibility Low Biological Compatibility

0 1



Unaltered Highly Altered

0 ←→ 1

Management Next Steps

Use Effective Sand Resource Management

- 87

- Restore natural sediment transport processes – In circumstances where coarse-grained sediments have accumulated on the updrift side of harbor structures, the physical setting of the harbor should be evaluated to determine the feasibility of sand bypassing to the downdrift side of the harbor within the littoral zone. If appropriate, sand bypassing should be initiated to reestablish protective beaches in the downdrift areas.
- Implement a “no net loss of sand to the system” management policy – The overall cost of shoreline protection compared to the loss of beaches and nearshore bar systems should be identified through various permitting processes. It is suggested that an application for a shore protection structure identify the amount of coarse-grained sediment that will be lost to nearshore areas as a result of the installation of the structure, and that a comparable amount of coarse-grained sediment be placed in the nearshore to compensate for this loss.

Protect Remaining High-Quality Shoreline Properties

- Identify and protect critical shoreline areas – Focus should be placed on identifying and acquiring undeveloped shoreline properties that may provide a source of material for beaches and bar systems. Avoiding development of these properties will allow natural systems to operate, and reduce the need to harden the shoreline with erosion control measures.

Rehabilitate Existing Structures to Restore Natural Habitat Functions and Processes

- Rehabilitate and restore natural habitats – Encourage rehabilitation of existing structures with “habitat” enhancements to restore natural habitat functions and processes in nearshore zones.
- Restore natural coastal and hydrologic processes – Restore and reconnect coastal wetlands, estuaries, embayments, and riparian areas with the lake. Where feasible, restore hydrologic and biological connectivity with the lake.

Finally, it is critically important that the appropriate stakeholders are involved early on in the design and planning process. Redevelopment projects that include soft engineering principles should be encouraged into future waterfront designs where appropriate (Caulk et al. 2000). Soft engineering is achieved by using vegetation and other materials to soften the land-water interface, thereby improving ecological features without compromising the engineered integrity of the shoreline. The design process must identify opportunities and establish partnerships early in the process that integrate ecological, economic, and societal objectives.

Research/Monitoring Needs

In order to help protect the economic investment along Ohio's western Lake Erie shoreline and restore and maintain the Lake Erie ecosystem, emphasis should be placed on addressing the following research and monitoring needs:

- quantifying and predicting future coastal erosion rates, including associated economic and environmental impacts and benefits;
- quantifying the environmental, economic, and social benefits of incorporating habitat features into shore protection structures;
- forecasting future shoreline erosion processes and rates under predicted water level fluctuation scenarios; and
- developing new best management practices for simultaneously achieving erosion protection and habitat/biological integrity.

References

Caulk, A.D., J.E. Gannon, J.R. Shaw, and J.H. Hartig. 2000. Best management practices for soft engineering of shorelines. Greater Detroit American Heritage River Initiative. <http://www.fws.gov/midwest/detroitriver/ahr/REPORT/treeview.pdf>

Fuller, J.A., and B.E. Gerke. 2005. Distribution of shore protection structures and their erosion effectiveness and biological compatibility. Ohio Department of Natural Resources, Sandusky, Ohio.

[LEC] Lake Erie Commission. 2004a. *State of Ohio, State of the Lake Report*. Toledo, Ohio.

[LEC] Lake Erie Commission. 2004b. *Second Progress Report, Lake Erie Protection and Restoration Plan*. Toledo, Ohio.

Links for More Information

Ohio's Nonpoint Source Pollution Control Program: <http://www.epa.state.oh.us/dsw/nps/NPSMP/docs/LEcoastobj.html>

Ohio's Coastal Zone Management Program: <http://www.ohiodnr.com/coastal/about/aboutocmp.htm>

Shore structure permits in Ohio: <http://www.ohiodnr.com/coastal/regs/factsheets/cmguide2.htm>

Ohio's coastal erosion area permits: <http://www.ohiodnr.com/coastal/regs/factsheets/cmguide5.htm>

Best management practices for soft engineering of shorelines: <http://www.fws.gov/midwest/detroitriver/ahr/REPORT/treeview.pdf>

Contact Information

Constance Livchak

Ohio Department of Natural Resources

E-mail Address: Constance.Livchak@dnr.state.oh.us

Scudder D. Mackey

University of Windsor/Habitat Solutions

E-mail Address: scudder@sdmackey.com

STATE INDICATORS

INDICATOR: LAKE ERIE WATER LEVELS

Background

Lake Erie water levels change on short-term (daily and seasonally) and on long-term scales (over years and decades). The longer-term levels are determined by changes in the net supply of water received from the watershed and the upper Great Lakes on a seasonal and annual basis. Storm surges and seiche events (long waves that will move back and forth as they reflect off the opposite ends of the basin) cause changes on a daily or weekly basis (Lee et al. 1996). Historically, the natural water level of the lake has varied over a range of about 2 meters (6 feet) (Lenters 2001; Quinn 2002; Lofgren et al. 2002) and the lake level has tended to cycle through highs and lows over 30-year periods (Figure 1). High-water periods were recorded in Lake Erie in the 1950s and 1980s-1990s, while low-water periods have occurred in the 1930s and 1960s.

Changing water levels and the resulting shifts in the location of the shoreline and the littoral zone have an important impact on structure, function, and productivity in aquatic systems (Chubb and Liston 1985). Given the relatively flat topography associated with Lake Erie, Lake St. Clair, and associated connecting channels, large expanses of shoreline areas typically become inundated and/or exposed when the lake level

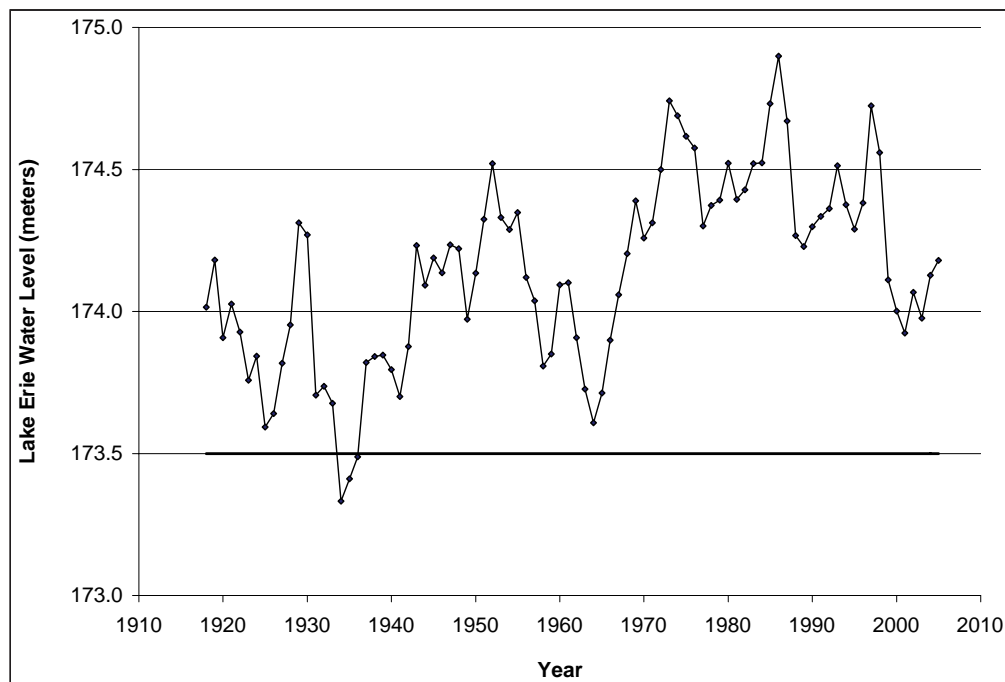


Figure 1. Average annual Lake Erie water levels (International Great Lakes Datum 1985), 1918-2005. The line at 173.5 represents low water datum (International Great Lakes Datum 1983) (United States Army Corps of Engineers, Detroit District, Engineering and Technical Services, Great Lakes Hydraulics and Hydrology Office, 477 Michigan Ave., Detroit, MI 48226).

changes. Hydraulic connectivity, water exchange, and the ability of fish to move between coastal wetlands, embayments, and the open lake are directly related to the size, timing, duration, frequency, and rate of change of these fluctuating water levels (S.D. Mackey, pers. comm.). One factor that may have an impact on long-term changes of water levels in Lake Erie, Lake St. Clair and connecting channels is global climate change. Most Global Circulation Models predict that reductions in precipitation, an increase in evaporation, and less ice cover will lead to lower Lake Erie water levels (Lofgren et al. 2002).

Status and Trends

Lake Levels

Currently, Lake Erie's water level is slightly below the long-term average (Figure 1) and still coming down from historic highs seen in the 1980s. The rate of decline in annual water levels in 1998-1999 was similar to that seen in the early 1930s, which was the period that established historic low-water levels. Lake Erie water levels have rebounded slightly to 174.2 meters until 2005. Through July 2006, Lake Erie water levels were slightly below those seen in 2005. In May 2007, Lake Erie water levels were slightly above those seen in May 2006. Projections for June-December indicated that lake levels were expected to be at or below (by 0.3 m) mean lake levels in 2007.

Even though there is considerable uncertainty as to the impact of global climate change, a decline in Lake Erie water levels over the next several decades, regardless of cause (e.g., water withdrawals, diversions, modifications to connecting channels, or global climate change) will create new, natural shorelines. For example, the best estimates of the effects of global climate change over the next 70 years predict a 1-2 meter (3-6.5 foot) decline in water levels of Lake Erie (Lofgren et al. 2002; Mortsch and Quinn 1996). A 1.5-meter drop in Lake Erie's water level from the 1992 level was expected to result in a 4% reduction in the surface area of the western basin and a 20% reduction in the volume of water in the western basin of Lake Erie. The shoreline would move lakeward by distances of less than 1 km to as much as 6 km (Lee et al. 1996).

Currently, the western basin shoreline of Lake Erie is highly altered. More than 85% of the southwestern shoreline has been armored over the past three decades (Ohio Department of Natural Resources, Geological Survey, unpublished data). As water levels decline, the shoreline will recede lakeward and the existing shoreline structures and armoring will become exposed in many locations. The lower water levels could hydraulically isolate many high-quality wetland and estuarine areas, which provide spawning, nursery, and forage habitat for Lake Erie and Lake St. Clair fish communities. There are many diked wetlands along portions of southwestern Lake Erie. If the desire is to maintain water levels in them, Lake Erie water would have to be pumped over distances of up to a kilometer.

A 1.5-meter decline in lake levels will significantly affect Sandusky Bay. Most areas will become less than 1 meter deep and may become colonized by submerged aquatic plants (Figure 2). Continuing development pressures threaten newly exposed areas, resulting in degradation and the risk of permanent loss of these critical fishery habitats and associated biodiversity, as well as a loss of productive capacity.

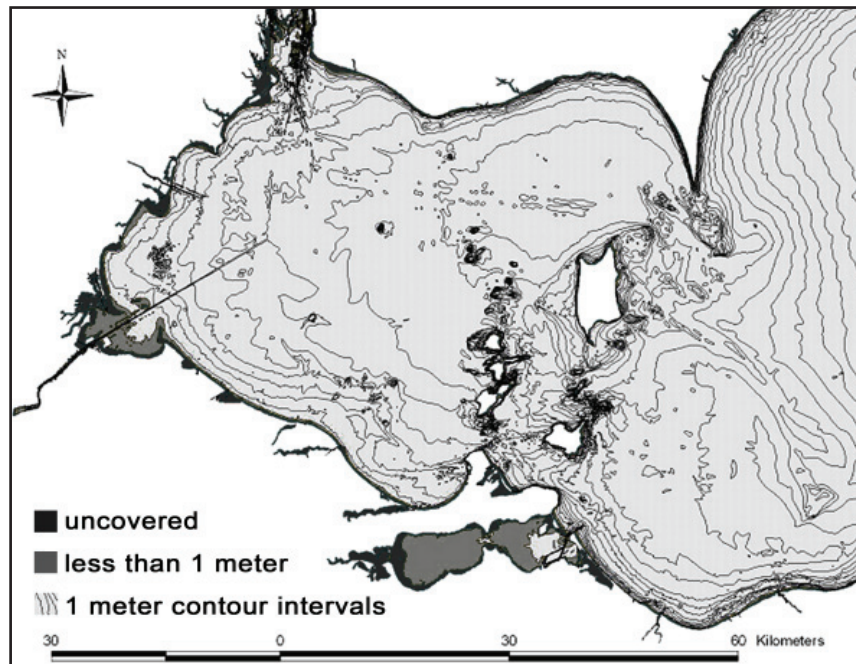


Figure 2. Western Lake Erie projected with 1-m decline in water levels (International Great Lakes Datum 1985) showing areas that will uncover with a 1-m decline and those that will be less than 1 meter in depth, and have the potential for establishing submerged aquatic macrophytes. Bathymetric 1-m contour intervals are shown (adapted from National Geophysical Data Center 1998).

Moreover, reduced water levels will alter nearshore littoral (shallow water) and sub-littoral habitats, permanently altering benthic and fish community structure throughout Lake Erie and Lake St. Clair. The effects of lower water levels may also fundamentally affect seasonal timing and connectivity, food web dynamics, and the distribution, structure, composition and abundance of fish communities in Lake Erie, Lake St. Clair, and associated connecting channels (Casselman 2002; Kling et al. 2003). For example, a decrease in total water volume could lead to greater spatial overlap between predators and prey leading to greater loss of young fish to their predators. Changes in lake levels may also alter the hydrodynamic environment. Altered lake currents can modify habitat by changing substrate compositions, circulation patterns, and nutrient dynamics. This would lead to the establishment of new plant and animal assemblages in some places, but may cause their elimination in other locations. The permanent loss/change in the distribution of existing critical wetland, estuarine, and nearshore habitats could have potential long-term detrimental consequences for Lake Erie and Lake St. Clair fisheries and fish communities.

However, suitable planning could create the potential to reestablish some new connected coastal features with associated submerged and emergent aquatic vegetative communities outside of altered shorelines. This would present an opportunity for fish and wildlife managers, as well as the general public, to offset some of the existing wetlands that are expected to be lost if lake levels decline to the extent predicted (Lee et al. 1996).

Fish Community

Changes in both lake level and thermal regime could have significant impacts on the fish community of western Lake Erie and Lake St. Clair. Lower lake levels could potentially affect the amount of habitat available for cold- and cool-water species and limit their production.

If lower lake levels resulted in development of a natural (unhardened) shoreline, this could potentially have a significant positive impact on plant-loving species such as northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), and largemouth bass (*Micropterus salmoides*), particularly if subsequent submersed vegetation accompanies these changes. The waters of western Lake Erie have become clearer over the last ten years (perhaps due to activities of zebra mussels) and the Lake Erie fish community may currently be responding to these recent changes in habitat (and possibly the warming thermal regime). Western basin bottom trawling has been conducted to track the fish community in Ohio waters of Lake Erie each year since 1969. Bottom trawling programs are not designed to specifically assess the Lake Erie nearshore fish community. However, by-catch information from trawls can tell us about trends in the nearshore fish community.

In nearshore areas (places where water is < 6 meters deep) there have been dramatic shifts in species composition and abundance over the past 25 years (Figure 3). In the late 1970s and early 1980s, catches of centrarchids (which include sunfishes, crappies, smallmouth and largemouth bass) in bottom trawls were dominated by white crappie (*Pomoxis annularis*), a more tolerant centrarchid species that is not associated with submersed aquatic macrophytes. More recently (2002-2005), catches of plant-loving centrarchids have generally doubled, and are dominated by pumpkinseeds (*Lepomis gibbosus*) and bluegill (*Lepomis macrochirus*). These changes are likely associated with declining lake levels, clearer and warmer water, and a resurgence in submersed aquatic macrophytes in many of the bays and harbors around Lake Erie.

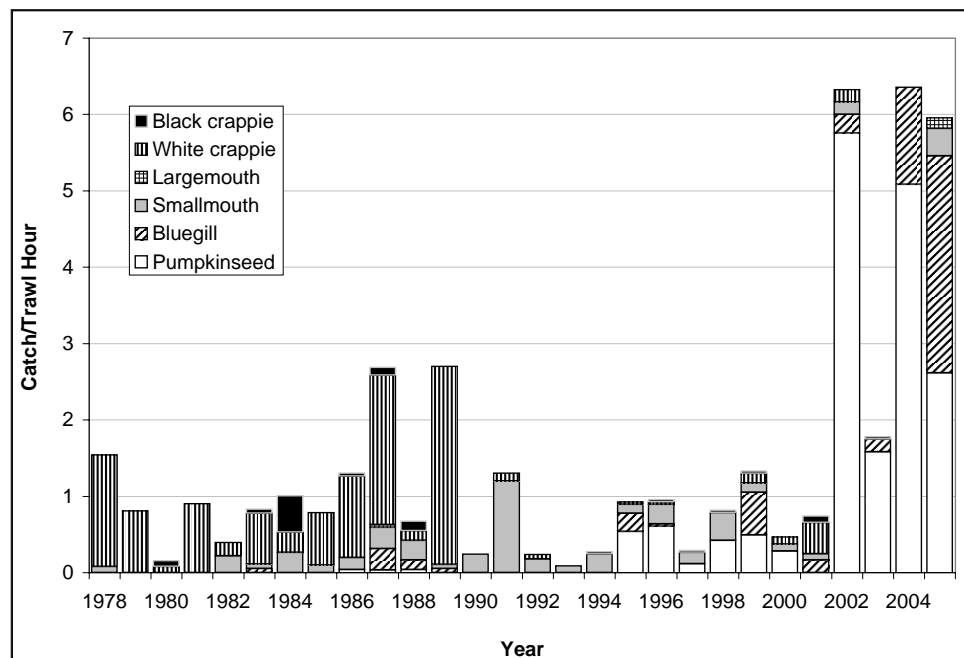


Figure 3. Catch/trawl hour of selected nearshore fishes from Ohio Department of Natural Resources, Lake Erie western basin trawling surveys, May-September, 1978-2005. Nearshore was defined as waters < 6 m in depth.

Management Next Steps

The nearshore fish community in Lake Erie is managed by a cooperative and collaborative process of the Great Lakes Fishery Commission's Lake Erie Committee (LEC) member jurisdictions. This culture of collaboration includes fisheries management agencies, land use planners, land management agencies, and other organizations, and is critical to the proper management of the Lake Erie nearshore fish communities. The LEC has recognized the significance of lake level changes in two important documents – the *Fish-Community Goals and Objectives for Lake Erie* (Ryan et al. 2003) and the *Lake Erie Environmental Objectives* (Davies et al. 2005). The LEC has also written a position statement outlining some recommendations for first management steps with respect to changes in lake levels (see http://www.glfc.org/lakecom/lec/EOs_July5.pdf).

The following are the Lake Erie Committee's goals and objectives that are relevant to the fish community with respect to lake level changes and climate change as described in the *Fish-Community Goals and Objectives for Lake Erie* (Ryan et al. 2003):

- secure a balanced, predominantly cool-water fish community with walleye as a key predator in the western basin, central basin, and nearshore waters of the eastern basin, characterized by self-sustaining indigenous and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem; and
- maintain nearshore habitats that can support high quality fisheries for smallmouth bass, northern pike, muskellunge, yellow perch, and walleye.

The following are objectives from the *Lake Erie Environmental Objectives* (Davies et al. 2005) that are relevant to the fish community with respect to lake level changes and climate change:

- recognize and anticipate natural water level changes and long-term effects of global climate change and incorporate them into management decisions;
- restore natural coastal systems and nearshore hydrological processes;
- restore submerged macrophyte communities in estuaries and embayments and protected nearshore areas; and
- halt cumulative incremental loss and degradation of fish habitat and reverse, where possible, loss and degradation of fish habitat.

Management actions recommended by the LEC (Davies et al. 2005) with respect to changing water levels include:

- promoting general recognition that protection and restoration of coastal land-margin ecosystems is crucial to ecosystem rehabilitation and achievement of *Environmental Objectives* (Davies et al. 2005) and *Fish-Community Goals and Objectives* (Ryan et al. 2003);
- developing and using predictive models to quantify changes in habitat in response to changing water level regimes, identify existing and future habitat areas requiring protection and restoration, and identify future habitat areas that can be enhanced based upon changing water level regimes;

- once identified, developing and implementing conservation and protection actions to protect potential refugia, transitional, and newly created habitats in coastal and nearshore areas from anthropogenic modification and/or degradation; and
- adopting a proactive approach to fisheries that recognizes and anticipates potential long-term changes in water level and thermal conditions resulting from global climate change.

Research/Monitoring Needs

To help ensure maintenance and restoration of the nearshore Lake Erie fish community, a number of areas need further research and monitoring:

- understanding how lower water levels will change basin and connecting channel configurations and flows; there is a special need for high resolution bathymetric maps in nearshore waters;
- predicting how lower water levels will alter the distribution of critical fisheries habitat, fish recruitment, and fish community structure in Lakes Erie and St. Clair;
- predicting and assessing the *future* location and extent of essential coastal, nearshore, and benthic habitats in response to varying lake level and thermal regimes and likely consequences for the long-term sustainability of the food web and fish community; and
- coordinating nearshore fish and habitat monitoring programs across the Lake Erie basin.

References

- Casselman, J.M. 2002. Effects of temperatures, global extremes, and climate change on year-class production of warmwater, coolwater and coldwater fishes in the Great Lakes basin. In *Fisheries In a Changing Climate*, ed. N.A. McGinn, pp. 39-60. American Fisheries Society Symposium 32. Bethesda, Maryland.
- Chubb, S., and C.R. Liston. 1985. Relationships of water level fluctuations and fish. In *Coastal Wetlands*, eds. H.H. Prince and F.M. D'Itri, pp. 121-140. Chelsea, MI: Lewis Publishers, Inc.
- Davies, D.H., B. Haas, L. Halyk, R. Kenyon, S. Mackey, J. Markham, E. Roseman, P. Ryan, J. Tyson, and E. Wright. 2005. *Lake Erie Environmental Objectives*. Great Lakes Fishery Commission, Ann Arbor, MI. http://www.glfc.org/lakecom/lec/EOs_July5.pdf.
- Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson. 2003. *Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems*. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, DC.
- Lee, D.H., R. Moulton, and D.A. Hibner. 1996. *Climate Change Impacts On Western Lake Erie, Detroit River, and Lake St. Clair Water Levels*: Great Lakes – St. Lawrence Basin Project Report, Environment Canada and NOAA, GLERL Contribution #985.

Lenters, J.D. 2001. Long-term trends in the seasonal cycles of Great Lakes water levels. *Journal of Great Lakes Research* 27(3):342-353.

Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel, A.J. Eberhardt, and C.L. Luukkonen. 2002. Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCMs. *Journal of Great Lakes Research* 28:537-554.

Mackey, Scudder D., Habitat Solutions, 37045 North Ganster Road, Beach Park, IL 60087. Personal Communications.

Mortsch, L.D., and F.H. Quinn. 1996. Climate change scenarios for Great Lakes Basin ecosystem studies. *Limnology and Oceanography* 401:903-911.

National Geophysical Data Center. 1998. Bathymetry of Lake Erie and Lake Saint Clair. In *World Data Center for Marine Geology and Geophysics Report #MGG-13*, eds. L.A. Taylor, P. Vincent, and J.S. Warren. National Geophysical Data Center. Boulder, CO.

Quinn, F.H. 2002. Secular changes in Great Lakes water level seasonal cycles. *Journal of Great Lakes Research* 28:451-465.

Ryan, P.A., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. *Fish-Community Goals and Objectives for Lake Erie*. Great Lakes Fishery Commission Special Publication 03-02.

Links for More Information

Great Lakes Levels Forecast: <http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/waterlevelforecasts/monthlybulletinofgreatlakeswaterlevels/>

Great Lakes Information Network. Lake Erie Current Water Levels: <http://www.great-lakes.net/envt/water/levels/levels-cur/eriewlc.html>

Ohio Department of Natural Resources, Division of Water: http://www.dnr.ohio.gov/water/lake_erie/

NOAA, Great Lakes Environmental Research Laboratory. Great Lakes Water Levels: <http://www.glerl.noaa.gov/data/now/wlevels/levels.html>

Contact Information

Jeff Tyson
Ohio Department of Natural Resources, Division of Wildlife
E-mail Address: jeff.tyson@dnr.state.oh.us

Jan Ciborowski
Department of Biological Sciences
University of Windsor
E-mail Address: cibor@uwindsor.ca

INDICATOR: WATER CLARITY IN WESTERN LAKE ERIE

Background

Public alarm about Lake Erie's water quality began in the 1960s with the realization that the lake no longer looked as clean as it should have. Because of the algal blooms caused by accelerated eutrophication (see "Algal Blooms in Western Lake Erie" indicator), the water at times looked green and opaque. Transparency or clarity of lake water helps determine perceived value of the water. Clear water allows fish and bottom structures to be seen and appears attractive, whereas opaque water hides in-water features and looks dirty and unattractive. Clear water allows the growth of aquatic macrophytes that create fish habitat and provide food. Clarity can be affected by the presence of abiotic particles such as clay or other soil fractions derived from watershed erosion; these may be resuspended by waves and currents in the lakes. Too much sediment in the water is even toxic to fish as they have to spend too much time clearing their gills. Biotic particles such as algae also contribute to turbidity. In shallow waters like western Lake Erie, turbidity is caused by a combination of sediment or soil and algae, but in deeper offshore areas, the majority of the turbidity is caused by algae.

The western basin of Lake Erie, with a typical depth of 10 meters, is shallow enough to have dramatic wind/wave driven sediment resuspension, and at the same time a considerable algal biomass. Rivers can also influence water clarity as shown by the areas around the mouths of the Maumee and Detroit rivers (see Figure 1 in "Algal Blooms in Western Lake Erie" indicator). There is no one measure of turbidity that can separate these two causes. Despite this problem, only one common measuring device has historically been used.

Status and Trends

The Secchi disk is a flat black and white disk that is lowered through the water on a rope which has markings to determine the depth. The disk eventually disappears at a depth determined by water turbidity and the depth is noted as transparency or Secchi depth. The Secchi disk was developed by Pietro Angelo Secchi (1818-1878), a Jesuit Italian astrophysicist, and has a long history of use in oceanography and limnology. Some of the best aspects of its use is its long history and the fact that nonscientists can visualize it and easily interpret statements such as "the Secchi disk disappeared in 1 meter of water" to mean the water was quite turbid and unattractive.

The relationship between transparency and trophic status has been summarized by Carlson (1977) as ranges of Secchi transparency corresponding to trophic state.

Oligotrophic: 4-8 m
Mesotrophic: 2-4 m
Eutrophic: 0.5-2 m

Secchi disk depth data are available from western Lake Erie from the late 1960s to the early 2000s (Figure 1). These data show a wide variation of results. Each point with error bars represents measurements in a summer month. Episodic winds and algal blooms cause high variability of Secchi data, as can be seen by the wide spread of the data around each mean dot. According to the trophic scale, the conditions are largely still in the eutrophic to mesotrophic range. It was thought that the water clarity would change with decreased nutrient loads (refer to “Phosphorus Discharges from the Detroit Wastewater Treatment Plant” indicator). However, although the phosphorus loads stabilized at low levels in the early 1980s, the water clarity data didn’t begin to change until the late 1980s and early 1990s. The increasing tendency for higher values coincided with the invasion of zebra mussels (and quagga mussels) that began around 1988. The zebra mussels filter the water and thus, in the shallow western basin, are able to render the water more transparent. At the same time, benefits of the nutrient reductions probably occurred, but were confused by the effects of the mussels. Recent data show variability due to sediment resuspension and algal blooms so that scientists and managers still do not have a good understanding of the causes and changes in water clarity.

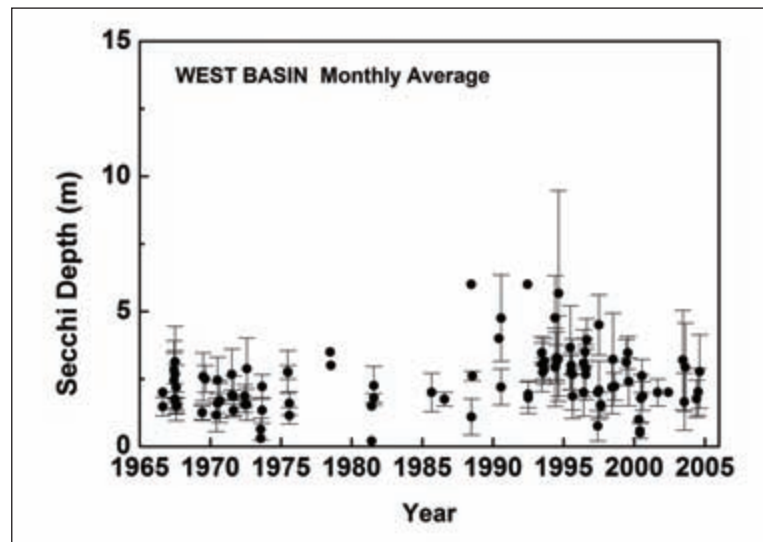


Figure 1. Secchi disk depth data from Canadian sources (from Charlton and Milne 2004).

Management Next Steps

Continued emphasis should be placed on controlling inputs of phosphorus, especially from nonpoint sources. In addition, management emphasis should be placed on stopping the introduction of invasive aquatic species.

Research/Monitoring Needs

Using Secchi transparency or other electronic means of measuring light attenuation in the western basin is not easy. Algal blooms can start in the Maumee River which flows into Lake Erie. High nutrient loads occur in the western flow of the Detroit River, but relatively clean water prevails on the eastern flow. Sediment resuspension can be localized, as well as seasonal. To sample all of these variations in space and time would require many samples from ships. A solution to this problem is remote sensing from satellites.

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS), in orbit since 1997, provides aquatic color imagery suitable for the study of water quality parameters such as phytoplankton pigments (chlorophyll), mineral suspended particulates, and dissolved organic matter (McClain et al. 2004). With daily observations over the Great Lakes region at a ground resolution of 1 km, SeaWiFS data enable trends in water quality parameters such as clarity to be identified and monitored, providing significant advantages over ground-based monitoring programs in terms of spatial and temporal coverage and cost-efficiency.

To summarize, water clarity results from a combination of biotic and abiotic particles in water. Generally, clarity that would allow a Secchi disk to be seen at a depth of three meters would be considered adequate by many people. Research is warranted on newer remote sensing technologies that offer a means of monitoring water clarity with better resolution in space and time than is possible with conventional shipboard methods.

References

- Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography* 22:361-369.
- Charlton M., and J. Milne. 2004. Review of thirty years of change in Lake Erie water quality. NWRI Environment Canada Contribution No. 04-167.
- McClain, C.R., G.C. Feldman, and S.B. Hooker. 2004. An overview of the SeaWiFS project and strategies for producing a climate research quality global ocean bio-optical time series. *Deep Sea Research II* 51:5-42.

Links for More Information

The secchi disk – what is it? <http://www.mlswa.org/secchi.htm>

The changing Lake Erie ecosystem: http://www.ijc.org/php/publications/html/12br/pdf/ecosystem_e.pdf

International Joint Commission's 12th biennial report: <http://www.ijc.org/php/publications/html/12br/english/report/ecosystem/rtpc.html>

International Association for Great Lakes Research press release: http://www.iaglr.org/jglr/release/31/31_sup2_195-207.php

Contact Information

Murray Charlton
Environment Canada
National Water Research Institute
E-mail Address: Murray.Charlton@ec.gc.ca

Caren Binding
Environment Canada
National Water Research Institute
E-mail Address: Caren.Binding@ec.gc.ca

INDICATOR: LAKE ERIE ICE COVER

Background

Winter ice cover on Lake Erie affects the amount of heat and moisture transferred between the lake and the atmosphere. During winter, ice and snow can decrease the amount of light available below the ice surface for photosynthesis. In the absence of an ice cover, winds can cause mixing of the water column and in some cases resuspend bottom sediment. If ice cover is present, high winds can cause rafting of ice that sometimes causes ice-scouring along the lake bottom. In the nearshore region, erosion can occur when ice attached to the shore is moved by winds. Ice cover also affects lake levels by reducing lake evaporation.

Ice cover can impact the economy by impeding or stopping navigation, interfering with power plants and cooling water intakes, and damaging shore structures. Potential economic impacts of reduced ice cover could include a longer shipping season, increased evaporation, lower lake levels, increased dredging for navigation, lower ship cargo

capacity, reduced winter recreational activities such as ice fishing, and loss of critical habitats.

Winter ice formation and seasonal ice cycles have been documented over the past 43 winters through visual observation, radar, and satellites (Figure 1).



Figure 1. Moderate Resolution Imaging Spectroradiometer (NASA) satellite image of Lake Erie for March 12, 1999. The lake is approximately 50% ice covered; note that the north portion of the lake is open water.

Status and Trends

Lake Erie develops an extensive ice cover most winters because, in comparison to the other Great Lakes, it is relatively shallow (mean depth: 19 meters), it has a relatively small volume that does not store a lot of heat, and it has sufficiently low fall and winter air temperatures. The Annual Maximum Ice Cover (AMIC) is a useful indicator of ice cover trends (Assel et al. 2003) that measures the maximum lake surface area covered by ice each year. AMIC was greater than or equal to 80% in

37 of the 43 winters between 1963 and 2005 (Figure 2). Extremely mild winters occurred in 1983 (AMIC 41%), 1991 (AMIC 38%), 1998 (AMIC 5%), and 2002 (AMIC 14%). These winters contributed to the observed downward trend in the 4-year AMIC running average.

The western basin of Lake Erie, i.e., the lake approximately west of a diagonal line from Point Pelee to Sandusky Bay, is relatively shallow which favors winter ice formation. Western basin January through March average ice cover (Figure 3) was calculated from daily averages (Assel 2004). This 3-month average ice cover varied from approximately

5% to 90% over the winters of record. The two extremely mild winters, 1998 and 2002, are noteworthy as they set new record lows for average winter ice cover (Assel 2005). The western basin was virtually free of any significant ice cover in 1998 and, with the exception of portions of January, the same was true for 2002. The 4-year running average ice cover (Figure 3) shows a maximum value in the late 1970s followed by a general downward trend thereafter. Winter 2006 also had below-normal ice cover. Extensive December ice cover was lost by mid-January due to mild air temperatures. Cold air temperatures brought limited new ice formation during the last ten days of February. That ice cover was lost during the first week of March. What are the ecosystem consequences of the anomalously low ice cover during the winter of 2006?

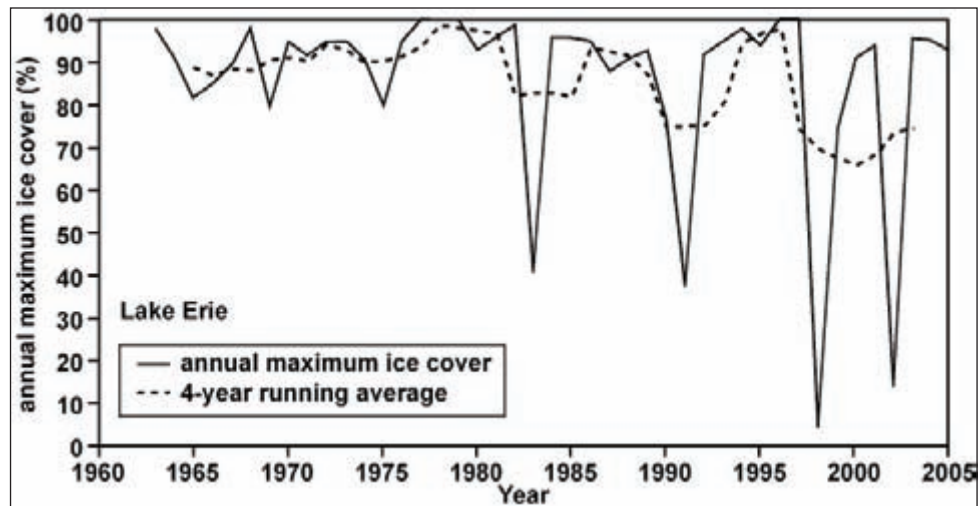


Figure 2. Lake Erie annual maximum ice cover for winters 1963-2005. Mild winters in 1983, 1991, 1998, and 2002 contributed to the observed downward trend in the 4-year AMIC running average.

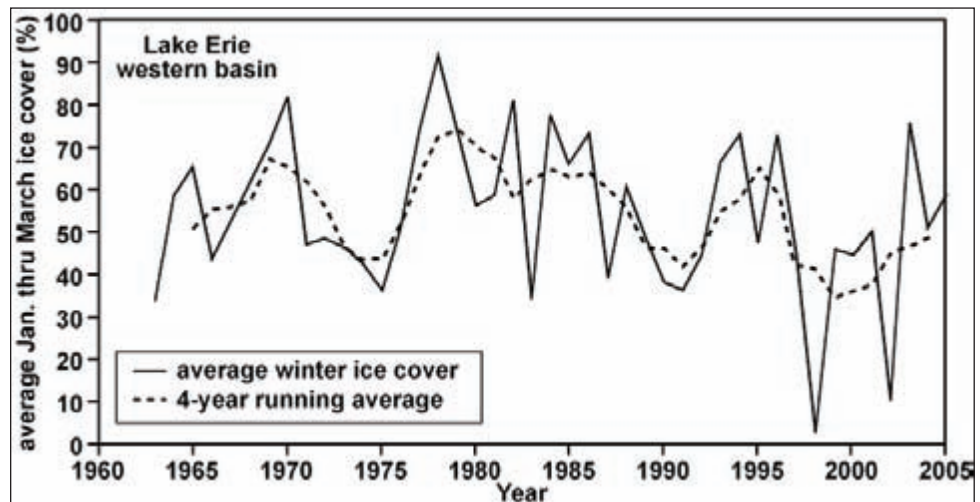


Figure 3. Western basin 3-month average ice cover. Ice cover prior to 1972 is modeled using a freezing degree-day ice cover model. The 4-year moving average of the 3-month average ice cover is plotted on the third year.

Management Next Steps

Climatic warming may cause a dramatic reduction in ice cover with unknown consequences to Lake Erie and the other Great Lakes. The combined influence of climatic warming, and other new alterations such as invasive species, on Lake Erie needs to be evaluated in order to develop better tools for decision makers and managers. This evaluation should include a historical analysis of changes in the winter ecosystem relative to changes in ice cover.

Research/Monitoring Needs

The current remote sensing (satellite and aerial reconnaissance) program to observe and document Great Lakes ice cover should be continued and expanded for use in the development, calibration, and verification of lake ice and winter lake biogeochemical models.

The impact of ice on lake plants and animals is not well-known because of limited below-ice observations of plants and animals, and the physical factors that affect them. A long-term winter field program of surface and subsurface observations is recommended in order to develop a better understanding of the physical and biological characteristics and processes of the winter aquatic ecosystem.

References

Assel, R.A. 2004. Lake Erie ice cover climatology - basin averaged ice cover: Winters 1898-2002. NOAA Technical Memorandum GLERL-128. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI.

Assel, R.A. 2005. Classification of annual Great Lakes ice cycles: Winters of 1973-2002. *Journal of Climate* 18:4895-4905. <http://www.glerl.noaa.gov/pubs/fulltext/2005/2005002.pdf>

Assel, R.A., K. Cronk, and D.C. Norton. 2003. Recent trends in Laurentian Great Lakes ice cover. *Climatic Change* 57:185-204. <http://www.glerl.noaa.gov/pubs/fulltext/2003/20030001.pdf>

Links for More Information

NOAA Great Lakes ice atlas: <http://www.glerl.noaa.gov/data/ice/atlas/index.html>

Contact Information

Raymond Assel, Scientist Emeritus
NOAA, Great Lakes Environmental Research Laboratory
Email Address: Ray.Assel@noaa.gov

INDICATOR: PHOSPHORUS CONCENTRATIONS IN THE WESTERN BASIN OF LAKE ERIE

Background

In the early 1970s it was widely recognized that areas of the Great Lakes, including the western basin of Lake Erie, had become nutrient enriched (eutrophic). These nutrient enriched areas supported excessive algal growth resulting in nuisance blooms and/or adverse effects on other components of the ecosystem. A series of research initiatives identified phosphorus as the primary nutrient limiting the growth of algae in the Great Lakes.

The Great Lakes Water Quality Agreements (GLWQA) of 1972 and 1978 recognized the damage caused by phosphorus pollution and the need for society to control phosphorus inputs. Therefore, the GLWQA included a binational phosphorus abatement program in order to restore the lakes to a more natural state. Due to the strong link between phosphorus and algal growth, ambient phosphorus concentrations and phosphorus loading are routinely used to evaluate the trophic status and overall ecosystem health of the Great Lakes.

Since 1976, as part of a monitoring program to track nutrient levels and trophic conditions in the nearshore areas of the Great Lakes, the Ontario Ministry of the Environment (MOE) has analyzed the untreated water from selected Great Lakes water treatment (drinking water) facilities for nutrients and other water quality parameters. The data record for the MOE Great Lakes intake biomonitoring program spans three decades, with an approximately weekly sampling interval. While the water intake datasets are extensive, the use of such data to track changes in water quality also has disadvantages. Because the intakes are typically located at a limited distance from the shoreline in relatively shallow water, there is an increased potential for localized nearshore influences on the collected data. For example, on the exposed shoreline of the Great Lakes, the wind-induced suspension of sediments can result in the periodic elevation of turbidity and suspended solids' levels in samples derived from shallow water intakes that are not reflected in the offshore condition. Nevertheless, while using intake data to infer offshore or basin-wide conditions contains some elements of uncertainty, there is strong evidence that trends identified within the water intake data do reflect changes in water quality that have occurred within the nearshore and offshore environments.

The Union (Essex County) Water Treatment Plant is located 5-6 km west of Leamington, Ontario. It draws its source water from western Lake Erie and supplies potable water to the Municipality of Leamington (which includes the towns of Leamington, Kingsville, Essex, and Lakeshore). The water intake pipe is located approximately 0.46 km offshore and 1 meter above the lake bottom (Nicholls et al. 2001) in an area where the lake depth is approximately 4 meters.

Nutrients and other water quality parameters from untreated (raw) water at the Union Water Treatment Plant have been analyzed on an ongoing basis as part of the intake biomonitoring program since 1976. Water quality data collected at the Union Intake have been used to analyze the response of phytoplankton and nutrients in western Lake Erie to phosphorus control strategies, to the invasion of zebra mussels, to variation in weather patterns, and to changes in trophic interactions (Nicholls et al. 1980; Nicholls and Hopkins 1993; Nicholls et al. 2001). Trends in total phosphorus concentrations from 1976 to 1999 in water collected at the Union plant, as well as 17 other intakes around the Great Lakes were reported by Nicholls et al. (2001). Additional data for the years 2000 to 2004 are provided in the section below.

Status and Trends

Total phosphorus (TP) concentrations measured at the Union Intake have varied strongly since 1976. For consistency with Nicholls et al. (2001), running medians approximating a year period (48 samples – average number of samples per year) are plotted along with monthly mean concentrations (Figure 1). Values exceeding 208 µg/L have been excluded as outliers. Medians along with 10th and 90th percentiles are plotted in Figure 2.

The wide ranges between the 10th and 90th percentiles (Figure 2) and the similarly wide range in monthly mean concentrations (Figure 1) indicate appreciable variability in concentration among samples and within years. Nicholls et al. (2001) reported that there was statistically significant seasonality in the 1976 to 1999 data with high summer TP levels maintained through the late fall. The high short-term variability in TP concentrations in the western basin is considered to be a result of multiple factors, including seasonal tributary loading and sediment resuspension from storms (Neilson et al. 1995).

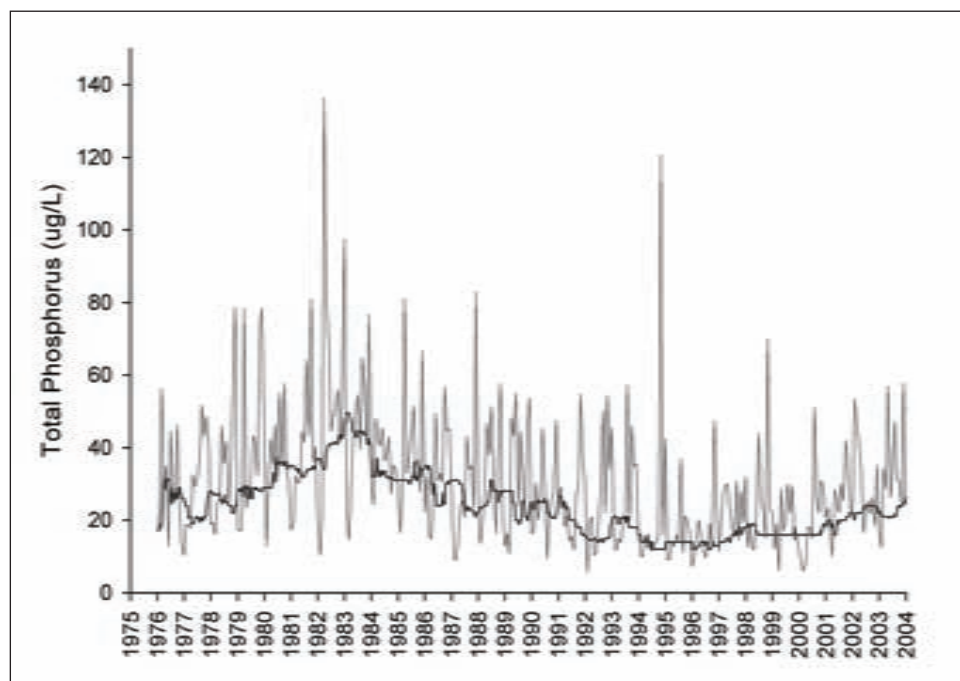


Figure 1. Monthly mean concentration of total phosphorus (dark line) and running median of 48 approximately weekly samples for raw water collected at the Union Water Treatment Plant, 1976-2004.

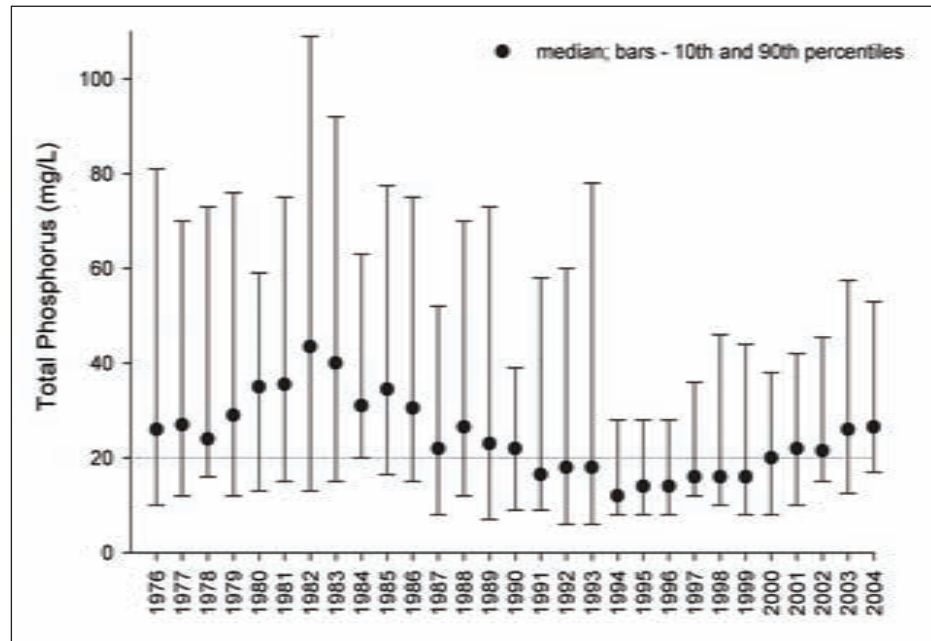


Figure 2. Median annual concentration of total phosphorus (circle) and 10th and 90th percentiles (bars) of approximately weekly samples for raw water collected at the Union Water Treatment Plant, 1976-2004.

Overall, Nicholls et al. (2001) noted a significant downward trend in TP concentrations from 1976 to 1999. Within that time period, Nicholls et al. (2001) detected three periods where the annual trend in TP concentrations changed. From 1976 to 1983 TP increased at a rate of 3.4 $\mu\text{g/L/year}$, from 1983 to 1994 TP declined at a rate of 1.5 $\mu\text{g/L/year}$, and from 1995 to 1999 TP tended to increase, but was not statistically significant. The overall long-term trend of declining TP has been attributed to the reductions in phosphorus entering Lake Erie. Whole lake TP loads have declined appreciably over the last three decades (Dolan and McGunagle 2005). From 1967 to 1991, point source phosphorus loads into Lake Erie declined by approximately 745 metric tonnes per year (Dolan and McGunagle 2005). In 1967 the phosphorus load exceeded 25,000 metric tonnes/year and declined annually until finally reaching the GLWQA target of 11,000 metric tonnes/year for the first time in 1987. After 1991 to 2001, there was no consistent year-to-year trend in phosphorus loading; however, there was appreciable year-to-year variability, much of which was attributed to nonpoint sources and differing amounts of tributary inputs.

Nicholls (1999) attributed the increase in TP during the late 1970s to the early 1980s to possible sediment regeneration of dissolved phosphorus associated with calm weather and low oxygen levels at the lake bottom. Evidence for this hypothesis was a strong negative relationship between summer wind speed and TP concentration. As noted with the overall decline in TP from 1976 to 1999, the decline in TP during the 1983 to 1994 period was attributed to the annual declines in phosphorus loading. While Nicholls et al. (2001) were not able to detect a significant change in TP concentrations from 1995 to 1999, data from subsequent years (2000-2004) suggest a continued increasing trend in TP concentration since 1994 (Figure 2).

Based on statistical analyses, median total phosphorus appears to be increasing at a rate of approximately 1.4 $\mu\text{g/L/year}$ from 1994 to 2004. The consistent pattern of increasing TP concentration from 1994 to 2004 does not appear to be aligned with trends in

phosphorus loading from point sources or nonpoint sources. Estimated annual loads to the western basin from 1994 to 2001 have ranged from 4,140 to 9,588 tonnes/year (4,564 to 10,569 tons/year) (Dolan and McGunagle 2005) with little evidence of a consistent trend among years; loads were less than 4,500 tonnes/year (4,960 tons/year) in 1994, 1995, 1999 and 2001. The update to the Lake Erie Lakewide Management Plan (2006) notes the possibility that the period of turbidity in the spring is persisting longer than previously and the intensity and timing of storms may be having a greater effect on among-year variability in TP in the last few years.

The underlying cause of the increasing trend in TP concentration since 1994 is unknown. However, two major ecological disruptions have occurred in Lake Erie that are coincident with, and may be contributing to, the trends in TP in recent years. First, while zebra mussels became established in western Lake Erie during 1989-90, stable populations were not reached until the mid-1990s. During their initial invasion period, dreissenids (zebra and quagga mussels) achieved exceptionally high densities, and may have exerted a larger influence on suspended particulate matter than during the period where their population numbers declined and stabilized. It is possible that at least part of the increase in TP from 1994 to 2004 resulted from this stabilization of the dreissenid population.

The second major ecological disruption during this period was the successful invasion of the round goby into western Lake Erie. The timing of the invasion and expansion of the round goby in Lake Erie is curiously coincident with the increasing trend in TP after 2004. The goby was first detected in 1993 and underwent an exponential increase in abundance over the following five years (Bunnell et al. 2005). Johnson et al. (2005) estimated that there were 9.9 billion round gobies in the western basin in 2002. Bunnell et al. (2005) modeled the potential effect of the goby invasion on phosphorus cycling in the central basin of Lake Erie using bioenergetics models and field data. They concluded that even at peak densities observed up to 2003, the development of the goby population would have little effect on phosphorus supply.

Management Next Steps

The recent increases in TP concentrations are unexpected and without an easily identifiable cause. The Union Intake is located in shallow water in relatively close proximity to land. Evaluating the degree to which the intake data represents TP levels and trend over larger areas of the western basin is a necessary step before the significance of the increasing trend can be placed in context. Determining the factors contributing to the apparent rise in water column concentrations, whether they be operating on a local or wider scale, may provide insight on the biological availability of the phosphorus and the potential for adverse ecological effects such as nuisance algae.

The complexity of human-induced, ecological and physical conditions in the western basin makes it difficult to determine the factors causing the recent changes in water column phosphorus levels. A multi-faceted approach which draws upon research and monitoring initiatives will likely be needed.

There have been periodic blooms of cyanobacteria during late summer in the western basin since 1995 (Brittain et al. 2000; Vincent et al. 2004; Rinta-Kanto et al. 2005). While ecological factors (namely, selective grazing by dreissenid mussels) have been implicated in the recent onset of algae blooms (Vanderploeg et al. 2001), excessive growth of algae

is dependent on nutrient availability. The degree to which changing TP levels may be contributing to the competitive advantage of bloom-forming species or to the achievement of bloom levels appears to be uncertain.

In 1995, median TP concentrations in water collected at the Union Water Treatment Plant intake were near the lowest levels observed over the 1976 to 2004 period. This suggests that either the intake data may not be representative of the western basin, in particular the southern side of the basin where the blooms have appeared to be more prevalent, or alternatively, that the interplay between ecological process and nutrient availability is as important as nutrient concentration in determining susceptibility to cyanobacteria blooms. Further examination of the role that present levels of nutrients play in the promotion of cyanobacteria blooms is warranted.

Research/Monitoring Needs

Spatial variability in water quality in the western basin is pronounced. As noted above, the degree to which the intake data reflect broader conditions in the basin is unknown and should be evaluated before broad, basin-wide conclusions are made. Further, an improved understanding of the spatial diversity in water quality in the western basin would allow for a more exact analysis of changes through time. An improved understanding of the spatial diversity of water quality would also provide a basis to better account for local or regional factors.

References

- Brittain, S.M., J. Wang, L. Babcock-Jackson, W.W. Carmichael, K.L. Rinehart, and D.A. Culver. 2000. Isolation and characterization of microcystins, cyclic heptapeptide hepatotoxins from a Lake Erie strain of *Microcystis aeruginosa*. *Journal of Great Lakes Research* 26:241-249.
- Bunnell, D.B., T.B. Johnson, and C.T. Knight. 2005. The impact of introduced round gobies (*Neogobius melanostomus*) on phosphorus cycling in central Lake Erie. *Canadian Journal of Fisheries and Aquatic Science* 62:15-19.
- Dolan, D.M., and K.P. McGunagle. 2005. Lake Erie total phosphorus loading analysis and update: 1996 to 2002. *Journal of Great Lakes Research* 31(Supplement 2):11-22.
- Johnson, T.B., M. Allen, L.D. Corkum, and V.A. Lee. 2005. Comparison of methods needed to estimate population size of round gobies (*Neogobius melanostomus*) in western Lake Erie. *Journal of Great Lakes Research* 31:78-86.
- Lake Erie LaMP. 2006. Lake Erie Lakewide Management Plan (April 2006 update) <http://www.epa.gov/glnpo/lakeerie/> (September 2006).
- Nicholls, K.H. 1999. Evidence for a trophic cascade effect on north-shore western Lake Erie phytoplankton prior to zebra mussel invasion. *Journal of Great Lakes Research* 25:942-949.
- Nicholls, K.H., and G.J. Hopkins. 1993. Recent changes in Lake Erie (north shore) phytoplankton: Cumulative impacts of phosphorus loading reductions and zebra mussel introduction. *Journal of Great Lakes Research* 19:637-647.

- Nicholls, K.H., G.J. Hopkins, S.J. Standke, and L. Nakamoto. 2001. Trends in total phosphorus in Canadian near-shore waters of the Laurentian Great Lakes: 1976-1999. *Journal of Great Lakes Research* 27:402-422.
- Neilson, M., S. L'Italien, V. Glumac, D. Williams, and P. Bertram. 1995. 1994 State of the Lakes Ecosystem Conference Background Paper. Nutrients: Trends and system response. EPA 905-R-95-015.
- Nicholls, K.H., D.W. Standen, and G.J. Hopkins. 1980. Recent changes in the near-shore phytoplankton of Lake Erie's western basin at Kingsville, Ontario. *Journal of Great Lakes Research* 6:146-153.
- Rinta-Kanto, J.M., A.J.A. Ouellette, M.R. Twiss, G.L. Boyer, T. Bridgeman, and S.W. Wilhelm. 2005. Quantification of toxic *Microcystis* spp. during the 2003 and 2004 blooms in western Lake Erie using quantitative real-time PCR. *Environmental Science and Technology* 39:4198-4205.
- Vanderploeg, H.A., J.R. Liebig, W.W. Carmichael, M.A. Agy, T.H. Johengen, G.L. Fahnenstiel, and T.F. Nalepa. 2001. Zebra mussel (*Dreissena polymorpha*) selective filtration promoted toxic *Microcystis* blooms in Saginaw Bay (Lake Huron) and Lake Erie. *Canadian Journal of Fisheries and Aquatic Science* 58:1208-1221.
- Vincent, R.K., X. Qin, R.M.L. McKay, J. Miner, K. Czajkowski, J. Savino, and T. Bridgeman. 2004. Phycocyanin detection from LANDSAT TM data for mapping cyanobacterial blooms in Lake Erie. *Remote Sensing of Environment* 89:381-392.

Links for More Information

Phosphorus targets achieved in Lake Erie. Lake Erie Committee, Great Lakes Fishery Commission, 1998: <http://www.gllfc.org/pressrel/prlecpos.htm>

Biomass, condition of western Lake Erie Dreissenids. NOAA: http://www.glerl.noaa.gov/res/Task_rpts/2004/aisnalepa04-1.html

Lake Erie, Great Lakes Information Network: <http://www.great-lakes.net/lakes/erie.html>

Lake Erie: A lake in flux, Great Lakes portraits. Environment Canada: <http://www.on.ec.gc.ca/laws/coa/2001/lake-erie-e.html>

Contact Information

Todd Howell
Ontario Ministry of the Environment
Environmental Monitoring and Reporting Branch
E-mail Address: todd.howell@ontario.ca

Lynda Nakamoto
Ontario Ministry of the Environment
Environmental Monitoring and Reporting Branch
E-mail Address: lynda.nakamoto@ontario.ca

INDICATOR: CHLORIDE LEVELS IN WESTERN LAKE ERIE WATER SAMPLES COLLECTED FROM THE MONROE WATER INTAKE

Background

Chloride is a salt compound resulting from the combination of the gas chlorine and a metal. Common chlorides include sodium chloride (NaCl) and magnesium chloride (MgCl_2). Chlorine alone is highly toxic and is often used as a disinfectant. In combination with a metal such as sodium, it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plants and animals.

Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Sodium chloride may impart a salty taste at 250 mg/L; however, calcium or magnesium chloride is not usually detected by taste until levels of 1,000 mg/L are reached. Public drinking water standards require chloride levels not to exceed 250 mg/L.

For many decades there has been concern about increasing chloride concentrations in Lake Erie (Beeton 1961; Thomas 1981). Increased chloride concentrations may have caused changes in the biota of the Great Lakes, particularly halophytic (i.e., salt-loving) algae such as *Bangui atropurpurea* (Sonzogni et al. 1983). The chloride concentration of Lake Erie is more than three times that of Lake Huron (Beeton et al. 2002). This is the result of Lake Erie's shallowness and small water volume, combined with significant urban and industrial areas that are sources of chloride (Figure 1).

All municipal water intakes routinely monitor the quality of their water supplies. The Monroe Water Intake has continuously monitored its water supply since 1969. The intake structure is located 1,524 meters offshore in western Lake Erie and draws from a depth of 4.9 meters.



Figure 1. Salt pile in Detroit, Michigan (Photo credit: Emily Wilke).

Status and Trends

Lake Erie chloride concentrations increased from about 7-8 mg/L in the early 1900s to approximately 20-25 mg/L in the 1960s (Figure 2; Beeton 1969). Since the late 1960s, continuous chloride monitoring has been performed at the Monroe Water Intake. In general, there has been high seasonal and year-to-year variability (Whyte et al. 1990). Whyte et al. (1990) found that between 1968 and 1985 there was a slight decreasing chloride trend at the Monroe Water Intake and attributed this slight decreasing trend to reduced loadings from point source discharges and the cessation of certain industrial operations that historically discharged high chloride loadings. Further, the U.S. Environmental Protection Agency's Great Lakes National Program Office has reported that mean, lake-wide chloride concentrations in Lake Erie have declined from approximately 20 mg/L in 1975 to 14 mg/L in 2000.

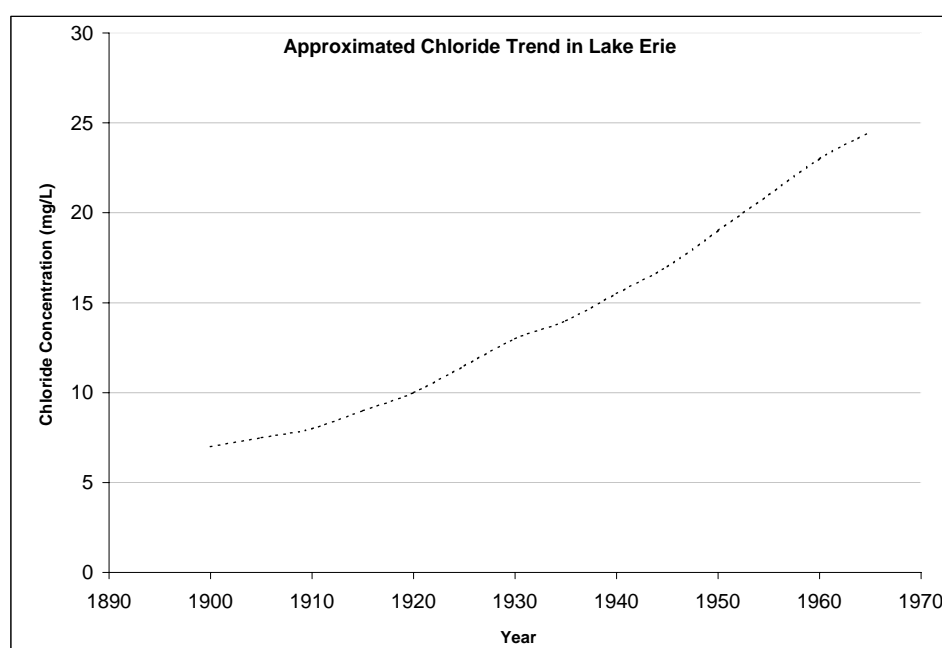


Figure 2. Changes in Lake Erie chloride concentration as reported by Beeton (1969), 1900-1965 (trendline approximated from Beeton, 1969).

Crucil et al. (1991) further investigated this decreasing trend and found that five of the six major industrial point sources in the Detroit River (i.e., Detroit River accounts for 94% of the inflow to Lake Erie), which historically contributed high chloride loadings, had ceased certain operations. The combined chloride loadings from these five industrial facilities decreased from an apparent high of 4,247 tonnes/day (4,681 tons/day) in 1964-1966 to zero in 1986, when the last of the five industrial facilities closed. Each of these facilities was involved in two specific industrial processes, which characteristically discharged large amounts of chloride: the production of soda ash by the Solvay method and the production of various inorganic chemicals by chlor-alkali methods. Reduced chloride loadings occurred from voluntary stipulations, cessation of these operations, and indirect regulatory controls.

Chloride concentrations in water samples from the Monroe Water Intake remain below state regulatory standards. However, from the late 1980s to the early 2000s there appears to be a slight increase in chloride levels in water samples collected from the Monroe Water Intake (Figure 3). Further monitoring will be required to confirm this trend. Average chloride concentrations in four of the last five years have been approximately 27-31 mg/L.

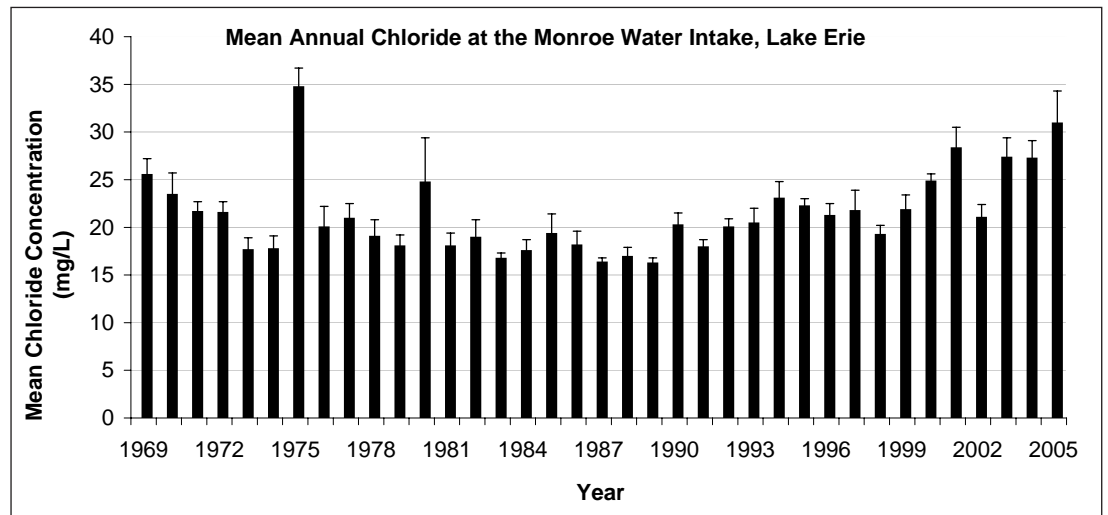


Figure 3. Mean annual chloride concentrations, including standard deviations, in raw water intake samples collected from western Lake Erie by the Monroe Water Intake, 1969-2005 (data provided by Gregory S. Allen, Superintendent, Monroe Water Filtration Plant; statistical support provided by Lisa Perschke of Washtenaw County Conservation District, Emily Wilke of University of Michigan, Richard Hug of Indiana University N.W., and Don Busek of Belleville, Michigan).

Management Next Steps

Industrial process changes and the cessation of certain industrial operations have resulted in substantial reductions in point source (i.e., a specific or fixed point where pollution enters a stream or lake – an identifiable location such as an industrial discharge) chloride loadings to western Lake Erie. However, as the relative contribution of point source loadings of chloride has decreased, the relative contribution of nonpoint source (i.e., diffuse sources of pollution such as runoff from precipitation that do not enter a river or lake at a fixed point) loadings of chloride have increased. Holland et al. (1995) have shown that the annual chloride loading to Lake Erie is presently from diffuse sources (e.g., agricultural runoff, highway deicing, sheet and gully erosion, and stream bank erosion) and that maximum loading to the lake occurs during spring runoff and episodically during severe storms. As human population densities in the Detroit River-western Lake Erie watershed (and urban sprawl) increases, it is likely that road salt usage will increase. Thus, any efforts to stop or slow the apparent increasing chloride trend will require the controlling of these nonpoint sources, such as road salting.

Considerable effort is being made by public works departments and transportation departments at all levels to improve the management of road salts. Some departments are well advanced with the introduction of technologies such as electronic spreader controllers, anti-icing, pre-wetting, and road weather information systems, whereas others are just beginning to investigate best management practices. The assessment of road

salting impacts has led to a heightened interest in the use of best management practices for road salting throughout the Great Lakes Basin.

Research/Monitoring Needs

Continued monitoring of chloride levels by municipal water intakes like Monroe, Michigan is warranted to track long-term trends. Efforts should also be made to quantify chloride loadings associated with road salting and other nonpoint sources. Further, biological monitoring should be enhanced (particularly of phytoplankton) to document ecological changes associated with any further increases in chloride concentration in Lake Erie.

References

- Beeton, A.M. 1961. Environmental changes in Lake Erie. *Transactions of the American Fisheries Society* 90:152-159.
- Beeton, A.M. 1969. Changes in the environment and biota of the Great Lakes. In *Eutrophication: Causes, Consequences, Correctives*, ed. G.A. Rohlich, pp. 150-187. Washington, DC. National Academy of Sciences.
- Beeton, A.M., C.E. Sellinger, and D.F. Reid. 2002. An introduction to the Laurentian Great Lakes ecosystem. In *Great Lakes Fisheries Policy and Management*, eds. C.P. Ferreri and W.W. Taylor, pp. 3-54. East Lansing, MI: Michigan State University Press.
- Crucil, C., L. McGee, and J.H. Hartig. 1991. Why have Lake Erie chloride concentrations decreased? *Canadian Water Resources Journal* 16(1):97-102.
- Holland, R.E., T.H. Johengen, and A.M. Beeton. 1995. Trends in nutrient concentrations in Hatchery Bay, western Lake Erie, before and after *Dreissena polymorpha*. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1202-1209.
- Sonzogni, W.C., W. Richardson, P. Rodgers, and T.J. Monteith. 1983. Chloride pollution of the Great Lakes. *Water Pollution Control Federation* 55:513-521.
- Thomas, N.A. 1981. Ecosystem changes in lakes Erie and Ontario. *Bulletin of the Buffalo Society of Natural Sciences* 25:1-20.
- Whyte, R.S., J.H. Hartig, and G.J. Hopkins. 1990. Decreasing chloride trends observed at Lake Erie municipal water intakes. *Journal of Great Lakes Research* 16(2):233-240.

Links for More Information

U.S. EPA drinking water regulations: <http://www.epa.gov/safewater/consumer/2ndstandards.html>

The Center for Science and Environmental Outreach. Road salt in Michigan: http://emml.mtu.edu/gem/community/publications/wellspring/salt_follow-up.html

Executive summary: Deicer effects and mitigating measures: http://www.michigan.gov/documents/summary_51450_7.pdf

Contact Information

John H. Hartig, Refuge Manager
Detroit River International Wildlife Refuge
E-mail Address: John_Hartig@fws.gov

Lisa Perschke
Washtenaw County Conservation District
AmeriCorps Groundwater Educator
E-mail Address: lisa.perschke@mi.nacdnet.net

INDICATOR: DISSOLVED OXYGEN LEVELS IN THE ROUGE RIVER

Background

The Rouge River watershed in southeast Michigan is largely urbanized, spans approximately 1,134 square kilometers (438 square miles), is home to over 1.5 million people in 48 communities and three counties, and is a tributary to the Detroit River. From the very beginning, the Rouge River has been recognized for its strategic location and beneficial uses. Native people settled along the shores of the river to use it as a transportation route, take advantage of the water supply, and benefit from the incredible fishing and hunting (Bean et al. 2003). In 1701, the French built their fort and established the first permanent settlement in the region. Later in the eighteenth century, gristmills would be established on main forks in the river and shipyards established on the lower river. The lower Rouge River was dredged in the early 1900s to accommodate shipbuilding and the rapidly growing automobile industry. Henry Ford consolidated automobile manufacturing operations into one geographical area to create efficiencies and synergies, turning Zug Island and the lower Rouge River into the heartland of the Industrial Revolution. The Rouge River became the recipient of waste oil and other industrial pollutants.

Mass production of automobiles and subsequent intense urbanization of the Rouge River watershed placed additional stresses on the river, including storm water runoff and other diffuse sources. Chief among these were sanitary sewer overflows and combined sewer overflows (CSOs) that discharged untreated sanitary waste into the river during wet weather conditions. A study of the Rouge River in the early 1970s (Jackson 1975) reported, “approximately 40 miles of the Rouge River were characterized by very poor water quality as evidenced by a macroinvertebrate community dominated by animals tolerant of severely polluted waters. The principal contaminants at that time were raw sewage and inorganic sediment entering the river via combined and/or storm sewers.”

As industrial point sources of pollution were being addressed during the 1960s and 1970s through both federal and state regulatory initiatives, it soon became clear that more would need to be done to address nonpoint sources of pollution (pollution which cannot be traced back to a single origin or source such as storm water runoff, water runoff from urban and agricultural areas, and failed septic systems). The Rouge River was still highly polluted during the 1970s; raw sewage from CSOs and sanitary sewer overflows was being discharged, there were odor problems, and fish were dying. Urbanization of the watershed had significantly increased the impervious surfaces in the watershed resulting in significant increases in the volume and amount of energy in the runoff waters after wet weather events.

CSOs and polluted storm water runoff result in many water quality problems, including extreme flow variations, streambank erosion, flooding, loss of habitat, high bacteria levels, and low dissolved oxygen. Polluted storm water runoff contains bacteria, heavy

metals, nutrients, oil, and pesticides. Minimizing the impact of both CSOs and polluted storm water is critical to the restoration of the Rouge River and its impact on the Detroit River.

Dissolved oxygen is an important parameter in defining the health of aquatic ecosystems. When dissolved oxygen concentrations are below 4.0 mg/L, there are potentially adverse impacts on aquatic life. To protect aquatic life, State of Michigan water quality standards specify that dissolved oxygen must be greater than 7 mg/L at all times for streams designated as cold water fisheries and must be greater than 5 mg/L at all times for streams designated as warm water fisheries. All of the Rouge River and its tributaries are designated as warm water streams except for Johnson Creek, which is designated as a cold water fishery.

Therefore, dissolved oxygen levels in the Rouge River have been identified as a key indicator of environmental quality and a key indicator that tracks effectiveness of water pollution control programs. It should be noted that this indicator is important to both the restoration of the Rouge River and its subsequent impact on the Detroit River.

Status and Trends

Many initiatives have taken place in support of forging a holistic approach to watershed management for the Rouge River. The Rouge River Remedial Action Plan (RAP) process began in 1985 with the recognition that state government had the authority to force corrective action, but due to the diffuse nature of the problem and large expense, public awareness and local community commitment, cooperation, and involvement were essential to restoring the Rouge (Bean et al. 2003). The Rouge River Basin Committee was established to work with local governments and stakeholder groups to bring about local ownership of the RAP. All 48 communities in the watershed participated on the Rouge River Basin Committee along with other stakeholders.

The initial Rouge River RAP was completed in 1988. The RAP focused heavily on sanitary sewer overflows and CSOs because approximately 29,526,212 cubic meters (7.8 billion gallons) of combined sewage was being discharged into the Rouge River during rain events annually. It is important to note, however, that although the 1988 RAP recommendations focused on sanitary sewer capacity and CSO control, it also recognized polluted storm water from separated sewers as a significant problem across the entire watershed. In 1992, the Rouge River National Wet Weather Demonstration Project (Rouge Project) was established with funding from the U.S. Environmental Protection Agency to Wayne County's Department of Environment to implement the RAP (Murray 1994). The Rouge Project recognizes that to be cost-effective, pollution problems in the river must be addressed collaboratively by all of the local governments, the counties, and the other stakeholders, and with flexibility across the regulatory programs. Decisions should be made and success based on results made in the resource, and/or in creating the capacity to better manage the resource, and not solely on meeting permit compliance requirements and timelines. This comprehensive implementation effort deals with the problems of sanitary sewer overflows, CSOs, and polluted storm water runoff. Regulatory policy, programs and financial institutional arrangements have also been a major effort of the Rouge Project. Outcomes include the State of Michigan's Watershed-Based Storm Water Permit, passage of the Watershed Alliance Act (Public Act 517 of 2004),

the establishment of the Alliance of Rouge Communities, and the implementation of a comprehensive monitoring plan for the Rouge River watershed.

For the purposes of this indicator report, it was decided to focus on one of the best long-term indicators of environmental quality – dissolved oxygen levels in two key subwatersheds (Main 3 and 4) of the Rouge River. Main 3 and 4 subwatersheds are located in the lower (most downstream) end of the Rouge River. Consequently, these subwatersheds are the recipient of all the upstream impacts from human activity, and historically have been the portion of the river that has had the poorest water quality. Figure 1 presents the long-term trend for dissolved oxygen in Main 3 and 4 sub-watersheds of the Rouge River. The earliest dissolved oxygen data were from the 1973 study conducted by the Michigan Department of Natural Resources (Jackson 1975). These dissolved oxygen trend data show that the percentage of dissolved oxygen measurements that exceed the 5 mg/L state standard for protection of a warm water fishery has increased from approximately 20% in 1973 to over 80% in recent years. Although there are still violations in this most downstream and heavily impacted portion of the Rouge River watershed, this dissolved oxygen trend documents that substantial improvements are occurring as a result of the watershed restoration measures.

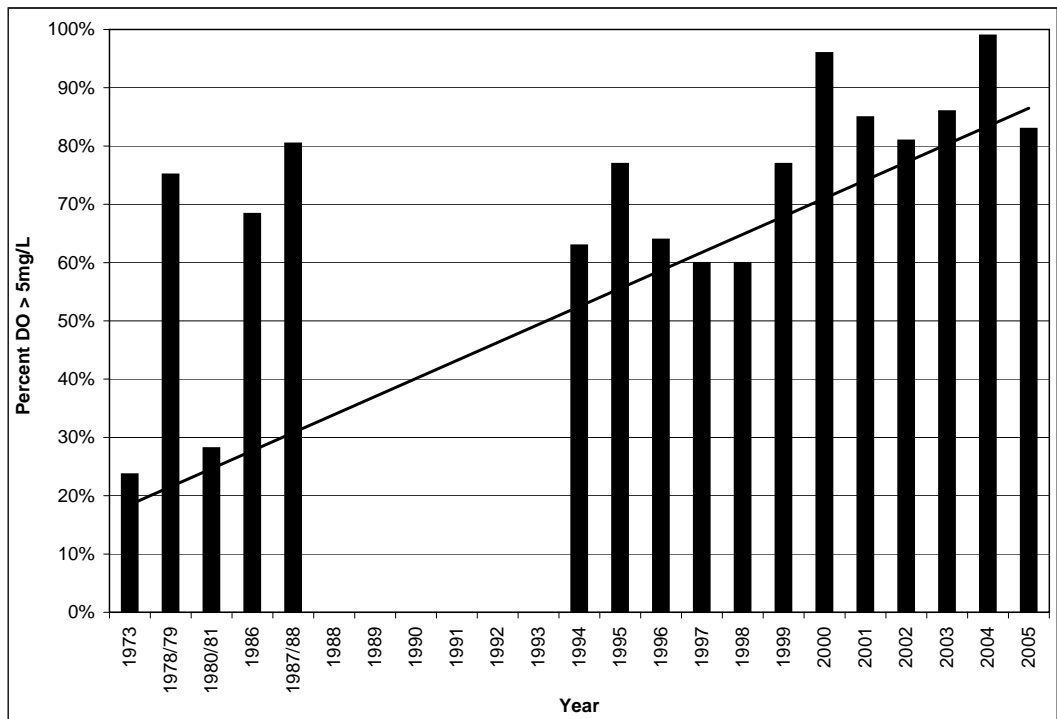


Figure 1. The percentage of dissolved oxygen measurements in Main 3 and 4 subwatersheds of the Rouge River that exceed the Michigan standard of 5 mg/L for protection of a warm water fishery, 1973-2005. A higher percentage means that these subwatersheds more frequently exceed the Michigan dissolved oxygen standard and that dissolved oxygen conditions are improving.

It is recognized that many indicators are needed to fully assess the health of the Rouge River watershed. In December of 2005, the Rouge RAP Advisory Council published an update to the *Rouge River Report Card*. A brief summary of indicator trends from this *Rouge River Report Card* is presented below:

- 10 of the 18 *Rouge River Report Card* indicators are “making progress”;
- four of the six pollution control and water quality indicators show that management efforts are “making progress”; none of the six pollution control and water quality indicators are “losing ground”; and
- while five of the six habitat and wildlife indicators are reported as “losing ground,” all six of the indicators relating to stewardship are reported as “making progress.”

The 2005 *Rouge River Report Card* can be downloaded from the Friends of the Rouge website (www.therouge.org).

Management Next Steps

Key management actions for the Rouge River watershed include:

- complete Phase 2 CSO control projects (planned CSO controls on all remaining combined sewer areas);
- continue sanitary sewer capacity improvements;
- promote the economic importance of the region’s “Green” (plants) and “Blue” (waters) infrastructure to encourage adequate public investment in continued restoration and protection efforts;
- ensure sufficient collaboration among the 48 watershed communities, the three watershed counties, the Michigan Department of Environmental Quality, and the U.S. Environmental Protection Agency to secure adequate funding for discharge elimination; and
- sustain the public education and watershed monitoring and restoration activities initiated via the Rouge Project (MIG619000) (Wayne County Department of Environment 2006).

Research/Monitoring Needs

Monitoring is essential for proper watershed management. Priority must be given to ensuring sufficient monitoring to be able to adequately evaluate effectiveness of programs and to make midcourse corrections. Further, research is needed on innovative funding mechanisms for storm water and watershed management in order to maintain the momentum for restoration and protection efforts.

References

- Bean, C.J., J.H. Hartig, and N. Mullett Jr. 2003. Watershed planning and management: The Rouge River experience. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 185-198. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Jackson, G. 1975. A biological investigation of the Rouge River, Wayne and Oakland counties, May 17-October 19, 1973. Department of Natural Resources. Lansing, MI.

Murray, J. 1994. *Rouge River Watershed Management: Implementing a Remedial Action Plan (RAP)*. Proceedings of 67th Annual Conference of the Water Environment Federation. Alexandria, VA.

Wayne County Department of Environment. 2006. *Seventh Annual Report*. Certificate of Coverage MIG610040. General Storm Water Permit.

Links for More Information

Friends of the Rouge: <http://www.therouge.org>

Rouge River National Wet Weather Demonstration Project:
<http://www.rougeriver.com>

Wayne County Department of Environment: <http://www.wcdoe.org>

Contact Information

Noel Mullett Jr., Technical Projects Coordinator
Wayne County Department of Environment
Water Quality Division
E-mail Address: nmullett@co.wayne.mi.us

Patrick Cullen, Department Manager
Wayne County Department of Environment
Water Quality Division
E-mail Address: pcullen@co.wayne.mi.us

Dean Tuomari, Department Manager
Wayne County Department of Environment
Water Quality Division
E-mail Address: dtuomari@co.wayne.mi.us

INDICATOR: CONTAMINANTS IN WESTERN LAKE ERIE SEDIMENTS

Background

Over the past century, discharges of liquid and solid waste from industrial, agricultural and domestic sources have introduced a multitude of toxic substances into the waters of the Great Lakes. The presence of these toxics can adversely impact Great Lakes wildlife, biodiversity and aquatic ecosystems. Many of these contaminants bond to the particles suspended in water, which are subsequently deposited in open lake areas based on their size and the speed of the current. Accumulation of these particles in successive layers constitutes a veritable historical record of the natural and anthropogenic events that have shaped the environment in the watershed. Therefore, it is important to understand and assess the extent of the contamination in sediments.

Environment Canada, together with collaborating agencies, routinely conduct Great Lakes surveys to measure the occurrence and spatial distribution of toxic substances in order to further our understanding of the role human activities play in releasing these compounds to the environment. The repetition of these surveys also provides information for devising effective strategies to mitigate potentially deleterious health effects. Remedial activities related to contaminant control routinely address sources. The reduction of point source discharges is often followed by a decrease in the amount of contaminants in the ambient environment and can be reflected in downstream sediments. The use of sediment contamination as an indicator of contaminant loading is a valuable tool for environmental monitoring. The study of sediment contamination also allows assessment of the success of remedial actions related to the elimination or reduction of contaminant sources. Sediment quality is monitored by analyzing both the deep layer of sediment, considered a trap for toxic substances, and surface sediments, which are examined to characterize recent inputs of particles.

Sediment Quality Assessment Criteria

The chemical quality of sediment is generally assessed by means of criteria relative to the degree of toxicity to benthic aquatic organisms. Two levels are generally considered: the threshold effect level (TEL), below which adverse biological effects are expected to occur rarely, and the probable effect level (PEL), above which adverse effects are expected to occur frequently. These concentrations were established by the Canadian Council of Ministers of the Environment (CCME), and are routinely used as screening tools by different stakeholders involved in sediment management activities (CCME 1999).

Status and Trends

Lake Erie discharges a watershed characterized by both urban/industrial and agricultural activities. In its western portion, it receives the waters of the Detroit River and Lake St. Clair whose shores are home to many manufacturing and processing plants.

In 1971, Environment Canada conducted a survey in Lake Erie to characterize the spatial extent of sediment contamination by metals and organochlorine contaminants using surficial sediment samples (Frank et al. 1977; Thomas and Jaquet 1976; Thomas et al. 1976). In addition, the cultural impact of human activities over time was assessed using sediment cores (Kemp and Thomas 1976; Kemp et al. 1976). Sediment levels of metals, including total mercury, lead, zinc, cadmium, and copper, were compared to precolonial concentrations; the highest total mercury concentrations occurred in the western basin adjacent to the Detroit River. DDT was similarly distributed. Inputs of PCBs were apparent along the southern shore while dieldrin appeared to have sources along both the south and north shores. A western basin core sample indicated that PCBs and other organochlorines began to accumulate in the sediments during the period 1953 to 1958. In general, sediments in the western basin of Lake Erie exhibited high levels of contamination. Sediments in the central and eastern basins exhibited levels that were intermediate between those in the western basin and lower levels in sediments in Lake St. Clair, which discharges into the Detroit River.

In 1995, Environment Canada revisited 50 of the original 259 sites from the 1971 survey. The 1995 sediment samples, as well as archived 1971 samples, were analyzed for PCBs (Figure 1) and other organochlorine pollutants. Encouragingly, the PCB and organochlorine concentrations had decreased considerably from those reported in 1971. As a follow-up measure, Environment Canada in collaboration with the Ohio Environmental Protection Agency conducted additional Lake Erie surveys in 1997 and 1998 to enable a broader range of analyses for the assessment of current sediment contamination. Organochlorine pollutants such as hexachlorobenzene were analyzed (Figure 2). The surveys provided further documentation of the improvement in sediment contaminant concentrations from the original 1971 survey. In 1971, as in 1997 and 1998, the sediments with the highest mercury contamination occupied the western basin of the lake. Results of the 1997 and 1998 surveys confirmed the initial conclusion that contaminant concentrations had been significantly reduced. Since the 1970s, average mercury concentrations in surface sediment in the lake as a whole fell by about 70%, dropping from 0.61 µg/g in 1971 to 0.190 µg/g in 1997 and 1998. This trend is also evidenced by the profiles of core samples from the three major basins.

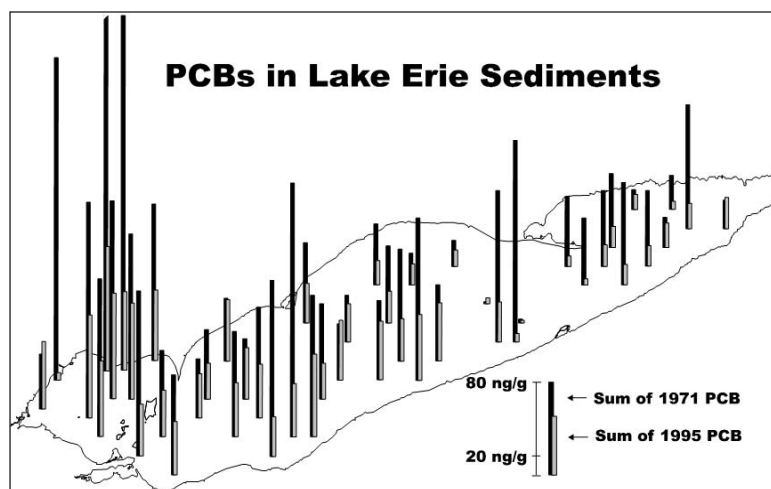


Figure 1. Comparison of Lake Erie surficial sediment total PCB concentrations (ng/g dry wt.) in samples collected in 1971 and 1995. Canadian Sediment Quality Guidelines threshold effect level (TEL) = 34.1 ng/g, probable effect level (PEL) = 277 ng/g.

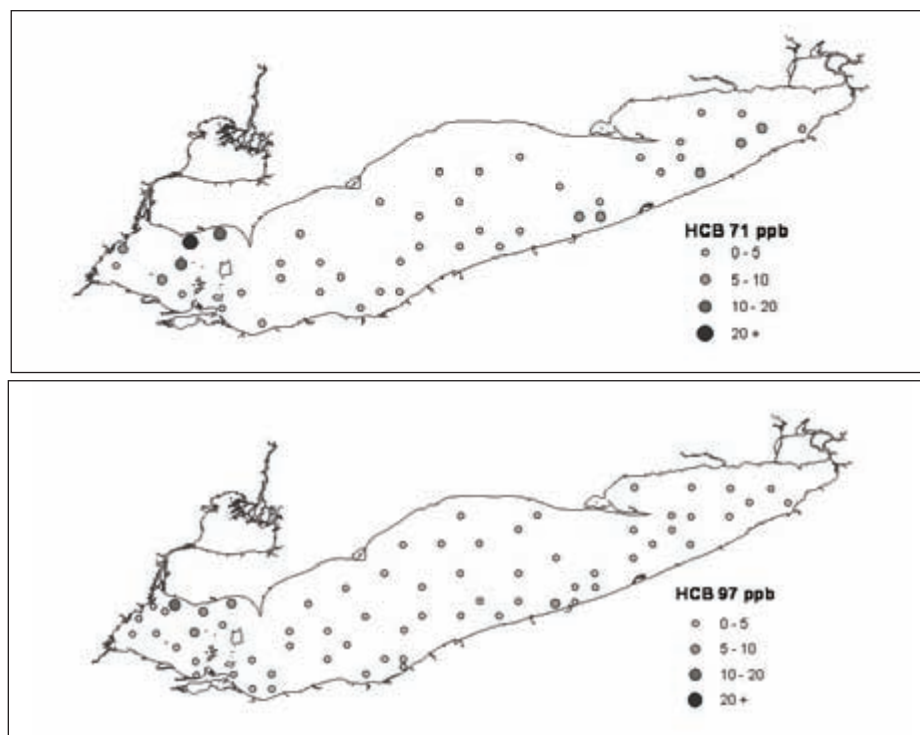


Figure 2. Lake Erie surficial sediment hexachlorobenzene concentrations (ng/g dry wt.) in samples collected in 1971 (top) and 1997 (bottom).

Spatial trends in sediment contamination in Lake Erie are similar for a number of compound classes including total PCBs, dioxins and furans, total mercury, and metals. There is a trend toward increasing contamination from the eastern basin to the western basin, and from the northern portion of the central basin to the southern portion of the central basin. Presumably, these trends are influenced by industrial activities in the watersheds along major tributaries including the Detroit River, and areas along the southern shoreline. Other major influences may include prevailing currents, sediment transport and deposition processes, open-lake disposal of dredged material, and remediation of contaminated areas. Environment Canada's monitoring of suspended sediment quality in Lake Erie has shown that the western basin continues to be subjected to active loadings of contaminants. The Detroit River has been identified as a primary vector for these contaminants, but potential loadings from other tributaries cannot be discounted. In addition, atmospheric deposition may have contributed to these loadings.

Sediments in some areas of Lake Erie still exceed the strictest Canadian and Province of Ontario Sediment Quality Guidelines as defined by the threshold effect level (TEL) or lowest effect level (LEL), respectively. Exceedances of sediment guidelines are largely restricted to the western basin and the southern portion of the central basin. Exceedances of Canadian Sediment Quality probable effects guidelines (PEL) are most numerous for dioxins and furans (40%), followed by mercury (6%). The Canadian threshold effects guideline (TEL) for PCBs and the Provincial lowest effect guideline (LEL) were exceeded at 52% and 22% of the sites, respectively, in the 1997 and 1998 surveys. Of the pollutants identified as exceeding various guidelines, mercury, PCBs, and dioxins and furans are responsible for the fish consumption advisories in Lake Erie. However, the current trend in sediment contamination toward lower concentrations suggests that the strictest criteria for sediment quality in Lake Erie for some contaminants will be eventually achieved (Figure 3).

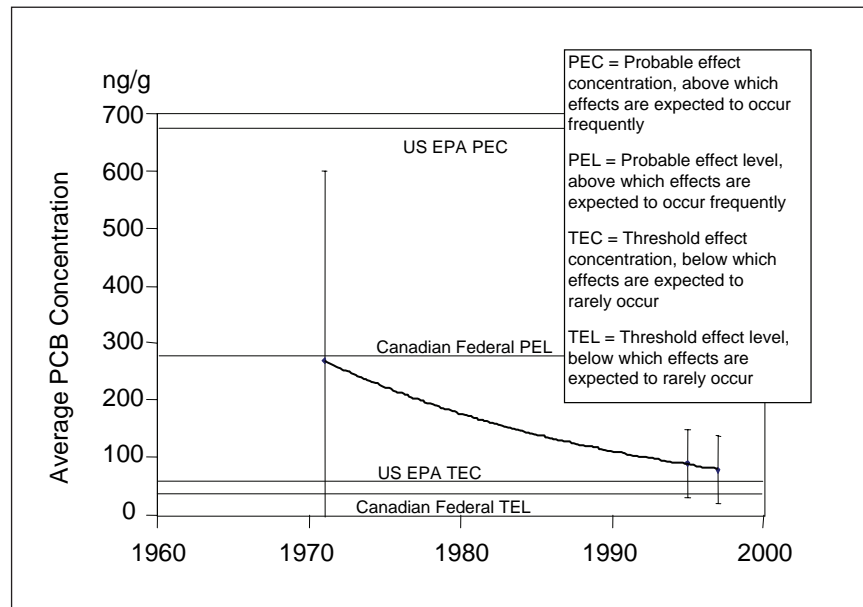


Figure 3. Lake Erie lakewide average PCB concentrations compared to Canadian and U.S. sediment quality guideline values.

Management Next Steps

The reduction in sediment contamination in all areas of Lake Erie comes in the wake of regulatory measures implemented by public authorities, particularly binational initiatives. The regulatory measures resulted in the closure of industrial facilities and improvements in industrial processes and water cleanup operations. Indeed, for over 30 years, Canada and the U.S. have jointly undertaken to reduce discharges of toxics and to work toward the rehabilitation of contaminated sites through initiatives such as the Great Lakes Water Quality Agreement and the Great Lakes Binational Toxics Strategy. This binational collaboration in reducing discharges, research and monitoring, and working toward virtual elimination of toxic substances must continue.

Research/Monitoring Needs

Long-term research and monitoring of suspended and bottom sediments in the Detroit River-western Lake Erie corridor must continue, particularly in light of ongoing remediation of areas of contaminated sediment in the lower reaches of the river. Suspended sediments serve as a useful indicator of contaminants entering the open-lake area; sampling downstream of contaminated areas can serve as a useful indicator of the efficacy of remedial activities. Bottom sediments remain a key indicator of the response of the open-lake areas to reductions in contaminant loadings.

References

[CCME] Canadian Council of Ministers of the Environment. 1999. *Canadian Environmental Quality Guidelines*. Winnipeg, Manitoba.

Frank, R., M. Holdrinet, H.E. Braun, R.L. Thomas, A.L.W. Kemp, and J.M. Jaquet. 1977. Organochlorine insecticides and PCBs in sediments of Lake St. Clair (1970 and 1974) and Lake Erie (1971). *Science of the Total Environment* 8:205-227.

Kemp, A.L.W., and R.L. Thomas. 1976. Impact of man's activities on the chemical composition in the sediments of lakes Ontario, Erie, and Huron. *Water, Air, and Soil Pollution* 5:469-490.

Kemp, A.L.W., R.L. Thomas, C.I. Dell, and J.M. Jaquet. 1976. Cultural impact of the geochemistry of sediments in Lake Erie. *Journal of the Fisheries Research Board of Canada* 33:440-462.

Marvin, C.H., M.N. Charlton, E.J. Reiner, T. Kolic, K. MacPherson, G.A. Stern, E. Braekevelt, J.F. Estenik, L. Thiessen, and S. Painter. 2002. Surficial sediment contamination in lakes Erie and Ontario: A comparative analysis. *Journal of Great Lakes Research* 28(3):437-450.

Marvin, C.H., S. Painter, and R. Rossmann. 2004. Spatial and temporal patterns in mercury contamination in sediments of the Laurentian Great Lakes. *Environmental Research* 95:351-362.

Marvin, C.H., S. Painter, M.N. Charlton, M.E. Fox, and P.A. Thiessen. 2004. Trends in spatial and temporal levels of persistent organic pollutants in Lake Erie sediments. *Chemosphere* 54:33-40.

Painter, S., C.H. Marvin, F. Rosa, T. Reynoldson, M.N. Charlton, M. Fox, P.A. Thiessen, and J.F. Estenik. 2001. Sediment contamination in Lake Erie: A 25-year retrospective analysis. *Journal of Great Lakes Research* 27(4):434-448.

Thomas, R.L., and J.M. Jaquet. 1976. Mercury in the surficial sediments of Lake Erie. *Journal of the Fisheries Research Board of Canada* 33:404-412.

Thomas, R.L., J.M. Jaquet, A.L.W. Kemp, and C.F.M. Lewis. 1976. Surficial sediments of Lake Erie. *Journal of the Fisheries Research Board of Canada* 33:385-403.

Links for More Information

Great Lakes success stories: <http://www.on.ec.gc.ca./success-stories/gl/chris-e.html>

Contact Information

Chris Marvin, Research Chemist
Environment Canada
E-mail Address: Chris.Marvin@ec.gc.ca

INDICATOR: CRITERIA AIR POLLUTANTS IN SOUTHEAST MICHIGAN

Background

The federal Clean Air Act (CAA) requires the U.S. Environmental Protection Agency (U.S. EPA) to establish National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to the public and the environment. These standards define the maximum permissible concentration¹ of “criteria pollutants” in the air. Criteria pollutants are those common throughout the United States. They are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO₂), ground-level ozone (O₃), particulate matter (PM) less than or equal to 10 (PM₁₀) or 2.5 (PM_{2.5}) micrometers in diameter, and sulfur dioxide (SO₂). Of the six pollutants, PM and ground-level ozone are the most widespread health threats. In the Detroit area, PM_{2.5} and ozone continue to violate the NAAQS.

The NAAQS established for the six criteria pollutants are monitored by the Michigan Department of Environmental Quality (MDEQ) through the Michigan Air Sampling Network (MASN) for compliance. Currently there are eleven MASN stations in Wayne County for the various criteria pollutants.

Carbon Monoxide

Carbon monoxide is a colorless, odorless, and poisonous gas that is created during the incomplete burning of fuel. In cities, as much as 95% of all CO emissions come from automobile exhaust. Michigan’s on-road motor vehicle sources account for 69% of the state’s CO emissions. Michigan’s non-road vehicle sources contribute 28% of the state’s CO emissions. These sources include aircraft, marine vessels, non-road two and four stroke engines, and railroads. CO emissions from Michigan’s industries (point sources) account for only 2%. For the Detroit area, fossil fuel combustion from electric utilities, industrial, commercial and residential sources, as well as iron and steel manufacturing and foundries, were the leading point sources of CO.

Lead

In the past, automobile sources were the major contributor of lead emissions to the atmosphere. Industrial and combustion sources are now the dominant lead emission sources, especially smelting/refining of lead, copper and zinc, and the production of iron, steel, brass and bronze. The highest air concentrations of lead are usually found in the vicinity of smelters and battery manufacturers. For combustion sources, lead is an

¹ For this report, the NAAQS for criteria pollutants are: **CO** – 8-hour average < 10,000 µg/m³ (9 ppm), not more than one exceedance/year; 1-hour average < 40,000 µg/m³ (35 ppm), not more than once/year. **Pb** – max quarterly average ≤ 1.5 µg/m³. **NO₂** – annual average ≤ 100 µg/m³ (0.053 ppm). **Ozone** – annual second highest 1-hour daily max average across 3 years ≤ 235 µg/m³ (0.12 ppm); annual fourth highest 8-hour daily max average across 3 years ≤ 166 µg/m³ (0.085 ppm). **PM₁₀** – annual average must not exceed 50 µg/m³; 24-hour concentration limit of 150 µg/m³ (average number of expected exceedances per year not to exceed one over the most recent 3-year period). **PM_{2.5}** – annual average ≤ 15 µg/m³, averaged over 3 years; 98th percentile of 24-hour concentration not to exceed 65 µg/m³ (based on a 3-year average). **SO₂** – annual average ≤ 80 µg/m³ (0.030 ppm); 24-hour concentration limit not to exceed 365 µg/m³ (0.14 ppm) more than once/year.

impurity found in coal, oil, and waste oil, as well as municipal solid waste and sewage sludge incineration.

Nitrogen Dioxide

The major man-made sources that result in the production of NO_2 are high temperature combustion processes. In Michigan, 46% of NO_2 producing compounds come from on-road sources, and 31% come from point sources such as industrial, commercial, institutional and residential fossil fuel combustion. Nitrogen dioxide can sometimes be seen as a reddish-brown layer over the city.

Ozone

Depending on its location in the atmosphere, ozone is considered either good or bad. Good ozone occurs naturally in the stratosphere approximately 16-48 km (10-30 miles) above the Earth's surface and forms a layer that protects the Earth from the sun's harmful rays. In the Earth's lower atmosphere, ground-level ozone is considered bad. Ground-level ozone is created by chemical reactions in the atmosphere involving other air pollutants in the presence of sunlight. These reactions usually occur during the hot summer months.

Major sources of the pollutants that form ozone are engine exhaust, emissions from industrial facilities, combustion from electric utilities, gasoline vapors, chemical solvents, and emissions from natural sources. Ground-level ozone can be transported hundreds of kilometers. As a result, the long-range transport of air pollutants impacts the air quality of areas far downwind. Transported ozone and ozone precursors from Gary, Indiana, Chicago, Illinois, and Milwaukee, Wisconsin, and other upwind source areas affect the levels of ground-level ozone in Michigan.

Of the sources of ozone producing pollutants in Michigan, 63% are emitted by vehicles, and the other 37% are emitted from combustion of fuels, chemical and petroleum manufacturing, and naturally from vegetation.

Particulate Matter

Particulate matter is a general term used for a mixture of solid particles and liquid droplets found in the air. Some particles are large enough to be seen as dust or dirt where others are so small they can only be detected with an electron microscope. The larger PM (PM_{10}) are particles less than 10 micrometers [μm] in diameter which is equal to about 1/7th the diameter of a human hair. In Michigan, 34% of PM_{10} comes from particles that originate from point sources, such as power plants, and various manufacturing and industrial processes; 32% comes from "area" sources, such as wood stoves and fireplaces, agriculture and forestry practices, oil and gas production, paper manufacturing, and small airborne particles that do not originate from any specific point; and another 34% comes from vehicle emissions. Fine PM ($\text{PM}_{2.5}$) are particles less than 2.5 μm in diameter. $\text{PM}_{2.5}$ comes from the same sources as PM_{10} , but can also form in the air through chemical reactions with atmospheric pollutants. $\text{PM}_{2.5}$ from vehicle emissions comprises 50% of the ambient $\text{PM}_{2.5}$ in Michigan. Area sources make up 37% and point sources contribute 13%. Particles with diameters of less than 50 μm are classified as total suspended particulates (TSP), an older measure of PM.

Sulfur Dioxide

In Michigan, 85% of the overall SO₂ emissions are from point sources. These point sources are from industrial processes that burn fossil fuels, chemical manufacturing, metals processing, petroleum-related industries, and incineration. Other sources include residential, commercial, and industrial space-heating.

Status and Trends

Carbon Monoxide

From 1979 to 1984, the CO levels in the Detroit area had exceeded the NAAQS for 8-hour exposure. Since that time, there have been no exceedances. Figure 1 indicates a clear downward trend since 1979 (when U.S. EPA first established criteria for the National Air Monitoring Sites). This trend represents a 50% decrease in average CO levels every 10 years, or 0.31 ppm/year. On August 30, 1999, the Detroit area was taken off the list of problem areas for carbon monoxide.

The decline of CO in the Detroit area follows a national trend, even though there is an increase in the distance vehicles travel. Starting with the Clean Air Act of 1970, catalytic converters, fuel economy standards, national standards for tailpipe emissions, new vehicle technologies, clean fuels programs, and state and local emissions reduction measures are credited with the decrease in emissions of CO.

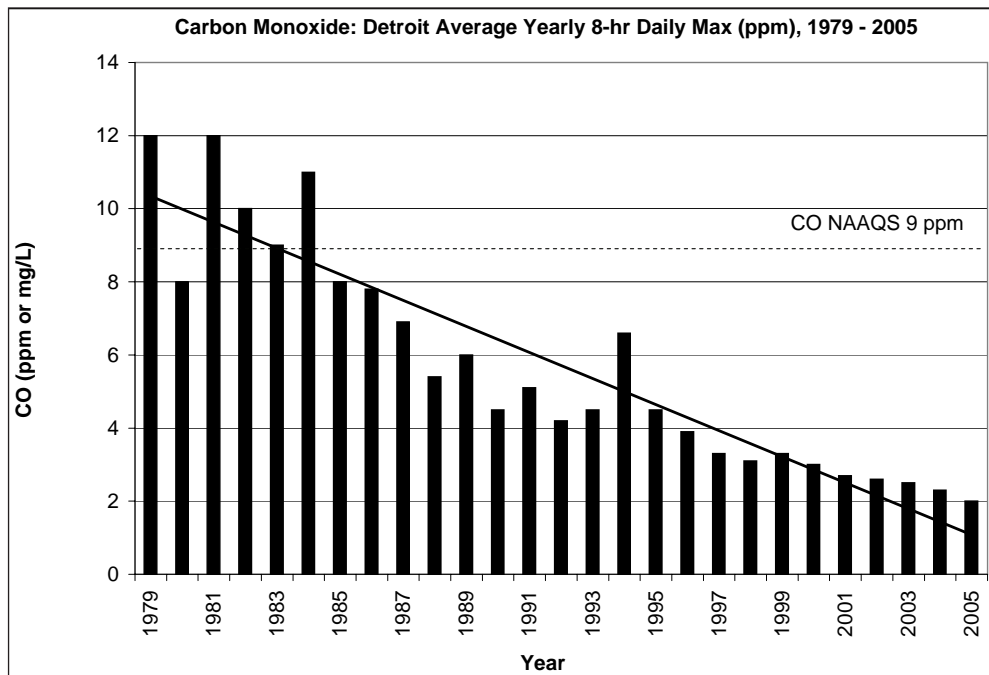


Figure 1. The average yearly 8-hour daily maximum levels of CO in Detroit, 1979-2005. Compliance with the CO standard is met when the 35 ppm 1-hour average standard and/or the 9 ppm 8-hour average standard is not exceeded more than once per year.

Lead

Ambient lead levels have been consistently below NAAQS since 1981, when the U.S. EPA established new ambient lead monitoring criteria, and the average air quality concentration for lead in the Detroit area in 2005 was 98% lower than the high in 1983 (Figure 2).

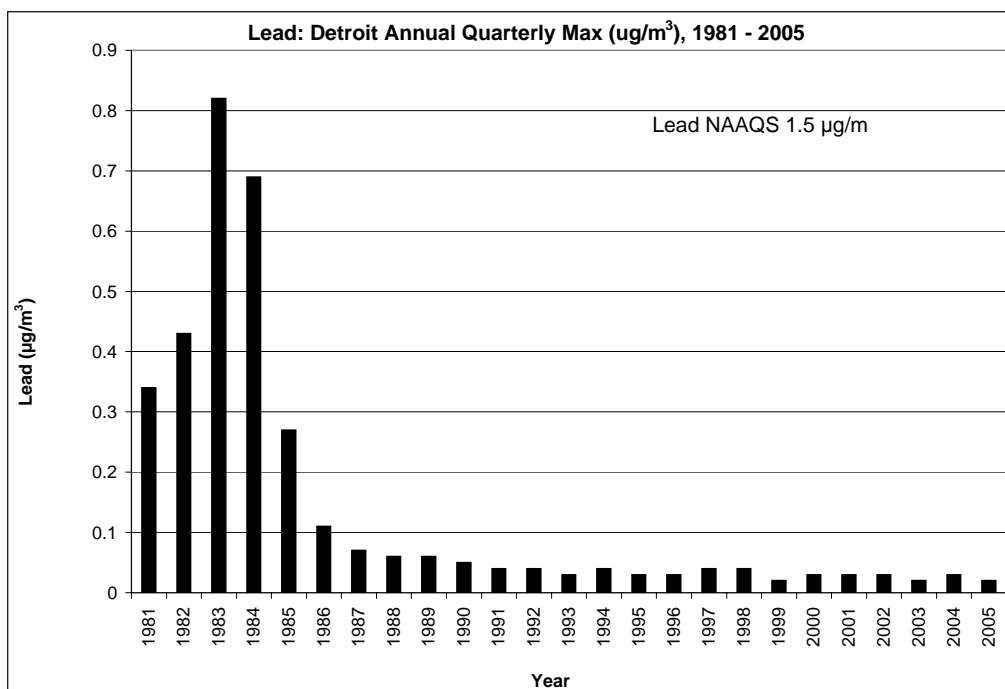


Figure 2. The annual quarterly maximum ($\mu\text{g}/\text{m}^3$) lead levels in Detroit, 1981-2005. Daily values are collected for three consecutive months (by calendar quarter), averaged, and then compared to the $1.5 \mu\text{g}/\text{m}^3$ standard.

Due to the phase-out of leaded gasoline, ambient lead concentrations in air sharply declined during the 1980s and early 1990s, and in Michigan, vehicle emissions no longer contribute quantifiable lead emissions. Because of the success of reduction of lead from auto emissions, in 1999, the U.S. EPA reduced requirements for measuring lead air pollutant concentrations near major highways, while focusing on point sources. Point sources such as nonferrous smelters and battery plants now contribute 100% of Michigan's overall lead emissions. However, there are no large sources of lead in Michigan and the average ambient lead levels are less than one-tenth of the NAAQS.

Nitrogen Dioxide

Michigan has never recorded a violation of the nitrogen dioxide standard. From 1979 to 2005, the Detroit area has been well below the NAAQS for NO_2 at an average of 43% (Figure 3). Regulations on vehicle emissions over the past few decades and reductions in emissions from power plants due to stricter regulations and new technologies have contributed to a decreasing trend.

Ozone

In 1979, the U.S. EPA established a 1-hour standard for ozone. Since then, there has been a slight downward trend in the 1-hour ozone level in the Detroit area (Figure 4a). From 1979 to 1989, the standard was exceeded five out of the ten years. From 1990 to 2000, the standard was exceeded only once, and since 1995 there have been no exceedances.

In the past, 8-hour ozone measurements were taken to help estimate the 1-hour standard. In 1997, based on the latest scientific information showing adverse effects from exposures allowed by the 1-hour standard, the U.S. EPA strengthened the ozone NAAQS by adopting the 8-hour averaging time. By 2005, the 1-hour standard was mostly phased out in favor of the 8-hour standard.

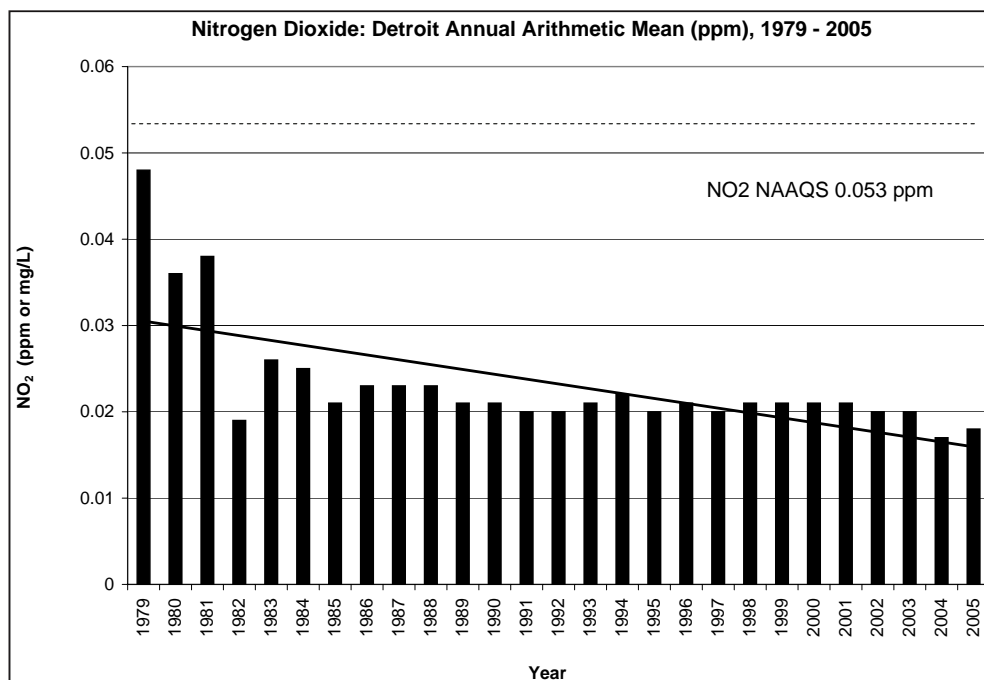


Figure 3. The annual average (ppm) of nitrogen dioxide in Detroit, 1979-2005. Compliance is met when the annual average concentration does not exceed 0.053 ppm.

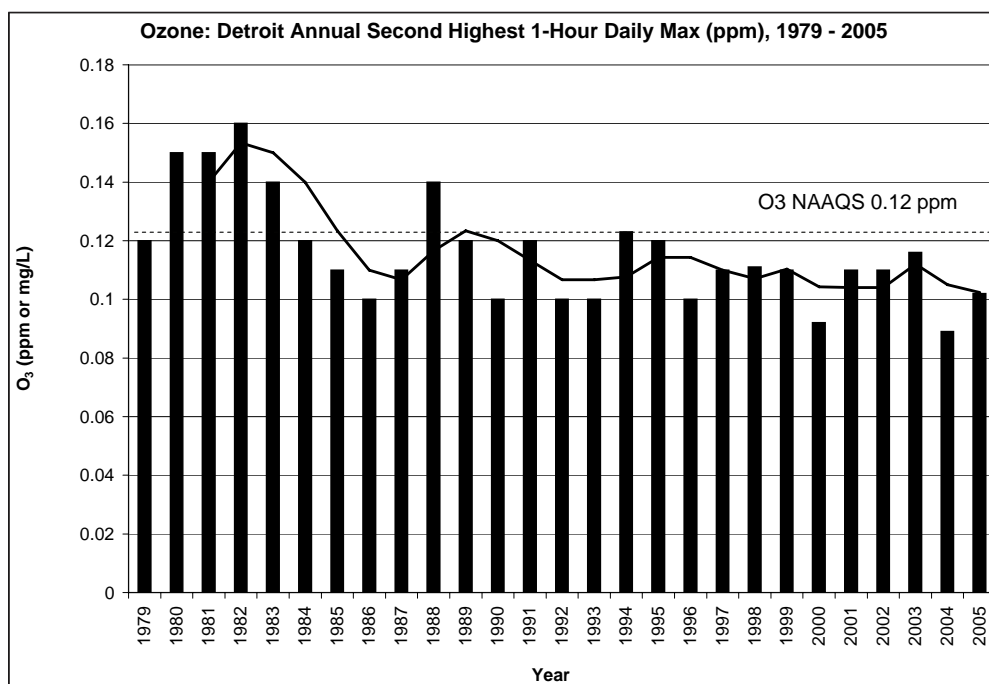


Figure 4a. The annual second highest 1-hour daily maximum average (ppm) of ground-level ozone in Detroit, 1979-2005. The 1-hour ozone standard is violated when the annual second highest maximum hourly average concentration, averaged over three years, exceeds 0.12 ppm (see bold line).

There is no clear trend for the Detroit area 8-hour ozone levels (Figure 4b). Currently, the Detroit area is not considered in compliance with the NAAQS. In 2006, MDEQ instituted measures aimed at meeting the NAAQS by 2007. The most significant action is a requirement for low-vapor pressure gasoline to be sold in the Detroit area during summer months to reduce the amount of ozone-causing air pollutants.

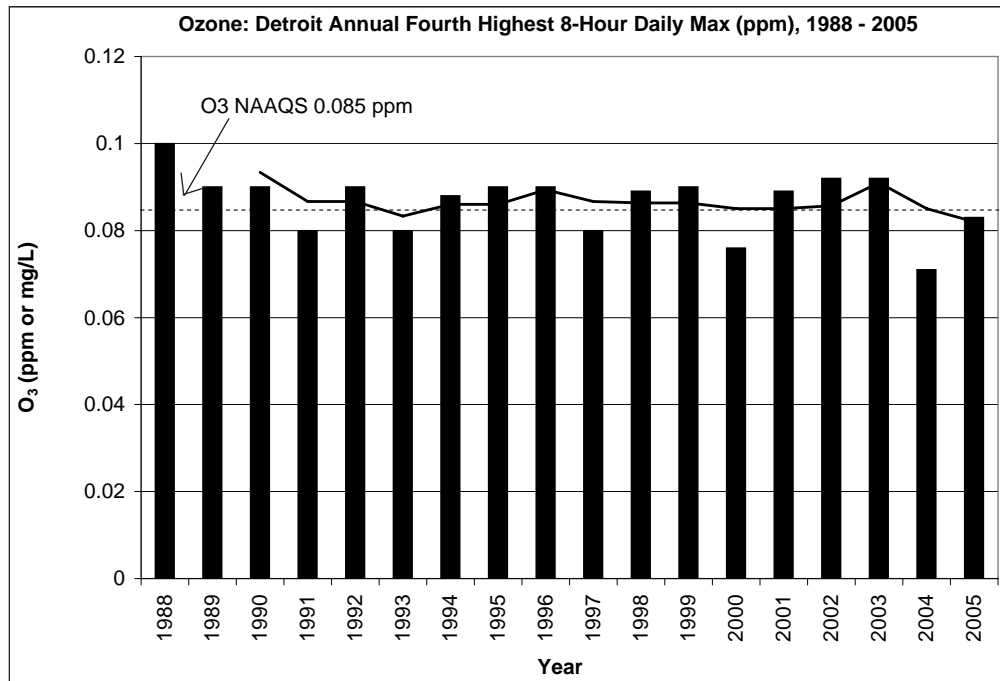


Figure 4b. The annual fourth highest 8-hour average daily maximum (ppm) for ground-level ozone in Detroit, 1988-2005. The 8-hour ozone standard is violated when the annual fourth highest daily maximum 8-hour concentration, averaged over three years, exceeds 0.085 ppm (see bold line).

Particulate Matter

From 1960 to 1985, the TSP standard in the Detroit area was exceeded every year, with no clear trend toward improvement (Figure 5). The standard was revised from TSP to PM₁₀ in 1987, as research demonstrated smaller sized particles presented a greater health risk. From 1988 (the first full year of monitoring under the new PM₁₀ standard) to 2005, there were no exceedances, on average, of the NAAQS for PM₁₀ in the Detroit area. However, the Dearborn station did register a few exceedances of the 24-hour PM₁₀ standard during that time and continues to have the highest maximum annual average (39.7 µg/m³) in the state. In 1997, the PM₁₀ standard was revised and a new standard was added for PM_{2.5}. Since 1999 (the first full year of monitoring under the new PM_{2.5} standard), the Detroit area has met the standard only once (in 2004). Due to failure to meet the PM_{2.5} standard, MDEQ is required to develop control strategies to bring the area into attainment by 2010.

Along with the requirement for MDEQ to reduce the level of PM_{2.5}, there are several federal measures in place that are intended to reduce vehicle emissions nationwide, which is expected to have an impact for Wayne County. One program is aimed at reducing the level of sulfur in gasoline and sets standards for tailpipe emissions. Another addresses emission control technologies for new diesel engines and reduces the allowable level of sulfur in non-road diesel fuel. Other measures to reduce air pollutants from

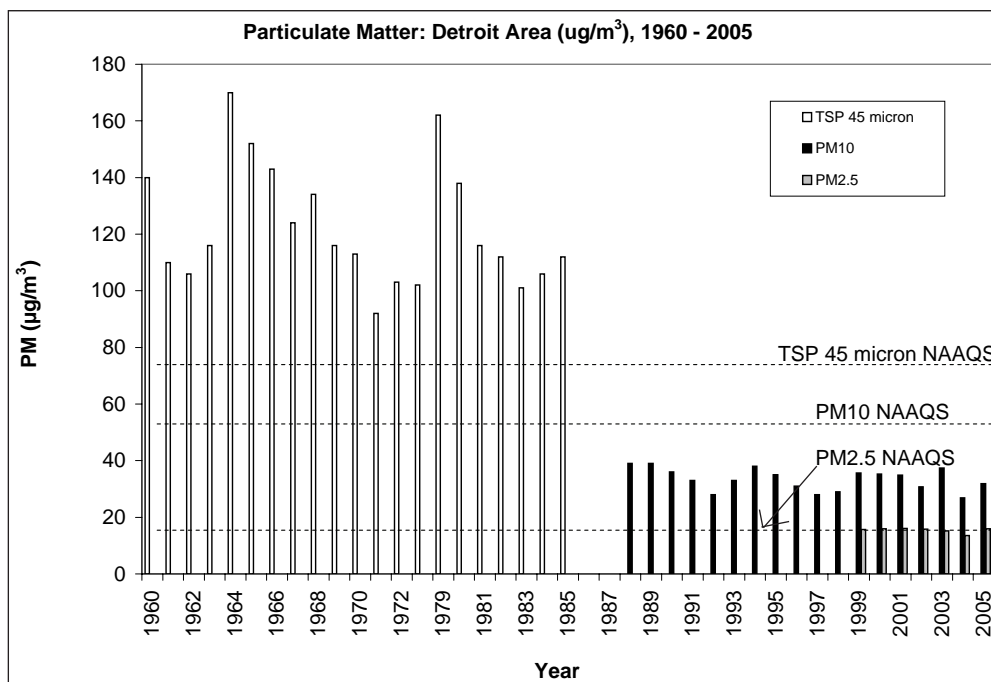


Figure 5. Particulate matter in the Detroit area using three criteria, TSP 45 micrometers, PM_{10} and $PM_{2.5}$, 1960-2005. TSP NAAQS - $75 \mu\text{g}/\text{m}^3$ annual geometric mean. PM_{10} NAAQS - annual average must not exceed $50 \mu\text{g}/\text{m}^3$. (Average number of expected exceedances per year not to exceed one over the most recent three-year period). $PM_{2.5}$ NAAQS - annual average must not exceed $15 \mu\text{g}/\text{m}^3$ (based on a 3-year average).

power plants are also expected to have a positive effect on limiting the generation of $PM_{2.5}$. Controls being implemented at local steel mills and oil refineries are expected to result in significant reductions and will help bring the area into attainment by 2010.

Sulfur Dioxide

In the Detroit area, SO_2 levels have consistently been well below the NAAQS since 1979 and show a clear downward trend. The ambient level of sulfur dioxide has decreased by 73% since 1979 (Figure 6). This reduction was due to new technology at coal-burning power plants, reducing the average sulfur content of fuels burned, and the increased use of natural gas for heating homes and businesses.

Management Next Steps

Efforts must continue to increase the availability and implementation of new technologies so that all air quality standards are met. There must be open dialogue with all parties involved and allow public access to data on current air conditions to foster an environment of continuous improvement in emissions reductions. On March 29, 2007, the U.S. EPA defined requirements for plans submitted by states that did not reach attainment based on their compliance with $PM_{2.5}$ standards implemented in 1997. Nonattainment states have been required to submit plans by April 2008 outlining measures to reach attainment by 2010. MDEQ submitted documentation in February 2005 showing only Wayne County as nonattainment for $PM_{2.5}$. The U.S. EPA determined that the six counties surrounding Wayne were contributing to its nonattainment status. Michigan is required to bring these areas into attainment by 2010.

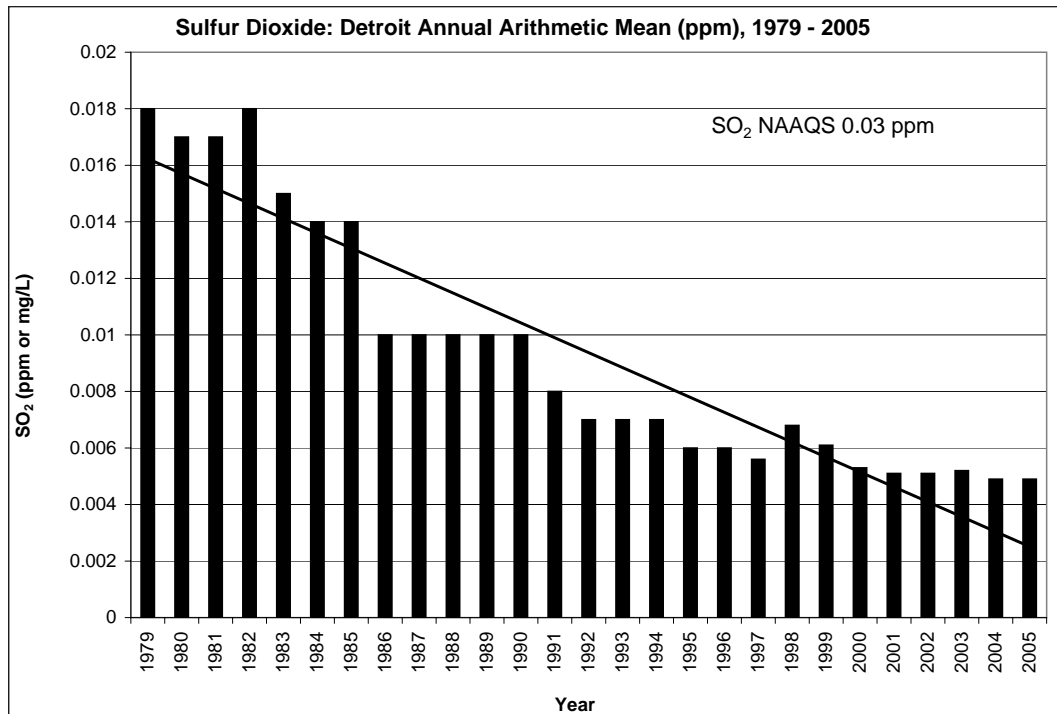


Figure 6. The annual arithmetic mean (ppm) of sulfur dioxide in Detroit, 1979-2005. The annual arithmetic mean concentration shall not exceed 0.03 ppm more than once per year and/or 24-hour limit not to exceed 0.14 ppm more than once per year.

SEMCOG's Southeast Michigan Air Quality Task Force and MDEQ have developed an attainment strategy for bringing the region into compliance with the annual standard by 2010. However, the new daily standard poses additional challenges. Much work still needs to be done to understand the characteristics of different species of PM_{2.5}, particularly organic carbon.

In 2005, MDEQ and SEMCOG submitted an ozone attainment strategy to U.S. EPA, identifying the control measures that would be implemented to meet the 8-hour ozone standard. While southeast Michigan has not measured a violation of the standard in the last three years, and MDEQ has requested the region be redesignated as attainment, the State and SEMCOG have moved forward with implementation of the control measures in the attainment strategy. These include a decrease in the allowable vapor pressure of summertime gasoline from 7.8 to 7.0 psi, and a reduction in allowable volatile organic compound emissions from consumer and commercial products. Both of these measures went into effect in 2007.

Research/Monitoring Needs

Air quality monitoring that will support the development of effective attainment strategies is critical to meeting standards. More quality monitoring data are needed to understand the specific sources of the various pollutants and the most effective ways to control them. Additional research exploring the specific links between air pollution and respiratory problems is also needed. In particular, a better understanding is needed of why asthma rates are increasing at the same time air quality is improving.

PM_{2.5} is currently monitored according to a federal reference method which allows comparisons to NAAQS. Hourly PM_{2.5} is monitored using a Tapered Element Oscillating Microbalance (TEOM) instrument. In order to identify and characterize the components within PM_{2.5} samples, a Met-One spiral ambient speciation sampler (SASS) is used. Both TEOM and SASS have been recently implemented throughout the state. There must be a close coupling of monitoring and characterization (i.e., stack testing and other analyses to understand where pollutants are coming from) with the response to meet air quality objectives for all six criteria pollutants. According to the Air Quality Technical Advisory Group at SEMCOG, there is more need for high-frequency speciated data collection and analysis of PM_{2.5}. More information is also needed specifically for condensable PM. In addition, research must address how quickly and under what conditions secondary PM_{2.5} forms in the region. Measures need to be undertaken to properly identify the sources of organic carbon in certain areas. Ozone research must address the specific types of volatile organic compounds in the air so that effective strategies for attainment can be implemented. Increased air quality regulations are being implemented in the midst of federal funding cutbacks for monitoring. However, reduced monitoring decreases the ability to develop effective attainment strategies. Every effort must be made to ensure adequate monitoring to be able to achieve effective management.

References

- U.S. EPA. 1973. *National Air Monitoring Program: Air Quality and Emissions Trends Annual Report, Vol. 1 and 2* (EPA 450/1-73-001a & b). Research Triangle Park, NC.
- U.S. EPA. 1973. *Monitoring and Air Quality Trends Report, 1972*. EPA 450-1-73-004. Research Triangle Park, NC.
- U.S. EPA. 1974. *Monitoring and Air Quality Trends Report, 1973*. EPA 450-1-74-007. Research Triangle Park, NC.
- Federal Register 64 (June 30, 1999): 35017-35023. Approval and Promulgation of State Implementation Plans; Michigan, Final Rule. <http://www.epa.gov/fedrgstr/EPA-AIR/1999/June/Day-30/a16372.htm>
- U.S. EPA. 1981. *National Air Quality and Emissions Trends Report, 1981*. EPA 450/4-83-011. Research Triangle Park, NC.
- U.S. EPA. 1984. *National Air Quality and Emissions Trends Report, 1982*. EPA 450/4-84-002. Microfiche. Research Triangle Park, NC.
- U.S. EPA. 1986. *National Air Quality and Emissions Trends Report, 1984*. EPA 450/4-86-001. Research Triangle Park, NC.
- U.S. EPA. 1987. *National Air Quality and Emissions Trends Report, 1985*. EPA 450/4-87-001. Research Triangle Park, NC.
- U.S. EPA. 1996. *National Air Quality and Emissions Trends Report, 1995*. EPA 454/R-96-005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd95/report/>.
- U.S. EPA. 2000. *National Air Pollutant, Emissions Trends, 1900-1988*. EPA-454/R-00-002. Research Triangle Park, NC.

U.S. EPA. 2003. *National Air Quality and Emissions Trends Report, 2003*. Special Studies Report. EPA/R-03-005. <http://www.epa.gov/air/airtrends/aqtrnd03/pdfs/chapter2crit.pdf>

MDEQ. 2006. *Air Quality Reports, 2000 - 2005*. http://www.michigan.gov/deq/0,1607,7-135-3310_4195-79055~,00.html

Links for More Information

U.S. EPA Technology Transfer Network, Air Quality System: <http://www.epa.gov/ttn/airs/aqsdatamart/>

U.S. EPA Office of Air and Radiation: <http://www.epa.gov/air/>

- U.S. EPA Air Trends website: <http://www.epa.gov/air/airtrends/>
- U.S. EPA National Ambient Air Quality Standards (NAAQS): <http://www.epa.gov/air/criteria.html>

MDEQ Air website: <http://www.michigan.gov/deq/0,1607,7-135-3310~,00.html>

MDEQ Annual Air Quality Reports: http://www.michigan.gov/deq/0,1607,7-135-3310_4195-79055~,00.html

Contact Information

Sheila Blais
Michigan Department of Environmental Quality
blaiss@michigan.gov

INDICATOR: CONTAMINANTS IN WESTERN LAKE ERIE FISH COMMUNITY

Background

Since 1977, the Department of Fisheries and Oceans Canada has been conducting an annual monitoring program to assess the temporal trends of contaminant burdens in representative top predator and forage fish species from Lake Erie (Figure 1). The Lake Erie survey is part of a binational Great Lakes Fish Contaminants Surveillance Program which was initiated in response to the specific requirements of Annex 11 (Surveillance & Monitoring) of the Great Lakes Water Quality Agreement. The intent of this program was: *"To survey collectively, the concentration of contaminants in selected species of Great Lakes fish and other biota with the specific purpose of determining environmental trends in contaminant*



Figure 1. Rainbow smelt (*Osmerus mordax*) averages 18-20 centimeters (7-8 inches) (Photo credit: New York State Department of Environmental Conservation).

levels and relating these, where possible, to sources of such pollution, the effectiveness of remedial actions, and the potential implications to Great Lakes fish stocks" (Whittle et al. 2002).

Remedial activities, related to contaminant control, routinely address sources. The reduction of point source discharges is often followed by a decrease in the amount of contaminant in the

ambient environment and, therefore, available for accumulation by the biological community. The use of fish as indicators of the level of bioavailable contaminants has long been seen as a valuable tool for environmental monitoring and a measure of the success of remedial actions related to the elimination or reduction of contaminant sources. Assessment of temporal trend contaminant burden data for fish has often focused on the fact that changes in concentrations are uniquely related to changes in point source discharges.

Pressures

The issue of the impact of changes in the abundance and variety of invasive nuisance species on toxic chemical cycling in the Great Lakes is still an expanding topic. The number of both exotic invertebrates and fish species proliferating in Great Lakes ecosystems continues to increase both temporally and spatially. Changes imposed on the form and function of native fish communities by exotics will subsequently alter ecosystem energy flows. As a consequence the pathways and fate of persistent toxic substances will be altered resulting in different accumulation patterns, particularly at the top of the food web. This phenomenon was witnessed in the late 1980s in the Lake Erie system after the invasion and proliferation of zebra mussels. Some contaminant levels peaked for short periods in fish and subsequently decreased. Each of the Great Lakes is currently experiencing changes in the structure of the aquatic community and

hence there may be periods of increases in contaminant burdens of some fish species. An added stressor in the future will be climate change with the potential for warming effects to change the availability of Great Lakes critical habitats, change the productivity of some systems, accelerate the movement of contaminants from abiotic sources into the biological community and further affect the composition of biological communities. All of the above will affect temporal trends in contaminant burdens measured in various fish species throughout the Great Lakes basin (Morrison et al. 2000).

Status and Trends

Since the late 1970s, concentrations of historically regulated contaminants such as polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloro-ethane (DDT) and mercury have generally declined in most monitored fish species. The changes are often lake specific and relate both to the specific characteristics of the substances involved and the biological conditions of the fish community (Whittle et al. 2004).

Rainbow smelt represents a major prey species in the Lake Erie fish community. For this indicator report, the rainbow smelt data are from fish collected throughout Lake Erie (i.e., western, central, and eastern basins) and are known to be representative of conditions in the western basin. Levels of mercury measured in 2002 Lake Erie smelt samples were the highest concentrations reported since the whole lake survey was initiated in 1977 (Figure 2). The 2003 levels then declined by 66%; the mean value was the second lowest concentration reported since 1977. The levels then increased again in 2004.

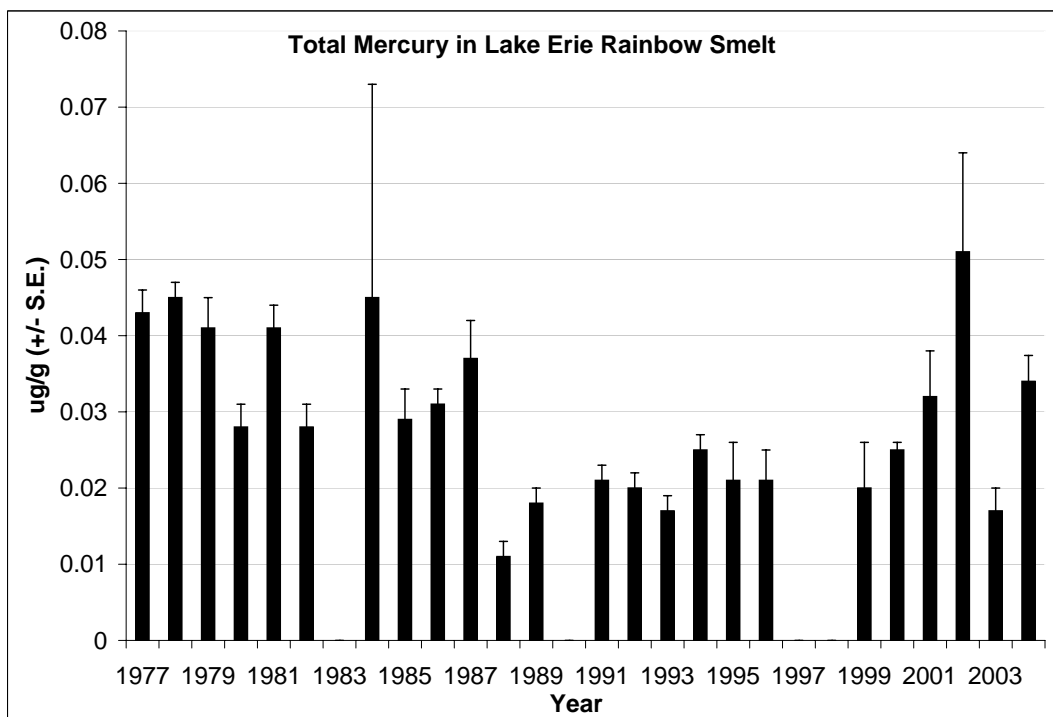


Figure 2. Total mercury levels in Lake Erie rainbow smelt (ug/g +/- S.E. wet weight, whole fish), 1977-2004 (2004 data unpublished).

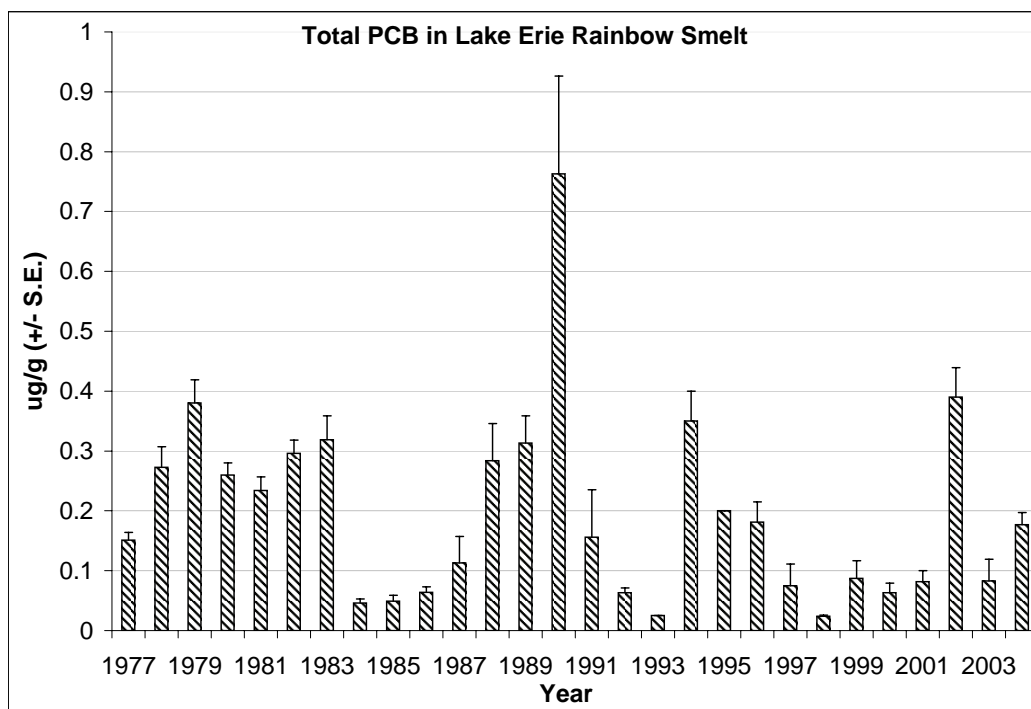


Figure 3. Total PCB levels in Lake Erie rainbow smelt (ug/g +/- S.E. wet weight, whole fish), 1977-2004 (2004 data unpublished).

Total PCB levels in rainbow smelt have also been measured since 1977 (Whittle 1998). PCB levels demonstrated a rapid and continuous significant increase from the period 1985-1986 through 1990 when they reached a maximum level of 0.76 ug/g, most likely due to the invasion of zebra and quagga mussels (Figure 3). After 1990, total PCB levels in smelt declined and remained at levels averaging about 0.10 ug/g through 2001. PCBs then exhibited a significant concentration increase in 2002. Levels were anomalously high (0.39 ug/g) for that single year and then declined by 80% in 2003.

Overall, concentrations of total DDT in rainbow smelt were about 60% lower in recent years compared to the late 1970s, but exhibited a fair degree of year-to-year variability (Figure 4). The pattern of a dramatic increase from 1985-1986 through 1989 was also evident with respect to total DDT levels in Lake Erie rainbow smelt. Between 1989 and recent years, DDT concentrations generally declined, but still showed a fair degree of year-to-year variability. For example, the 2003 mean value was almost an order of magnitude lower (0.01 vs. 0.09 ug/g) than the 1989 value measured during the apex of the zebra and quagga mussel proliferation in Lake Erie.

For this indicator report 4+-6+ year old walleye (*Sander vitreus*) were collected exclusively from the western basin of Lake Erie. Walleye are collected in the fall, but fish are known to migrate between the western and central basins at points throughout the year.

After a period of rapid decline (approximately 60%) from 1977 through 1983, mercury concentrations in Lake Erie walleye have remained fairly steady (Figure 5). After 1996 the frequency of annual measurements of mercury burdens in walleye was reduced. The mean of two recent measurements made in 1999 and 2003 was approximately 15% greater than the five-year mean of the period 1992 through 1996.

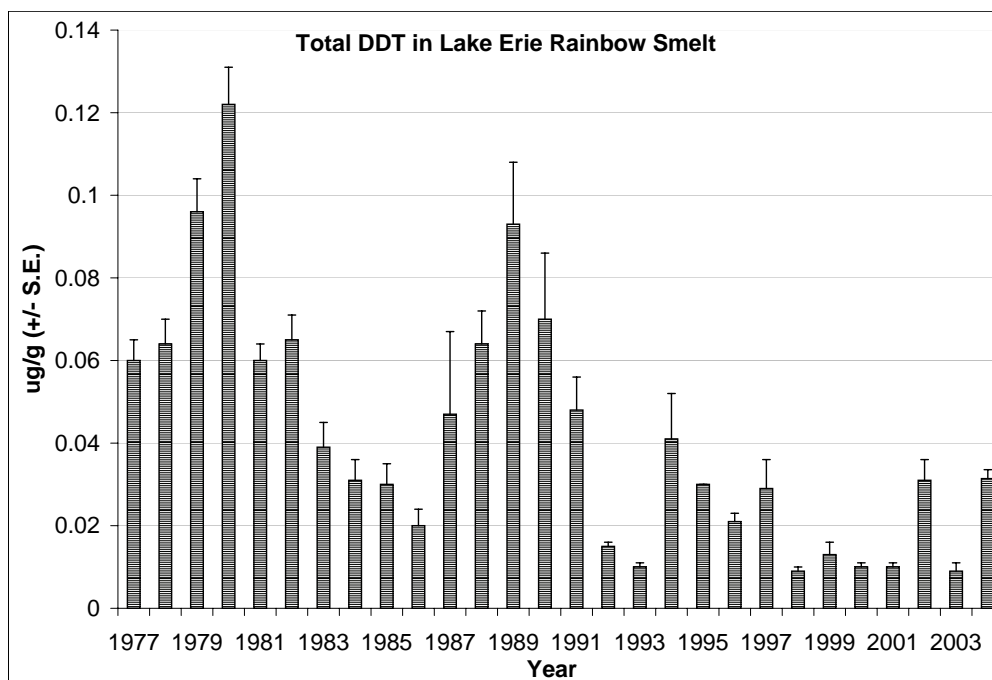


Figure 4. Total DDT levels in Lake Erie rainbow smelt ($\mu\text{g/g} \pm \text{S.E.}$ wet weight, whole fish), 1977-2004 (2004 data unpublished).

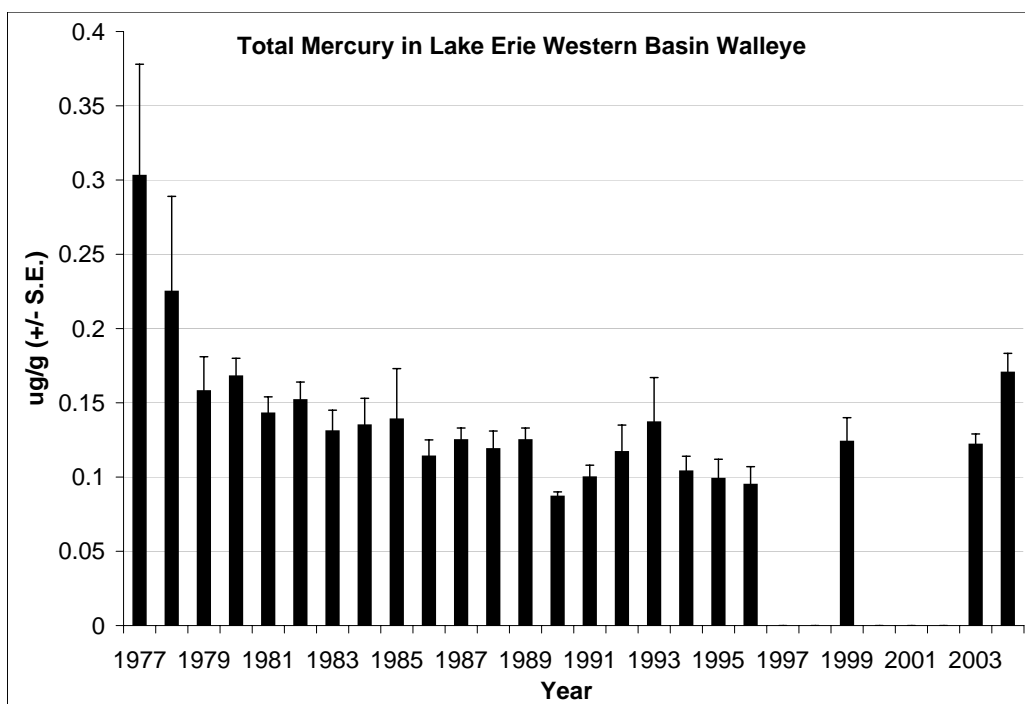


Figure 5. Total mercury levels in 4+6+ year old walleye from the western basin of Lake Erie ($\mu\text{g/g} \pm \text{S.E.}$ wet weight, whole fish), 1977-2004 (2004 data unpublished).

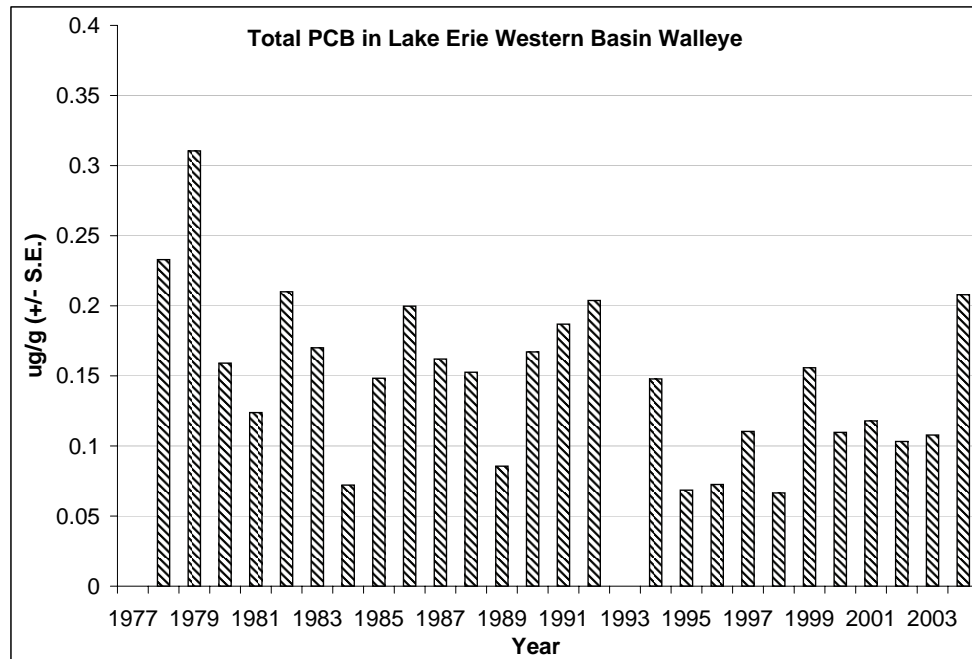


Figure 6. Total PCB levels in 4+6+ year old walleye from the western basin of Lake Erie (ug/g +/- S.E. wet weight, whole fish), 1977-2004 (2004 data unpublished).

In general, total PCB levels in walleye from the western basin were lower in the 1980s and 1990s compared to late 1970s (Figure 6). However, over the 28-year period, concentrations fluctuated considerably. There have been periodic increases (1984-1986, 1989-1992) in PCB body burdens followed by decreases through to the mid-1990s (Whittle 1998).

Total DDT levels in walleye have declined by an order of magnitude since monitoring commenced in 1977. Levels increased modestly during the period 1987 through 1989, which was coincidental with the zebra and quagga mussel invasion period. Since 1989 total DDT levels have declined consistently in walleye samples and the 2003 mean concentration (0.06 ug/g) is the lowest ever measured since the initiation of the Department of Fisheries and Oceans Canada monitoring program in 1977 (Figure 7).

Management Next Steps

Control of contaminants at their source remains the primary imperative for management action. Additional sediment remediation will be required at certain locations (e.g., Trenton Channel of the Detroit River, Lower Rouge River, River Raisin, Ottawa River) to restore uses and meet the objectives of the Great Lakes Water Quality Agreement.

Research/Monitoring Needs

Contaminants contained in the sediments of the shallow western basin of Lake Erie are often resuspended during storm events and become available in the water column in the freely dissolved form. Based on models developed by Morrison et al. (1997, 2002), the continued reduction in contaminant inputs to the system and a decontamination of the bottom sediments would reduce the availability of contaminants to aquatic biota.

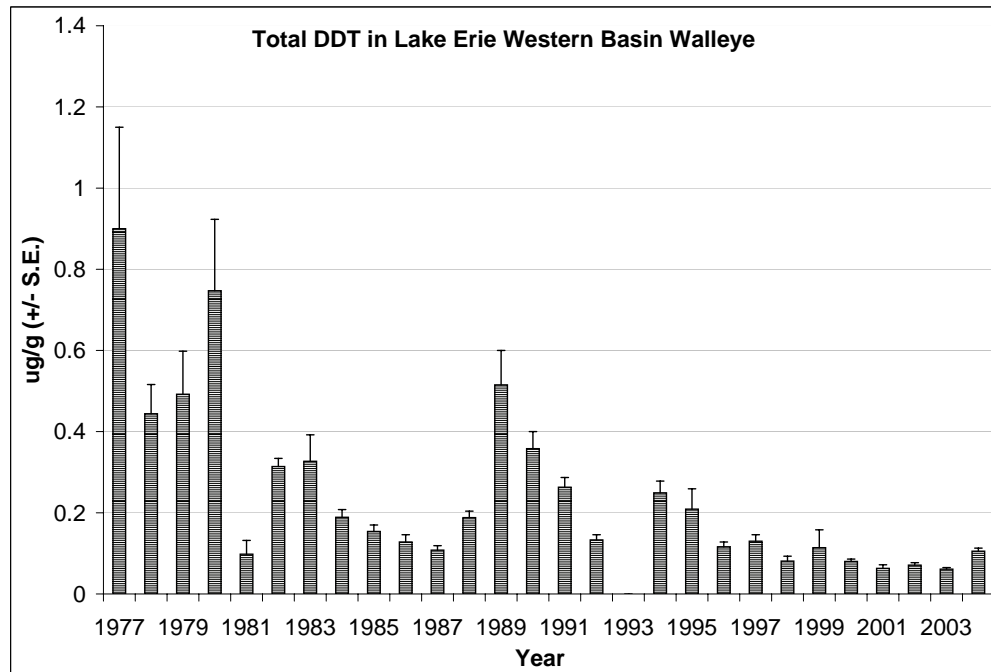


Figure 7. Total DDT levels in 4+6+ year old walleye from the western basin of Lake Erie (ug/g +/- S.E. wet weight, whole fish), 1977-2004 (2004 data unpublished).

A continuation of this modeling activity to incorporate both changes in upstream loadings of contaminants and the ongoing response of the biological community to introductions of additional exotic invading species would be useful in focusing future remedial activities. These modeling activities would support the analyses of temporal trend contaminant data as measured in aquatic biota representing different trophic levels (Whittle et al. 2002).

References

- Morrison, H.A., F.A.P.C. Gobas, R. Lazar, D.M. Whittle, and G.D. Haffner. 1997. Development and verification of a benthic/pelagic food web bioaccumulation model for PCB congeners in western Lake Erie. *Environmental Science Technology* 31:3267-3273.
- Morrison, H.A., D.M. Whittle, and G.D. Haffner. 2000. The relative importance of species invasions and sediment disturbance in regulating chemical dynamics in western Lake Erie. *Ecological Modeling* 125:279-294.
- Morrison, H.A., D.M. Whittle, and G.D. Haffner. 2002. A comparison of the transport and fate of PCBs in three Great Lakes food webs. *Environmental Toxicology and Chemistry* 21:683-692.
- Whittle, D.M. 1998. The Great Lakes ecosystem. In *Chemical Contaminants in Canadian Aquatic Ecosystems*, eds. R.C. Pierce, D.M. Whittle, and J.B. Bramwell, pp. 105-135. PWGSC Publishers.
- Whittle, D.M., M.J. Keir, and A.A. Carswell. 2002. Western Lake Erie fish community contaminant trends (1977-2001). In *Evaluating Ecosystem Results of PCB Control Measures within the Detroit River-Western Lake Erie Basin*, eds. Thomas M. Heidtke, John Hartig, and Bonnie Yu, Appendix 15, pp. 89-91. U.S. Environmental Protection Agency.

Whittle, D.M., M.J. Keir, and J.F. Gorrie. 2004. DFO Open Lake Fish Contaminants Monitoring Program. Great Lakes Laboratory for Fisheries & Aquatic Sciences. Burlington, ON.

Links for More Information

Department of Fisheries and Oceans Canada: http://www.dfo-mpo.gc.ca/regions/CENTRAL/science/great-grand/ecotox_e.htm

Evaluating ecosystem results of PCB control measures within the Detroit River-western Lake Erie basin: <http://www.tellusnews.com/epa/appn15.shtml>

Contact Information

Sean Backus
Environment Canada
E-mail Address: sean.backus@ec.gc.ca

Report prepared by:
D.M. Whittle (retired), Fisheries and Oceans Canada

INDICATOR: MERCURY IN LAKE ST. CLAIR WALLEYE

Background

In 1969, the Ontario Water Resources Commission (the predecessor of the Ontario Ministry of the Environment) discovered elevated levels of mercury in sediments of the St. Clair River. Follow-up monitoring of mercury in fish by government and university scientists found sufficient mercury contamination to close the fishery from southern Lake Huron to Lake Erie in 1970. The St. Clair commercial fisheries were substantial, providing about 40 small family companies with \$1-2 million worth of fish per year. This became known as the “Mercury Crisis of 1970.”



Figure 1. A 14-pound walleye caught in the Detroit River (Photo credit: Jim Barta).

The industry responsible for this contamination was the Dow Chemical Chlor-Alkali Plant in Sarnia, Ontario. Since 1949, Dow Chemical had been operating a mercury cell plant in Sarnia (a second plant came on line in 1965) for production of chlorine and caustic soda. From their production process, mercury was being discharged into the river and contaminating the fishery.

Mercury is a naturally occurring metal, familiar to most people through the use of thermometers. It is used in some industrial processes and in the manufacture of some types of electrical apparatus. At one time, mercury was widely used as an antifouling agent in paints and as a controller of fungal diseases of seeds, flower bulbs, and other vegetation. It is still used as an antimicrobial agent.

Mercury is also toxic. It is found in the environment in different chemical and physical forms, the most toxic being methylmercury. In its elemental form, mercury is not regarded as a major contaminant in water because it is almost completely insoluble in water. However, elemental mercury in sediments can be transformed by microorganisms into a form which is much more water soluble, biologically mobile, and toxic than other forms. Certain fishes have been found to accumulate mercury in their tissues at concentrations 5,000 to 50,000 times greater than in surrounding waters.

Status and Trends

Since 1970, Ontario Ministry of the Environment has systematically monitored mercury in 45 cm walleye using standard sampling and analytical techniques (Figure 1). In 1970, mercury in Lake St. Clair walleye was approximately 2.3 mg/kg. That same year Dow Chemical of Canada was directed by the Ontario Water Resources Commission to

install treatment facilities to eliminate mercury discharges to the St. Clair River. Later, Dow Chemical voluntarily shut down its mercury cell plants in Sarnia and Thunder Bay, Ontario (Hartig 1983). Another mercury cell plant that discharged to the Detroit River in Wyandotte, Michigan was also shut down in 1972.

Authorities estimated that the effluent from the Sarnia plants ran as high as 50 mg/L at times, amounting to a release of approximately 91 metric tons of mercury into the St. Clair River, which flowed downstream to contaminate Lake St. Clair, the Detroit River and Lakes Erie and Ontario. Since these actions to stop the inputs of mercury into the St. Clair River, the mercury content in Lake St. Clair walleye has decreased more than 80%; similar reductions have occurred in other fish species (Figure 2).

A 1999 water and sediment study revealed that the current mercury distribution was quite even throughout the Detroit River, instead of the historic pockets of high concentration (Kreis et al. 2001). Mercury concentrations found in Detroit River fish were slightly lower than in the same species from Lake St. Clair. However, health advisories remain in effect for certain sizes of some fish species from both Lake St. Clair and the Detroit River. Today, the primary source of mercury is contaminated sediment from historic discharges (Michigan Department of Natural Resources and Ontario Ministry of the Environment 1991) and atmospheric loadings.

Management Next Steps

Control of mercury at its source is the primary imperative for action. The Canada-U.S. Great Lakes Water Quality Agreement calls for zero discharge of persistent bioaccumulative toxic substances such as mercury. Priority should be given to reducing loadings from active sources such as power plants and incinerators, and to remediating mercury-contaminated sediment hot spots throughout the corridor.

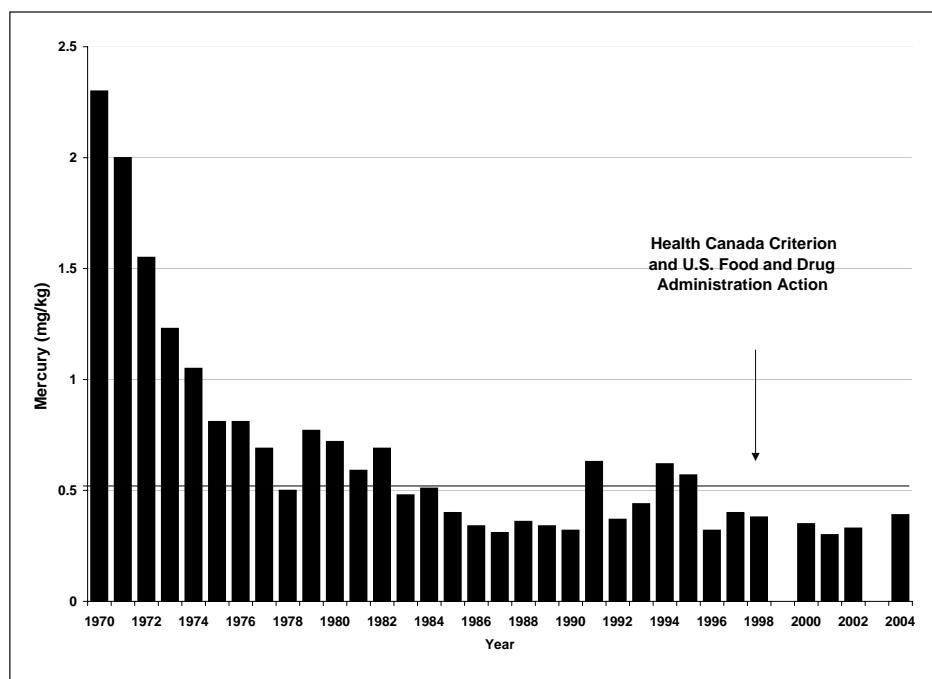


Figure 2. The concentration of mercury in 45 cm walleye in Lake St. Clair, 1970-2004 (data collected by Ontario Ministry of the Environment).

Research/Monitoring Needs

Mercury monitoring in 45 cm walleye should be continued. Annual mercury loadings from active sources should be made readily available to policymakers and to the public. Sources-fate-transport-effects modeling should be a priority to evaluate further remediation options and make midcourse corrections sufficient to remove health advisories on fish from the St. Clair River, Lake St. Clair, Detroit River, and Lake Erie.

References

Hartig, J.H. 1983. Lake St. Clair: Since the Mercury Crisis. *Water Spectrum* 15(1):18-25.

Kreis, R.G. Jr., G.D. Haffner, and M. Tomczak. 2001. Contaminants in water and sediments. *State of the Strait: Status and Trends of the Detroit River Ecosystem*. University of Windsor.

Michigan Department of Natural Resources and Ontario Ministry of the Environment. 1991. *Stage 1 Remedial Action Plan for the Detroit River*. Lansing and Sarnia, Ont.

Links for More Information

Ontario Ministry of the Environment: <http://www.ene.gov.on.ca/>

EPA, St. Clair River Report: <http://www.epa.gov/glnpo/aoc/st-clair.html>

Global Mercury Assessment; Impacts of Mercury on the Environment: <http://www.chem.unep.ch/mercury/Report/Final%20report/chapter5.pdf>

State of the Strait Conference; Contaminants in Water and Sediment:
<http://crons.uwindsor.ca/units/glier/stateofthestrat/main.nsf/1fe8a6f51f92512185256a000074dc22/d3f57482f4955c9085256b430044ff8d!OpenDocument>

2004 Michigan Family Fish Consumption Guide: http://www.michigan.gov/documents/FishAdvisory03_67354_7.pdf

Contact Information

Al Hayton
Ontario Ministry of the Environment
Sport Fish Contaminant Monitoring Program
E-mail Address: al.hayton@ene.gov.on.ca

INDICATOR: CONTAMINANTS IN HERRING GULL EGGS

Background

The herring gull (*Larus argentatus*) is a large omnivorous (i.e., it eats a wide range of food including fish, invertebrates, plants, and garbage) waterbird, about 64 cm (2 ft) from bill to tail (Figure 1). It is the most widely distributed gull in the Northern Hemisphere. In North America, it breeds across the northern third of the continent, including all of Ontario, and is found on all five of the Great Lakes. In the early 1900s, herring gull populations were nearly extirpated due to earlier persecution at nesting sites and the



Figure 1. Herring gull (*Larus argentatus*)
(Photo credit: National Park Service, Indiana
Dunes National Lakeshore).

demand for bird feathers by the millinery trade during the late 1800s. During that time, herring gull populations on the Great Lakes were at an all-time low. The Migratory Bird Convention of 1916 placed the herring gull under protection from further persecution allowing populations to expand both their range and breeding numbers. On the Great Lakes, herring gull populations began to increase in the 1940s.

Herring gulls are social birds preferring to nest in colonies, usually on small islands, but always near a body of water. This makes them very easy to locate and study. Once birds reach breeding

age at four years, they become established at a colony site where adult birds use the same nesting site year after year, many for as long as 10 to 20 years.

Adult herring gulls usually arrive at their breeding sites by early March, and by early to mid-May females have laid their three-egg clutch in a nest made of dead plant material. Females will generally lay additional eggs to replace any that are lost early in the nesting season. Eggs are normally incubated for 26-28 days. High mortality is normal among herring gull chicks and is mainly caused by food shortages and predation (usually by neighboring gulls). On average, only between one and two chicks per nest will survive and leave the colony. After about six weeks, young birds begin to fly, but may continue to be fed by their parents for several more weeks.

Status and Trends

The herring gull has been used by the Canadian Wildlife Service to track annual contaminant levels in the Great Lakes for more than 30 years (Weseloh et al. 1990; Hebert et al. 1999). It has many advantages over other species: as an adult, it is a year-round resident on the Great Lakes, feeds primarily on fish, has relatively high lipid content in its eggs, is a top food web predator, and is distributed in all five Great Lakes

(Mineau et al. 1984). Several lake-specific presentations of the monitoring data have appeared elsewhere (e.g., Weseloh et al. 1990; Ewins et al. 1992) and Great Lakes-wide data have appeared in various atlases and papers (Pekarik et al. 1998; Pekarik and Weseloh 1998; Jermy-Gee et al. 2005).

Up to 13 fresh herring gull eggs were collected from both Fighting Island in the Detroit River and Middle Island in western Lake Erie during early incubation in late April to early May most years from 1974-2004. Eggs were analyzed individually from 1974 to 1986, but have been analyzed as site pools since 1987. PCB trends in herring gull eggs from Fighting and Middle Islands showed a significant decrease from the mid- to late 1970s to the early 1990s, but a nonsignificant trend from the early 1990s to the early 2000s (Figure 2). PCB levels in herring gull eggs have declined by 83% and 75% on Fighting and Middle Islands, respectively.

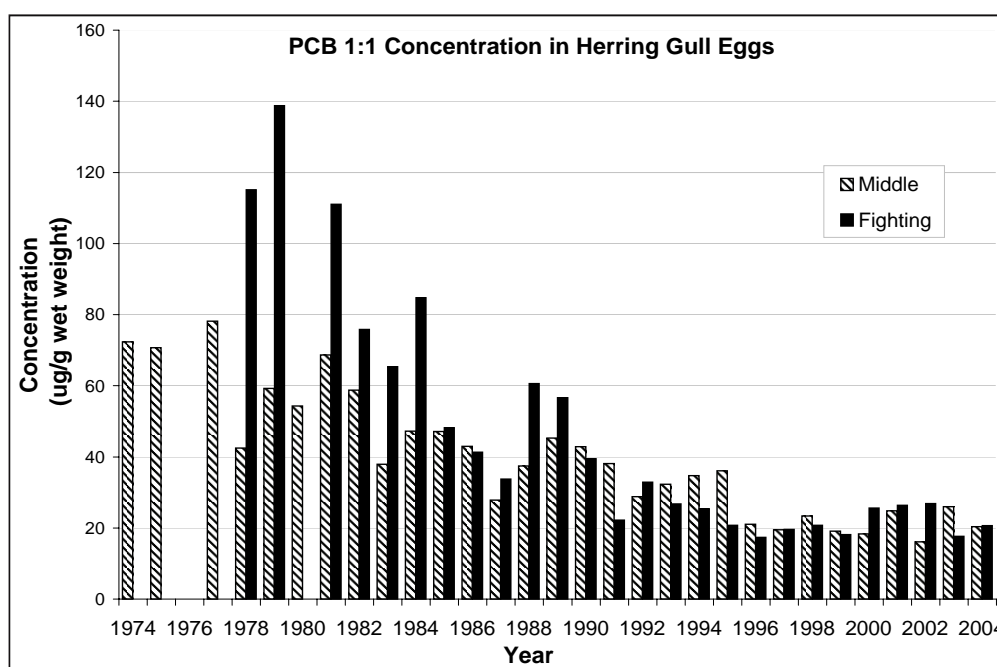


Figure 2. PCB 1:1 concentration in herring gull eggs on Fighting Island and Middle Island, 1974-2004 (data collected by Canadian Wildlife Service).

DDE (the product that results from the breakdown of DDT) in herring gull eggs from Fighting and Middle Islands showed a significant decrease from the late 1970s to the mid-1990s, but no significant change has been found between the mid-1990s and early 2000s (Figure 3). DDE levels in herring gull eggs from Fighting and Middle Islands have declined by approximately 90% over the period of record.

Dioxin (2,3,7,8 TCDD) trends in herring gull eggs from Fighting and Middle Islands show a general pattern of lower concentrations in the late 1990s and early 2000s compared to the period spanning the mid-1980s to the mid-1990s, with the exception of an elevated dioxin concentration on Fighting Island in 2003 (Figure 4).

In general, these trend data show that levels of persistent toxic contaminants decreased substantially from the high levels reported in the 1970s. Reproductive success has improved and visual abnormalities in birds are seldom seen (Gilbertson 1988).

Herring gull eggs from Fighting Island have significantly higher levels of PCB and DDE than other monitoring locations in the Great Lakes; however, the populations have comparable productivity levels to other colonies throughout the Great Lakes. There was a statistical correlation between contaminant levels and location of colony, meaning herring gulls are indicators of regional contamination in the Great Lakes (Weseloh et al. 1990).

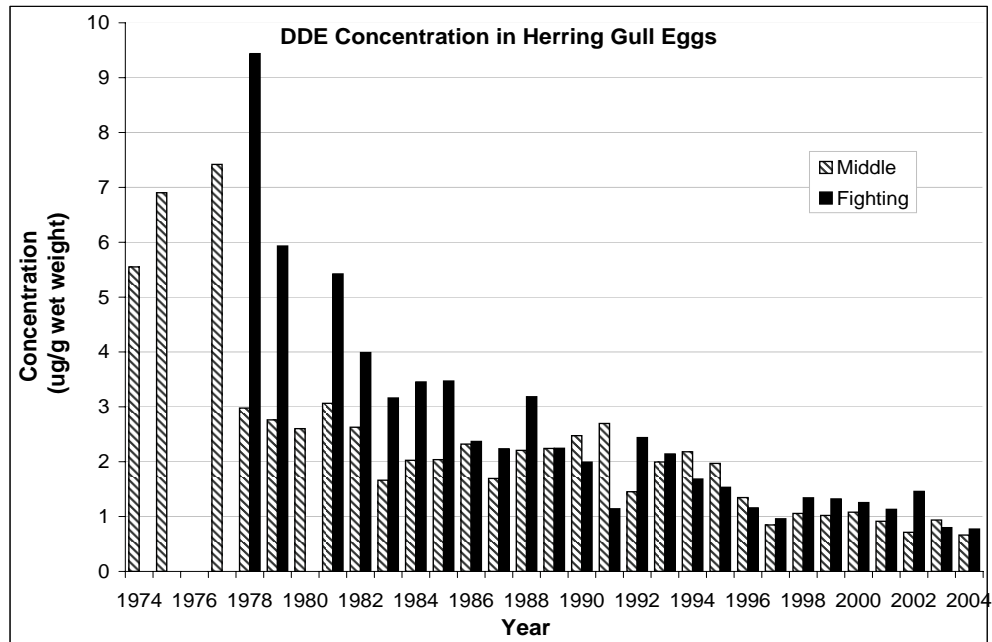


Figure 3. DDE in herring gull eggs on Fighting Island and Middle Island, 1974-2004 (data collected by Canadian Wildlife Service).

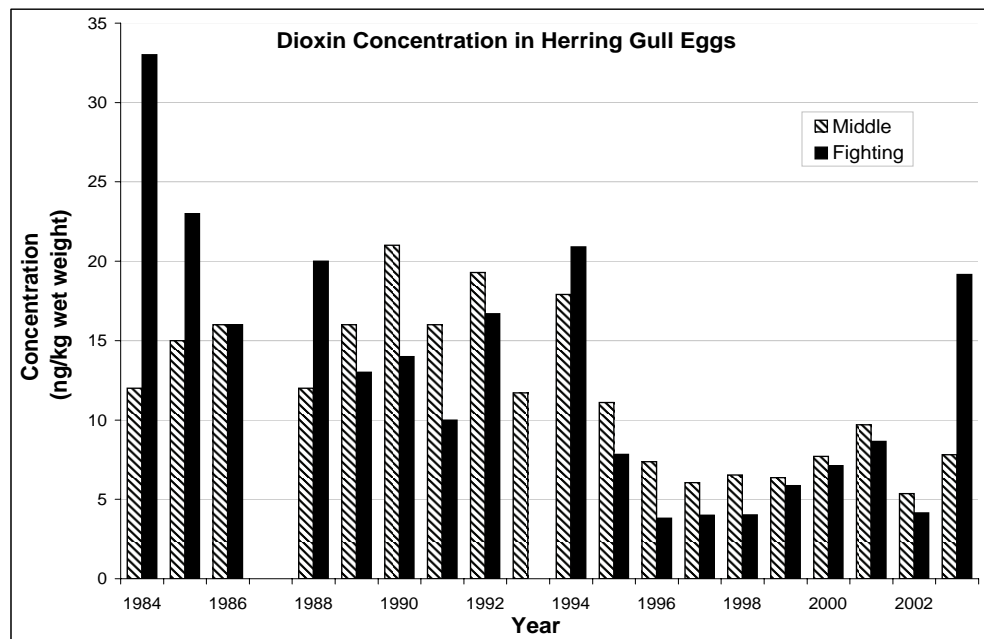


Figure 4. Dioxin (2,3,7,8 TCDD) in herring gull eggs on Fighting Island and Middle Island, 1984-2003 (data collected by Canadian Wildlife Service).

Management Next Steps

Control of contaminants at their source remains the primary imperative for action. Responsible agencies in the U.S. and Canada must remain strongly committed to virtual elimination of persistent toxic substances as defined in the Canada-U.S. Great Lakes Water Quality Agreement. Both the Detroit River Remedial Action Plan (RAP) and the Lake Erie Lakewide Management Plan (LaMPs) should:

- Identify and quantify remaining sources;
- Identify schedules for reduction targets to achieve virtual elimination; and
- Identify action plans to further reduce loadings and fully restore uses as called for in the RAPs and LaMPs.

Further, hot spots of contaminated sediment remain and are contributing to beneficial use impairments; sediment remediation must continue to be a priority to fully restore all beneficial uses.

Research/Monitoring Needs

Research indicates that levels of persistent toxic chemicals in the Great Lakes have been substantially reduced over the past 25 years. Although this stands as a major achievement, there is still a long way to go to restoring the Great Lakes ecosystem to a healthy state. Current contaminant trends indicate a sustained contaminant load to the Great Lakes. Even though these contaminant levels are much lower than in the 1970s, levels of dioxins, PCBs and other related chemicals in the Great Lakes are still present due to undetected sources, atmospheric deposition and release from contaminated bottom sediments.

Fish-eating birds such as the herring gull continue to be good sentinels of aquatic food web contamination and associated biological abnormalities occurring in animals living in the Great Lakes basin. By monitoring contaminant levels in the eggs, researchers can detect the presence of biologically significant concentrations of chemicals in the Great Lakes that may, for example, interfere with the normal development of embryos or cause other subtle reproductive effects. These contaminants would be expected to occur in the tissues of any species, including humans, that eat a large number of fish from the Great Lakes basin.

Obviously there are differences between birds and human beings, so the exact health effects found in the birds are not necessarily indicators of the same health impacts in humans. However, studies of infants of mothers who ate large amounts of highly contaminated Great Lakes fish indicate that some developmental effects can occur in the children. Assessment of potential effects of contaminants in human populations is usually based on the available information, including the results of toxicological studies in other mammals, studies of highly exposed populations, and the degree of exposure. The effects of long-term exposure to small concentrations of contaminants should remain the focus of research on wildlife and human health.

The incidences of dead embryos in eggs, and deformities and biochemical changes in birds in the Great Lakes, should not be taken lightly. They are indicators of something amiss in the ecosystem and are linked to the emerging issue of chemicals and endocrine disruption. Other top-predator species in the Great Lakes have demonstrated similar

responses, including humans. The Great Lakes must be clean enough for all species to live and reproduce normally. The challenge of restoring the Great Lakes ecosystem must be met in the future by the whole global community if virtual elimination of contaminants is to be achieved.

References

- Ewins, P.J., D.V. Weseloh, and P. Mineau. 1992. Geographical distribution of contaminants and productivity measures of herring gulls in the Great Lakes: Lake Huron 1980. *Journal of Great Lakes Research* 18(2):316-330.
- Gilbertson, M. 1988. Restoring the Great Lakes-Means and ends. *Canadian Field Naturalist* 102(3):555-557.
- Hebert, C.E., R.J. Norstrom, and D.V.C. Weseloh. 1999. A quarter century of environmental surveillance: The Canadian Wildlife Service's Great Lakes herring gull monitoring program. *Environmental Reviews* 7:147-166.
- Jermyn-Gee, K., C. Pekarik, T. Havelka, G. Barrett, and D.V. Weseloh. 2005. An atlas of contaminants in eggs of fish-eating colonial birds of the Great Lakes (1998-2001). Vol. I. Accounts by Location. Vol. II. Accounts by Chemical. Technical Report Series No. 417. Canadian Wildlife Service, Environment Canada. Downsview, Ontario.
- Mineau, P., G.A. Fox, R.J. Norstrom, D.V. Weseloh, D.J. Hallett, and J.A. Ellenton. 1984. Using the herring gull to monitor levels and effects of organochlorine contamination in the Canadian Great Lakes. In *Toxic Contaminants in the Great Lakes*, eds. J.O. Nriagu and M.S. Simmons, pp. 425-452. Wiley and Sons.
- Pekarik, C., and D.V. Weseloh. 1998. Organochlorine contaminants in herring gull eggs from the Great Lakes, 1974-1995: Change point regression analysis and short-term regression. *Environmental Monitoring and Assessment* 53:77-115.
- Pekarik, C., D.V. Weseloh, G.C. Barrett, M. Simon, C.A. Bishop, and K.E. Pettit. 1998. An atlas of contaminants in eggs of fish-eating colonial birds of the Great Lakes (1993-1997). Vol. I. Accounts by Location. Vol. II. Accounts by Chemical. Technical Report Series No. 321. Canadian Wildlife Service, Environment Canada. Downsview, Ontario.
- Weseloh, D.V., P. Mineau, and J. Strugger. 1990. Geographical distribution of contaminants and productivity measures of herring gulls in the Great Lakes: Lake Erie and connecting channels 1978/79. *Science of the Total Environment* 91:141-159.

Links for More Information

Sustainable development indicators: http://www.sdi.gov/Curtis/Pollut_Trends.html

Evaluating ecosystem results of PCB control measures within the Detroit River-western Lake Erie basin: http://www.tellusnews.com/art/pfd/PCB_Final_ReportUEF.pdf

Contact Information

D.V. Chip Weseloh
Canadian Wildlife Service
E-mail Address: chip.weseloh@ec.gc.ca

INDICATOR: ALGAL BLOOMS IN WESTERN LAKE ERIE

Background

Since the 1960s scientists have recognized that Lake Erie has been undergoing accelerated or cultural eutrophication (Beeton 1961). Eutrophication is a natural aging process of lakes, but it can be accelerated by human activities. Cultural eutrophication refers to the accelerated aging of a lake caused by elevated nutrient loadings (primarily phosphorus in freshwater systems) from human activities.

Concurrently during the 1960s, the public at large recognized that Lake Erie was highly eutrophic, as evidenced by:

- algal blooms covering large areas of the lake during summer months (Figure 1);
- attached green algae, called *Cladophora*, covering most rocky and human-made structures;
- decomposing algae washing up on bathing beaches which had to be removed by bulldozers;
- blue-green algae causing taste and odor problems in some municipal water supplies; and
- dissolved oxygen being depleted (used up by decomposing algae) from many of the deeper areas of the lake.



Figure 1. *Microcystis aeruginosa* bloom in western Lake Erie (Photo credit: NASA Landsat Program).

Status and Trends

In response to algal blooms in Lake Erie during the 1960s (Table 1), the U.S. and Canada signed the 1972 Great Lakes Water Quality Agreement that led to a coordinated effort to reduce phosphorus inputs to the Great Lakes, including Lake Erie. Between the late 1960s and early 1980s there was an approximate 60% reduction in phosphorus loading to Lake Erie. Lake Erie responded with reduced phosphorus concentrations (Panek et al. 2003). Lower phosphorus concentrations reduced algal biomass

(Nicholls et al. 1977), including an 89% decline of the blue-green alga *Aphanizomenon flos-aquae* between 1970 and 1983-1985 (Makarawicz and Bertram 1991).

Table 1. A summary of the history of algal blooms in western Lake Erie.

Decade	Algal Blooms	Reference
1960s	By the mid- to late 1960s, seasonal algal blooms were reported over the entire portion of the western basin of Lake Erie. Mats of algae washed ashore, fouling beaches. Newspaper headlines announced, "Lake Erie Is Dead," when actually the lake was more alive than ever. It was undergoing cultural eutrophication, aging caused by a high influx of nutrients (primarily phosphorus) due to human activities. The blue-green algal blooms were composed of <i>Anabaena</i> , <i>Aphanizomenon</i> , and <i>Microcystis</i> . In addition, massive growths of the attached green algae <i>Cladophora</i> were reported as prevalent in the western basin.	Bentley 2000
1970s	Algal blooms occurred annually, predominated by <i>Aphanizomenon flos-aquae</i> , but were reported as decreasing in intensity and number during the 1970s.	Herdendorf 1986; Ohio Sea Grant 1995
1980s	No massive algal blooms were reported during the early 1980s. Algal blooms, when present, were predominated by <i>Aphanizomenon flos-aquae</i> . Zebra and quagga mussels arrived in the mid- to late 1980s.	Herdendorf 1986; Ohio Sea Grant 1995
1990s	Large algal blooms of <i>Microcystis</i> were reported in western Lake Erie in 1995 and 1998. During September of 1995 an algal bloom resembling a thick slick of grass-green paint extended over the entire surface of the western basin.	Great Lakes Environmental Research Laboratory 2006; Vanderploeg 2002
2000s	During the 2000s blooms of toxic <i>Microcystis</i> were reported as common in the western basin. In August 2003, a massive bloom of the cyanobacteria <i>Microcystis aeruginosa</i> formed in western Lake Erie and persisted for nearly a month. Surface scums of <i>Microcystis</i> containing high concentrations of the toxin microcystin washed ashore in Michigan and Ohio, resulting in foul-smelling, rotting, algal mats. Beaches and recreational boating areas were rendered unusable and sport fishing was adversely affected. The <i>Microcystis</i> bloom of 2003 was perhaps the most severe in Lake Erie's recent history, but it was only the latest in a trend towards increasing frequency of <i>Microcystis</i> blooms in the last decade. The 2003 bloom was followed by smaller blooms in 2004 and 2005. <i>Microcystis</i> has reappeared in 2006, but the extent of the bloom remains to be determined.	Bridgeman 2005; Ouellette et al. 2006

Zebra mussels arrived in the Great Lakes in the mid- to late 1980s. The mussels are filter feeders capable of removing much of the planktonic algae (phytoplankton) from the water. Colonization of Lake Erie by zebra mussels resulted in several years of improved water clarity and dramatic food web changes, especially a shift in algal production from phytoplankton to bottom-dwelling algae and plants.

In the 1990s, however, large late-summer algal blooms began to reappear in western Lake Erie. Blooms occurred sporadically in the late 1990s, but seem to be increasing in frequency since at least 1992 (Table 1). The summers of 2003-2006 have all had blooms of varying magnitude. These recent blooms have been dominated by the blue-green alga (cyanobacteria) *Microcystis aeruginosa*. *Microcystis* had been a common species in Lake Erie for at least a century, but rarely grew to nuisance bloom proportions. Blooms of *Microcystis* become most evident during calm periods when the cells float to the surface

and form a scum. Continually windy weather may prevent the formation of surface scums, but the overall biomass of algae in the water may still be high (as in 2005).

Blooms of *Microcystis* are of concern because *Microcystis* is poor food for the tiny grazing crustaceans (zooplankton) that are, in turn, important food for larval fish. In addition, *Microcystis* often contains a potent toxin called microcystin that when ingested by animals may damage the liver. Since most municipalities along the lakeshore obtain drinking water from Lake Erie, this is of special concern. It is believed that water treatment procedures are effective in removing the toxin and, to date, there have been no reports of the toxin in drinking water supplies.

It appears from several research studies that recent algal blooms in western Lake Erie are linked to nutrient loading, nutrient releases by zebra mussels, and selective feeding by zebra mussels, but much more work needs to be done. Research performed by the Great Lakes Environmental Research Laboratory (GLERL) and partners has provided hypotheses and some answers to explain the zebra mussel-*Microcystis* connection.

Experiments at GLERL with water from Saginaw Bay and Lake Erie have shown that zebra mussels selectively filter and reject phytoplankton so as to promote and maintain *Microcystis* blooms (Vanderploeg 2002). Using special video equipment, GLERL showed that mussels filter the water whether or not *Microcystis* is present, but they spit *Microcystis* back into the water, while at the same time they eat other algae. Thus, the competitors of *Microcystis* are removed. This probably explains why *Microcystis* has been a dominant alga in many summers. At the same time this selective feeding process is occurring, the mussels are excreting nutrients (phosphate and ammonia) derived from the phytoplankton they eat as part of digestion and metabolic processes. These nutrients, in turn, serve to fertilize further growth of *Microcystis*.

Management Next Steps

Canadian and United States governments have supported a “hold the line on phosphorus levels” position to help prevent further deterioration of Lake Erie. In addition, much more effort must be expended on preventing exotic species, like zebra and quagga mussels, from entering the Great Lakes.

Currently, there is much uncertainty as a result of insufficient knowledge of how the Lake Erie ecosystem is functioning and the factors and processes driving the ecosystem. The major, poorly understood changes in Lake Erie have taught us that management programs, research, and monitoring must be sustained and closely coupled in order to achieve our goals for Lake Erie. In addition, some managers have recommended that we explore development of management strategies to adapt to these invaders, like zebra mussels, which are now a permanent part of the Great Lakes ecosystem.

Research/Monitoring Needs

Much greater emphasis needs to be placed on detection, characterization, and prediction of harmful algal blooms. In addition, research is warranted on evaluating the role of habitat alteration on increasing nutrient loadings resulting from changes in land use practices, altered hydrology, and further food web changes.

Research, in support of modeling for adaptive management, is warranted on the following:

- upper food web predator-prey interactions, population dynamics and coupling with the lower food web;
- determination of organic carbon flow pathways through the microbial food chain, benthic primary and secondary production, and coupling with pelagic food web;
- zebra and quagga mussel population dynamics and processing of nutrients; and
- the impact of fine-scale physical processes on ecosystem-level biological interactions in Lake Erie.

Further, monitoring of key stressors like nutrient loads, zebra mussel density distribution, and food web dynamics is necessary for site-specific calibration of a Lake Erie ecosystem model.

Microcystis is known to produce toxins called microcystins that have been responsible for some bird and fish kills. Further research is warranted into what triggers *Microcystis* to produce the toxins because they are not always in production.

References

- Beeton, A.M. 1961. Environmental changes in Lake Erie. *Transactions of the American Fisheries Society* 90:153-159.
- Bentley, L. 2000. Biosphere 2000 project, Environmental science in action: Lake Erie.
- Bridgeman, T. 2005. Water quality monitoring in western Lake Erie and Maumee Bay. <http://www.lakeerie.utoledo.edu/html/tomres1.htm> (August 2006).
- [GLERL] Great Lakes Environmental Research Laboratory. 2006. The role of zebra mussels in promoting *Microcystis* blooms and other ecosystem changes in Saginaw Bay and in Lake Erie. http://www.glerl.noaa.gov/res/Task_rpts/1991/nsvander10-1.html (August 2006).
- Herdendorf, C.E. 1986. Lake Erie water quality: 1970s to mid-1980s. Ohio Sea Grant College Program. Projects M/P-1 and M/P-2 under grant NA46RG0482.
- Makarawicz, J.C., and P. Bertram. 1991. Evidence for the restoration of the Lake Erie ecosystem. *Bioscience* 41(4):216-223.
- Nicholls, K.H., D.W. Standen, G.J. Hopkins, and E.C. Carney. 1977. Declines in the nearshore phytoplankton of Lake Erie's western basin since 1971. *Journal of Great Lakes Research* 3:72-78.
- Ohio Sea Grant. 1995. Thick slick of green ick: Bloom of blue-green algae returns to Lake Erie. <http://www.mdsg.umd.edu/~seagrantmedia/news/algae.html> (August 2006).
- Ouellette, A.J., S.M. Handy, and S.W. Wilhelm. 2006. Toxic *Microcystis* is widespread in Lake Erie: PCR detection of toxin genes and molecular characterization of associated cyanobacterial communities. *Microbial Ecology* 51(2):154-165.

Panek, J., D.M. Dolan, and J.H. Hartig. 2003. Detroit's role in reversing cultural eutrophication of Lake Erie. In *Honoring Our Detroit River: Caring for Our Home*, ed. J.H. Hartig, pp. 79-90. Bloomfield Hills, MI: Cranbrook Institute of Science.

Vanderploeg, H. 2002. The zebra mussel connection: Nuisance algal blooms, Lake Erie anoxia, and other water quality problems of the Great Lakes. National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory.

Links for More Information

Great Lakes Environmental Research Laboratory. The zebra mussel connection: Nuisance algal blooms, Lake Erie anoxia, and other water quality problems of the Great Lakes: <http://www.glerl.noaa.gov/pubs/brochures/mcystisflyer/mcystis.html>

Ohio Sea Grant College Program. Lake Erie water quality, 1970s to mid-1980s PDF: http://ohioseagrant.osu.edu/_documents/publications/FS/FS-040%20Lake%20Erie%20water%20quality%201970s%20to%20mid-1980s.pdf

Contact Information

Tom Bridgeman
Lake Erie Center
University of Toledo
E-mail Address: Thomas.Bridgeman@utoledo.edu

INDICATOR: PLANKTON COMMUNITIES

Background

Studies of zooplankton and phytoplankton communities of the western basin of Lake Erie extend back to the late nineteenth/early twentieth centuries (Herdendorf 2005). More recently, research associated with the 1970 “Project Hypo” study of the central basin provided important information on the spatial and temporal dynamics of both phytoplankton (Munawar and Munawar 1976) and zooplankton (Watson 1976) for the western basin. Data collected and analyzed from this “Project Hypo” study provide us with information regarding the western basin of Lake Erie at its most degraded state (Kane et al. 2005).

Degradation of the plankton communities was already evident by the mid-twentieth century (Beeton 1965), with evidence for increases in abundance of phytoplankton (Davis 1964) and zooplankton (Bradshaw 1964) associated with eutrophic conditions (high productivity associated with phosphorus enrichment), and decreases in abundance of pollution-intolerant zooplankton taxa (i.e., *Limnocalanus macrurus*) (Kane et al. 2004). Since the late 1970s, the U.S. Environmental Protection Agency has monitored the phytoplankton and zooplankton communities of western Lake Erie (Makarewicz 1993a,b). The data available from the different studies mentioned above, combined with more recent data collected, allow for the determination of the biological integrity of the offshore waters of the western basin of Lake Erie.

One measure of the biological integrity of offshore waters of Lake Erie is the Planktonic Index of Biotic Integrity (P-IBI) (Kane et al. 2005). This indicator is based on the abundance and different kinds of phytoplankton and zooplankton. The P-IBI integrates information about both phytoplankton and zooplankton communities in the open waters of western Lake Erie to help determine trophic status, the productivity associated with levels of phosphorus enrichment (oligotrophic = low productivity associated with low phosphorus levels; mesotrophic = moderate productivity associated with moderate phosphorus levels; eutrophic = high productivity associated with high phosphorus levels).

Status and Trends

The Planktonic Index of Biotic Integrity uses five characteristics or metrics (Table 1). Values obtained for these planktonic metrics are classified to reflect different levels of productivity by nutrients, especially phosphorus. Each metric is scored as a 1, 3, or 5, with 5 representing the most oligotrophic conditions. Because both phytoplankton and zooplankton communities change throughout the year (Sommer et al. 1986), each metric has a specific time component during which it is measured (June-August; Table 1). The metric scores for all of the months are then averaged.

Table 1. Metrics used to calculate Planktonic Index of Biotic Integrity (P-IBI).

Metrics	Months Measured
Phytoplankton Metrics	
Biomass of edible algal taxa	June
% <i>Microcystis</i> , <i>Anabaena</i> , and <i>Aphanizomenon</i> of total phytoplankton biomass	June
Zooplankton Metrics	
Zooplankton ratio (calanoid copepod abundance/cyclopoid copepod + cladoceran abundance)	June, August
<i>Limnocalanus macrurus</i> density	July
Crustacean zooplankton biomass	August

The P-IBI suggests that the overall condition of the western basin of Lake Erie's offshore waters for the most recent years is eutrophic (Figure 1). During 1995 and 1997 the P-IBI scores were higher, reflecting a more mesotrophic western basin. During 2000-2003 the P-IBI scores were below 3 and similar to the score for 1970 (Figure 1), reflecting eutrophic conditions. These scores reflect increased frequency of blooms of the toxic phytoplankter *Microcystis* (Budd et al. 2002), increases in phytoplankton community biomass (Conroy et al. 2005b), and declines in the zooplankton ratio (Conroy et al. 2005a).

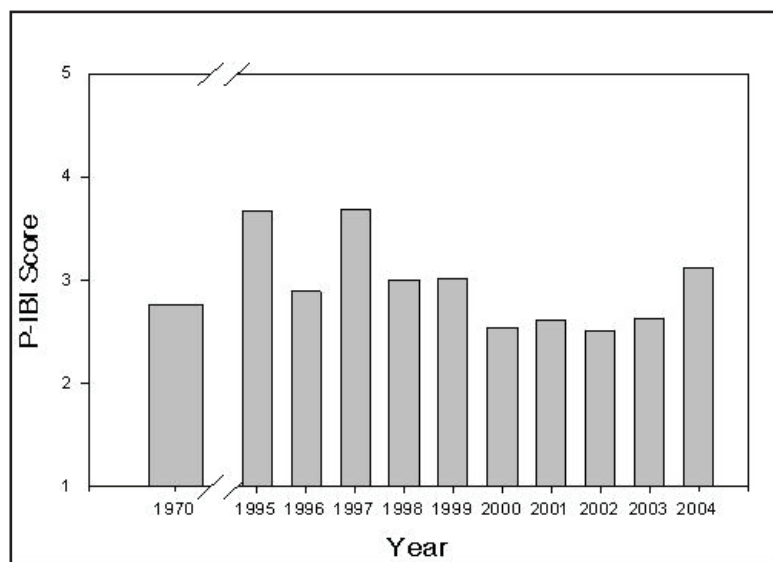


Figure 1. P-IBI scores in the western basin of Lake Erie, 1970 and 1995-2004. Trophic status classifications are based on IBI scores and are based on the scale of < 3 reflecting eutrophic conditions, 3-4 reflecting mesotrophic conditions, and > 4 reflecting oligotrophic conditions.

Management Next Steps

A number of different agencies and academic researchers collect plankton samples in the western basin of Lake Erie (Figure 2). However, there is no coordinated effort to maximize spatial and temporal coverage, standardize methods among research/management agencies, or share the results among all interested parties. A binational "plankton monitoring summit" would be helpful for all of the parties involved, as a coordinated monitoring effort would have greater spatial and temporal coverage, greater comparability of data, and likely be more cost-efficient.

Research/Monitoring Needs

Phytoplankton and zooplankton are good indicators of changes in nutrient pollution over time in Lake Erie because they respond quickly to changes in nutrient input to the lake. Further, they can be sampled extensively in many locations with relative ease. Future monitoring of plankton dynamics in Lake Erie will enable us to evaluate the biological water quality of Lake Erie's offshore waters. The Ohio Department of Natural Resources, the National Water Research Institute in Canada and other state, provincial, and federal agencies have shown a long-term commitment to plankton monitoring, which has allowed for the calculation of P-IBI scores for nearly 10 years' worth of data. This monitoring has also allowed for the early detection of invasive species new to the western basin of Lake Erie (i.e., fishhook waterflea *Cercopagis pengoi*) (Therriault et al. 2002) and needs to continue in the future in order to detect changes in the lake.



Figure 2. Researcher taking a zooplankton sample in the western basin of Lake Erie near the Bass Islands (Photo credit: Doug Kane).

References

- Beeton, A.M. 1965. Eutrophication of the St. Lawrence Great Lakes. *Limnological Oceanography* 10:240-254.
- Bradshaw, J.S. 1964. The crustacean zooplankton picture: Lake Erie 1939-49-59, Cayuga 1910-51-61. *Verh. Int. Ver. Theor. Angew. Limnol.* 15:700-708.
- Budd, J.W., A.M. Beeton, R.P. Stumpf, D.A. Culver, and W.C. Kerfoot. 2002. Satellite observations of *Microcystis* blooms in western Lake Erie. *Verh. Int. Ver. Theor. Angew. Limnol.* 27:3787-3793.
- Conroy, J.D., D.D. Kane, and D.A. Culver. 2005a. Declining Lake Erie ecosystem health? Evidence from a multi-year, lake-wide, plankton study. In *Checking the Pulse of Lake Erie*, eds. M. Munawar and R. Heath, 41 manuscript pp. Ecovision World Monograph Series. In Press.
- Conroy, J.D., D.D. Kane, D.M. Dolan, W.J. Edwards, M.N. Charlton, and D.A. Culver. 2005b. Temporal trends in Lake Erie plankton biomass: Roles of external phosphorus loading and dreissenid mussels. *Journal of Great Lakes Research* 31(Supplement 2):89-110.
- Davis, C.C. 1964. Evidence for the eutrophication of Lake Erie from phytoplankton records. *Limnological Oceanography* 9:275-283.
- Herdendorf, C.E. 2005. Scientific surveys of Lake Erie: A historical review. Ohio Sea Grant Technical Bulletin (TB-077).
- Kane, D.D., J.E. Gannon, and D.A. Culver. 2004. The Status of *Limnocalanus macrurus* (Copepoda: Calanoida: Centropagidae) in Lake Erie. *Journal of Great Lakes Research* 30:22-30.

- Kane, D.D., S.I. Gordon, M. Munawar, M.N. Charlton, and D.A. Culver. 2005. A Planktonic Index of Biotic Integrity (P-IBI) for Lake Erie: A new technique for checking the pulse of Lake Erie. In *Checking the Pulse of Lake Erie*, eds. M. Munawar and R.T. Heath. Backhuys Publishers. Leiden, The Netherlands. In press.
- Makarewicz, J.C. 1993a. A lakewide comparison of zooplankton biomass and its species composition in Lake Erie, 1983-87. *Journal of Great Lakes Research* 19:275-290.
- Makarewicz, J.C. 1993b. Phytoplankton biomass and species composition in Lake Erie, 1970-1987. *Journal of Great Lakes Research* 19:258-274.
- Munawar, M., and I.F. Munawar. 1976. A lakewide study of phytoplankton biomass and its species composition in Lake Erie, April-December 1970. *Journal of the Fisheries Research Board of Canada* 33:581-600.
- Sommer, U., Z.M. Gliwicz, W. Lampert, and A. Duncan. 1986. The PEG-model of seasonal succession of planktonic events in fresh waters. *Archives of Hydrobiology* 106:433-471.
- Therriault, T.W., I.A. Grigorovich, D.D. Kane, E.M. Haas, D.A. Culver, and H.J. MacIsaac. 2002. Range expansion of the exotic zooplankter *Cercopagis pengoi* (Ostroumov) into western Lake Erie and Muskegon Lake. *Journal of Great Lakes Research* 28:698-701.
- Watson, N.H.F. 1976. Seasonal distribution and abundance of crustacean zooplankton in Lake Erie, 1970. *Journal of the Fisheries Research Board of Canada* 33:612-621.

Links for More Information

Great Lakes Environmental Research Laboratory. Great Lakes Water Life Photo Guide: <http://www.glerl.noaa.gov/seagrant/GLWL/GLWLife.html>

Ohio Lake Erie Commission. *State of the Lake Report 2004*, Lake Erie Quality Index: <http://www.epa.state.oh.us/oleo/reports/leqi/leqi2004/pdf/2004lakeeriequalityindex.pdf>

U.S. EPA. Great Lakes plankton monitoring: <http://www.epa.gov/glnpo/monitoring/plankton/images/index.html>

Contact Information

Douglas D. Kane
Department of Biology/Toxicology
Ashland University
E-mail Address: dkane@ashland.edu

David A. Culver
Department of Evolution, Ecology, and Organismal Biology
The Ohio State University
E-mail Address: culver.3@osu.edu

INDICATOR: RECOVERY OF WILD CELERY

Background

Wild celery (*Vallisneria americana*) (Figure 1) is a submersed aquatic plant that is a very important food for diving ducks in the Detroit River. Extensive wild celery beds in the lower Detroit River attract canvasbacks and other diving ducks that feed on the tubers of wild celery for energy during migration (Miller 1943; Jones 1982).



Figure 1. Wild celery (*Vallisneria americana*) (Photo credit: Ben Legler).

Wild celery is also an important ecological indicator in the Detroit River because it is very sensitive to pollution and will not grow where pollutants, such as oil, contaminate bottom sediment (Schloesser and Manny 1990).

Status and Trends

Before the beginning of the twentieth century, contiguous coastal wetlands up to a mile wide existed along both shores of the Detroit River (Manny 2003). By 1950, wild celery beds in the river had decreased because of oil pollution (Hunt 1963). Despite pollution abatement programs implemented in the 1960s and 1970s, wild celery in the lower Detroit River decreased even further between 1950 and 1984-1985 (Schloesser and Manny 1990). In 1986, the nonnative zebra mussel (*Dreissena polymorpha*) began to colonize Lake St. Clair located immediately upstream of the Detroit River. These filter-feeders are responsible for increasing water clarity by filtering large quantities of suspended particulate matter from the water.

It is believed that increased water clarity allowed more light penetration, which then increased wild celery abundance (Schloesser and Manny 2007).

Including 1950-1951, wild celery abundance has been measured three times at five historically important duck-feeding locations in the lower Detroit River. Wild celery tubers or winter buds in river bottom sediments were collected and enumerated at Ballard Bar, Sugar Island Bar, Swan Island Bar, North Bar, and Humbug Bar in May of 1950-1951, 1984-1985, and 1996-1997. Sampling locations were located in areas of shallow water where waterfowl were seen feeding (Schloesser and Manny 1990).

Wild celery tuber abundance declined 72% between 1950-1951 and 1984-1985, and then increased 200% between 1984-1985 and 1996-1997 (Figure 2). In 1985, wild celery beds had decreased, resulting in a net loss of 36,720,000 tubers at the five locations (Schloesser and Manny 1990).

From 1950-1951 to 1984-1985 there were small increases in wild celery abundances at Swan Island Bar and North Bar, however, the increases were not significant enough

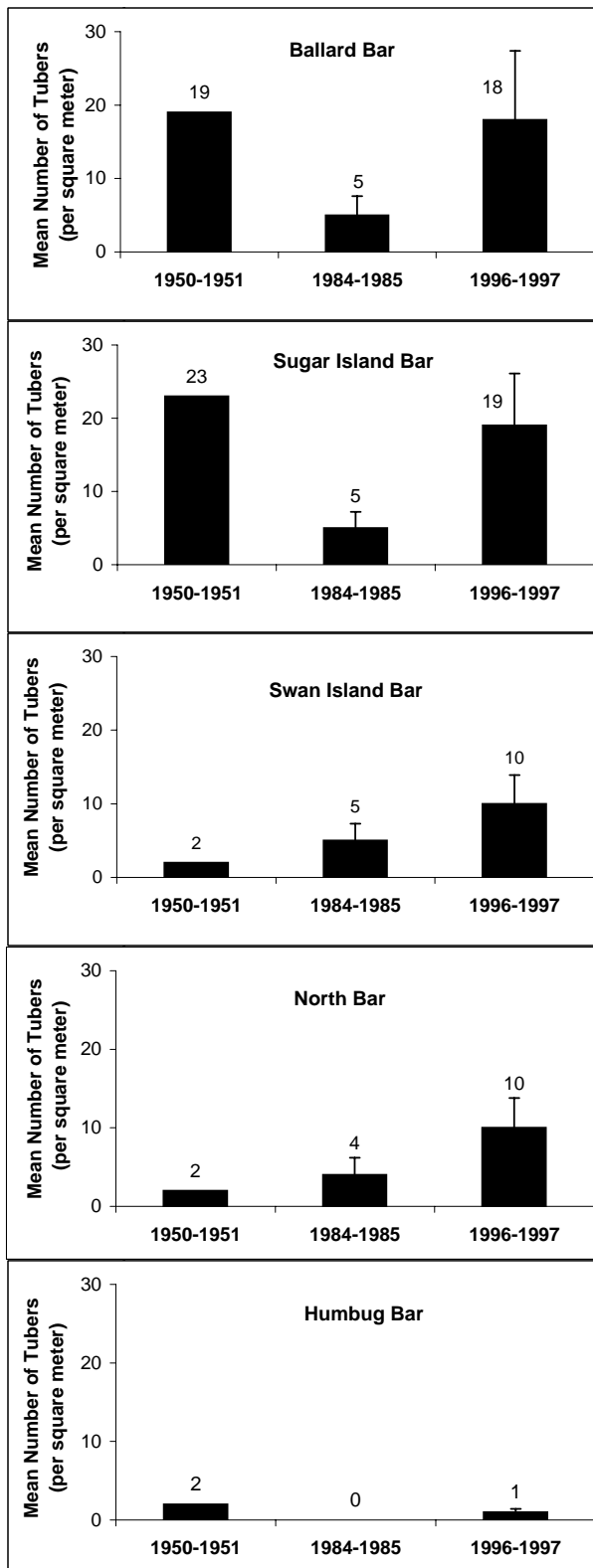


Figure 2. Mean number of wild celery tubers per site at five historic sampling locations in the Detroit River including: Ballard Bar, Sugar Island Bar, Swan Island Bar, North Bar, and Humbug Bar in May 1950-1951, 1984-1985, and 1996-1997. Standard errors available only for 1984-1985 and 1996-1997 data (data collected by U.S. Geological Survey).

to compensate for the large losses of wild celery at other locations sampled. From 1984-1985 to 1996-1997 the mean density of wild celery tubers increased significantly at all five sites. The Humbug Bar site increased the least amount, from zero to one, most likely because bottom sediments were contaminated with oil. The Swan Island Bar and North Bar had a higher mean number of tubers in 1994-1995 than in 1950-1951. However, the total estimated number of tubers was not significantly different at all locations between 1950-1951 and 1994-1995 counts (Schloesser and Manny 2007).

In general, less wild celery means less food for ducks. For example, an average daily meal (feeding twice a day) of a canvasback feeding on wild celery buds in the Detroit River is 78.47 ml. The decrease in the mean number of tubers from the 1950s to the 1980s was equivalent to a net loss of 11,540,000 ml of food. This net loss corresponds to a potential loss of 147,000 waterfowl feeding-days in the spring for canvasbacks, assuming that they did not consume other food (Schloesser and Manny 1990). It should be noted that these feeding-day figures are likely an underestimate because more wild celery tubers were consumed by the higher numbers of diving ducks that migrated through Michigan in 1950 than in 1984-1985 (Hunt 1957; Martz et al. 1976). Further, there was an increase in duck feeding-days between 1984-1985 and 1996-1997 because of the slight increase in the migrating waterfowl population.

Management Next Steps

It is recommended that management agencies continue to place priority on pollution abatement programs that aid in improving water quality and clarity to encourage recovery of wild celery beds. Priority should also be placed on preserving remaining coastal wetland habitats and rehabilitating degraded ones to support wildlife populations.

Research/Monitoring Needs

Scientists should continue to monitor wild celery abundance at the five historical sampling locations. The next logical period of sampling is 2006-2007, which would span a period of 10 years since the last survey was done. Future wild celery monitoring should be performed in conjunction with waterfowl surveys and parallel feeding habit studies. Research should also be undertaken to fully understand the factors affecting wild celery abundance, such as the proliferation of zebra mussels, water clarity, and oil pollution.

References

- Hunt, G.S. 1957. Causes of mortality among ducks wintering on the lower Detroit River. Ph.D. dissertation, University of Michigan, Ann Arbor, MI.
- Hunt, G.S. 1963. Wildcelery in the lower Detroit River. *Ecology* 44:360-370.
- Jones, J.J. 1982. Potential effects of winter shipping on diving ducks wintering in the Detroit River. M.S. Thesis, University of Michigan, Ann Arbor.
- Manny, B.A. 2003. Setting priorities for conserving and rehabilitating Detroit River habitats. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 121-139. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Martz, G.F., J.W. Aldrich, and D. Ostyn. 1976. History and future of canvasback populations in Michigan's Great Lakes habitat during fall migration and early winter. Michigan Department of Natural Resources, Wildlife Development Report 2759. Lansing, MI.
- Miller, H.J. 1943. Waterfowl survey of Saginaw Bay, Lake St. Clair, Detroit River, Lake Erie and marshes adjacent to these waters. Project No. 13-R Wildlife Division, Michigan Department of Natural Resources. Lansing, MI.
- Schloesser, D.W., and B.A. Manny. 1990. Decline of wildcelery buds in the lower Detroit River, 1950-1985. *Journal of Wildlife Management* 54(1):72-76.
- Schloesser, D.W., and B.A. Manny. 2007. Recovery of wildcelery, *Vallisneria americana*, in the lower Detroit River of the Lake Huron-Lake Erie corridor. *Journal of Great Lakes Research* 33(supl):8-19.

Links for More Information

USGS - American wildcelery (*Vallisneria americana*): Ecological considerations for restoration: <http://www.npwrc.usgs.gov/resource/plants/wildcel/value.htm>

Contact Information

Don Schloesser
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: dschloesser@usgs.gov

Bruce A. Manny
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: bmanny@usgs.gov

INDICATOR: REESTABLISHMENT OF LONG-ABSENT AQUATIC MACROPHYTES IN WESTERN LAKE ERIE

Background

The first well-documented survey and inventory of the aquatic plants, or macrophytes, in Lake St. Clair was conducted by Adrian J. Pieters (1894). The methodology developed in that study was incorporated in a much larger survey conducted in western Lake Erie from 1898-1901. These studies were part of a systematic inventory of the biology of the Great Lakes for the U.S. Department of Agriculture focusing primarily on fish production and their food sources (Stuckey 1988; 1989). Edwin Moseley's Sandusky Flora (1899) also lists the aquatic macrophytes he encountered in his surveys. These two works, along with the notes, collections, and observations of William Kellermann, Otto Jennings, John Schaffner, Paul Sears, David Stansbery, and Earl Core, provide additional descriptions of the aquatic macrophyte flora of the western Lake Erie basin (Stuckey 1989). From these descriptions of the habitats visited by Pieters and others, we have a long-term perspective of the dramatic changes in the aquatic macrophyte communities for more than a century. Ronald Stuckey and a number of students examined the species composition and distribution of plants in the region, and assessed changes in a number of sites in the western basin of Lake Erie and associated wetlands (Stuckey 1971; 1989). Since 1995, David Moore has systematically documented the relatively rapid changes in the composition of the submersed aquatic macrophytes near the southern shore of western Lake Erie in the Put-in-Bay area.

Status and Trends

Pieters (1901) recorded 40 taxa of aquatic macrophytes at Put-in-Bay in 1898, eight of which were not reported in Earl Core's 1940 survey:

<i>Potamogeton amplifolius</i>	Large-leaved Pondweed
<i>Megalodonta beckii</i>	Water Marigold
<i>Potamogeton friesii</i>	Fries' Pondweed
<i>Najas guadalupensis</i>	Guadalupe Naiad
<i>Potamogeton praelongus</i>	White-stemmed Pondweed
<i>Scirpus expansus</i>	Wood Bulrush
<i>Potamogeton perfoliatus</i>	Clasping-leaved Pondweed
<i>Carex aquatilis</i>	Water Sedge

By 1949, Core reported that an additional six had disappeared:

<i>Potamogeton filiformis</i>	Slender-leaved Pondweed
<i>Potamogeton nodosus</i>	Long-leaved Pondweed
<i>Potamogeton gramineus</i>	Variable-leaved Pondweed

<i>Nuphar advena</i>	Spadderdock
<i>Potamogeton natans</i>	Floating Pondweed
<i>Sagittaria rigida</i>	Broad-leaved Arrowleaf

And by 1957, Stansbery reported that another six taxa had disappeared (Stuckey 1989):

<i>Potamogeton pusillus</i> ssp. <i>tenuissimus</i>	Narrow-leaved Pondweed
<i>Najas flexilis</i>	Slender Naiad
<i>Potamogeton foliosus</i>	Leafy Pondweed
<i>Nymphaea tuberosa</i>	White Waterlily
[<i>Nymphaea odorata</i> ssp. <i>tuberosa</i>]	
<i>Potamogeton zosteriformis</i>	Flat-stemmed Pondweed
<i>Elodea canadensis</i>	Canadian Waterweed

What happened in the intervening 69 years? Stuckey surveyed Put-in-Bay in 1967 when he began to teach his aquatic plants course at F.T. Stone Laboratory of Ohio State University, confirming Stansbery's observations (Figure 1):

- a. 20 of the 40 original taxa had disappeared = 50%
- b. 11 of the 20 were of northern distribution = 55%

If we consider only suspended and submersed taxa noted by Pieters (22 of 40), the number of taxa lost from the waters of Put-in-Bay is 16 of the 22, or 73%. Increased nutrients (principally phosphate and nitrate) from fertilizer and sediment runoff on South Bass Island in Put-in-Bay caused algal blooms and increased suspended sediment. The decomposing algae decreased the amount of oxygen in the water and the suspended sediment reduced light available for plant growth (Figure 2). Of the 16 suspended and

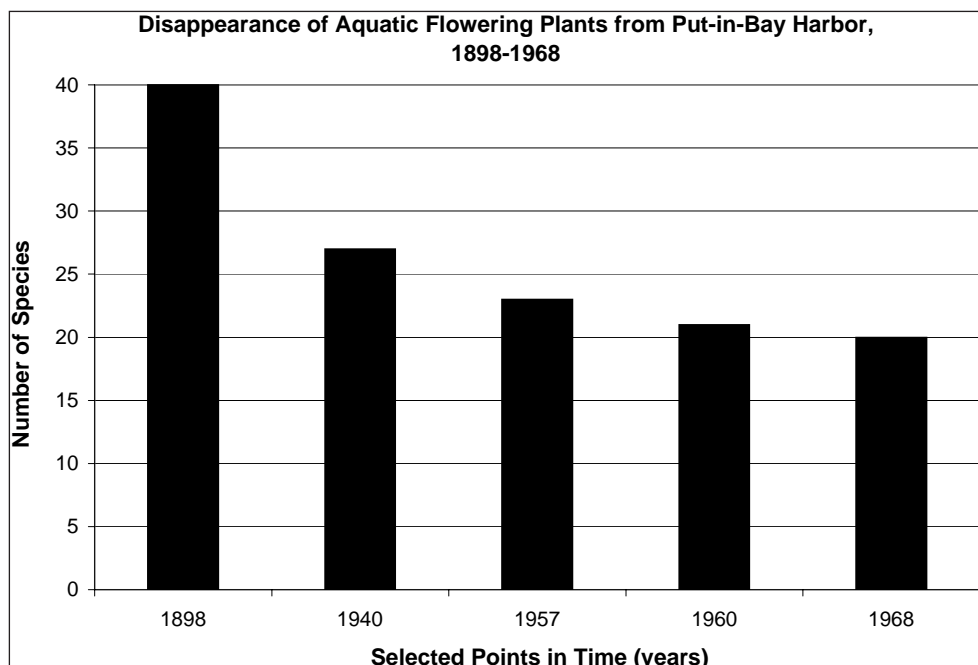


Figure 1. Ronald Stuckey's overview showed a 50% loss of aquatic macrophyte diversity by 1968 (adapted from Stuckey 1971).



Figure 2. Algal blooms were common in 1972 (Photo credit: Ronald Stuckey).

submersed taxa lost from Put-in-Bay, 12 are of northern distribution, which at Put-in-Bay are at their southernmost limit, and “sensitive” to stressful environmental conditions.

Of the other 18 (emergent) taxa reported by Pieters (1901), nine have widespread distributions. These taxa are generally tolerant of turbid, warmer water, and would be expected to endure in Put-in-Bay Harbor, although *Carex aquatilis* (water sedge) did disappear. Figure 3 displays all 40 aquatic macrophytes from Pieters (1901) showing the significant decline of species with northern distribution (81%), southern distribution (50%),

and the more tolerant species with widespread distributions (only 19%). An additional five new taxa, also generally tolerant of turbid, warmer water, have arrived since Pieters’ 1898 study:

<i>Potamogeton crispus</i>	Curly Pondweed
<i>Elodea nuttallii</i>	Nuttall’s Waterweed
<i>Myriophyllum spicatum</i>	Eurasian Water-milfoil
<i>Butomus umbellatus</i>	Flowering Rush
<i>Potamogeton pusillus</i> ssp. <i>tenuissimus</i>	Narrow-leaved Pondweed

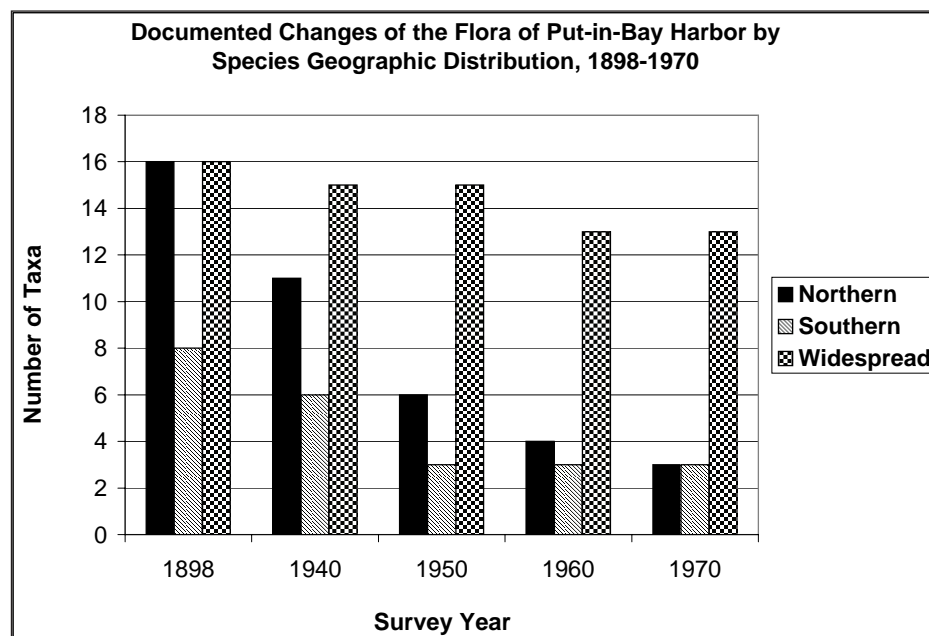


Figure 3. Documented changes of the 40 aquatic macrophytes Pieters (1901) listed from Put-in-Bay Harbor, Lake Erie, Ohio, compiled from literature, herbarium records, and surveys with northern, southern, and widespread distribution. Species with northern distribution are those at the edge of their range and are therefore susceptible to environmental change and had declined the most. See Attachment 1 at the end of this indicator for species-specific data.



Figure 4. Light availability in Hatchery Bay, at three meters depth showing Myriophyllum (Photo taken in ambient light by David Moore).

In summer 1985, the open water of Put-in-Bay had relatively low diversity with only six dominant taxa and an additional two taxa found only occasionally within the harbor:

<i>Stuckenia pectinatus</i>	Sago Pondweed	} Dominant
<i>Zosterella dubia</i>	Water Stargrass	
<i>Myriophyllum spicatum</i>	Eurasian Water-milfoil	
<i>Ceratophyllum demersum</i>	Coontail	
<i>Potamogeton pusillus</i> <i>ssp. tenuissimus</i>	Narrow-leaved Pondweed	
<i>Potamogeton crispus</i>	Curly Pondweed	
<i>Vallisneria americana</i>	Wild Celery	} Occasional
<i>Elodea canadensis</i>	Canadian Waterweed	

Long-term water transparency data indicated a dramatic increase in light penetration between Stuckey's 1968 survey and a 1994 Put-in-Bay survey led by David Moore and his students (Table 1 and Figure 4). There was a dramatic increase in light availability since 1985 and this was a primary factor causing change in the submersed macrophyte community structure. Wild celery (*Vallisneria americana*) according to Stuckey (1968) was an uncommon plant, but by 1994, it dominated the community structure and was considered by some locals to be a "weed" by 1994. In addition, seven taxa originally reported by Pieters, but absent since 1951, had returned to Put-in-Bay Harbor (Figure 5).

Table 1. Water transparency data summary (adapted from Stuckey and Moore 1995).

Mean Secchi disk values (m) for the western basin of Lake Erie and Put-in-Bay Harbor, Ohio.								
Month	1967-1982 ¹	1988 ²	1988-1990 ³	1990 ⁴	1991	1992	1993	1994
March	-		-	-	1.29	2.56	2.02	1.90
April	-		-	1.00	.90	3.69	1.55	1.83
May	-		-	1.82	2.65	3.92	2.06	2.14
June	-		-	2.11	2.80	3.17	2.92	3.40
July	-		-	2.79	3.32	3.18	3.14	3.58
August	-		-	3.44	3.42	3.05	3.70	3.93
Sept.	-		-	3.90	3.33	3.29	3.94	3.76
Oct.	-		-	2.87	3.59	2.83	2.55	3.61
Nov.	-		-	1.37	2.47	-	-	-
Annual	.80		2.10	2.42	2.64	3.21	2.74	3.02

¹ Data for 1967-1982 from Bolsenga and Herdendorf (1993).

² Year of zebra mussel introduction.

³ Data for 1988-1990 (May-November each year) from Leach (1993).

⁴ Data for 1990-1994 (unpublished) from J. Hageman, Manager of F.T. Stone Laboratory, Put-in-Bay, Ohio.

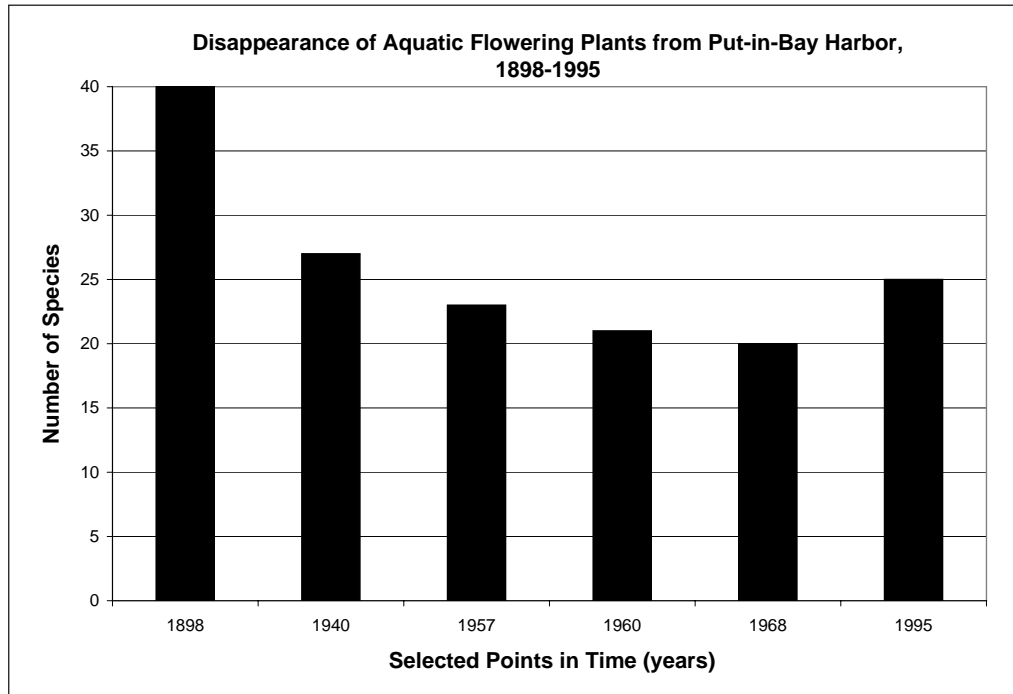


Figure 5. Revision of Stuckey's 1968 graph shows the increase in species of aquatic macrophytes that had returned by 1995 (adapted from Stuckey and Moore 1995).

Since 1995, there have been additional submersed aquatic macrophytes returning to Put-in-Bay. In 2006, two additional taxa were rediscovered in Hatchery Bay: *Potamogeton nodosus* was growing in substantial colonies in 1.5 meters of water, and one large colony of *Potamogeton zosteriformis* was observed growing near the Ohio State University docks (Moore 2006a). In addition, a 38 cm stem segment with leaves and a cluster of flowers of *Potamogeton illinoensis* was also discovered near the Ohio State University docks (Figure 6). With the continued water clarity, recolonization of the waters around Put-in-Bay by additional taxa is not unexpected. Whether the *P. illinoensis* will establish as reproducing components of the submersed aquatic macrophyte flora remains to be seen. There is concern regarding the increased algal blooms of mostly *Cladophora* and cyanobacteria in Put-in-Bay Harbor (Figure 7). What impact that will have on the submersed macrophyte community is uncertain at present.



Figure 6. Newly returned taxa at Put-in-Bay Harbor (Photo credits: David Moore).

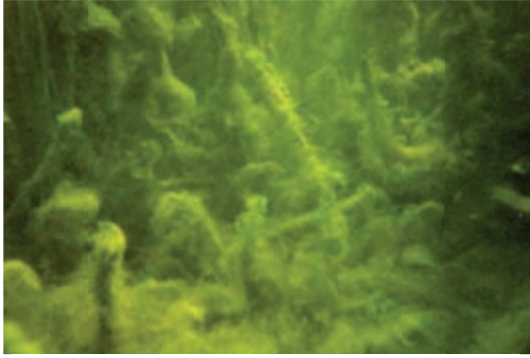


Figure 7. Colonization of submersed aquatic macrophytes by *Cladophora* in summer 2006 (Photo credit: David Moore).

Management Next Steps

Priority should be placed on controlling inputs of nonpoint pollutants, especially phosphorus. Further, a higher priority needs to be placed on stopping the entry of invasive species. Finally, more effort should be focused on coupling research, monitoring, and management.

Research/Monitoring Needs

Ongoing monitoring, especially of the submersed macrophyte flora in the waters of western Lake Erie, is crucial to understanding the changes taking

place and their consequences on fisheries and benthic production. Additional aquatic macrophyte monitoring sites need to be established to assess the shifting composition of the submersed aquatic flora and the associated benthic communities. For instance, the large reproducing colonies of *P. nodosus* and *P. illinoensis* that were observed near the State Park docks on South Bass Island were previously known to be only occasionally found in Fox's Marsh on North Bass Island and in West Quarry on Kellys Island. They have since disappeared from Fox's Marsh because of invasive forms of *Phragmites australis*. Another pondweed, *P. richardsonii*, had almost disappeared by 1951, but since 1994 has been rapidly expanding and establishing numerous additional locations within Put-in-Bay Harbor, as well as along the south sides of South, Middle, and North Bass Islands (Moore 2006b). In addition, emergent shoreline taxa have become less common (or even rare) because of extensive shoreline development. Further monitoring will allow us to understand these changes that ultimately reflect the status and the health of the entire aquatic ecosystem of the western Lake Erie basin.

References

- Core, E.L. 1948. The plants of western Lake Erie, after fifty years. Unpublished manuscript. Typewritten copy in possession of Ronald L. Stuckey.
- Moore, D.L. 2006a. A century's perspective of changes in the aquatic macrophyte flora of western Lake Erie. University of Windsor, Ontario, Canada.
- Moore, D.L. 2006b. Aquatic Macrophyte Survey. Unpublished inventory from EEOB 611 Aquatic and Wetland Plants course taught at The Ohio State University Stone Laboratory, Put-in-Bay, Ohio.
- Moseley, 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 State Academic Scientific Special Papers No.1.
- Pieters, A.J. 1894. The plants of Lake St. Clair. *Bulletin of the Michigan Fish Commission* 2:1-12.
- Pieters, A.J. 1901. The plants of western Lake Erie, with observations on their distribution. *Bulletin of the United States Fish Commission* 21:57-79.

Stuckey, R.L. 1968. Western Lake Erie's changing aquatic and marsh flora (Abstract). *American Journal of Botany* 55:735.

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

Stuckey, R.L. 1988. Twenty years of field research (1967-1987): The rare aquatic-wetland vascular plants at East Harbor State Park, Ottawa County, Ohio. *Ohio Journal of Science* 88(2):9.

Stuckey, R.L. 1989. Western Lake Erie aquatic and wetland vascular plant flora: Its origin and change. In *Lake Erie Estuarine Systems: Issues, Resources, Status, and Management*, ed. K.A. Kreiger, pp. 205-256. NOAA Estuary-of-the-Month Seminar Series No. 14. Department of Commerce, Washington, DC.

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 Journal of Science* 95(3):262-266.

Links for More Information

Franz Theodore Stone Laboratory: <http://ohioseagrant.osu.edu/stonelab/>

Bibliography of research at Stone Lab 1895-1968: https://kb.osu.edu/dspace/bitstream/1811/5602/1/V71N02_081.pdf

Contact Information

David Moore
Department of Biology
Utica College
E-mail Address: dmoore@utica.edu

Attachment 1

Documented changes of the 40 aquatic macrophytes Pieters (1901) listed from Put-in-Bay Harbor, Lake Erie, Ohio, compiled from literature, herbarium records, and surveys; a – l. (+ = present; R = rare; O = occasional; C = common; A = abundant; SA = super abundant; W = widespread; ? = species status unknown; --> = no direct data, but presumed continuation in place). * Adapted and expanded from Stuckey and Moore 1995.

			1900	1925	1940	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2006
	Submersed or Emergent	Geographic Distribution	a.	b.	c.	d.		e.		f.		g.	h.	i.	j.	k.	l.	m.
<i>Potamogeton amplifolius</i>	S	N	+															
<i>Potamogeton friesii</i>	S	N	O															
<i>Potamogeton praelongus</i>	S	N	+															
<i>Potamogeton perfoliatus</i>	S	N	+															
<i>Megalodonta beckii</i>	S	N	+															
<i>Najas guadalupensis</i>	S	S	+									+	+	R	O	O	O	R
<i>Scirpus expansus</i>	E	S	+															
<i>Carex aquatilis</i>	E	W	+															
<i>Potamogeton filiformis</i>	S	N	R	-->	+													
<i>Potamogeton gramineus</i>	S	N	C	-->	+													
<i>Potamogeton natans</i>	S	N	+	-->	+													
<i>Sagittaria rigida</i>	E	N	C	-->	+													
<i>Potamogeton nodosus</i>	S	S	+	-->	+												O	O
<i>Myriophyllum exalbescens</i>	S	N	C	-->	+													
<i>Nuphar advena</i>	E	S	C	-->	+										R	R	R	?
<i>Potamogeton pusillus</i> ssp. <i>pusillus</i>	S	W	A	-->	+	A								C	C	C	C	A
<i>Potamogeton foliosus</i>	S	N	+	-->	+	+								+	O	C	O	O
<i>Nymphaea odorata</i> ssp. <i>tuberosa</i>	E	S	+	-->	+	C							+	+	+	+	+	+
<i>Elodea canadensis</i>	S	W	C	-->	+	+	+						O	O	C	O	R	R
<i>Najas flexilis</i>	S	N	A	-->	+	A	+							+	R	R	R	O
<i>Potamogeton zosteriformis</i>	S	N	A	-->	+	C	-->	+										+
<i>Typha latifolia</i>	E	W	+	-->	+	-->	-->	-->	-->	R	-->	-->	R	R	R	R	?	?
<i>Nelumbo lutea</i>	E	S	+	-->	+	+	-->	-->	-->	R	-->	-->	R	R	?	R	?	?
<i>Potamogeton richardsonii</i>	S	N	A	-->	+	A	+	-->	-->	R	-->	-->	O	O	C	C	C	A
<i>Zannichellia palustris</i>	S	W	R	-->	+	R	-->	-->	-->	R	-->	-->	O	R	R	R	O	R
<i>Justicia americana</i>	E	S	+	-->	+	+	-->	-->	-->	R	-->	-->	R	R	R	R	R	R
<i>Carex comosa</i>	E	W	+	-->	-->	-->	-->	-->	-->	R	-->	-->	R	R	R	R	R	R
<i>Scirpus acutus</i>	E	N	+	-->	+	O	-->	-->	-->	R	-->	-->	O	O	O	O	O	O
<i>Scirpus pungens</i> (= <i>americanus</i>)	E	W	C	-->	+	O	+	-->	-->	R	-->	-->	O	O	O	O	O	R
<i>Juncus torreyi</i>	E	W	+	-->	-->	-->	-->	-->	-->	R	-->	-->	R	R	?	?	?	?
<i>Scirpus atrovirens</i>	E	W	+	-->	-->	-->	-->	-->	-->	O	-->	-->	R	R	R	R	R	R
<i>Scirpus fluviatilis</i>	E	N	+	-->	+	-->	-->	-->	-->	O	-->	-->	-->	-->	O	O	R	R
<i>Rumex verticillatus</i>	E	S	+	-->	+	-->	-->	-->	-->	O	-->	-->	-->	-->	O	O	R	R
<i>Sparganium eurycarpum</i>	E	W	+	+	+	-->	-->	-->	-->	O	-->	-->	-->	-->	O	R	R	R
<i>Asclepias incarnata</i>	E	W	C	-->	+	-->	-->	-->	-->	O	-->	-->	-->	-->	O	R	R	R
<i>Sagittaria latifolia</i>	E	W	+	-->	+	-->	-->	-->	-->	O	-->	-->	-->	-->	O	O	O	O
<i>Zosterella dubia</i> (= <i>Heteranthera dubia</i>)	S	W	A	-->	+	C	+	-->	-->	O	-->	-->	-->	-->	C	C	C	C
<i>Potamogeton pectinatus</i>	S	W	A	-->	+	A	-->	-->	-->	O	-->	-->	-->	-->	O	O	O	O
<i>Ceratophyllum demersum</i>	S	W	C	-->	+	A	+	-->	-->	O	-->	-->	-->	-->	C	C	C	C
<i>Vallisneria americana</i>	S	W	+	-->	+	A	+	-->	-->	A	-->	-->	C	A	SA	SA	SA	SA

* Documented records:

- a. Original survey by A.J. Pieters, 1898 (published 1901).
- b. Records from Stehle, 1920; Kennedy, 1923; Shawver, 1931; Tiffany, 1933; Krecker, 1935.
- c. Records from Doan, 1941; Core, 1948.
- d. Records from Core, 1949; McQuate, 1952.
- e. Records from Pinkava, 1959; Stansbery, 1957; Daniel, 1963.
- f. Records from Stuckey, 1956-1970.
- g. Records from Dorazio, 1978.
- h. Records from Moore, 1985.
- i. Records from Joseph, 1988; Burgess, 1989.
- j. Records from Stuckey and Moore, 1995.
- k. Records from Moore, 2000.
- l-m. Records from Moore (ongoing surveys).

INDICATOR: DETROIT RIVER COASTAL WETLANDS

Background

Wetlands are characterized by water saturation, which is the dominant factor determining the nature of soil development and the types of plant and animal communities living in



Figure 1. Coastal wetland restoration project at Grosse Ile, MI Nature Area (Photo credit: Emily Wilke).

the soil and on its surface. However, wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation, and other factors, including human disturbance. Often called “nurseries of life,” wetlands provide habitat for thousands of species of plants and animals (Figure 1).

Coastal wetlands are commonly formed where there is relatively flat land, shallow water, and a barrier to wave and wind action. They are valuable resources ecologically, recreationally, and aesthetically. Wetlands, which are often dependent upon wetland type and location, do the following:

- provide essential breeding, staging, and nursery grounds for many fish and wildlife, including endangered and threatened species;
- stabilize and maintain the water table by retaining water during dry periods and storing excess water during storm and flood conditions;
- minimize bank and shoreline erosion along rivers and lakes;
- serve as living filters by removing nutrients and sediments from upland runoff waters that could otherwise pollute lakes and rivers;
- function as sites for groundwater recharge, replenishing and purifying the water in aquifers that supply local drinking wells; and
- provide recreational opportunities such as hunting, fishing, bird-watching, and hiking.

Despite all of the benefits provided by wetlands, over half of them in Michigan have been drained, filled, and developed, particularly coastal wetlands along the Detroit River.

Status and Trends

Coastal wetlands were extensive along the Detroit River 200 years ago (Manny et al. 1988; Manny 2003). First explorers like Father Hennepin and Antoine Cadillac described the Detroit River as a pristine “paradise” with abundant edible fruits, lush meadows, forests, fish, and wildlife (Manny 2003). In 1815, the river shoreline consisted of contiguous coastal wetlands that were up to 1.6 kilometers (1 mile) wide along both sides of the river (Figure 2). Vegetation types included submersed marsh, emergent marsh, wet

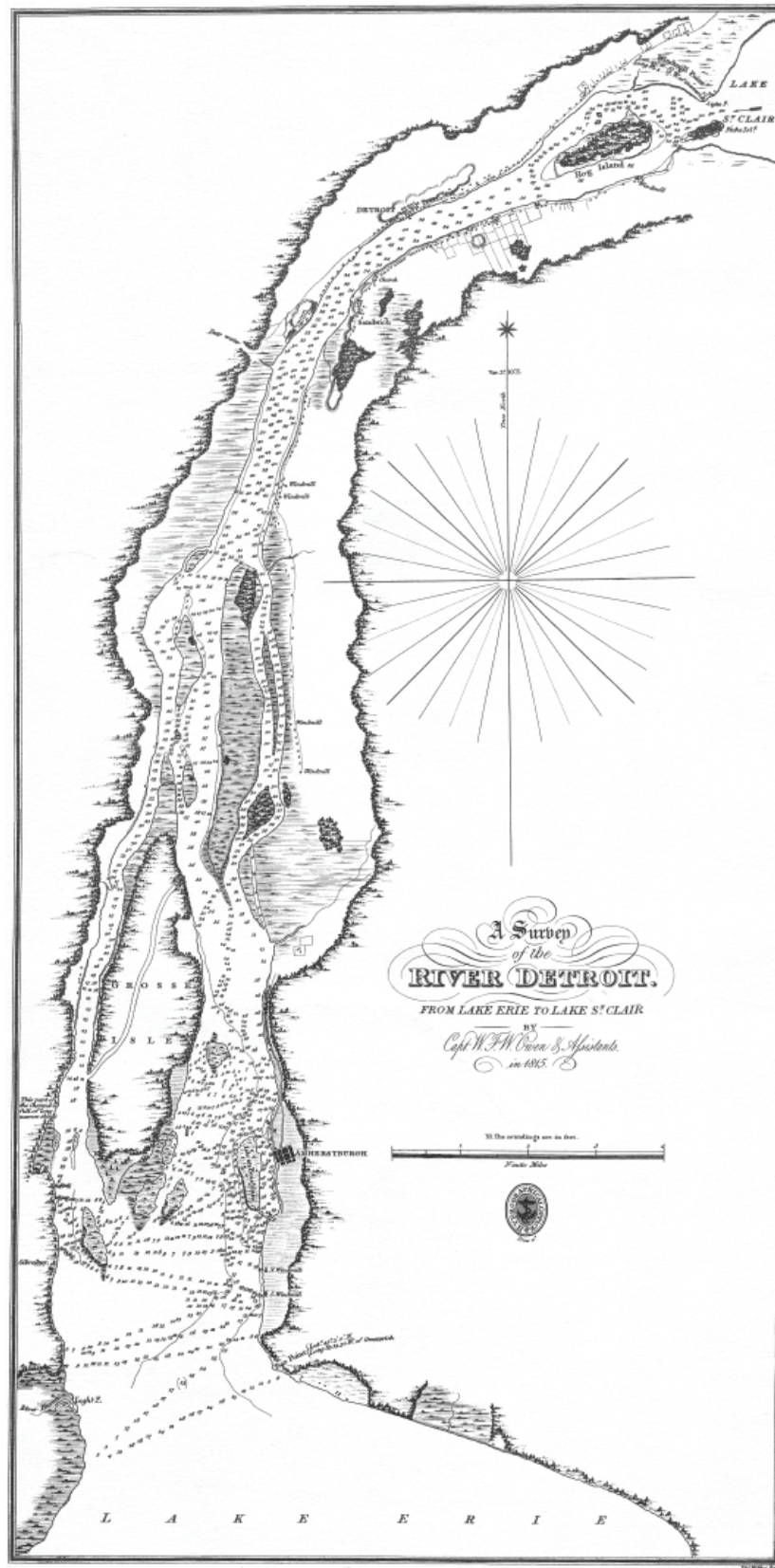


Figure 2. An 1815 map of the Detroit River with coastal wetlands up to a mile wide along both sides of the river for most of its length, prior to shoreline development (Map credit: Association of Canadian Map Libraries and Archives facsimile of an original held in Library and Archives Canada).

meadow and shrub swamp, swamp forest, and lakeplain prairie. Since 1815, the Detroit River ecosystem has undergone dramatic changes. Habitats for fish and wildlife in the river are now degraded by contaminants, largely destroyed by shoreline and channel modifications, and greatly reduced in abundance and quality from what was there historically.

The largest habitat change has been encroachment into the river and hardening of the shoreline by the addition of steel sheet-piling, concrete breakwalls, and fill material. Analysis of Figure 2 reveals that 2,768 hectares (10.7 square miles) of coastal wetlands were present along the Michigan shore of the Detroit River in 1815 (Manny 2003).

Analysis of 1982 Landsat photographs (Figure 3) reveals only 25.5 hectares (a tenth of a square mile) of coastal wetlands remained on the Michigan mainland, mostly in the

vicinity of Humbug Marsh (Manny 2003). By 1982, more than 99% of the coastal wetlands present in 1815 along the Michigan shore were converted to other land uses. In total, 97% of the coastal wetlands on both sides of the Detroit River have been lost to development. Other losses of habitat included removal of limestone spawning grounds for lake whitefish in order to create navigational channels, clearing of wooded areas for agriculture, and contamination of the water by waste effluents. In the process, people lost benefits provided by wetlands along the river, such as flood control, protection from shoreline erosion, and removal of nutrients and sediment.

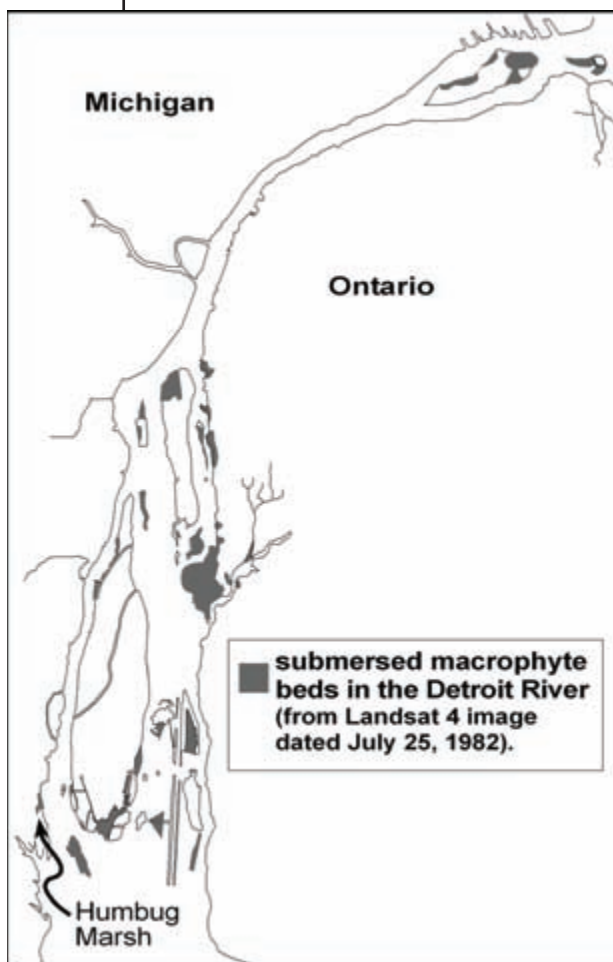


Figure 3. Distribution of wetlands and large submersed macrophyte beds in the Detroit River, July 1982 (from Manny et al. 1988).

Management Next Steps

Biologists from Canada and the U.S. should establish realistic, achievable, and quantitative targets for the protection and restoration of fish and wildlife habitat, including coastal wetlands, as called for in the U.S.-Canada Great Lakes Water Quality Agreement. These quantitative targets could then be used as benchmarks to measure progress in terms of acres of productive and uncontaminated habitat, kilometers/miles of natural shoreline, etc., that have been protected in perpetuity (Manny 2003).

Consistent with “A Conservation Vision for the Lower Detroit River Ecosystem,” coordinated efforts are needed to protect in perpetuity remaining marshes, coastal wetlands, islands, and natural shorelines from development, and to rehabilitate degraded marsh, wetland, island, and shoreline habitats (Metropolitan Affairs Coalition 2001). Additional management actions include:

- developers and communities could be encouraged to protect remaining wetlands in the Detroit River watershed through adoption of the best management practices;
- nonprofit organizations like the International Wildlife Refuge Alliance and Friends of the Detroit River could foster volunteer programs that utilize local expertise and interest, along with governmental technical assistance, to protect and enhance coastal wetlands on a watershed scale;
- governments could maintain a publicly-accessible, comprehensive, coastal wetland inventory that tracks changes in total wetland area;
- communities and private landowners could use soft engineering techniques on river shoreline redevelopment projects to a greater degree; and
- regulatory agencies could more adequately enforce wetland protection laws and stop the encroachment of development into floodplains.

Research/Monitoring Needs

There is a need to increase research and monitoring programs to quantify wetland losses, establish cause-and-effect relationships, evaluate and select appropriate wetland rehabilitation techniques, and quantify beneficial wetland functions (Tulen et al. 1998). In essence, wetland restoration and conservation projects should be treated like adaptive management experiments that explicitly link research/monitoring with restoration and management of wetlands. Further, available data on ways to protect and enhance wetland ecological functions need to be pooled and synthesized to sort out the most successful tools. For example, we could:

- assess the quality of wetland habitats for production of fish and wildlife to better rank candidate sites for wetland protection and enhancement;
- describe and characterize biodiversity in Detroit River coastal wetlands and habitats they provide for young fish and wildlife; and
- quantify economic, social, and ecological benefits resulting from wetland restoration and conservation projects.

References

- Association of Canadian Map Libraries and Archives Facsimile Map Series No. 20. Reproduced from an original in the National Map Collection, Public Archives of Canada. W.F.W. Owen, "A Survey of the River Detroit from Lake Erie to Lake St. Clair," London, 1828.
- Manny, B.A. 2003. Setting priorities for conserving and rehabilitating Detroit River habitats. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 79-90. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Manny, B.A., T.A. Edsall, and E. Jaworski. 1988. The Detroit River, Michigan: An ecological profile. U.S. Fish and Wildlife Service Biological Report 85 (7.17).

Metropolitan Affairs Coalition. 2001. *A Conservation Vision for the Lower Detroit River Ecosystem*. Detroit, MI.

Tulen, L.A., J.H. Hartig, D.M. Dolan, and J.J.H. Ciborowski. 1998. Rehabilitating and conserving Detroit River habitats. Great Lakes Institute for Environmental Research, University of Windsor, Ontario, Canada.

Links for More Information

Detroit River candidate sites for habitat rehabilitation: http://www.glsc.usgs.gov/main.php?content=research_detroitriver&title=Detroit%20River%20Candidate%20Sites%20for%20Habitat%20Remediation1&menu=research_RE_detroitriver

Rehabilitating and conserving Detroit River habitats: <http://www.mnsi.net/%7Ericcawu/title.html>

Contact Information

Bruce A. Manny
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: bmanny@usgs.gov

INDICATOR: INVASION OF THE ERIE MARSH PRESERVE BY COMMON REED (*PHRAGMITES AUSTRALIS*) OVER THE LAST 20 YEARS

Background

Coastal marshes and other wetlands in the western Lake Erie basin once covered about 4,000 km² (988,000 acres; Herdendorf 1987), but over the last approximately 150 years, more than 95% of the coastal marshes have been drained or converted to other uses (Herdendorf 1992). Draining of the marshes, hardening and armoring of shorelines, and other changes in land use have substantially altered the normal movement of marsh vegetation lakeward or landward in response to fluctuating lake levels (Gottgens et al. 1998). These coastal wetlands provide many benefits, including stabilizing and maintaining the water table, providing flood control, providing erosion protection, serving as living filters of nutrients and sediments, aiding in groundwater recharge, providing wildlife habitat, and offering recreational opportunities.

Compounding this loss of coastal marshes is the recent and dramatic invasion by nonnative plant species such as purple loosestrife (*Lythrum salicaria*) and narrow-leaved cattail (*Typha angustifolia*). Common reed (*Phragmites australis*) is also one of the biggest threats to native wetlands. It is a native species, but there are genetic types that originate elsewhere and are more aggressive. Invasion by these nonnative forms of common reed

has caused the plant to become dominant in many wetlands of western Lake Erie, especially on the U.S. shoreline. It is still expanding into new areas and out-competing native types of the plant because of physiological and behavioral advantages, and threatens the proper functioning of native wetland ecosystems. Common reed grows up to 366 cm (12 feet) in height, can shade out shorter native plants, decreases biological diversity, and degrades marsh habitat (Figure 1).



Figure 1. Common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) at Erie Marsh (Photo credit: The Nature Conservancy Photo Archives).

The Erie Marsh Preserve, located in North Maumee Bay on the western shore of Lake Erie (Figure 2), is a 897 hectare (2,217 acre) preserve owned by The Nature Conservancy and managed in partnership with the Erie Shooting and Fishing

Club. The preserve is now part of the Detroit River International Wildlife Refuge by virtue of a cooperative management agreement between the U.S. Fish and Wildlife Service and the Conservancy. Since first establishing the preserve in the 1870s, the Club has managed the marsh to maximize production of waterfowl. The Club generously donated the preserve to the Conservancy in 1978 and continues to lease the hunting rights and actively manage a central diked area of about 364 hectares (900 acres).

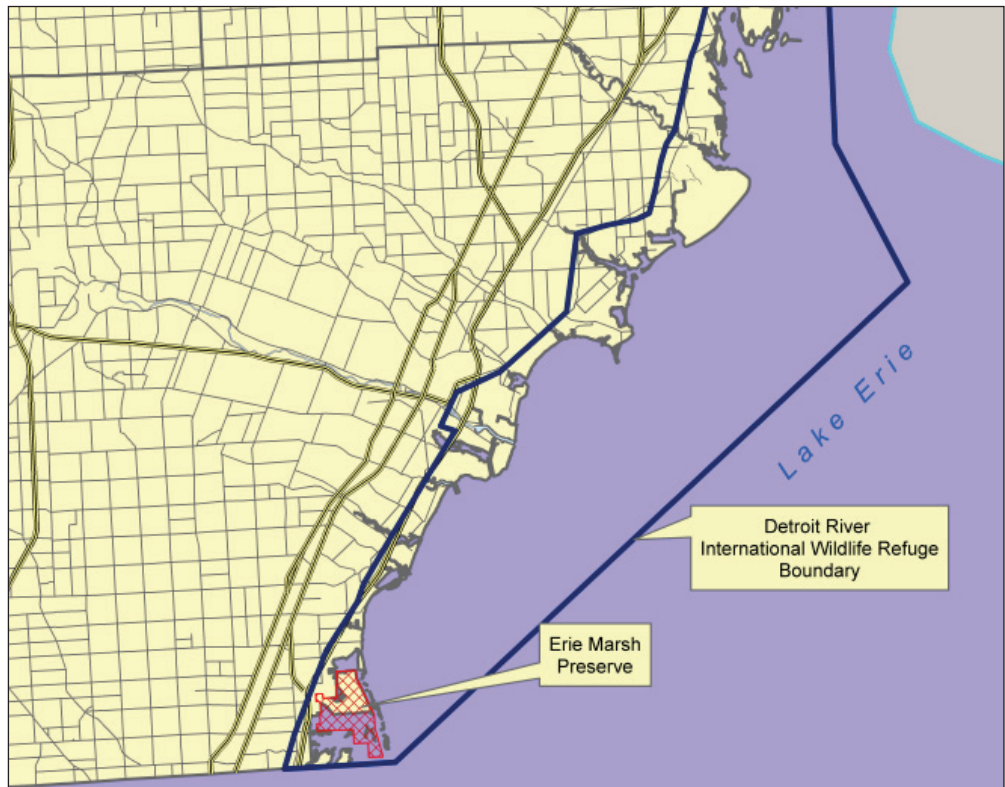


Figure 2. Location of the Erie Marsh Preserve in western Lake Erie.

Erie Marsh is a globally important stopover site for migrating waterfowl, land birds, and shorebirds, is home to the state-threatened Eastern fox snake (*Elaphe vulpina gloydi*), and is a breeding area for bald eagles. Invasive species compromise or eliminate the value of coastal marshes as bird stopover sites and as habitat for common and rare animals. In the last two decades, the marsh has undergone severe invasion by common reed.

Status and Trends

Vegetation in the marsh was relatively stable from the early part of the century until the early 1970s (Hunt and Mickelson 1976). Over this period, the marsh was characterized by “large stands of cattail, spike rush (*Eleocharis*) in the low areas, roundstem in the transition from water to marsh land, clumps of willow on high ground, thistles and weeds on the dikes, and bodies of shallow water with muddy bottom” (Douglass 1934, as reported by Pirnie and Foster 1964). Common reed has been present in the marsh for at least 50 years and presumably as long as there have been coastal marshes. Only recently has it been confirmed through genetic analysis that there are native types of common reed in North America (Saltonstall 2002). It was reported at low densities in the 1950s, though it is not clear whether the plants were native or nonnative types (Hunt 1957). Native types were first found at Erie Marsh in 2004 and it is unclear the degree to which cover of native common reed varieties have diminished as nonnative types have taken over. It is unclear exactly when common reed began to expand to become the dominant plant that it is today because even in reports from the early and mid-1980s, common reed was mentioned only as an associate to cattail and native marsh plants.

An assessment of aerial photographs from 1984 to 2003 indicates a dramatic increase in the coverage of common reed. In the 1984 photographs there are no clearly

distinguishable clones of common reed, whereas a conservative interpretation of the 1998 and 2003 imagery reveals at least 72 hectares (180 acres) and 132 hectares (325 acres) in those years, respectively (Figure 3). Although data from intervening years would be instructive in terms of the rate of expansion, it is clear from these few data points that the expansion is proceeding more quickly toward the end of this period than in the beginning, and is showing the characteristic exponential growth of many invasive species. Imagery from 2005 is currently being assessed.

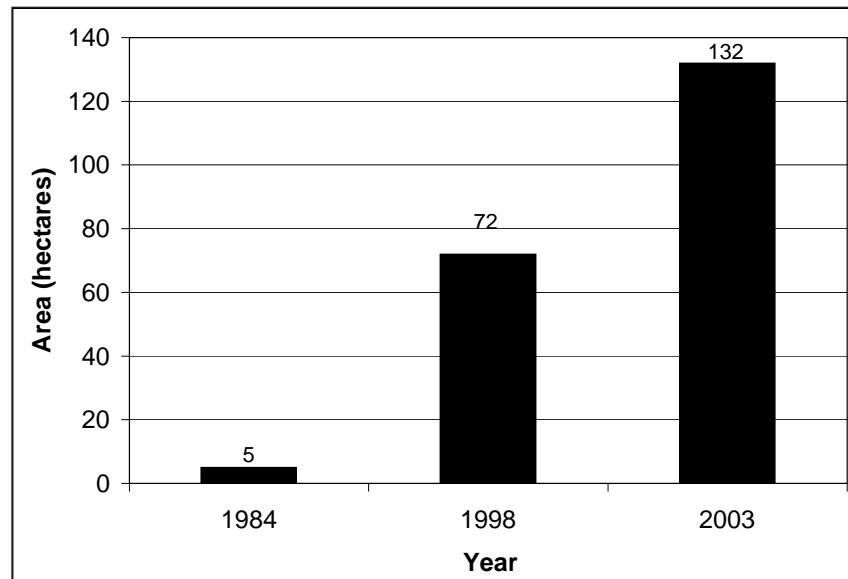


Figure 3. Area of dense coverage of common reed at the Erie Marsh Preserve, 1984, 1998, and 2003.

Management Next Steps

It is imperative that we protect the biological integrity of our Detroit and western Lake Erie coastal wetlands since they hold great diversity of species. Indeed, the Detroit River and western Lake Erie are one of twenty Biodiversity Investment Areas identified by the U.S. Environmental Protection Agency and Environment Canada through the State of the Lake Ecosystem Conference.

The Nature Conservancy is working with the Erie Shooting and Fishing Club, Ducks Unlimited, and the U.S. Fish and Wildlife Service on a habitat management plan for Erie Marsh. Currently, managers are implementing a combined program of herbicide application, flooding, and prescribed fire to restore large areas to native vegetation. Upon completion of the management plan for Erie Marsh, additional management actions will be taken through this partnership.

Research/Monitoring Needs

Continued emphasis needs to be placed on surveys, monitoring, and research. The data and information generated from these surveys, monitoring programs, and research projects will be used to foster an adaptive management approach at Erie Marsh where management priorities are set, actions taken, and surveys and monitoring undertaken in an iterative fashion for continuous improvement.

Moreover, Erie Marsh may be a reasonable indicator of marshes that are being managed by public and private organizations, but perhaps not a good indicator of the extent or trend in coverage of common reed across the entire western Lake Erie basin. The costs, benefits, and feasibility of a basin-wide monitoring effort through remote sensing techniques are worth exploring, especially as managers invest increasing amounts of resources into control efforts.

References

Gottgens, J.F., B.P. Swartz, R.W. Kroll, and M. Eboch. 1998. Long-term GIS-based records of habitat changes in a Lake Erie coastal marsh. *Wetlands Ecology and Management* 6:5-17.

Herdendorf, C.E. 1987. The ecology of the coastal marshes of western Lake Erie: A community profile. U.S. Fish and Wildlife Service Biological Report 85 (7.9).

Herdendorf, C.E. 1992. Lake Erie coastal wetlands: An overview. *Journal of Great Lakes Research* 18:533-551.

Hunt, G.S. 1957. Report of surveys on the Erie Shooting Club area. Erie Research Committee.

Hunt, G.S., and P.G. Mickelson. 1976. Ecological studies at the Erie Shooting and Fishing Club marsh and their management implications, Monroe County, MI. Erie Research Committee.

Pirnie, M.D., and J. Foster. 1964. Report of Erie researches, 1960 through 1963. Erie Research Committee & Wildlife Management Foundation.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis* into North America. *Proceedings of the National Academy of Sciences, USA*. 99(4):2445-2449.

Links for More Information

The Nature Conservancy's Global Invasive Species Initiative: <http://tncweeds.ucdavis.edu/links.html>

U.S. Department of Agriculture PLANTS database: <http://plants.usda.gov/>

Midwest Invasive Plant Network: <http://www.mipn.org/>

The Stewardship Network: <http://www.stewardshipnetwork.org/>

Michigan State University Invasive Species Initiative: <http://www.invasivespecies.msu.edu/index.asp>

Contact Information

Doug Pearsall
The Nature Conservancy
dpearsall@tnc.org

Barry Muller
DTE Energy
mullerb@dteenergy.com

INDICATOR: *HEXAGENIA* DENSITY AND DISTRIBUTION IN THE DETROIT RIVER

Background

The abundance of the different types of aquatic invertebrates in various places of the river is controlled largely by the current and its effects on the river bottom. These differences in habitat must be taken into account when one attempts to evaluate potential effects of human-related activities on the benthic community.

Currents in the main part of the river wash away fine sediments, leaving a substrate composed mainly of stones and hard clay (erosional areas). Some animals can shelter beneath or between the stones, but the most abundant species can attach themselves to the substrate or build shelters for themselves (e.g., net-spinning caddisflies, limpets, dreissenid mussels, flatworms).

Slower-flowing parts of the Detroit River (depositional areas) have a muddy or sandy bottom. These are also the areas where debris carried from upstream settles out. The benthic animals living here burrow into the mud and feed upon the organic debris and the attached bacteria and fungi present in the sediments. When the organic content of the sediments is high, bacterial respiration can remove much of the oxygen from the water, making the habitat suitable only for tolerant species. These are also regions where pollutants that aren't water soluble tend to collect. Because oils and trace amounts of metals adhere to the organic matter in the mud, the zoobenthos of depositional zones tend to bioaccumulate these materials from their food.

The most common benthic animals living in depositional zones are worms (Oligochaeta), midge larvae (Chironomidae), and *Hexagenia* mayfly nymphs (Ephemeroptera) (Figure 1). *Hexagenia* is a dominant component of the benthic fauna of muddy and silty sediments in mesotrophic lakes and rivers. Historically, *Hexagenia* mayflies were abundant throughout the Huron-Erie Corridor and the western basin of Lake Erie. Mayfly nymphs dig U-shaped burrows. They undulate their abdomen and wave their feather-like gills which forces oxygen-rich water through the burrow. Because mayflies can't survive in water that lacks oxygen, they are good indicators of the amount of organic pollution (e.g., sewage). For example, when water quality conditions are good, one expects to find 100 *Hexagenia* larvae/m² or more in clean muddy sediments of Lake Erie (Wright and Tidd 1933). *Hexagenia* mayflies have been proposed as an ecosystem indicator of mesotrophic conditions in soft-sediment habitats of the Great Lakes



Figure 1. *Hexagenia* mayfly nymphs (Ephemeroptera) (Photo credit: Lynda Corkum).

(Reynoldson et al. 1989). The Ohio Lake Erie Commission's (2004) *Hexagenia* index classifies conditions as excellent where sediments contain 200-300 larvae/m². Areas dominated by worms and midges, rather than mayflies, are classed as having degraded water quality or benthic conditions.

Thornley and Hamdy (1984), Hudson et al. (1986), Manny et al. (1988) and Farara and Burt (1993) all reported *Hexagenia* as an indicator of relatively undegraded benthic conditions in the soft sediments of the Detroit River. *Hexagenia* densities of less than 20/m² in depositional habitats suggest degradation (Thornley and Hamdy 1984; Ciborowski 2003b). However, Edsall et al. (2001) reported that *Hexagenia* production (i.e., a combined estimate of growth and abundance) was a more sensitive indicator of suitable ecological conditions than density alone.

Status and Trends

Larval Distribution

Some of the earliest Great Lakes zoobenthos surveys were conducted in 1929-1930 by Wright and Tidd (1933) in western Lake Erie and at the mouth of the Detroit River, as well as other Lake Erie tributaries. Among other zoobenthos, they reported snails, fingernail clams, and worms. However, mayfly larvae were conspicuously absent, indicating light to moderate pollution at the Detroit River mouth.

The Trenton Channel has long been identified as a degraded area based on zoobenthos composition and abundance. Surveys conducted between 1949 and 1956 showed that the lower Detroit River and the western Trenton Channel were dominated by pollution-tolerant forms, indicating a decrease in water quality from the 1929-1930 surveys.

Carr and Hiltunen (1965) showed that the spatial extent and severity of degradation at the mouth of the Detroit River had increased substantially from that described by Wright and Tidd (1933). Later surveys reported that although the Detroit River mouth contained only very pollution-tolerant organisms (worms and leeches), zoobenthos composition and abundance upstream of Belle Isle was indicative of good water quality (Vaughan and Harlow 1965).

Several surveys of the bottom fauna of the Detroit River were conducted between the 1960s and 1990 (Thornley 1985; Hudson et al. 1986; Ferrara and Burt 1993). In 1968, the bottom fauna over large tracts of the Detroit River suggested that sediments and water quality were degraded. Mayflies were found in only about 25% of the locations sampled, and then only in low numbers (10-20/m², Thornley and Hamdy 1984). Mayflies were completely absent from the United States shoreline except near the upstream end of Belle Isle (Figure 2). Almost no zoobenthos could be found in the vicinity of Zug Island.

Pollution controls put in place during the 1970s resulted in improved water and sediment quality in many areas. When the river was surveyed again in 1980, mayflies were found at over 70% of the locations examined, and they were 5 times more abundant than in 1968 (Thornley 1985; Figure 3). Densities exceeded 20/m² in both the upper and lower reaches of the Detroit River, being absent mainly south of Zug Island and in the Trenton Channel.

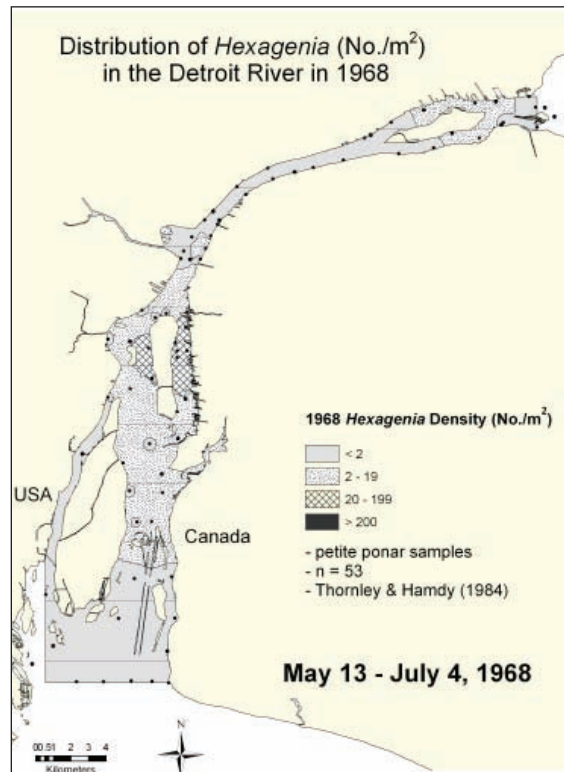


Figure 2. Density of *Hexagenia* in the Detroit River in 1968 interpolated from data compiled from Thornley and Hamdy (1984). Areas containing fewer than 20 nymphs/m² indicate either degraded benthic conditions (if sediments are soft) or unsuitable habitat for mayflies (if sediments are hard). Map by Anita Kirkpatrick.

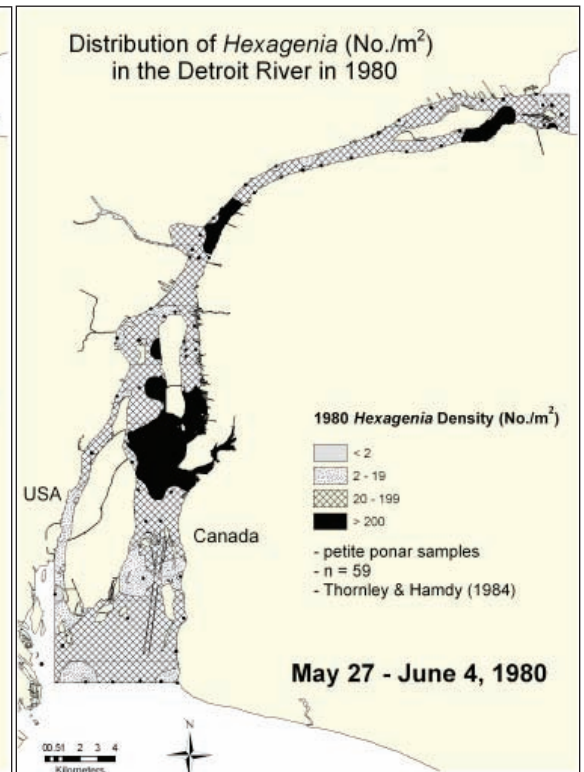


Figure 3. Density of *Hexagenia* in the Detroit River in 1980 interpolated from data compiled from Thornley and Hamdy (1984). Areas containing fewer than 20 nymphs/m² indicate either degraded benthic conditions (if sediments are soft) or unsuitable habitat for mayflies (if sediments are hard). Map by Anita Kirkpatrick.

Few changes in either the distribution or abundance of mayfly nymphs were seen between the 1980 survey, a 1983 investigation (Hudson et al. 1986), and a study done in 1991 (Farara and Burt 1993). In 1991, *Hexagenia* mayflies were found at about 60% of locations sampled, at densities of between 8 and 100 nymphs/m² (Figure 4). However, more of the river supported densities slightly less than the 20/m² criterion suggested to indicate impairment (Ciborowski 2003b) than had been observed in 1980. Worms and midges remained the most common invertebrates along the United States shoreline of the river downstream from Zug Island.

Little benthic sampling was conducted in the Detroit River through most of the 1990s, so information on health of the zoobenthic community during this time is scarce. However, the flying adult stages of *Hexagenia* and other aquatic insects became more numerous along both the Canadian and United States sides of the river and along the shores of Lake Erie (Ciborowski and Corkum 1988; Kovats 1990; Kovats et al. 1996; Corkum et al. 1997) suggesting that some improvements in river condition had been occurring.

The Detroit River was next intensively studied in 1999. Samples were collected from almost 150 locations (Wood 2004; Figure 5). Densities exceeded the 20 nymph/m² impairment threshold at the head of the river and on the Canadian side of the lower reaches. Few nymphs were collected in the midreaches, however.

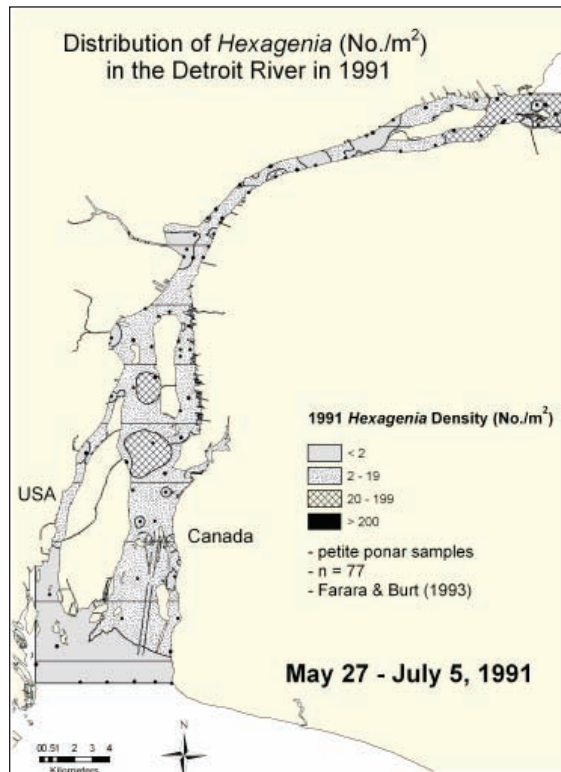


Figure 4. Density of *Hexagenia* in the Detroit River in 1991 interpolated from data compiled from Farara and Burt (1993). Areas containing fewer than 20 nymphs/m² indicate either degraded benthic conditions (if sediments are soft) or unsuitable habitat for mayflies (if sediments are hard). Map by Anita Kirkpatrick.

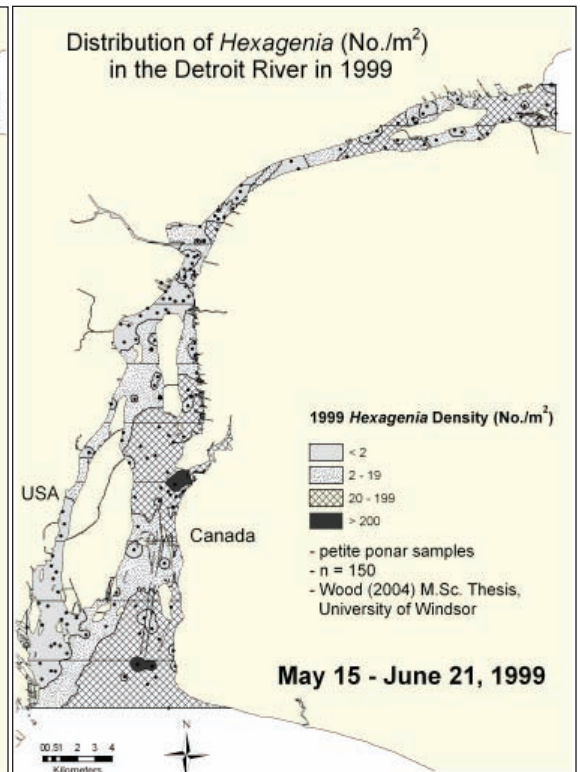


Figure 5. Density of *Hexagenia* in the Detroit River in 1999 interpolated from data compiled from Wood (2004). Areas containing fewer than 20 nymphs/m² indicate either degraded benthic conditions (if sediments are soft) or unsuitable habitat for mayflies (if sediments are hard). Map by Anita Kirkpatrick.

The entire Huron-Erie Corridor was sampled in 2004. A suite of 20 randomly-selected locations sampled in July and August 2004 produced a distributional pattern similar to that observed in 1968 (Ciborowski et al. 2006; Figure 6). However, this was partly due to the timing of sampling. In 2004, many samples were collected in July after the period of maximum emergence, but before nymphs representing the next generation had hatched from their eggs. Densities were moderate or high in much of Lake St. Clair and lower reaches of the St. Clair River (Figure 7).

Riverwide Frequency and Abundance

Figure 8 summarizes the trends in *Hexagenia* abundance average across all samples for surveys conducted since 1968. *Hexagenia* mayfly nymphs were found in 70% of the 59 stations sampled in 1980 compared to only 26% of 53 stations in 1968 (Thornley and Hamdy 1984). The greatest changes in occurrence occurred along the Canadian shoreline. The mean density of *Hexagenia* in 2004 was 20/m², but distribution was restricted to fewer locations than previously (Ciborowski et al. 2006), partly due to timing of sampling, as indicated above.

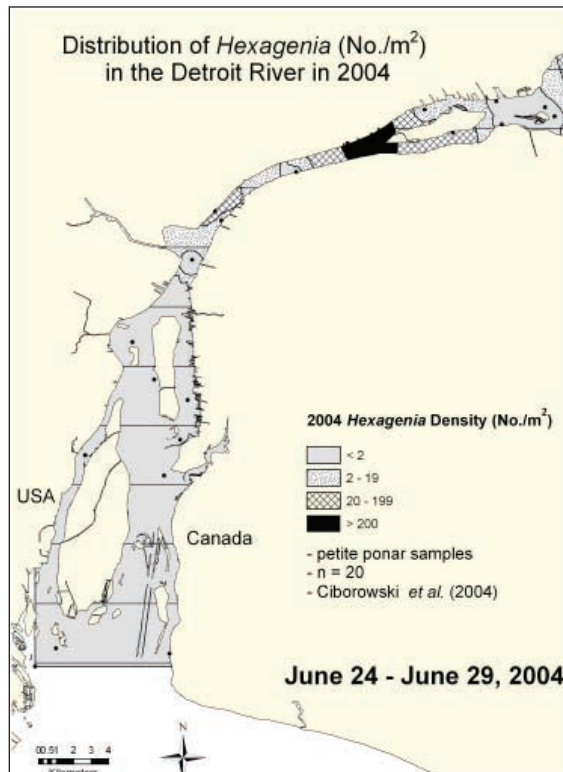


Figure 6. Density of *Hexagenia* in the Detroit River in 2004 interpolated from data compiled from Ciborowski et al. (2006). Areas containing fewer than 20 nymphs/m² indicate either degraded benthic conditions (if sediments are soft) or unsuitable habitat for mayflies (if sediments are hard). Map by Anita Kirkpatrick.

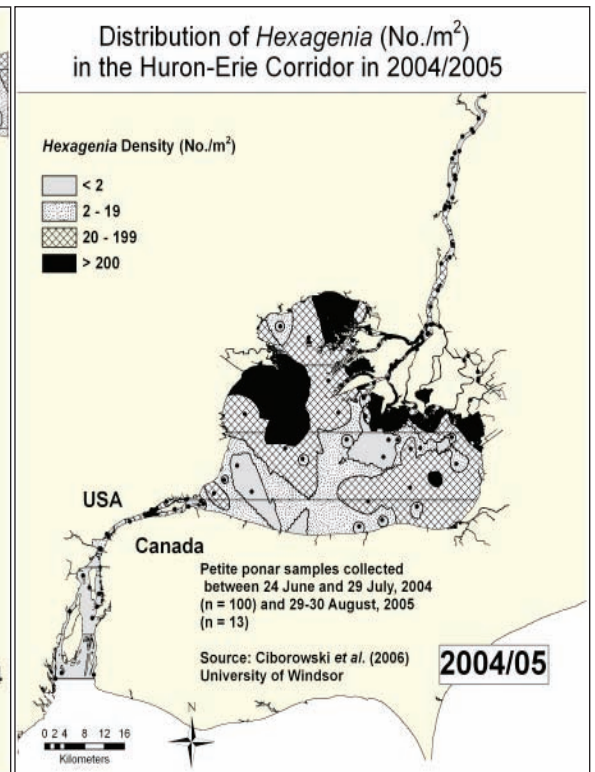


Figure 7. Density of *Hexagenia* in the Huron-Erie Corridor in 2004/05 interpolated from data compiled from Ciborowski et al. (2006). Areas containing fewer than 20 nymphs/m² indicate either degraded benthic conditions (if sediments are soft) or unsuitable habitat for mayflies (if sediments are hard). Map by Anita Kirkpatrick.

Adult Abundance and Contaminant Burdens

Improvements in Detroit River water quality have been most obviously shown in the numbers of night-flying insects that are attracted to streetlights and storefronts along the river during warm summer evenings. Both *Hexagenia* mayflies and moth-like caddisflies emerge from the river in summer to mate and lay their eggs. Emerging *Hexagenia* (commonly called fishflies or June bugs) are most abundant for a few weeks from the middle of June until mid-July. Strong winds can carry the insects long distances inland from the river, but typically, most travel only a few hundred meters (Kovats et al. 1996).

Although the insects are a nuisance, they are an important food for birds and fishes during their emergence period. They also provide a valuable tool for monitoring contaminant levels in the river. On a warm evening, a black light placed beside the river will quickly attract enough biomass to provide a sample that can be analyzed for PCBs, heavy metals, and other pollutants associated with contaminated sediments (Corkum et al. 1995). Ciborowski and Corkum (1988), Kovats (1990), and Corkum et al. (1997) analyzed organic contaminant burdens in *Hexagenia* mayflies emerging at the head of the Detroit River near Peche Island. Concentrations of PCBs, pesticides, and other organochlorine compounds were virtually identical in 1986, 1989, and 1994. Yet, the numbers of emerging insects, and their distribution along the river, have continued to increase through the 1990s (Corkum et al. 1997).

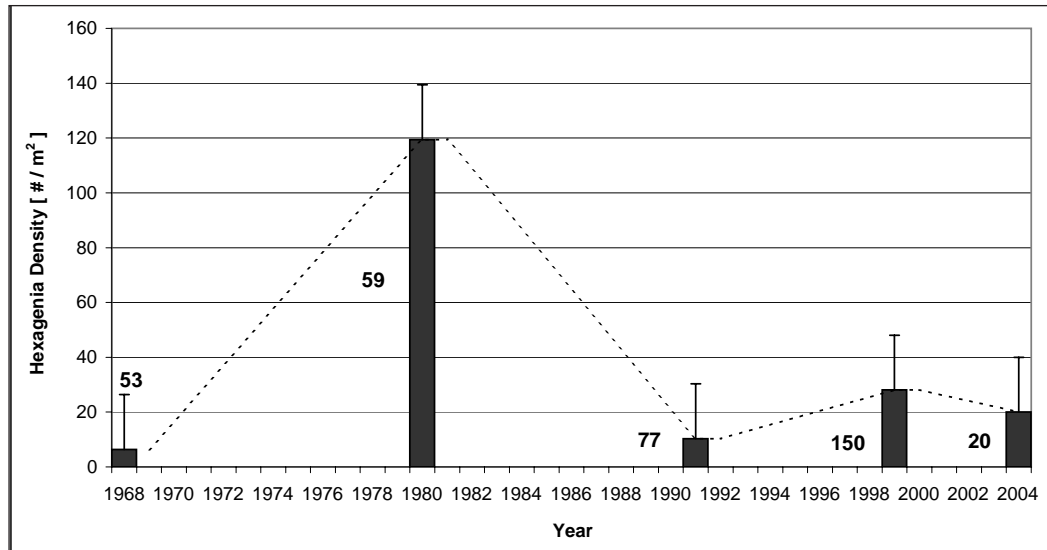


Figure 8. Mean \pm SE density of *Hexagenia* in the Detroit River between 1968 and 2004. The number of sites sampled each year is indicated. *Data compiled from Thornley and Hamdy (1984), Farara and Burt (1993), Wood (2004), and Ciborowski et al. (2006).

Contaminant burdens (PCBs, pesticides, and other organochlorine compounds) of *Hexagenia* adults collected from shorelines of western Lake Erie in 1994 were elevated relative to collections made in offshore areas. Adults collected from Monroe, Michigan, adjacent to the mouth of the Detroit River had the highest burdens of any samples. Burdens of trace metals were not unduly elevated. *Hexagenia* larvae collected from the vicinity of Middle Sister Island in western Lake Erie had high burdens of organochlorine compounds and polycyclic aromatic hydrocarbons (Corkum et al. 1997).

Management Next Steps

The available data show which portions of the river have historically been most heavily degraded by organic enrichment and those that are still affected by nutrient-rich water, primarily sewage and stormwater. The present-day distribution of *Hexagenia* nymphs suggests that current sediment and water quality conditions have not improved enough to permit nymphs to develop in those degraded areas. However, surveys have been conducted too infrequently to permit us to ascertain the extent to which year-to-year variation in distribution reflects changing pollution status vs. normal fluctuations in the mayfly population. Continued attention to point sources of pollution will be necessary to permit *Hexagenia* to populate all of the depositional habitats in the Detroit River.

Research/Monitoring Needs

Hexagenia surveys have been conducted too infrequently to permit one to ascertain whether the time trend patterns represent changing environmental conditions or random interannual variation. Ideally, sampling should be conducted yearly, and surveys should be completed in the spring, prior to the period of adult emergence (ideally during the months of April and May). Sampling methods (collection times, determination of site locations, number of sites sampled) should be standardized across years to improve the precision of riverwide density estimates.

References

- Carr, J.F., and J.K. Hiltunen. 1965. Changes in the bottom fauna of western Lake Erie from 1930 to 1961. *Limnology and Oceanography* 10:551-569.
- Ciborowski, J.J.H., and L.D. Corkum. 1988. Organic contaminants in adult aquatic insects of the St. Clair and Detroit Rivers, Ontario, Canada. *Journal of Great Lakes Research* 14:148-156.
- Ciborowski, J.J.H. 2003a. Lessons from sentinel invertebrates: Mayflies and other species. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 107-120. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Ciborowski, J.J.H. 2003b. Technical comments on delisting criteria for the Detroit River area of concern – Beneficial use impairment #6: Degradation of Benthos. In *Workshop on Delisting Criteria for the Detroit River Area of Concern*, Windsor, ON, eds. D. Dolan and P. Murray, pp. 78-87. April 26-27, 2002. Prep. for Detroit River Canadian Cleanup Committee.
- Ciborowski, J.J.H., J. Zhang, J. Baillargeon, and A. Kirkpatrick. 2006. Section 6 – Zoobenthos. Benthos and sediment chemistry studies on the Detroit and St. Clair rivers. In *Great Lakes Institute for Environmental Research et al.* Draft report prepared for Great Lakes Sustainability Fund.
- Corkum, L.D., J.J.H. Ciborowski, and Z.E. Kovats. 1995. Aquatic insects as biomonitors of ecosystem health in the Great Lakes area of concern. In *Biomonitoring and Biomarkers as Indicators of Environmental Change: A Handbook*, eds. F.M. Butterworth, L.D. Corkum, and L.J. Guzmán-Rincón, pp. 31-44. New York: Plenum Publishing Company.
- 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. *Journal of Great Lakes Research* 23:383-390.
- Edsall, T.A, R.C. Haas, and J.V. Adams. 2001. Annual production of burrowing mayfly nymphs (*Hexagenia* spp.) in U.S. waters of Lake St. Clair. *Journal of Great Lakes Research* 27:449-456.
- Farara, D.G., and A.G. Burt. 1993. Environmental assessment of Detroit River sediments and benthic macroinvertebrate communities – 1991. Report prepared for the Ontario Ministry of Environment and Energy by Beak Consultants Limited, Brampton, Ontario. Volume I.
- Hudson, P.L., B.M. Davis, S.J. Nichols, and C.M. Tomcko. 1986. Environmental studies of macrozoobenthos, aquatic macrophytes, and juvenile fishes in the St. Clair-Detroit River system, 1983-1984. U.S. Fish and Wildlife Service, Great Lakes Fish Lab, Administrative Report No. 86-7. Ann Arbor, MI.
- Kovats, Z.E. 1990. Adult aquatic insects as biomonitors of organochlorine contamination in freshwater habitats. M.Sc. Thesis, University of Windsor, Ontario, Canada.
- Kovats, Z.E., J.J.H. Ciborowski, and L.D. Corkum. 1996. Inland dispersal of adult aquatic insects. *Freshwater Biology* 36:265-276.

Manny, B.A., T.A. Edsall, and E. Jaworski. 1988. The Detroit River, Michigan: An ecological profile. U.S. Fish and Wildlife Service Biological Report 85 (7.17). Ann Arbor, MI.

Ohio Lake Erie Commission. 2004. *State of the Lake Report, 2004*. Toledo, OH. <http://www.epa.state.oh.us/oleo/reports/leqi/leqi2004/leqiz.htm>

Reynoldson, T.B., D.W. Schloesser, and B.A. Manny. 1989. Development of a benthic invertebrate objective for mesotrophic Great Lakes waters. *Journal of Great Lakes Research* 15(4):669-686.

Thornley, S., and Y. Hamdy. 1984. An assessment of bottom fauna and sediments of the Detroit River. Ontario Ministry of Environment Report, Toronto, Ontario, Canada.

Thornley, S. 1985. Macrozoobenthos of the Detroit and St. Clair rivers with comparison to neighboring waters. *Journal of Great Lakes Research* 11:290-296.

Vaughan, R.D., and G.L. Harlow. 1965. Report on pollution of Detroit River, Michigan waters of Lake Erie, and their tributaries. U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Water Supply and Pollution Control. U.S. Government Printing Office, Washington, DC.

Wood, S. 2004. The use of benthic macroinvertebrate community composition as a measure of contaminant induced stress in the sediments of the Detroit River. M.Sc. Thesis, University of Windsor, Ontario, Canada.

Wright, S., and W.M. Tidd. 1933. Summary of limnological investigations in western Lake Erie in 1929 and 1930. *Transactions of the American Fisheries Society* 63:271-285.

Contact Information

Jan Ciborowski
Department of Biological Sciences
University of Windsor
E-mail Address: cibor@uwindsor.ca

(Sections of this summary are taken directly from Ciborowski (2003a))

INDICATOR: ABUNDANCE OF BURROWING MAYFLIES IN THE WESTERN BASIN OF LAKE ERIE

Background

Burrowing mayfly populations (*Hexagenia* spp.) were extirpated in the 1940s and 1950s from western Lake Erie. During the first half of the twentieth century, major urban impacts, such as municipal and industrial pollution associated with urban growth, greatly decreased the likelihood of mayfly reoccurrence (Schloesser 2005). Before the 1950s, mayflies were found in nearshore areas, harbors, and tributary mouths throughout the Great Lakes (Schloesser 2005). Mayfly populations do well in shallow, productive lakes

with soft, organically rich sediments (Figure 1). They are important in the diets of many Lake Erie sport and commercial fish such as yellow perch, freshwater drum, channel catfish, trout perch, spottail shiner, and mooneye (Ohio Lake Erie Commission 2004).



Figure 1. *Hexagenia* spp. nymphs. Difference in body length, from 1 to 30 mm, is mostly dependent upon age and food (Photo credit: U.S. Geological Survey).

Mayflies are considered an ecological “keystone” species and their presence is believed to be an important environmental indicator of mesotrophic (i.e., moderately productive) conditions. Mayflies are ecologically important as a trophic indicator, linking detrital (bottom litter) energy resources directly to the many fish species that feed on *Hexagenia* (USGS 2005). Mayfly nymphs prefer to burrow in soft sediment, which often carries high concentrations of pollutants in contaminated areas.

Nymphs are intolerant of polluted sediment associated with eutrophication and a lack of oxygen in the lowest layer of the water column (Ohio Lake Erie Commission 2004). Extended lack of oxygen eliminates the nymphs. Mayflies are also useful indicators because they are highly visible, relatively easy to sample, and provide “real proof” that lake restoration has been effective. Mayflies may be used to measure restoration progress and success/failure of aquatic restoration goals in the western basin because enough data are being collected to establish biological reference points suitable for the public to understand ecosystem health.

Status and Trends

Hexagenia spp. mayfly nymphs returned to sediments of western Lake Erie in 1992-93 after an absence of 40 years (Krieger et al. 1996). Their recovery was aided by pollution abatement programs combined with the invasion of exotic zebra mussels in 1986 that changed the trophic status of nearshore waters of the Great Lakes. By 1997 abundances of nymphs were similar to historical abundances before extirpation in the mid-1950s (Schloesser et al. 2000). Although mayflies were historically (pre-1950s) abundant and

important in the food web of western Lake Erie, there is very limited information prior to the 1950s and they disappeared from the lake shortly after an anoxic period (i.e., no dissolved oxygen near sediments) in 1953. This anoxia was attributed to organic loadings from municipal wastes. Between 1960 and 1990, few mayflies were found in Lake Erie (Schloesser 2005).

Between 1997 and 2004, mayflies gradually increased in distribution, spreading eastward in nearshore sediment and, by 2004, were present throughout the entire western basin of Lake Erie. However, their reestablishment in nearshore areas of the central and eastern basins was unsuccessful during that time (Krieger et al. In press). In 2004, biological reference points (density descriptors of excellent, good, fair, poor, and imperiled) were established based on mayfly abundance in the western basin (Ohio Lake Erie Commission 2004). These reference points are category descriptors of ranges of nymph densities that are easily understood by the general public and allow agencies to more easily communicate progress toward goals of lake-wide management plans (Schloesser 2005).

Recovery of the mayfly population in western Lake Erie has happened much quicker than models predicted (Schloesser et al. 2000). Again, few mayflies were present in western Lake Erie between the 1950s and 1992. Beginning in the early 1990s, the average number of nymphs in the soft bottom sediments increased. They increased between 1992 and 1997, then decreased in 1998. Data indicate there is a large year-to-year variation of nymph density (Figure 2). A three-year running average is now used to dampen this annual density variability and aid interpretation of population abundance. Researchers are investigating possible physical and biological causes to explain instability of mayfly abundance in Lake Erie and have discovered one or more parameters responsible for failed reproduction. It is believed that western Lake Erie stratifies for short periods of time causing a lack of oxygen. It is well documented that the central and eastern basins of the lake stratify for several months every year. The shallow nature of the western basin allows wind-induced turnover to occur frequently, severely limiting stratification events and duration.

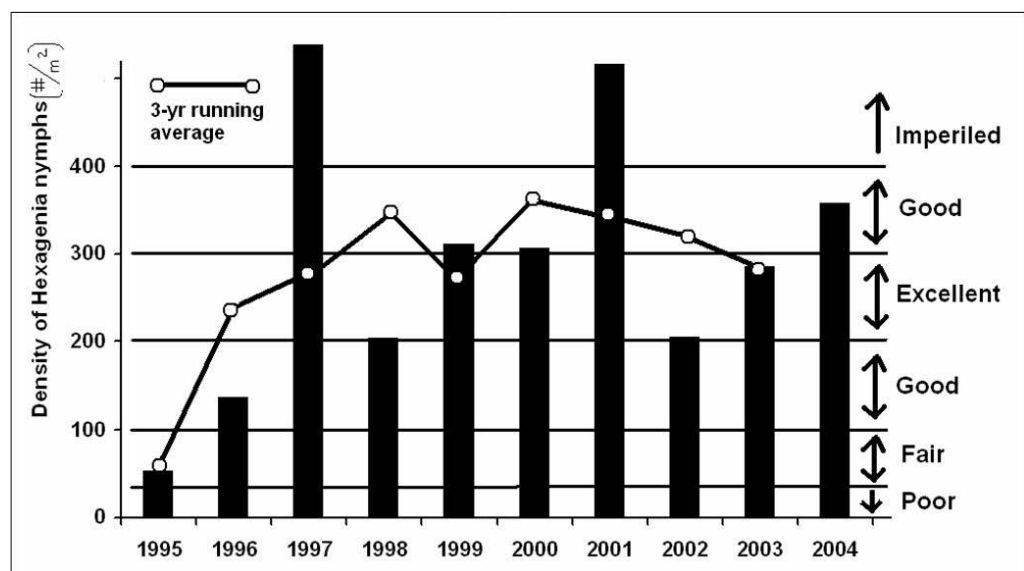


Figure 2. Density of *Hexagenia* nymphs in the western basin of Lake Erie, 1995-2004 (based on the three-year running averages and biological reference point density descriptors; some minor differences exist in annual sampling sites; data collected by USGS).

The 2003, three-year running average population of mayfly nymphs per square meter is equal to a rating of “excellent” under the biological reference point scoring system. The rating for this species between 1996 and 2004 ranged between good and excellent, but the mayfly population in portions of the basin exhibited large variation and appeared threatened in some years, possibly as a result of fluctuating dissolved oxygen concentrations. Any increase in the input of limiting nutrients (phosphorus) will probably yield an increase in primary and secondary productivity which, in turn, could lead to larger variation and possible declines in dissolved oxygen concentrations in summer months (Ohio Lake Erie Commission 2004). However, a very low percentage of the hundreds of basin-wide dissolved oxygen measurements have been below the concentration believed to be lethal to mayfly populations. Exceedingly high nymph density, as well as exceedingly low nymph density, may indicate an ecological imbalance. High nymph density may indicate a state of nutrient enrichment which, if continued, could cause oxygen depletion (Krieger 1999).

Management Next Steps

Mayfly nymph density for Lake Erie has been designated by the State of the Lake Ecosystem Conference (SOLEC) as an important indicator. Mayfly density and other SOLEC indicators will be used to report to the International Joint Commission and the public on progress made in restoring the chemical, physical, and biological integrity of the Great Lakes, as called for in the Canada-U.S. Great Lakes Water Quality Agreement (USGS 2005). As pollution-abatement programs continue, more Great Lakes areas should experience recovery of burrowing mayflies in the next 10-20 years (Schloesser 2005). Continued efforts are needed to adequately control municipal, industrial, and agricultural sources of pollution consistent with the Great Lakes Water Quality Agreement.

The Lake Erie Commission has set a desired abundance of 201-300 mayfly nymphs per square meter as a level to sustain the Lake Erie fishery (Ohio Lake Erie Commission 2004). This quantitative target may be incorporated in food web, nutrient, and hydrodynamic modeling in support of ecosystem-based management.

Research/Monitoring Needs

Emerging mayfly swarms in early summer are once again a major annual event warranting continuation of mayfly research. Research should continue to test surface and subsurface sediments to determine the cause of annual variation and exceedingly high and low abundances of mayflies. Parameters that should be investigated include sediment oxygen depletion and demand, pH, conductivity, organic content, persistent toxic organics, and grain size. This research will help determine the causes of unstable population abundances in western Lake Erie (Schloesser 2005).

References

Krieger, K. 1999. Ecosystem change in western Lake Erie: Causes and effect of burrowing mayfly recolonization. Lake Erie Protection Fund Project LEPF-08-94. <http://www.heidelberg.edu/offices/wql/LEPF-08-94.html>

Krieger, K.A., D.W. Schloesser, B.A. Manny, C.E. Trisler, S.E. Heady, J.J.H. Ciborowski, and K.N. Muth. 1996. Recovery of burrowing mayflies (*Ephemeroptera: Ephemeridae: Hexagenia*) in western Lake Erie. *Journal of Great Lakes Research* 22:254-263.

Krieger, K.A., M.T. Bur, J.J.H. Ciborowski, D.R. Barton, and D.W. Schloesser. In press. Distribution and abundance of burrowing mayflies (*Hexagenia* spp.) in Lake Erie, 1997-2005. *Journal of Great Lakes Research*.

Ohio Lake Erie Commission. 2004. Mayfly metric of the Lake Erie quality index: Design of an efficient censusing program, data collected, and development of the metric. *State of the Lake Report*. <http://www.heidelberg.edu/wql/LEQI%20FINAL%20REPORT1.pdf> (November 2005).

Schloesser, D. 2005. *Restoration of burrowing mayflies in the Great Lakes*. U.S. Geological Survey PowerPoint Presentation.

Schloesser, D.W., K.A. Krieger, J.J.H. Ciborowski, and L.D. Corkum. 2000. Recolonization and possible recovery of burrowing mayflies (*Ephemeroptera: Hexagenia* spp.) in Lake Erie of the Laurentian Great Lakes. *Journal of Aquatic Ecosystem Stress and Recovery* 8:125-141.

[USGS] Great Lakes Science Center. 2005. Burrowing mayflies (*Hexagenia*) as an indicator of ecosystem health. http://www.glsc.usgs.gov/main.php?content=research_NCE_coastal_mayflies&title=Coastal%20Ecology0&menu=research_NCE_coastal (August 2004).

Links for More Information

Biological indicators of watershed health: <http://www.epa.gov/bioindicators/html/mayflies.html>

Ohio Lake Erie Commission, biological indicator: <http://www.epa.state.oh.us/oleo/reports/leqi/leqi2004/pdf/biologicalindicator.pdf>

Report on tracking rapid population change of burrowing mayflies in the central basin of Lake Erie: <http://www2.heidelberg.edu/wql/FINALREPORT.pdf>

Contact Information

Don Schloesser
U.S. Geological Survey
E-mail Address: don_schloesser@usgs.gov

Kenneth A. Krieger
Heidelberg College, Water Quality Research Scientist
E-mail Address: kkrieger@heidelberg.edu

INDICATOR: CHIRONOMID ABUNDANCE AND DEFORMITIES

Background

Chironomids, commonly known as midges, are mosquito-like insects whose larvae live in the sediments of all types of aquatic habitats. They are abundant in western Lake Erie and the Detroit River. Swarms of adult midges emerge in the spring and summer. They can often be seen flying around lights on warm summer nights. After mating, females deposit their eggs on the water surface where they sink to the bottom and then hatch to become larvae. There are over a thousand species of chironomids in Canada and the U.S. Some species can complete their life cycle in just a few weeks. The larvae of other species of chironomids can spend up to several months feeding on organic matter in the sediments. Chironomids are an important food source for fish and waterfowl (Ciborowski and Corkum 2003). The adults provide food for amphibians, bats and insect-feeding birds such as purple martins and swallows (Smits et al. 2005).

Chironomids can be an important freshwater indicator. The larvae of some species are sensitive to specific forms of pollution, whereas others are quite tolerant. Because the larvae often feed on the debris in aquatic sediments, they are exposed to contaminants contained in the organic matter. The fact that chironomids live in such a wide variety of habitats makes them especially useful indicators. Large numbers of pollution-tolerant chironomids are often indicative of poor water quality conditions. These species have a substance similar to haemoglobin in their blood which allows them to survive in places where the oxygen has become depleted. Excellent water quality conditions (characterized by high dissolved oxygen and low nutrient concentrations) are often characterized by relatively low densities and high species diversity (50% or more of the species being chironomids). Chironomid species diversity and their sensitivity to eutrophic conditions have been used to create trophic status classifications of lakes (oligotrophic, mesotrophic and eutrophic; e.g., Saether 1975; Winnell and White 1985; Langdon et al. 2006).

The value of chironomids as an indicator pertains to more than just their abundance. Correlations have been found between larval mouthpart and antennae abnormalities and exposure to heavy metals and pesticides such as DDT, DDE, dieldrin and hexachlorobenzene (Warwick 1985; Dermott 1991; Hudson and Ciborowski 1996a; Doherty et al. 1999). Deformities in chironomids are relatively rare (although much more common than in other types of organisms), so detecting an increase above the baseline level of deformities may require looking at over 100 larvae per site (Hudson and Ciborowski 1996a; Burt et al. 2003). Midge larvae are able to metabolize organic contaminants such as PAHs (Harkey et al. 1994), but the breakdown products may also be responsible for morphological abnormalities. Research has also shown that sediments contaminated with trace metals and other pollutants harbor chironomids whose chromosomal activity levels are reduced, which could reflect lowered metabolic activity and inhibited RNA synthesis (Hudson and Ciborowski 1996b). The important role that

chironomids play in the food web is also significant for representing the possible transfer of contaminants (Ciborowski and Corkum 2003; Smits et al. 2005).

Status and Trends

Abundance

In western Lake Erie between 1930 and 1961, increasing eutrophication was evidenced by a fourfold increase in chironomid density (Carr and Hiltunen 1965). In 1961, the three most abundant and widely distributed groups of organisms were chironomid larvae, oligochaetes and fingernail clams. Chironomids made up 5% (355 larvae/m²) of the total zoobenthic abundance and were evenly distributed at all sites across western Lake Erie (Carr and Hiltunen 1965). There was no correlation with the number of oligochaete worms found, so chironomid larvae represent an independent indicator of environmental condition. Water conditions improved in Lake Erie through the 1980s and into the early 1990s. The benthic community slowly recovered as the western basin of Lake Erie returned from a eutrophic state to mesotrophic status. Doherty et al. (1999) examined the chironomid larvae in samples collected from western Lake Erie by the U.S. Geological Survey in 1982 and 1993. Between those periods of time, mean density declined whereas diversity (number of genera) rose (Figure 1).

In the Detroit River, the overall abundance of chironomids has increased steadily from 1968-2004 (Figure 2).

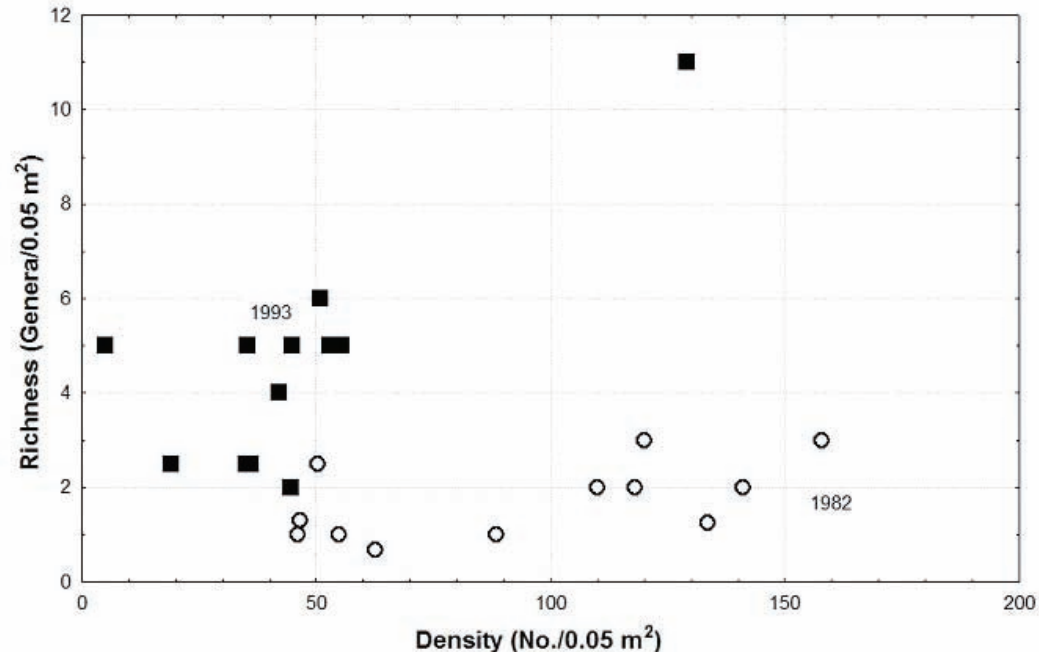


Figure 1. Comparison of number of genera and density of chironomid larvae collected from western Lake Erie locations in 1982 (open circles) and 1993 (filled squares). Data of Doherty et al. (1999) analyzed from samples provided by D.W. Schloesser, Great Lakes Science Center, USGS.

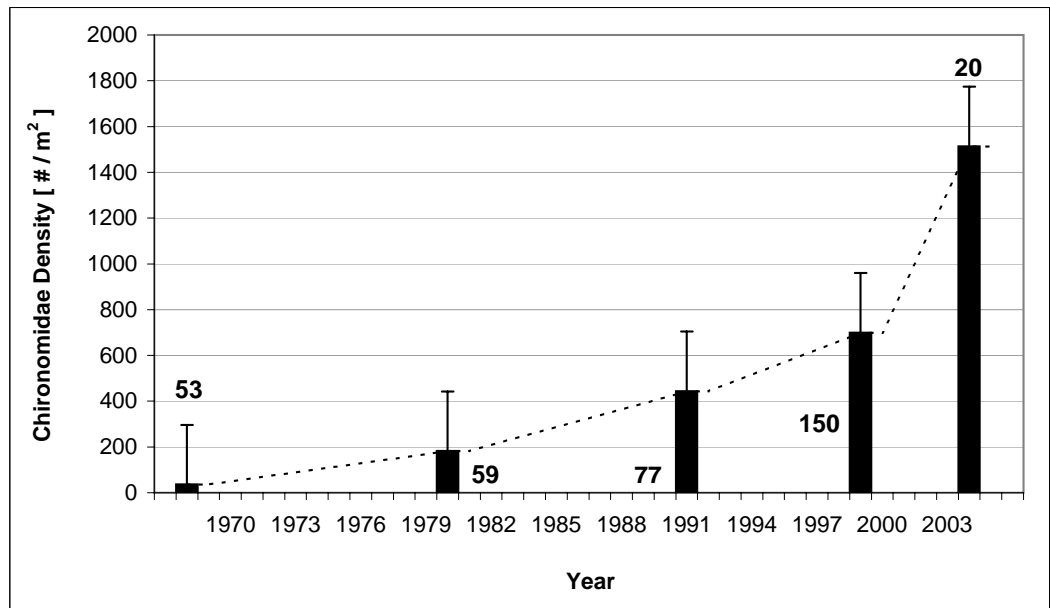


Figure 2. Mean \pm SE density of larvae of Chironomidae in the Detroit River between 1968 and 2004. The number of sites sampled each year is indicated. Data compiled from Thornley and Hamdy (1984), Farara and Burt (1993), Wood (2004), and Ciborowski et al. (2006).

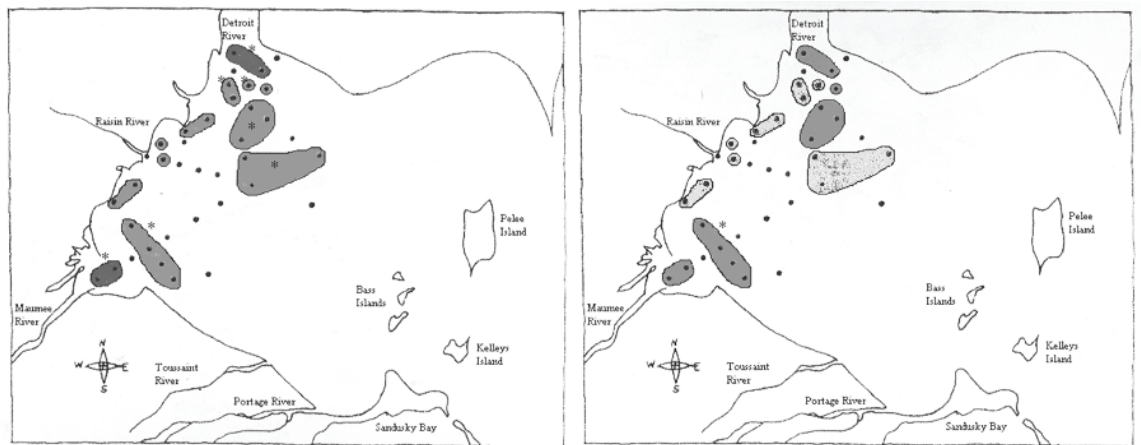


Figure 3. Incidence of mouthpart deformities in larvae of *Procladius* midges in western Lake Erie in 1982 (left) and 1993 (right). Data analyzed by Doherty et al. (1998) from samples provided by D.W. Schloesser, Great Lakes Science Center, USGS. Shaded areas enclose sampling sites (points) from which 75 or more larvae could be examined for deformities. Dark grey areas $>6.0\%$; medium grey areas $1.6-6.0\%$; light grey areas $<1.6\%$. Across the entire Great Lakes, approximately 2.3% of *Procladius* larvae have deformed mouthparts (Burt et al. 2003).

Deformities

The overall incidence of mouthpart deformities in two genera (*Procladius* and *Coelotanytus*) decreased from the 1980s to the 1990s (Doherty et al. 1999; Figure 3). Hudson and Ciborowski (1996a) studied the frequency of deformities in chironomids collected from five locations in the Huron-Erie Corridor in 1992 and 1993. Deformities were most commonly found at the head of the Detroit River near Peche Island. They were surprisingly rare at a location in the Trenton Channel, possibly because the larvae that could survive in Trenton Channel sediments were especially resistant to pollutants.

Midge larvae reared in Trenton Channel sediments in the laboratory were much more prone to deformities than those reared in reference sediments (Hudson and Ciborowski 1996b). The incidence of deformities in chironomids collected in the Detroit River in 2004 (J. Zhang, University of Windsor, pers. comm.) was lower than that observed in 1992 and 1993 (Hudson and Ciborowski 1996a).

Management Next Steps

The relative abundance, community composition and morphological condition of chironomid larvae are all useful indicators of the condition of water and sediments in the Detroit River and western Lake Erie. Time trends suggest that concentrations of deformity-inducing contaminants in Detroit River sediments declined meaningfully between the 1980s and the early 1990s. This reflects the concerted cleanup efforts that were undertaken at that time. We do not have current data to determine whether the continuing efforts to remediate sediment contamination in the Detroit River have resulted in continued reduction in the incidence of deformities. Increases in midge larval biodiversity (number of genera) also suggest improving water quality in western Lake Erie between the 1980s and 1990s. The trend of increasing mean density of larvae in the Detroit River could imply either improving water quality conditions (improved survival) or declining sediment quality (enriched sediments, which sustain more larvae). This uncertainty could be resolved by examining community composition using a genus index of pollution (e.g., Winnell and White 1985).

Research/Monitoring Needs

Chironomids are a dominant part of the benthic community of the Detroit River and western Lake Erie. Because they can be found year-round and live in all types of aquatic habitats, the timing of benthic sampling is not as critical for these organisms as it is for other zoobenthic indicators such as *Hexagenia* mayflies and caddisflies. However, assessment of deformities requires that adequate numbers of larvae be collected at each location. Consequently, multiple replicate samples should be collected during surveys to assure the availability of enough specimens. Community composition assessment can be a valuable tool, permitting use of richness or pollution indices to assess changes in water quality or local conditions. Genus level identification requires that larvae be mounted on microscope slides and examined by an expert. However, samples that are properly preserved and stored can be examined and identified many years after they have been collected.

References

- Burt, J., J.J.H. Ciborowski, and T. B. Reynoldson. 2003. Baseline incidence of mouthpart deformities in Chironomidae (Diptera) from the Laurentian Great Lakes, Canada. *Journal of Great Lakes Research* 29:172-180.
- Carr, J., and J. Hiltunen. 1965. Changes in the bottom fauna of Western Lake Erie from 1930 to 1961. *Limnology and Oceanography* 10:551-569.
- Ciborowski, J.J.H., and L.D. Corkum. 2003. Appendix 9: Sediment-zoobenthos interactions. In *Evaluating Ecosystem Results of PCB Control Measures within the Detroit River–Western Lake Erie Basin*, 78-82. United Earth Fund.

- Ciborowski, J.J.H., J. Zhang, J. Baillargeon, and A. Kirkpatrick. 2006. Section 6 – Zoobenthos. Benthos and sediment chemistry studies on the Detroit and St. Clair rivers. In *Great Lakes Institute for Environmental Research et al.* Draft report prepared for Great Lakes Sustainability Fund.
- Dermott, R.M. 1991. Deformities in larval *Procladius* spp. and dominant Chironomini from the St. Clair River. *Hydrobiologia* 219:171-185.
- Doherty, M.S.E., P.L. Hudson, J.J.H. Ciborowski, D.W. Schloesser. 1999. Morphological Deformities in Larval Chironomidae (Diptera) from the Western Basin of Lake Erie: A Historical Comparison. In *Proceedings of the 25th Annual Aquatic Toxicity Workshop: October 18-21, 1998, Quebec City*, eds. R. Van Collie, R. Chasse, L. Hare, C. Julien, L. Mattel, C. Thelland, and A.J. Niimi. Canadian Technical Report of Fisheries and Aquatic Sciences. No. 2269:134.
- Farara, D.G., and A.G. Burt. 1993. Environmental assessment of Detroit River sediments and benthic macroinvertebrate communities – 1991. Report prepared for the Ontario Ministry of Environment and Energy by Beak Consultants Limited, Brampton, Ontario. Volume I.
- Harkey, G.A., P.F. Landrum, and S.J. Klaine. 1994. Comparison of whole-sediment, elutriate and pore-water exposures for use in assessing sediment-associated organic contaminants in bioassays. *Environmental Toxicology and Chemistry* 13:1315-29.
- Hudson, L.A., and J.J.H. Ciborowski. 1996a. Spatial and taxonomic variation in incidence of mouthpart deformities in midge larvae (Diptera: Chironomidae: Chironomini). *Canadian Journal of Fisheries and Aquatic Sciences* 53:297-304.
- Hudson, L.A., and J.J.H. Ciborowski. 1996b. Teratogenic and genotoxic responses of larval *Chironomus salinarius* group (Diptera: Chironomidae) to contaminated sediment. *Environmental Toxicology and Chemistry* 15:1375-1381.
- Langdon, P.G., Z. Ruiz, K.P. Broderson, I.D.L. Foster. 2006. Assessing lake eutrophication using chironomids: Understanding the nature of community response in different lake types. *Freshwater Biology* 51:562-577.
- Saether, O. 1975. Chironomid communities as water quality indicators. *Holarctic Ecology* 2:65-74.
- Smits, J.E., G.R. Bortolotti, M. Sebastian, and J.J.H. Ciborowski. 2005. Spatial, temporal, and dietary determinants of organic contaminants in nestling tree swallows in Point Pelee National Park, Ontario, Canada. *Environmental Toxicology and Chemistry* 24:3159-3165.
- Thornley, S., and Y.H. Hamdy. 1984. An assessment of the bottom fauna and sediments of the Detroit River. Ontario Ministry of the Environment, Southwestern Region and Water Resources Branch, Toronto, ON.
- Warwick, W.F. 1985. Morphological abnormalities in Chironomidae (Diptera) larvae as measures of toxic stress in freshwater ecosystems: Indexing antennal deformities in *Chironomus* Meigen. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1881-1914.
- Winnell, M.H., and D.S. White. 1985. Trophic status of southeastern Michigan based on the Chironomidae (Diptera). *Journal of Great Lakes Research* 11:540-548.

Wood, S. 2004. The use of benthic macroinvertebrate community composition as a measure of contaminant induced stress in the sediments of the Detroit River. M.Sc. Thesis, University of Windsor, Ontario.

Contact Information

Jan Ciborowski
Department of Biological Sciences
University of Windsor
E-mail Address: cibor@uwindsor.ca

INDICATOR: OLIGOCHAETE DENSITIES AND DISTRIBUTION

Background

Members of the class Oligochaeta include common earthworms. But the aquatic sludge worms (family Tubificidae) are best known for their value as environmental indicators. The name Oligochaeta means “few bristles,” which refers to the small bundles of hair-like bristles (chaetae) that occur on each body segment (Figure 1). Tubificid worms have long been recognized as pollution-tolerant because of their ability to thrive under poor water quality conditions. Their blood contains hemoglobin, which enables them



Figure 1. Oligochaete with setae visible. Oligochaetes typically have four pairs of setae (chaetae) per segment which are used during burrowing and crawling movements (Photo credit: USGS, Great Lakes Science Center).

to survive in waters where oxygen is lacking. Hemoglobin (the same oxygen transporting protein in our blood) absorbs and retains oxygen from the water. Because oligochaetes are small and relatively immobile, they lack the ability to escape environmental stress (e.g., contaminated sediments), making them a useful indicator of local benthic conditions (Farara and Burt 1993). Howmiller and Scott (1977) showed that low oligochaete diversity occurs in unpolluted, undisturbed environments. However, low densities of worms do not always indicate clean water conditions. Sediments severely polluted with toxic materials may be degraded to the point where even oligochaete survival is unlikely and densities may be low for this reason (Ciborowski 2003).

Typically, benthic environments rich in organic materials (such as algae and bacteria stimulated by sewage or nutrient runoff) support a disproportionately large abundance of oligochaetes (Hynes 1971).

A healthy aquatic ecosystem supports a balanced benthic community that is made up of a mix of benthic species and is not dominated by oligochaetes. When an area becomes disturbed, species diversity declines and pollution-tolerant organisms such as oligochaetes and chironomid midge larvae replace pollutant-sensitive species (Farara and Burt 1993). Wright (1955) suggested that the degree of pollution in Great Lakes locations could be summarized by aquatic oligochaete abundance. Worm densities of 100-999/m² were said to indicate light pollution, moderately polluted areas supported 1,000-5,000 worms/m², and densities of worms exceeding 5,000/m² were representative of heavily polluted areas. When oligochaete worms are used as pollution descriptors, they are often evaluated in reference to the bottom sediment from which they are found. Lafont (1984) compared oligochaete communities from fine sediments of polluted rivers to toxicity measurements in the water. He found that the fewest oligochaete species and the highest relative abundance of Tubificidae occurred in the most polluted areas.

Milbrink (1983) developed an environmental index based on oligochaete abundance and species diversity, arguing that it is more useful to examine oligochaete community composition than to use a single indicator species on its own. Milbrink's environmental index is based on the Saprobien System, which classifies organisms according to their tolerance to organic pollution in streams. The index characterizes the ecological requirements of each oligochaete species with respect to its tolerance of organic pollution or eutrophic conditions.

Status and Trends

The oligochaetes of western Lake Erie and the lower Detroit River have been studied since as early as 1929 when Wright and Tidd (1933) conducted a density survey of various zoobenthic fauna. At that time, areas with densities $>5,000$ worms/m² were found near the mouths of the Maumee River and River Raisin (Ciborowski 2003).

Between the 1960s and early 1990s, oligochaete worms indicated that parts of the Detroit River were severely enriched. Downstream of Belle Isle, densities were approximately 500,000/m², and downstream of the confluence between the Detroit and Rouge rivers, densities were as high as one million per m² (Thornley and Hamdy 1984). Both of these areas were likely affected primarily by effluents from sewage treatment plants.

Canadian shoreline water quality conditions were apparently less degraded at this time, as indicated by a more balanced benthic community structure (Thornley and Hamdy 1984). Along the U.S. shoreline, worms accounted for 78% of the total number of organisms collected in both 1968 and 1980 (Thornley and Hamdy 1984). In 1980, downstream of the mouth of the Rouge River, aquatic worms constituted 80-99% of the total number of invertebrates. *Tubifex tubifex* was the dominant species, reaching numbers as high as 1.5 and 1.9 million/m² at these locations. Thornley and Hamdy (1984) stated that "the 1980 data were essentially unchanged from 1968 and represented a continuing major disruption of the benthos."

Zoobenthic community composition also suggested that the lower Detroit River was very degraded prior to the mid-1960s. In 1961, 99% of the oligochaete species collected in the Detroit River were Tubificidae (Carr and Hiltunen 1965). Overall, oligochaetes were the most numerous zoobenthos collected (greatest abundance at all but three sites) and at only ten stations did they contribute less than 50% of the total organisms (Carr and Hiltunen 1965). Carr and Hiltunen (1965) used these worm densities to estimate the area (km²) of zones of pollution. They classified 12% of the Detroit River as lightly polluted, 53% as moderately polluted and 35% as heavily polluted (compared to 1930 data in which no part of the Detroit River was heavily polluted).

Estimates of oligochaete abundance are available from five Detroit River surveys conducted between 1968 and 2004 (Figure 2). Because the data were collected and compiled from various sources* there is variation in the number and location of sites sampled, and the times of year during which they were sampled. Riverwide estimates of average densities have ranged from about 1,200 worms/m² (in 1999) to almost 7,000/m² (in 1991). Densities in 2004 were substantially higher than they were in 1999, suggesting that water quality was poorer in 2004. However, surveys have been conducted too irregularly to indicate whether the differences seen among years represent progressive changes in the river's condition or merely year-to-year variation.

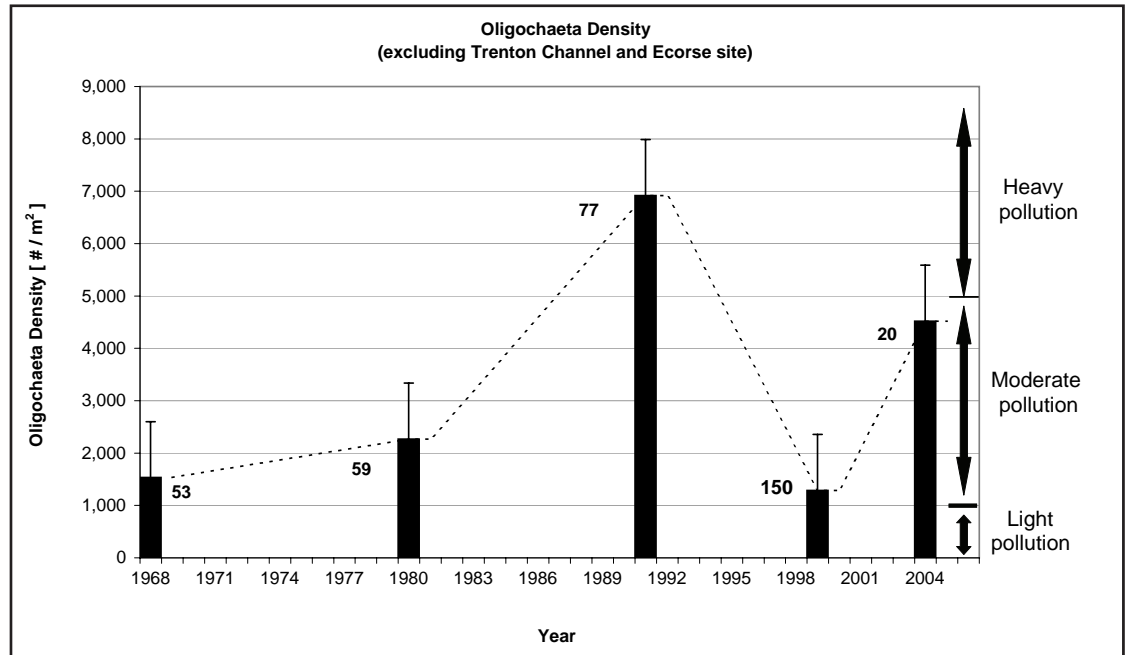


Figure 2. Mean \pm SE density of oligochaetes in the Detroit River between 1968 and 2004. The numeral beside each bar indicates the number of sites sampled during that year. *Data compiled from Thornley and Hamdy (1984), Farara and Burt (1993), Wood (2004), and Ciborowski et al. (2006). Ranges of eutrophication are based on Wright (1955).

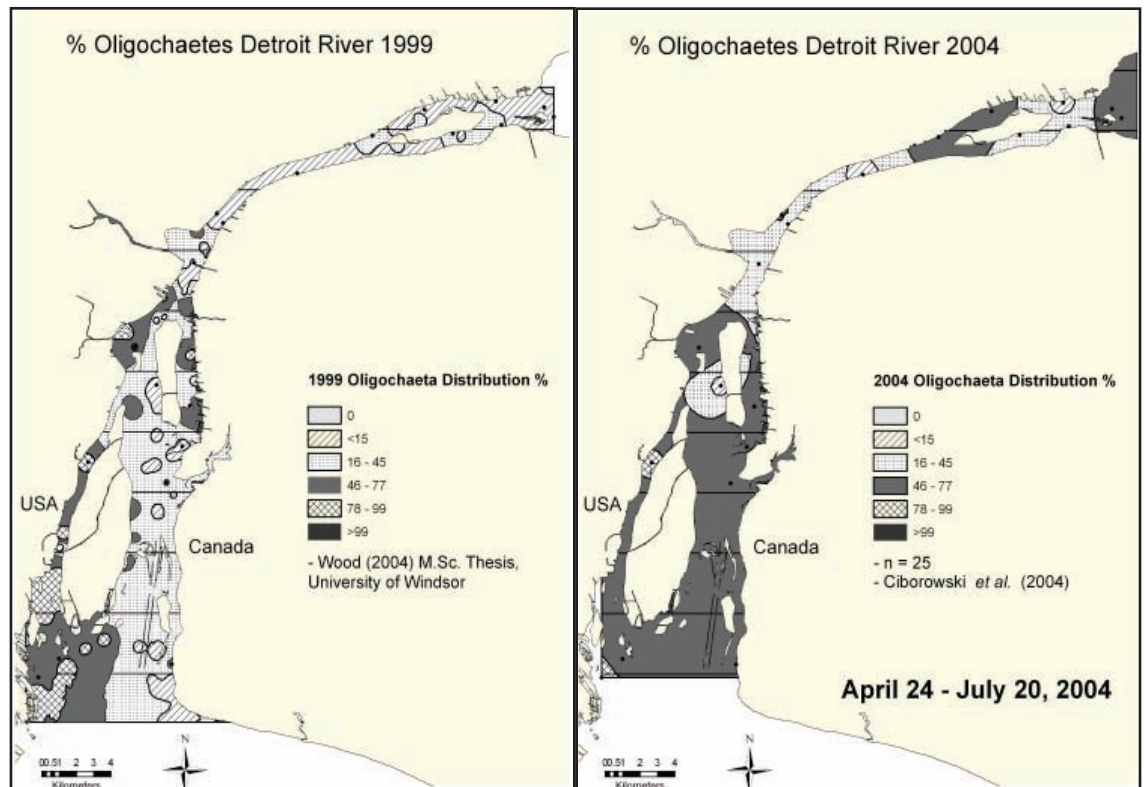


Figure 3. Percentage of oligochaetes in the Detroit River in 1999 interpolated from data compiled from Wood (2004). Map by Anita Kirkpatrick.

Figure 4. Percentage of oligochaetes in the Detroit River in 2004 interpolated from data compiled from Ciborowski et al. (2006). Map by Anita Kirkpatrick.

Oligochaete abundances are especially useful at showing the location of point source pollution “hot spots” (Figures 3 and 4). Sites located along the Trenton Channel and one site (Ecorse site) located just downstream of Ecorse, Michigan (where U. S. Steel is located) have historically been recognized as among the most polluted areas of the Detroit River due to urban and industrial development along the shorelines. Mean oligochaete densities at these sites greatly exceeded the designated heavy pollution value of 5,000/m² in all years except 1999. Prior to 1980, these locations had between 100,000 and 1 million worms/m² (Figure 5). Although conditions have dramatically improved and worm densities have been reduced by 80-90% since 1990, the numbers present suggest that these locations still fall in the “heavily polluted” category.

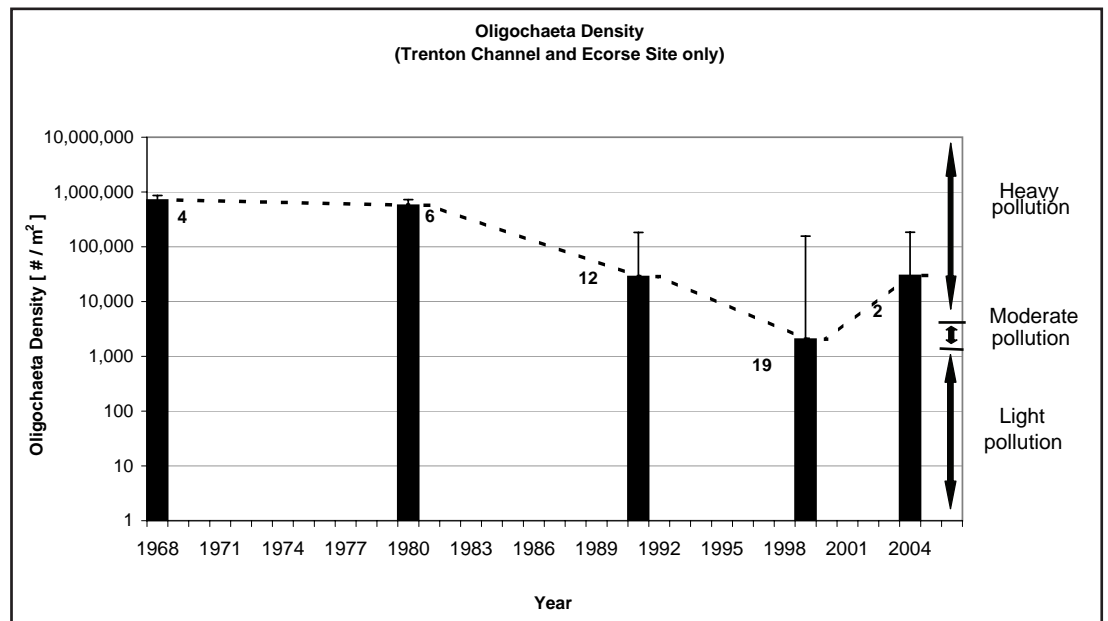


Figure 5. Geometric mean \pm SE density of oligochaetes in the Trenton Channel and at one Ecorse site between 1968 and 2004 (note logarithmic scale). The numeral beside each bar indicates the number of sites sampled during that year. *Data compiled from Thornley and Hamdy (1984), Farara and Burt (1993), Wood (2004), and Ciborowski et al. (2006).

Some oligochaete data also exist for western Lake Erie. In 1982, oligochaete and sediment samples were collected at 40 stations along the coast of western Lake Erie and compared to samples collected at the same sites in 1961 (Schloesser et al. 1995). Total worm densities, as well as species diversity, were used to infer pollution levels. The comparison indicated improved water quality in the nearshore areas, but increased eutrophic substrate conditions in the western basin of Lake Erie near the mouth of the Detroit River (Schloesser et al. 1995).

Management Next Steps

The available data clearly indicate portions of the river that have historically been most heavily degraded by organic enrichment and those that are still affected by nutrient-rich water, primarily sewage and storm water. The oligochaete data show the extent to which river water quality in the Trenton Channel has improved between 1980 and the early 1990s. However, continued attention to point sources of pollution will be necessary to bring the oligochaete classification into the “moderately polluted” category.

Research/Monitoring Needs

Oligochaete monitoring needs to be conducted yearly if precise time trends are to be determined. Sampling methods (collection times, site locations, number of sites sampled) should be standardized among years to improve the precision of riverwide density estimates.

An oligochaete species index has the potential to be an effective indicator of water quality issues. However, implementation relies on intensive and frequent sampling in addition to the ability to identify Oligochaete worms to genus and/or species level.

References

- Carr, J., and J. Hiltunen. 1965. Changes in the bottom fauna of western Lake Erie from 1930 to 1961. *Limnology and Oceanography* 10(4):551-569.
- Ciborowski, J.J.H. 2003. Lessons from sentinel invertebrates: Mayflies and other species. In *Honoring Our Detroit River: Caring For Our Home*, ed. John H. Hartig, pp. 107-120. Bloomfield Hills, MI: Cranbrook Institute of Science.
- Ciborowski, J.J.H., J. Zhang, J. Baillargeon, and A. Kirkpatrick. 2006. Section 6 – Zoobenthos. Benthos and sediment chemistry studies on the Detroit and St. Clair rivers. In *Great Lakes Institute for Environmental Research et al.* Draft report prepared for Great Lakes Sustainability Fund.
- Farara, D.G., and A.G. Burt. 1993. Environmental assessment of Detroit River sediments and benthic macroinvertebrate communities–1991. Report prepared for the Ontario Ministry of Environment and Energy by Beak Consultants Limited, Brampton, Ontario. Volume I.
- Howmiller, R.P., and M.A. Scott. 1977. An environmental index based on the relative abundance of oligochaete species. *Journal of the Water Pollution Control Federation* 49:809-815.
- Hynes, H.B.N. 1971. *The Biology of Polluted Waters*. Toronto, Ontario: University of Toronto Press.
- Lafont, M. 1984. Oligochaete communities as biological descriptors of pollution in the fine sediments of rivers. *Hydrobiologia* 115:127-129.
- Milbrink, G. 1983. An improved environmental index based on the relative abundance of oligochaete species. *Hydrobiologia* 102:87-89.
- Schloesser, D.W., T.B. Reynoldson, and B.A. Manny. 1995. Oligochaete fauna of western Lake Erie 1961 and 1982: Signs of sediment quality recovery. *Journal of Great Lakes Research* 21(3):294-306.
- Thornley, S., and Y.H. Hamdy. 1984. An assessment of the bottom fauna and sediments of the Detroit River. Ontario Ministry of the Environment, Southwestern Region and Water Resources Branch, Toronto, Ontario.

Wood, S. 2004. The use of benthic macroinvertebrate community composition as a measure of contaminant induced stress in the sediments of the Detroit River. M.Sc. Thesis, University of Windsor, Ontario.

Wright, S., and W.M. Tidd. 1933. Summary of limnological investigations in western Lake Erie in 1929 and 1930. *Transactions of the American Fisheries Society* 63:271-285.

Wright, S. 1955. Limnological survey of western Lake Erie. U.S. Fish and Wildlife Service, Special Scientific Report: Fisheries No. 139.

Links for More Information

Wetland impacts on quality of inland waters: Invertebrate communities: <http://epa.gov/OWOW/wetlands/wqual/miv.html>

Biological indicators of watershed health – Aquatic worms: <http://www.epa.gov/bioindicators/html/worms.html>

Contact Information

Jan Ciborowski
Department of Biological Sciences
University of Windsor
E-mail Address: cibor@uwindsor.ca

INDICATOR: INVASION OF ZEBRA MUSSELS (*DREISSENA POLYMORPHA*) AND QUAGGA MUSSELS (*DREISSENA BUGENSIS*)

Background

Zebra mussels (*Dreissena polymorpha*) are bivalve mollusks approximately 1 to 5 cm long that live in freshwater lakes (Figure 1). They siphon and filter phytoplankton and organic sediment from water with staggering efficiency, and have the ability to permanently attach to hard substrates. Zebra mussels are not native to the Great Lakes. Their free-swimming larvae (called “veligers,” referring to the presence of a velum, a larval organ of feeding and locomotion) arrived via ballast from commercial ships. This ballast is composed of water, stones, plants and sediment taken up by the ship somewhere in its journeys to stabilize



Figure 1. Zebra mussel (*Dreissena polymorpha*) cluster from the Detroit River (Photo credit: Center for Great Lakes and Aquatic Sciences).

the vessel during travel without heavy loads; it is discharged elsewhere along with any organisms associated with the ballast as the ship is loaded with cargo. The mussels are from the Black and Caspian seas, and the Sea of Azov, but they have invaded many Russian and European waterways within the last 200 years.

One of the most disturbing and direct consequences for the Great Lakes ecosystem from the recent invasion of zebra mussels is the local extirpation of the native mussel populations. These beneficial members of the Great Lakes ecosystem belong to the family Unionidae. They live in mud or sandy sediment. Before the arrival of zebra

mussels, there were approximately 40 species of native mussels in the Detroit River and approximately 20 in Lake St. Clair. Nalepa et al. (1996) collected Unionidae from 29 sites in Lake St. Clair in 1986 (before the first zebra mussels were found), 1990, 1992, and 1994. They collected 281 (18 species), 248 (17 species), 99 (12 species), and 6 (5 species) native mussels in the four years, respectively, which shows the devastating impact to native mussels. Zebra mussels attach themselves to unionids by byssal threads. The zebra mussels interfere with the unionid mussels' ability to open and close their shells (Figure 2). This prohibits the unionids' ability to burrow. The zebra mussels also consume the algae and suspended sediment that the unionids would otherwise filter from the water.

Zebra mussels alter the nutrient cycling of the aquatic ecosystem. They filter sediment and food particles out of the water. The solid waste particles (feces and pseudofeces) are much larger than the food particles eaten, and build up on the lake bottom, thereby transferring energy from the pelagic (open water) to the benthic (bottom) zone. Pseudofeces are materials that collect on the zebra mussel's gills and are rejected before entering the gut. Through filtration, zebra mussels clarify the water and decrease local algal densities (Mellina et al. 1995; see Water Clarity indicator).

Experiments at the Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan with water from Lake Erie have shown that zebra mussels reject inedible phytoplankton. Many species of bluegreen algae are apparently distasteful to aquatic biota. The mussels' selective feeding habits seem to promote and maintain *Microcystis* blooms, which at high levels can be toxic to aquatic life (Vanderploeg et al. 2001; see

Algal Blooms in Western Lake Erie indicator). Using special video equipment, GLERL showed that mussels filter any water, but expel only *Microcystis* back into the water. Thus, the competitors of *Microcystis* are removed. The mussels' excreted waste products are rich in nutrients (phosphate and ammonia) derived from their phytoplankton food. These nutrients, in turn, serve to fertilize further phytoplankton growth, especially growth of *Microcystis*.



Figure 2. Native mussel shell with attached zebra mussels (Photo credit: U.S. Fish and Wildlife Service).

Zebra mussels accumulate contaminants such as polychlorinated biphenyls (PCBs) as they filter water and take in algae, as well as suspended

sediment particles that have associated contaminants. Their tissues accumulate and store some of the contaminants, but some are carried out in the feces and accumulate in the bottom sediment. Dreissenids are so abundant that they can produce large amounts of contaminated feces. These feces are then consumed by benthic invertebrates such as *Gammarus fasciatus*, a shrimp-like crustacean. These organisms are, in turn, important food for fish, which then acquire the contaminants. These same contaminants are ultimately transferred further up the food web to organisms such as waterfowl, hawks and eagles, as well as people.

Zebra mussels have also had a large economic impact on the Great Lakes. Many power plants and water users have had to spend millions of dollars cleaning out zebra mussels from their facilities. In addition, more money has been spent on retrofitting facilities with devices to keep zebra mussels out and to monitor for them. These costs get passed along to the consumers.

Status and Trends

The zebra mussel is now well established throughout the Great Lakes and the Mississippi River watershed, while the related invasive quagga mussel (*Dreissena rostriformis bugensis*) is currently limited to the southern Great Lakes and the St. Lawrence River. Zebra mussels were first found in Lake St. Clair in June 1988 and probably arrived in 1986 (Hebert et al. 1989). The first quagga mussel was found in the Erie Canal in 1989, but was not recognized as a distinct species until 1991 (May and Marsden 1992). It does not have the tolerance for warm water and desiccation that zebra mussels do (Ricciardi et al. 1995) and its range is currently much more limited. However, quagga mussels have become the dominant dreissenid species in many areas once dominated by zebra mussels. Quagga mussels generally are able to live under wider environmental conditions than zebra mussels (Baldwin et al. 2003; Mills et al. 1996; Ricciardi and Whoriskey 2004). There is evidence that suggests quagga mussels could outcompete zebra mussels in more shallow, warm locations, or that hybridization may occur. Although morphological intermediates

between the two species do occur, the frequency of hybridization was found to vary by basin. In 2004, D.R. Barton et al. (University of Waterloo, unpublished data) found specimens that had physical features intermediate between zebra mussels and quagga mussels at 31% of the stations sampled in the western basin, but only at 4% of those sampled in the central basin, and none in the eastern basin.

The U.S. Geological Survey (2007) has compiled annual distribution data that it obtained from many sources throughout the zebra mussel range (Table 1). Within one year of the initial discovery in Lake St. Clair in 1988, zebra mussels had become established along southern Lake Erie, western Lake Ontario and into the St. Lawrence River probably by way of commercial barges. By 1990, they had colonized Saginaw Bay and southern Lake Michigan. Surveys conducted in 1991 showed that the species colonized along the Mississippi River and the western portion of Lake Michigan, and by 1992 they were observed throughout the Mississippi River watershed. During this period, ships were observed with thousands of zebra mussels attached to their hulls, and barge ships were still the most significant mode of dispersal (Keevin et al. 1992). Rapid population growth and range expansion continued, but slowed down in 1993/1994. At this time, increases in density were found in the Detroit River and western Lake Erie, and expansion of inland lakes began in earnest. By 1994, they were in 10 inland lakes in Michigan. The 1995 survey showed an exceptional expansion in the number of inland lakes colonized by zebra mussels bringing the number to 29. From the late 1990s into the 2000s, zebra mussel densities continue to be high, with high numbers even appearing on soft substrate (Berkman et al. 2000), and quagga mussels are expanding their range in local areas.

Table 1. A summary of the history of zebra and quagga mussels in western Lake Erie and the Detroit River.

Time Period	Zebra and Quagga Mussel Population
1986	Arrival of zebra mussels from ballast as veligers or adults
1988	First established zebra mussel population confirmed in Lake St. Clair
1989	First quagga mussel sighted in Lake Erie
Early 1990s	Peak zebra mussel density and impact on ecosystem
Mid- to late 1990s	Leveling off of zebra mussel population, but more colonization on soft substrate; densities of quagga mussels increasing
2000s	Quagga mussels displacing zebra mussels in some warm littoral areas previously dominated by zebra mussels; quagga mussels reach their peak density in the central basin in 1998 and in the eastern basin in 2002
2004	Zebra mussels only common in the western basin; quagga mussel population numbers declining, but still remain highest in the eastern basin

As of January 2007, zebra mussels have been documented in all of the Great Lakes and in 225 inland lakes in Michigan (USGS 2007). The rate of inland expansion has declined considerably since 1998. The spread of zebra mussels is much faster in shipping routes and much slower across isolated bodies of water. Johnson et al. (2006) reported a peak invasion of inland lakes in 1993-1995 and another in 1998. Oakland County is the most invaded inland region in the state.

Quagga mussels dominate the soft substrates in the eastern basin of Lake Erie, which is the deepest of the three basins. Patterson et al. (2005) found that quagga mussels are present at all depths, but are most commonly found between 18 and 23 meters. The abundance of quagga mussels began increasing in 1992, at approximately the same time that zebra mussels reached their peak density in Lake Erie. Quagga mussel numbers continued to rise in all three basins, with the eastern basin exhibiting the greatest rise in abundance (Patterson et al. 2005). Population numbers leveled off in the central basin in 1998 and started to decline in subsequent years; densities in the eastern basin began to decline in 2002 (Patterson et al. 2005). In 2004, quagga mussels were present at approximately 65% of the 283 stations sampled and accounted for 93% of the total mussel mass (D.R. Barton et al., University of Waterloo, unpublished data). By this time, zebra mussels were common only in the western basin.

Management Next Steps

The management of all invasive species must center on prevention, as it is the most successful and economically viable method for ecosystem protection. The governments of the United States and Canada, as well as the eight Great Lakes states and the provinces of Ontario and Quebec, must stop the introduction of all exotic species into the Great Lakes. Stopping ballast water inputs of exotic species must be a priority. In 1997, the estimated cost of zebra mussels to raw-water dependent infrastructure at 339 facilities (e.g., power plants, drinking water treatment plants, etc.) was \$69 million (O'Neill 1997).

Currently, trailered-boating is the main mode of dispersal of zebra mussels into inland lakes. Attention to geographic human activity patterns (where boaters are traveling from one body of water to another) can help predict future large-scale colonization of other invasive species (Padilla et al. 1996). Boaters that travel among numerous bodies of water must be informed of the risk that their watercraft can transport mussels to inland lakes. Information must be widely available that boats that have been in waters containing zebra and quagga mussels must be cleaned with heated spray. Boater education and awareness is essential to prevent the further spread of zebra mussels. The Lewis and Clark Project, spearheaded by the Pacific States Marine Fisheries Commission, has shown leadership in preventing the westward spread of zebra mussels. Its six-step program could help prevent invasion of inland lakes in the Great Lakes region. The program includes regional publicity, a containment strategy whereby new invasions could be identified quickly, and quarantine plans (ANS Task Force 2004).

Immediate conservation action must occur to locate and protect existing native unionid populations. Some researchers (e.g., Ricciardi et al. 1998; Cope and Waller 1995) have suggested capture and relocation projects, as this holds the most promise in terms of creating sustainable populations of native mussels. Such capture and relocation projects must be closely coupled with sound research to be most effective. A project at Metzger Marsh, Lake Erie removed unionids for a 3-year period and successfully returned them when the marsh was dewatered (Nichols and Wilcox 2002). Although low recruitment continues to threaten the population, it does show the importance of soft marsh sediment and warm temperatures to unionid burrowing and separation from zebra mussels. These isolated populations of native mussels are vulnerable to water level fluctuations and attention to this must occur so that diverse unionid populations do not move to deeper waters where mortality from zebra mussels on the harder substrates

could occur. Ricciardi et al. (1998) also reiterate that management must focus on whole watersheds and not on single, rare species.

Research/Monitoring Needs

Continued research is needed to improve our understanding of food web changes and dynamics, as well as nutrient and contaminant cycling through time. It is not clear if the recent patterns interpreted from the data regarding the invasion of Dreissenids represent actual trends or simply year-to-year variation. Therefore, regular monitoring at particular locations is necessary. There is a need to further understand the potential spread of quagga mussels from the deep water zone to the more coastal areas and the possible occurrence of hybridization between the two species. Other research needs include obtaining a greater understanding of potential ecosystem control strategies, where the probability of colonization events can be reduced (Illinois River Biological Station 2007).

References

- ANS Task Force. 2004. Aquatic Nuisance Species Task Force Minutes, May 26-27, 2004. Columbia, MO.
- Baldwin, B.S., M.S. Mayer, J. Dayton, N. Pau, J. Mendillo, M. Sullivan, A. Moore, A. Ma, and E.L. Mills. 2003. Comparative growth and feeding in zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena bugensis*): Implications for North American lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 59:680-694.
- Berkman, P.A., D.W. Garton, M.A. Haltuch, G.W. Kennedy, L.R. Febo. 2000. Habitat shift in invading species: Zebra and quagga mussel population characteristics on shallow soft substrates. *Biological Invasions* 2(1):1-6.
- Cope, W.G., and D.L. Waller. 1995. Evaluation of freshwater mussel relocation as a conservation and management strategy. *Regulated Rivers: Research and Management* 11:147-155.
- Hebert, P.D.N., B.W. Muncaster, and G.L. Mackie. 1989. Ecological and genetic studies on *Dreissena polymorpha* (Pallas): A new mollusc in the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 46(9):1587-1591.
- Illinois River Biological Station. 2007. Current Research at the Illinois River Biological Station. Havana, IL.
- Johnson, L.E., J.M. Bossenbroek, and C.E. Kraft. 2006. Patterns and pathways in the post-establishment spread of non-indigenous aquatic species: The slowing invasion of North American inland lakes by the zebra mussel. *Biological Invasions* 8:475-489.
- Keevin, T., R. Yarbrough, and A. Miller. 1992. Inadvertent transport of live zebra mussels on barges - experiences in the St. Louis District, Spring 1992. Zebra Mussel Research Technical Notes ZMR-1-07. U.S. Army Corps of Engineers Waterways Experiment Station.
- May, B., and J.E. Marsden. 1992. Genetic identification and implications of another invasive species of dreissenid mussel in the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 49:1501-1506.

- Mellina, E., J.B. Rasmussen, and E.L. Mills. 1995. Impact of mussel (*Dreissena polymorpha*) on phosphorus cycling and chlorophyll in lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 52:2553-2573.
- Mills, E.L., G. Rosenberg, A.P. Spidle, M. Ludyanskiy, Y. Pligin, and B. May. 1996. A review of the biology and ecology of the quagga mussel (*Dreissena bugensis*), a second species of freshwater Dreissenid introduced to North America. *American Zoologist* 36:271-286.
- Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow, and G.A. Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair: from Unionidae to *Dreissena polymorpha* in eight years. *Journal of Great Lakes Research* 22(2):354-369.
- Nichols, S.J., and D. Wilcox. 2002. *Reestablishing the Freshwater Unionid Population of Metzger Marsh, Lake Erie*. IAG No. DW 14947830-01. USGS, Biological Resources Division.
- O'Neill, Jr., C.R. 1997. Economic impact of zebra mussels ~ Results of the 1995 National Zebra Mussel Information Clearinghouse Study. New York Sea Grant Institute, NY.
- Padilla, D.K., M.A. Chotkowski, and L.A.J. Buchan. 1996. Predicting the spread of zebra mussels (*Dreissena polymorpha*) to inland waters using boater movement patterns. *Global Ecology and Biogeography Letters* 5(6):353-359.
- Patterson, M.W.R., J.J.H. Ciborowski, and D.R. Barton. 2005. The distribution and abundance of *Dreissena* species (Dreissenidae) in Lake Erie, 2002. *Journal of Great Lakes Research* 31(2):223-237.
- Ricciardi A., R. Serrouya, and F.G. Whoriskey. 1995. Aerial exposure tolerance of zebra and quagga mussels (Bivalvia: Dreissenidae): Implications for overland dispersal. *Canadian Journal of Fisheries and Aquatic Sciences* 52:470-477.
- Ricciardi, A., R.J. Neves, and J.B. Rasmussen. 1998. Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (*Dreissena polymorpha*) invasion. *The Journal of Animal Ecology* 67(4):613-619.
- Ricciardi, A., and F.G. Whoriskey. 2004. Exotic species replacement: Shifting dominance of dreissenid mussels in the Soulanges Canal, upper St. Lawrence River, Canada. *Journal of the North American Benthological Society* 23:507-514.
- U.S. Geological Survey. 2007. Zebra mussel distribution in U.S. lakes. http://cars.er.usgs.gov/Nonindigenous_Species/Zebra_mussel_distribution/zebra_mussel_distribution.html
- Vanderploeg, H.A., J.R. Liebig, W.W. Carmichael, M.A. Agy, T. H. Johengen, G.L. Fahnenstiel, and T.F. Nalepa. 2001. Zebra mussel (*Dreissena polymorpha*) selective filtration promoted toxic *Microcystis* blooms in Saginaw Bay (Lake Huron) and Lake Erie. *Canadian Journal of Fisheries and Aquatic Sciences* 58(6):1208-1221.

Links for More Information

U.S. Geological Survey. Zebra mussel basic biology and impact: http://www.glsc.usgs.gov/main.php?content=research_invasive_zebramussel&title=Invasive%20Invertebrates0&menu=research_invasive_invertebrates

U.S. Geological Survey. Dreissena facts and figures: http://cars.er.usgs.gov/Nonindigenous_Species/Zebra_mussel_FAQs/Dreissena_FAQs/dreissena_faqs.html#Q9

The National Oceanic and Atmospheric Association (NOAA). The zebra mussel connection: Nuisance algal blooms, Lake Erie anoxia, and other water quality problems in the Great Lakes: <http://www.glerl.noaa.gov/pubs/brochures/mcystisflyer/mcystis.html>

The National Oceanic and Atmospheric Association (NOAA). The origin of the Great Lakes zebra mussels: http://www.research.noaa.gov/spotlite/archive/spot_zebramussels.html

Contact Information

Jan Ciborowski
Department of Biological Sciences
University of Windsor
E-mail Address: cibor@uwindsor.ca

INDICATOR: YELLOW PERCH POPULATION

Background

Yellow perch (*Perca flavescens*) is one of the most popular sport and commercial fish in Lake Erie. Residents along the Detroit River and western Lake Erie remember the once popular “all you can eat fish fries” on Friday nights overflowing with more perch than could be consumed. The big perch dinners disappeared for a while, but are once again appearing in cities along the water.

Yellow perch (Figure 1) feed on mayfly larvae, caddisfly larvae, amphipods, chironomids, and zooplankton. Mayflies are a very important food resource for the yellow perch fishery. From the late 1980s through the 1990s, after a 40-year absence due to pollution and eutrophication, large benthic invertebrates including mayfly larvae, caddisfly larvae, and amphipods recolonized the basin (Bridgeman et al. 2006). When burrowing mayflies



Figure 1. Yellow perch (*Perca flavescens*)
(Photo credit: Duane Raver, U.S. Fish and Wildlife Service).

(*Hexagenia* spp.) recolonized western Lake Erie in the mid-1990s as water quality improved, the yellow perch population once again increased. Yellow perch are very valuable economically and the species is an indicator of the ecological condition of Lake Erie (Bridgeman et al. 2006). Yellow perch are also beneficial because they feed on the nonnative, invasive round goby (Kubb 2000).

Status and Trends

In the early 1800s, a commercial fishery in the Detroit River produced tons of lake whitefish, yellow perch, and other species (Haas and Bryant 1978). Catches for yellow perch climaxed in the late 1800s and decreased substantially thereafter. However, yellow perch remained a large part of the fishery through the 1960s. Commercial fishing continued on the Ontario side of the Detroit River until 1970, when high levels of mercury found in Lake St. Clair closed all of the surrounding fisheries. The Detroit River commercial fishery was never again reopened (Manny et al. 1988).

The Great Lakes Fishery Commission’s Lake Erie Yellow Perch Task Group has collected yellow perch population and biomass data in Lake Erie since 1975. These data show that the Lake Erie yellow perch population increased through the late 1970s, possibly due to lake-wide pollution abatement programs and decreased fishing pressure (Figure 2; Kenyon and Murray 2001). Throughout the 1980s, the population was variable until it plummeted in the late 1980s, with very low numbers through the early 1990s. Population declines were possibly due to the lake-wide invasion of zebra and quagga mussels, overfishing and unfavorable weather (Kenyon and Murray 2001). The yellow perch

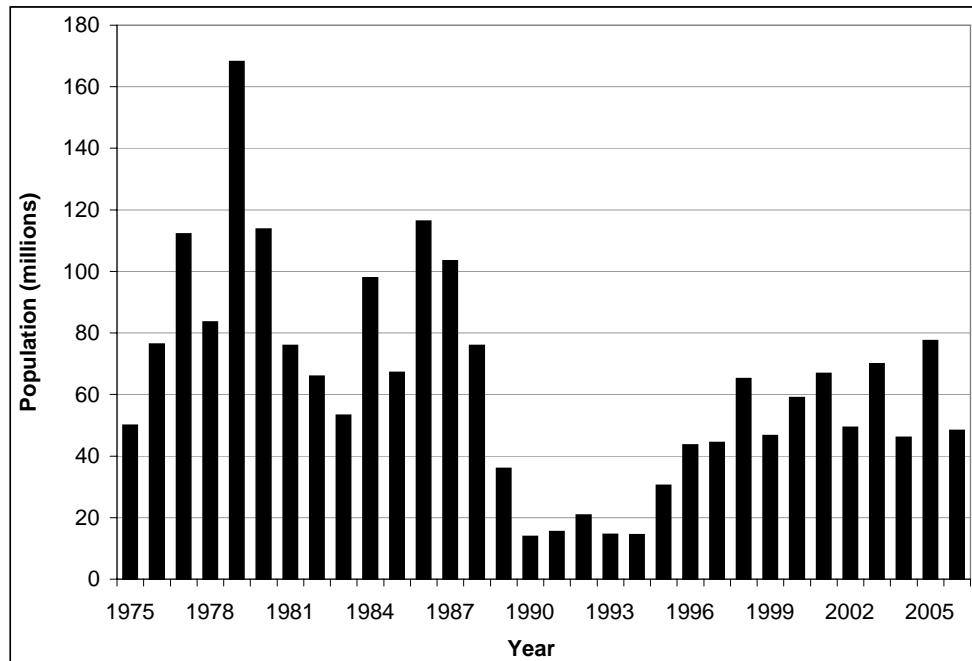


Figure 2. Estimated population in millions of yellow perch (ages 2+) in management unit 1 which encompasses western Lake Erie basin, 1975-2006 (data collected by the Great Lakes Fishery Commission, Lake Erie Yellow Perch Task Group).

population increased from the mid- to late 1990s and has remained steady through 2006. This higher reproduction rate is likely a result of a greater density of burrowing mayflies and an increase in the spawning success and survival of juvenile fish in the western basin. There also may be an inverse relationship between the peak walleye abundance periods (late 1980s-early 1990s, and more recently since 2003) with yellow perch abundance. When walleye abundance is very high, it appears that yellow perch abundance declines and probably is due to predation (M. Thomas, pers. comm).

Large-bodied benthic invertebrates were eliminated from the western basin from 1960 through 1980, mainly due to phosphorus-induced eutrophication. Therefore, yellow perch had to rely primarily on smaller chironomids and zooplankton as forage. Growth rates and abundance of yellow perch declined through this period in the western basin, in part because of food limitation (Hayward and Margraf 1987). As a result, size of the yellow perch in the western basin has fluctuated along with the population size depending on food supply. After the early 1990s, the yellow perch growth rates have increased along with abundance (Tyson and Knight 2001). Increases in benthic macroinvertebrate abundance are responsible, in part, for the increases in yellow perch growth and recruitment. This dependence on benthic organisms makes yellow perch a useful indicator of the health of the benthic community (Tyson and Knight 2001).

Management Next Steps

The plan for the management of Lake Erie yellow perch is a cooperative and collaborative effort of the Great Lakes Fishery Commission and the Lake Erie Committee member jurisdictions. It is an example of the jurisdictions' commitment to the ongoing sustainability and economic viability of this important fishery. Such collaboration is

critical to the proper management of the yellow perch fishery of Lake Erie. One objective is to maintain a sustainable harvest for all areas of the lake, and maintain and promote genetic diversity by identifying, rehabilitating, conserving, and protecting locally adapted stocks.

Researchers and managers should collaborate to estimate Lake Erie carrying capacity for yellow perch in order to help achieve a sustainable population. Further, researchers and managers should continuously assess, set management priorities, and take management action in a process of continuous improvement. Both sport and commercial harvest quotas should be established by managers at conservative levels to help achieve desired goals.

Research/Monitoring Needs

To help ensure maintenance of yellow perch stock diversity and sustainability of the population, a number of areas of needed research and investigation must be addressed. These include:

- Mortality – determine if current assessment programs provide accurate estimates of mortality, both at the population and stock-specific levels;
- Stock contribution – continue to develop tools to identify stock specific origin of individual fish to determine relative contribution of stocks to the Lake Erie yellow perch population;
- Size selective management – determine the utility and management implications of establishing size limits for angling fisheries and mesh size restrictions for commercial fisheries for achieving fishery objectives;
- Seasonal closures of fisheries/sanctuaries – evaluate the value of these techniques in improving fry survival and/or protecting fish before they spawn;
- Fish community interactions – identify interactions between populations that might impact production; and
- Social and economic effects of population abundance – estimate social and economic impacts of various fishery and harvest objectives in order to maximize benefits.

References

Bridgeman, T.B., D.W. Schloesser, and A.E. Krause. 2006. Recruitment of *Hexagenia* mayfly nymphs in western Lake Erie linked to environmental variability. *Ecological Applications* 16(2):601-611.

Haas, R.C., and W.C. Bryant. 1978. Status of the fisheries resources in Lake St. Clair and connecting waters. Michigan Department of Natural Resources, Lake St. Clair Great Lakes Station, Mt. Clemens, MI.

Hayward, R.S., and F.J. Margraf. 1987. Eutrophication effects of prey size and food available to yellow perch in Lake Erie. *Transactions of the American Fisheries Society* 116(2):210-223.

Kenyon, R., and C. Murray. 2001. A review of the Lake Erie and Presque Isle Bay yellow perch sport angling fisheries, 1997-2001. Pennsylvania Fish and Boat Commission, Lake Erie Research Unit, Fairview, PA.

Kubb, R. 2000. The 2000 Lake Erie perch report. <http://www.walleye.com/fall2000/perchreport2000.htm>

Manny, B.A., T.A. Edsall, and E. Jaworski. 1988. The Detroit River, Michigan: An ecological profile. U.S. Fish and Wildlife Service Biological Report 85 (7.17).

Tyson, J.T., and R.L. Knight. 2001. Response of yellow perch to changes in the benthic invertebrate community of Western Lake Erie. *Transactions of the American Fisheries Society* 130(5):766-782.

Links for More Information

University of Michigan, Animal Diversity Web, yellow perch: http://animaldiversity.ummz.umich.edu/site/accounts/information/Perca_flavescens.html

Contact Information

Michael Thomas
Michigan Department of Natural Resources, Fisheries Division
E-mail Address: thomasmv@michigan.gov

Michael Bur
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: mbur@usgs.gov

INDICATOR: LAKE WHITEFISH SPAWNING

Background

During the late nineteenth and early twentieth centuries, large numbers of lake whitefish (*Coregonus clupeaformis*) and lake herring (*Coregonus artedii*) entered the Detroit River in the fall to spawn. Natural bedrock (spawning grounds for lake whitefish, cisco, walleye, and trout) was blasted and removed during the construction of the Livingstone Channel from approximately 1907 to 1916. Whitefish prefer to spawn on rock, honeycomb limestone, and gravel or sand substrates (Hart 1930; Ihssen et al. 1981). Historic reports imply that the lower river was a prolific spawning area prior to the construction of the shipping channel (Goodyear et al. 1982). The timing of this construction coincides



Figure 1. Lake whitefish (*Coregonus clupeaformis*) caught in the Detroit River, November 2005 (Photo credit: U.S. Geological Survey).

with the demise of whitefish stock in the river; this alteration in river hydrology represents a major disconnection in the linkage between river spawning and incubation areas, and productive nursery habitats in western Lake Erie. Spawning runs of lake whitefish into the Detroit River almost disappeared by the early 1900s due to overfishing, degradation of habitat and eutrophication (Trautman 1957; Goodyear et al. 1982; Hartman 1972).

Lake whitefish feed on organisms on the bottom of the lake, primarily *Diporeia* and chironomids, in the Lake Erie basin. They are cold stenotherms (narrow

temperature tolerance) requiring cold, adequately oxygenated bottom waters for summer habitat, and relatively silt-free river or lake spawning areas for successful reproduction (Hartman 1973). Lake Erie is the southern edge of the species zoogeographical range. Lake whitefish are recognized as an indicator of ecosystem health and an integral component of the Great Lakes food web.

Status and Trends

By the 1960s and 1970s, lake whitefish were at an all-time low for a variety of reasons: overexploitation, predation by and competition with invasive species, degradation of water quality and habitat, and the loss of *Diporeia*, a major nutrient-rich food source (due to the introduction of zebra and/or quagga mussels). Reduced phosphorus loading to the lake resulted in more favorable conditions for whitefish by the early 1980s, following the implementation of the 1972 Great Lakes Water Quality Agreement (Mohr and Nalepa 2005).

The persistence of remnant self-sustaining lake whitefish stocks in Lakes Huron and Erie, coupled with habitat rehabilitation efforts, allowed the Lake Erie population to begin to

recover in the early 1980s (Lake Erie Coldwater Task Group 2005; Roseman et al. 2006a). Throughout the 1980s and 1990s, the species reached above average catches in Lakes Michigan and Huron (Mohr and Nalepa 2005). For Lake Erie as a whole, growth and condition of whitefish have remained stable and current landings values are within the range of historical means. Whitefish growth rates in Lake Erie after the recovery appear to be similar to rates prior to the period when populations reached all-time lows (Lake Erie Coldwater Task Group 2005).

Harvest in the Detroit River exceeded 227,000 kg (500,000 pounds) in the late 1800s and declined through the early part of the twentieth century (Figure 2). Overharvest and habitat degradation resulted in very low catches after about 1910. The decline of the lake whitefish coincided with the decline of the walleye, blue pike, and lake herring. The Lake Erie whitefish fishery lasted in the east end of the lake until the 1960s. After an absence of approximately 20 years, commercial fishing for lake whitefish in Lake Erie increased to over 454,000 kg (one million pounds) per year during the late 1990s and early 2000s (Figure 3). Even though landings in 2003 and 2004 declined to approximately 272,000 kg (600,000 pounds), this is evidence that lake whitefish populations have rebounded.

In 2005, U.S. Geological Survey researchers, in partnership with the U.S. Fish and Wildlife Service, collected a spermiating male and fertilized eggs from the Detroit River. This was the first fertile lake whitefish found in the river since 1916 (Roseman et al. 2006b). Several dozen fertilized lake whitefish eggs were collected from the river which subsequently hatched in the USGS laboratory in March 2006. On April 5th and 6th, 2006, U.S. Geological Survey found 62 whitefish larvae in the lower Detroit River and most were in the sac-fry stage. Since no larvae were found at sampling locations in the upper Detroit River (indicating spawning in Lake St. Clair or the St. Clair River), researchers concluded that these fry were produced in the Detroit River. This is the first time that there are confirmed native, reproducing lake whitefish in the Detroit River in approximately 100 years.

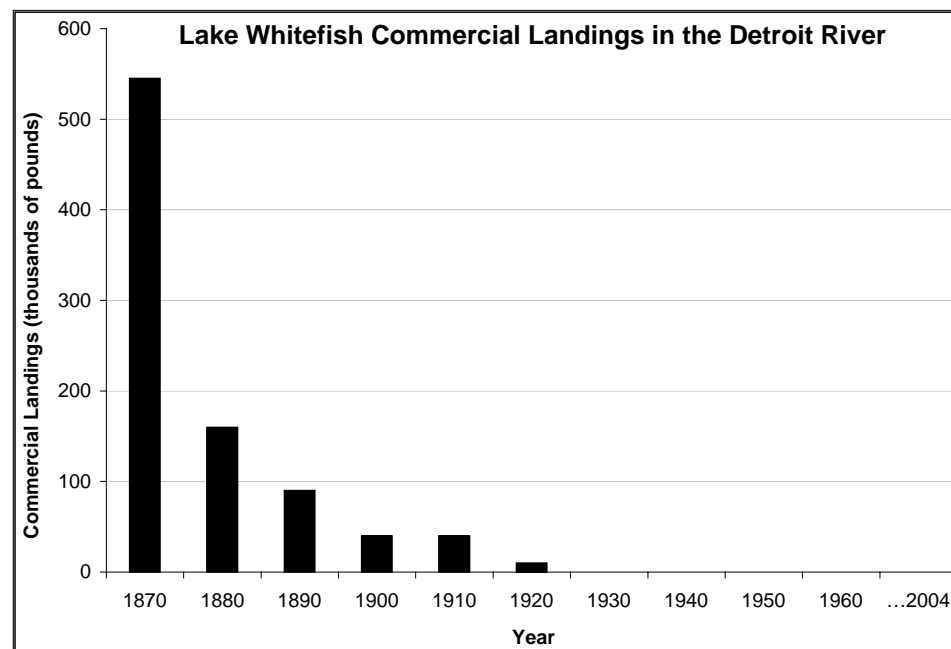


Figure 2. Lake whitefish commercial landings in the Detroit River. Catch is measured in thousands of pounds from 1870-2004 (data from Baldwin et al. 1979 and subsequently collected by U.S. Geological Survey). Note: One pound = 0.45 kg.

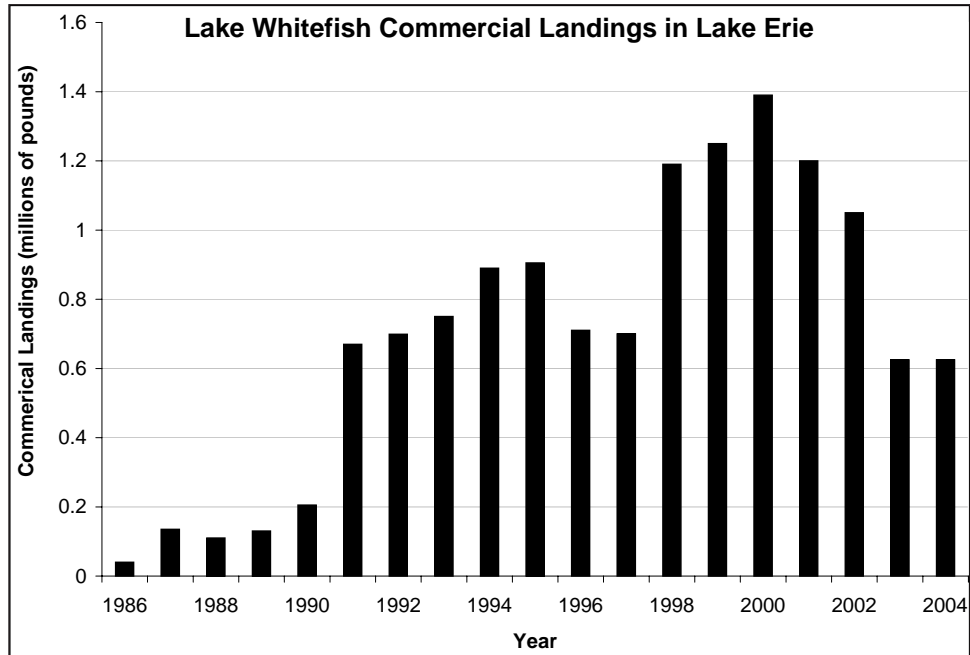


Figure 3. Lake whitefish commercial landings in Lake Erie. Catch is measured in millions of pounds from 1986-2004 (data from Lake Erie Coldwater Task Group 2005).

Note: One pound = 0.45 kg.

Management Next Steps

It is recommended that management agencies continue to monitor lake whitefish populations in the Detroit River and Lake Erie to ensure the continued recovery and the achievement of sustainable stocks. Emphasis should continue to be placed on controlling invasive species, such as dreissenids, which cause food web disruptions that influence whitefish abundance, growth, and condition. Management agencies should consider constructing whitefish spawning habitat in the Detroit River following completion of the fish spawning habitat research conducted in 2006-2008.

Research/Monitoring Needs

Little information exists regarding whitefish life history, habitat requirements, and ecological niche in Lake Erie and its tributaries, including the Detroit River. Data should be collected on the physical and biological characteristics of essential whitefish habitat, and on yield, diet, growth, recruitment, and reproduction rates. These types of information are critical for the successful management of fisheries in the Detroit River and its connecting waters. Further, efforts to rehabilitate fisheries habitat in the Detroit River rely on knowledge of habitat availability and function to use as a benchmark for restoration goals. Research projects should be designed to measure biotic and abiotic factors influencing different life history stages of lake whitefish. Such research should:

- identify spawning sites of multiple fish species;
- describe physical characteristics of spawning areas;
- quantify relative egg abundance and survival;

- assess egg viability and physiological condition;
- assess predation of fish eggs by fishes;
- assess spawning stock characteristics; and
- explore nursery habitat in the river (Roseman et al. 2006b).

Research on fall spawning habitat will continue. Finally, there is a need to further develop models to better predict and evaluate lake whitefish recovery.

References

- Baldwin, N.S., R.W. Saalfeld, M.A. Ross, and H.J. Buettner. 1979. Commercial fish production in the Great Lakes 1867-1977. Great Lakes Fishery Commission Technical Report no. 3, Ann Arbor, MI.
- Goodyear, C.D., T.A. Edsall, D.M. Ormsby-Dempsey, G.D. Moss, and P.E. Polanski. 1982. *Atlas of Spawning and Nursery Areas of Great Lakes Fishes*. FWS/OBS-82/52. Volumes 1-14. Washington, DC: U.S. Fish and Wildlife Service.
- Hart, J.L. 1930. Spawning and early life history of whitefish (*Coregonus clupeaformis*) in the Bay of Quinte, Ontario. *Contributions to Canadian Biology and Fisheries* 40:165-214.
- Hartman, W.L. 1972. Lake Erie: Effects of exploitation, environmental changes, and new species on the fishery resources. *Journal of the Fisheries Research Board of Canada* 29:931-936.
- Hartman, W.L. 1973. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie. Technical Report no. 22. Great Lakes Fishery Commission. Ann Arbor, MI.
- Ihssen, P.E., D.O. Evans, W.J. Christie, J.A. Rechahn, and D.L. DesJardine. 1981. Life history, morphology, and electrophoretic characteristics of five allopatric stocks of lake whitefish (*Coregonus clupeaformis*) in the Great Lakes region. *Canadian Journal of Fisheries and Aquatic Sciences* 38:1790-1807.
- Lake Erie Coldwater Task Group. 2005. *Report of the Lake Erie Coldwater Task Group*. Lake Erie Committee, Great Lakes Fishery Commission, Ann Arbor, MI.
- Mohr, L.C., and T.F. Nalepa (eds). 2005. Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great Lakes. Great Lakes Fishery Commission Technical Report 66.
- Roseman, E., B.A. Manny, G. Kennedy, and J. Boase. 2006a. Assessment of lake whitefish spawning in the Detroit River. Draft Proposal, U.S. Geological Survey Great Lakes Science Center, Ann Arbor, MI.
- Roseman, E., G. Kennedy, B.A. Manny, J. Nichols, and J. Boase. 2006b. Assessing lake whitefish spawning and nursery habitat in the Detroit River International Wildlife Refuge. Presentation.
- Trautman, M.B. 1957. *The Fishes of Ohio*. Columbus, OH: Ohio State University Press.

Links for More Information

Michigan Department of Natural Resources, Lake Whitefish: http://www.michigan.gov/dnr/0,1607,7-153-10364_18958-45680~,00.html

Michigan Interactive, Lake Whitefish: http://www.fishweb.com/recreation/fishing/fishfacts/fish/lake_whitefish/lake_whitefish.html

Contact Information

Edward Roseman
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: eroseman@usgs.gov

Bruce A. Manny
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: bmanny@usgs.gov

INDICATOR: LAKE STURGEON POPULATION

Background

The lake sturgeon (*Acipenser fulvescens*) is one of 29 species worldwide (five are native to North America) and is the only native sturgeon in the Great Lakes. This species still retains many characteristics from its existence 100-200 million years ago as evidenced from the fossil record (Figure 1). Lake sturgeon is considered a species of special concern by the U.S. Fish and Wildlife Service, a threatened species in North America by the American Fisheries Society, a globally rare species by The Nature Conservancy, and a threatened species in the State of Michigan. The lake sturgeon population in Michigan



Figure 1. Lake sturgeon (*Acipenser fulvescens*)
(Photo credit: U.S. Fish and Wildlife Service).

is estimated to be about one percent of its former abundance (Tody 1974; Michigan Sea Grant 2005). The Huron-Erie corridor was, at one time, one of the most productive waters for lake sturgeon in North America.

In Lake Erie in the 1800s, sturgeon frequently caused heavy damage to fishing gear in nearshore waters. As a result, they were perceived as a nuisance and frequently killed upon capture to eradicate them (Hartman 1973). In the 1860s, lake sturgeon were destroyed in large numbers as bycatch of the gill net fishery (Regier and Hartman 1973). Years following, the value of sturgeon increased as their eggs and smoked flesh became a delicacy. In 1890, a “caviar factory” was located in Algonac, Michigan on the St. Clair River (Harkness and Dymond 1961). Populations

quickly plummeted due to overharvesting, limited reproduction, and destruction of spawning habitats. Female lake sturgeon do not reproduce until they are approximately 20 years old and even then, they only spawn once every few years. Spawning sites also disappeared due to extensive dredging to create and maintain shipping channels in the Huron-Erie corridor. For example, the construction of the Livingstone Channel greatly decreased lake sturgeon and lake whitefish spawning habitats in Canadian waters, southeast of Stony Island.

Lake sturgeon are an indicator of ecosystem health because they are very sensitive to human disturbances, such as habitat destruction and pollution, as shown by their sharp decline in the late 1800s and early 1900s. Lake sturgeon are considered a keystone species in the Detroit River ecosystem.

Status and Trends

In 1880, Lakes Huron and St. Clair produced over 1.8 million kg (four million pounds) of lake sturgeon (Hay-Chmielewski and Whelan 1997). In 1890, Lake Erie produced over 272,000 kg (600,000 pounds) of lake sturgeon in Canadian waters. During the spawning

period in June 1890, upwards of 4,000 adult lake sturgeon were caught in Lake St. Clair and the Detroit River on setlines and in pond-nets (Figure 2; Post 1890; Harkness and Dymond 1961). Today, there is no active commercial fishery for lake sturgeon in the Huron-Erie corridor; sport fishing harvest is now restricted in the St. Clair River and Lake St. Clair, and no sturgeon may be possessed by anglers from Michigan or Ontario waters of the Detroit River (Great Lakes Fishery Commission 2003; MDNR 2005; OMNR 2005).

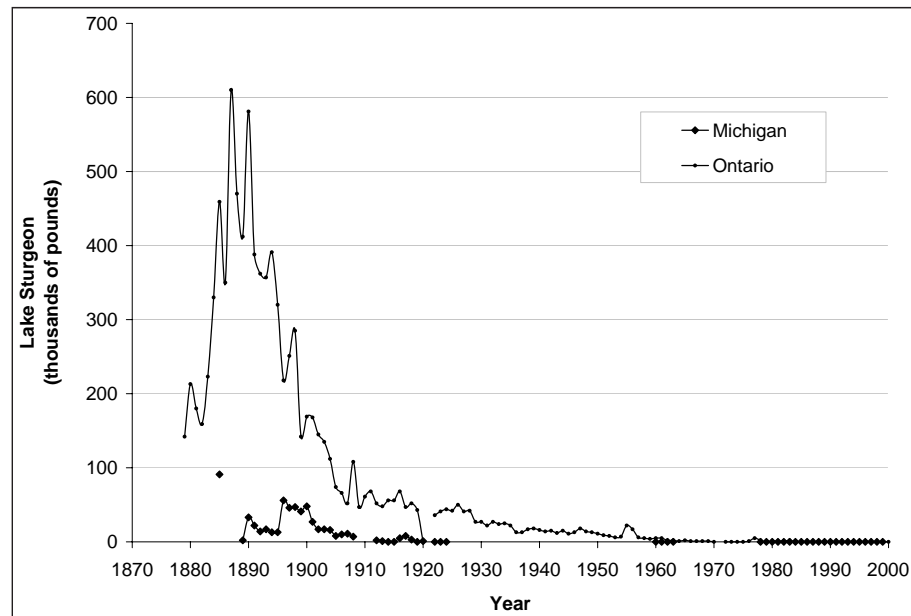


Figure 2. Lake Erie commercial fish catch in Michigan and Ontario waters, 1879-2000. The Canadian catch peaked in 1887 at 610,000 pounds, declining steeply until 1920 when commercial fishing of sturgeon was prohibited in Canadian waters. The Michigan catch was consistently lower than Canada's and its commercial fishery was closed in 1929 (data from U.S. Fisheries Commission Report - Fishing industry of the Great Lakes, Appendix 11 to the 1926 report by W. Koelz and in Baldwin et al. 2002). Note: One pound = 0.45 kg.

From the 1970s to 1999, no lake sturgeon spawning was reported in the Detroit River. In 2001, however, lake sturgeon spawning was documented on a cinder pile near Zug Island in the Detroit River for the first time in over 20 years (Caswell et al. 2004).

In response to the discovery of sturgeon spawning, scientists conducted research to determine the extent of the sturgeon population in the Detroit River, including possible spawning locations and success rates. From 2000 to 2002, they fished with setlines for 741 days total while the river was ice free and only caught 85 lake sturgeon. If this same experiment had been conducted in the late 1800s, over 1,000 lake sturgeon would likely have been captured. Relative to historical catch rates, the catch per unit of effort during 2000-2002 was low (Figure 3).

Management Next Steps

Restoration of lake sturgeon in Michigan waters is the primary goal of a lake sturgeon rehabilitation strategy developed by Hay-Chmielewski and Whelan with the Michigan Department of Natural Resources (1997). In that strategy, sub-goal one recommends "for

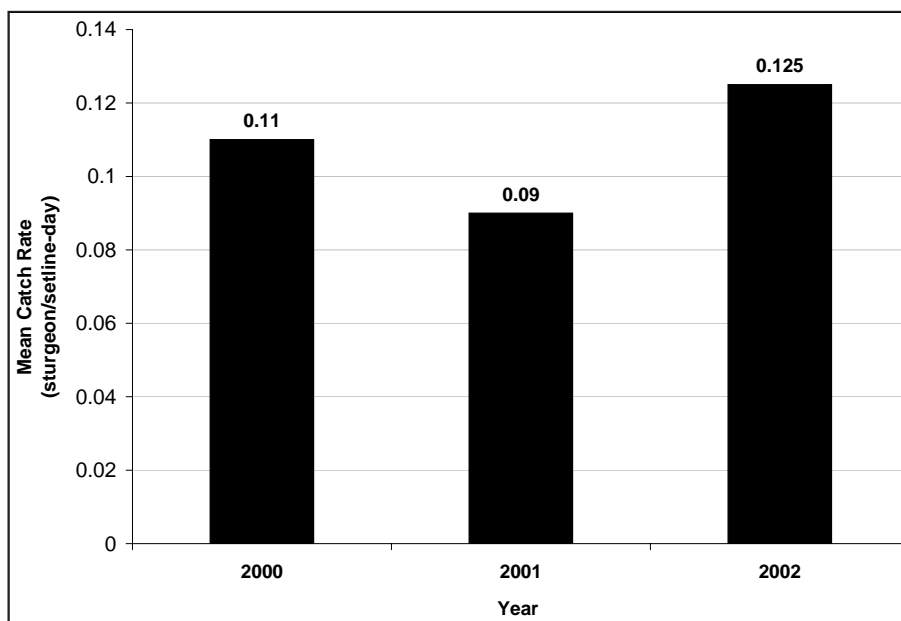


Figure 3. Lake sturgeon mean catch rate (sturgeon/setline-day) on the Detroit River in U.S. and Canadian waters, 2000-2002 (data collected in 2000 and 2001 by Nathan Caswell with Central Michigan University (Caswell 2003), in 2002 by James Boase with the U.S. Fish and Wildlife Service).

existing populations [of lake sturgeon] that have less than 100 adult breeding fish, raise populations to that level within 20 years to maintain genetic integrity..." and "...if a population (population is used referencing its true definition—a collection of organisms of a particular species living in a given geographic area) has 500 or more breeding adults, a harvestable fishery may be considered." For a basin of the Great Lakes, the age structure of a restored lake sturgeon population would include a gradient of year-classes with ten to fifteen percent of those being mature fish and three percent of those being 40 years or older (Holey et al. 2000). Recommended actions include:

- enforcing conservative sturgeon harvest regulations throughout the Huron-Erie corridor;
- enhancing and protecting sturgeon habitat in the Detroit River (sturgeon habitat has been constructed off Belle Isle in Detroit, McKee Park in Windsor, and Fort Malden in Amherstburg);
- controlling pollution from combined sewer overflows and other sources within the watershed;
- undertaking regular sturgeon population assessments, including the use of telemetry to decipher spawning sites; and
- establishing a Sturgeon Guarding Program with active, progressive public involvement.

Achievement of the above goals, in conformance with the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Raymakers and Hoover 2002), could in theory create a healthy, self-sustaining and harvestable lake sturgeon population in the Detroit River. Options for management of lake sturgeon populations in Ontario waters, including closed fishing seasons where sturgeon are rare or only a remnant population exist, are being considered by Ontario biologists (OMNR 2004).

Research/Monitoring Needs

Research and assessment to restore lake sturgeon at newly created spawning habitats in the Detroit River should continue. Such studies could address whether a discrete population of lake sturgeon inhabits the Detroit River. The need for the construction of additional spawning reefs could be determined by assessing whether lake sturgeon numbers in the Detroit River exceed the population size needed to sustain the lake sturgeon reproduction in this river. Additional monitoring is warranted using egg-mats and telemetry to verify spawning activity at suspected spawning sites near Fighting, Grassy, Sugar, and Zug Islands, as well as in the Amherstburg Channel.

References

- Baldwin, N.A., R.W. Saalfeld, M.R. Dochoda, H.J. Buettner, and R.L. Eshenroder. 2002. Commercial fish production in the Great Lakes 1867-2000. <http://www.glf.org/databases/commercial/commerc.php> (February 2006).
- Caswell, N.M. 2003. Population characteristics, spawning sites, and movements of lake sturgeon (*Acipenser fulvescens*) in the Detroit River. Masters thesis, Central Michigan University, Mount Pleasant, MI.
- Caswell, N.M., D.L. Peterson, B.A. Manny, and G.W. Kennedy. 2004. Spawning by lake sturgeon (*Acipenser fulvescens*) in the Detroit River. *Journal of Applied Ichthyology* 20:1-6.
- Great Lakes Fishery Commission. 2003. Lake sturgeon in the Great Lakes; Lake sturgeon, the giant of the Great Lakes. Great Lakes Fishery Commission, Ann Arbor, MI, draft 2-page pamphlet.
- Harkness, W., and J. Dymond. 1961. *The Lake Sturgeon*. Ontario Department of Lands and Forests, Fish and Wildlife Branch, Ontario.
- Hartman, W.L. 1973. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie. Great Lakes Fishery Commission, Technical Report no. 22. <http://www.glf.org/pubs/TechReports/Tr22.pdf> (February 2006).
- Hay-Chmielewski, E., and G. Whelan. 1997. Lake sturgeon rehabilitation strategy. Fish Division, Michigan Department of Natural Resources, Special Report no. 18, Ann Arbor, MI.
- Holey, M., E. Baker, T. Thuemler, and R. Elliott. 2000. Research and assessment needs to restore lake sturgeon in the Great Lakes. Results of a workshop sponsored by the Great Lakes Fishery Trust, June 27-28, 2000, Muskegon, Michigan.
- Koelz, W. 1926. Fishing industry of the Great Lakes. Appendix XI to the Report of the U.S. Commissioner of Fisheries for 1925. United States Bureau of Fisheries Document Number 1001.
- [MDNR] Michigan Department of Natural Resources. 2005. Fishing Regulations, Lake Sturgeon. http://www.michigan.gov/documents/lake-sturgeon-regs_119617_7.pdf
- Michigan Sea Grant. 2005. Lake Sturgeon Habitat Protection Background. <http://www.miseagrant.umich.edu/sturgeon/background.html> (February 2006).

[OMNR] Ontario Ministry of Natural Resources. 2004. Regulatory options for managing the sport fishery of lake sturgeon in Ontario. Fisheries Section. Ontario Ministry of Natural Resources. Peterborough, Ontario.

[OMNR] Ontario Ministry of Natural Resources. 2005. Fishing regulations for the province of Ontario. http://www.mnr.gov.on.ca/MNR/pubs/fishing/fishRegs/2005/Map_A_fr2005.pdf

Post, H. 1890. The sturgeon; Some experiments in hatching. *Transactions of the American Fisheries Society* 19:36-40.

Raymakers, C., and C. Hoover. 2002. Acipenseriformes: CITES implementation from range states to consumer countries. *Journal of Applied Ichthyology* 18:629-638.

Regier, H.A., and W.L. Hartman. 1973. Lake Erie's fish community: 150 years of cultural stresses. *Science* 180(4092):1248-1255.

Tody, W.H. 1974. Whitefish, sturgeon, and the early Michigan commercial fishery. In *Michigan Fisheries Centennial Report 1873-1973*. Michigan Department of Natural Resources, Lansing, MI.

Links for More Information

U.S. Environmental Protection Agency. Spawning by Lake Sturgeon in the Detroit River: <http://www.epa.gov/ecopage/aquatic/lkstrugeon/index.html>

Evaluation of Lake Sturgeon in the Detroit River as Reported by Sport Anglers, 1999: <http://www.fws.gov/midwest/alpena/rpt-detriv98.html>

USGS Great Lakes Science Center. Lake sturgeon, dinosaur of the Great Lakes: http://www.glsc.usgs.gov/main.php?content=research_sturgeon&title=Fish%20at%20Risk0&menu=research_risk_fish

Great Lakes lake sturgeon website: <http://www.fws.gov/midwest/sturgeon/michigan.htm>

Great Lakes lake sturgeon rehabilitation, 2005: <http://www.fws.gov/midwest/sturgeon/documents/CoopConservation-LAS1.pdf>

Development of a management plan for lake sturgeon within the Great Lakes basin based on population genetics structure, 2004: <http://www.fws.gov/midwest/sturgeon/documents/GLFTfinal-LASgeneticMgmt.pdf>

Contact Information

Bruce A. Manny
U.S. Geological Survey, Great Lakes Science Center
E-mail Address: bmanny@usgs.gov

James Boase
U.S. Fish and Wildlife Service, Alpena FRO
E-mail Address: james_boase@fws.gov

INDICATOR: THE WALLEYE POPULATION OF LAKE ERIE

Background

Walleye (*Sander vitreus*) live and breed in Lake Erie and the Detroit River. As juveniles, they consume mainly zooplankton, which are microscopic animals, aquatic insects, and other young fish, but their diet changes to mainly small forage fish as they mature. Successful maintenance of walleye populations depends heavily on successful spawning. Many factors affect the success or failure of walleye spawning, including water temperature, currents, wind and storm events, and also a healthy forage base.

As adults, walleye are top predators in Lake Erie's food web. This position makes them good indicators of ecological health not only because their health and distribution are dependent upon a healthy forage base, but also because they impact other populations. As a keystone species, instability in the walleye population could lead to instability in other populations as well. That, in turn, could possibly lead to a compromised ecosystem or deterioration of the entire fishery.

Annually, approximately three million walleye are harvested from the western and central Lake Erie basins for commercial and sport usage. The fishery is cooperatively managed by the Lake Erie Committee (LEC) of the Great Lakes Fishery Commission. The LEC is a binational group, with representation from the Michigan Department of Natural Resources, the New York State Department of Environmental Conservation, the Ohio Department of Natural Resources, the Pennsylvania Fish and Boat Commission, and the

Ontario Ministry of Natural Resources. Walleye are of enormous economic importance to all jurisdictions (Locke et al. 2005).

Conservatively, the walleye fishing economy is valued at tens of millions of dollars annually (Figure 1).



Figure 1. Participant in the Detroit River walleye tournament on April 8th, 2006 (Photo credit: John Hartig).

Status and Trends

In 1970, legal walleye harvest was prohibited due to mercury contamination coming from the St. Clair and Detroit rivers. Legal walleye harvest was renewed on a limited basis in 1972. International harvest quotas were later introduced in 1976. Throughout the 1980s, the combination of good water quality, many juvenile fish entering the exploitable stock, and management allowed the population to increase (Figure 2). This changed, however, when in the late 1980s to the early 1990s several factors in conjunction with fishing pressure and low amounts of juvenile fish caused walleye productivity in Lake Erie to decrease. Introduction of nonindigenous species, such as zebra mussels and round gobies, caused the food web in Lake Erie to shift from pelagic to benthic, or open water to bottom feeding, diverting energy away from walleye populations. In addition, warmer

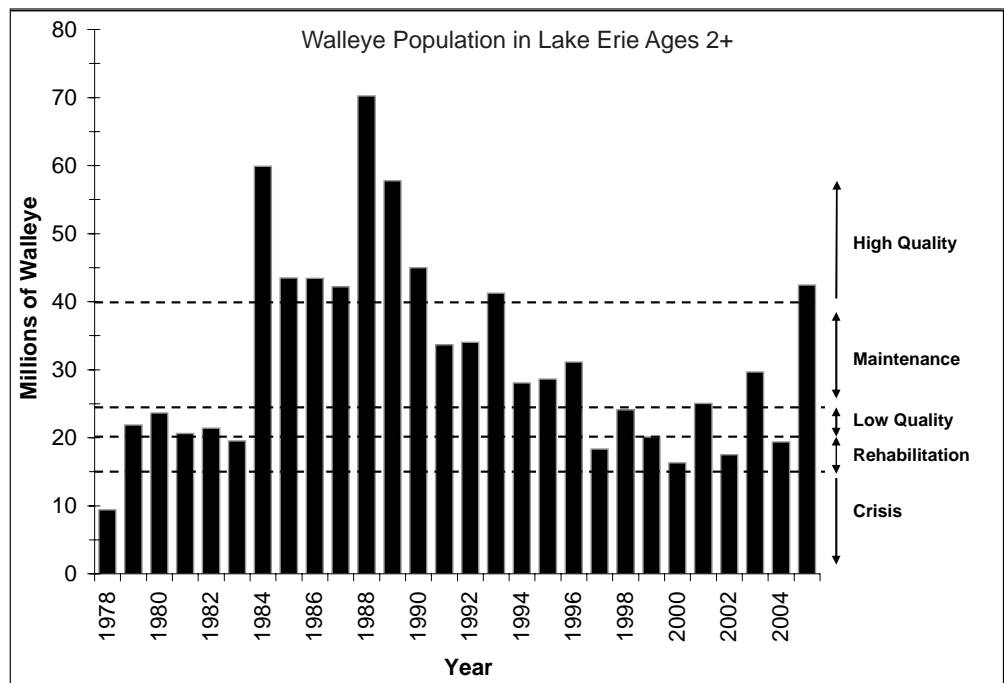


Figure 2. Walleye population (ages 2+) in Lake Erie, 1978 to 2005. Walleye population quality levels: 0-15 million = crisis, 15-20 million = rehabilitation, 20-25 million = low quality, 25-40 million = maintenance, 40 million and higher = high quality.

winters increased the numbers of predators, such as northern pike and muskellunge, present during spawning in the spring. Spawning habitat was also lost due to urban development, river barriers, lower lake levels and pollution. These factors induced a decline in the walleye population beginning in the late 1980s and lasting ten to fifteen years. A critical minimum in the population was reached in 2000, causing declining angler interest and compromised commercial economics (Locke et al. 2005).

In an attempt to control the walleye decline and restore the population, a Coordinated Percid Management Strategy was developed during 2001-2003 by the LEC which set that year's annual "total allowable catch" at 3.4 million fish. It also restricted harvest timing to reduce fishing pressures on isolated spawning walleye. However, due to low reproductive success during this time, the walleye population failed to improve, and the "total allowable catch" was reduced again to 2.4 million fish in 2004 (Locke et al. 2005).

To maintain a healthy fishery, the LEC has determined that the walleye population should be maintained between 25 and 40 million fish ("maintenance level"). This value is desirable to provide sufficient fish for commercial and angler use, and also to promote walleye migration from west to east.

The LEC has been estimating walleye population size in Lake Erie since 1978 (Lake Erie Walleye Task Group 2005). These population estimates are based on systematic gill net sampling, measured fishing effort and harvest, tag recovery rates, and use of mathematical models. Walleye population size in Lake Erie was rated in "crisis" in 1978 and generally increased through the 1980s (Figure 2). From the late 1980s through 2000 the walleye population exhibited a decreasing trend. From 2000 to 2005 it has exhibited an increasing trend, with the population rated as "high quality" in 2005. The "high quality" walleye population of 2005 is attributed to improved management techniques, increased food availability, and improved reproductive success in 2003.

Management Next Steps

The plan for the management of Lake Erie walleye is a cooperative and collaborative product of the LEC member jurisdictions. It is an example of all of the jurisdictions' commitment to the ongoing sustainability and economic viability of this important fishery. The culture of collaboration is critical to the proper management of the walleye fishery of Lake Erie.

The following are the goals and objectives from the "Fish Community Goals and Objectives for Lake Erie" (Ryan et al. 2003) that are relevant to walleye:

Relevant Goal – Secure a balanced, predominantly cool water fish community with walleye as a key predator in the western basin, central basin, and the nearshore waters of the eastern basin.

Relevant Objective – Provide sustainable harvests of walleye for all areas of the lake and maintain and promote genetic diversity by identifying, rehabilitating, conserving and protecting locally adapted stocks.

Researchers and managers have collaborated to estimate Lake Erie's carrying capacity for walleye in order to help achieve a sustainable population. Further, researchers and managers continuously assess, set management priorities, and take management action in a process of continuous improvement. Both sport and commercial harvest quotas are established by managers to help achieve desired goals and objectives.

Research/Monitoring Needs

To help ensure maintenance of walleye stock diversity and sustainability of the population, a number of areas of needed research and investigation must be addressed. These include:

- Mortality – determine if current assessment programs provide accurate estimates of mortality, both at the population and stock-specific levels;
- Stock contribution – continue to develop tools to identify stock specific origin of individual fish to determine relative contribution of stocks to the Lake Erie walleye population;
- Size selective management – determine the utility and management implications of establishing size limits for angling fisheries and mesh size restrictions for commercial fisheries for achieving fishery objectives;
- Seasonal closures of fisheries/sanctuaries – evaluate the value of these techniques in improving fry survival and/or protecting fish before they spawn;
- Fish community interactions – identify interactions between populations that might impact production; and
- Social and economic effects of population abundance – estimate social and economic impacts of various fishery and harvest objectives in order to maximize benefits.

References

Lake Erie Walleye Task Group. 2005. Report for 2004 by the Lake Erie Walleye Task Group. Lake Erie Committee, Great Lakes Fishery Commission, Ann Arbor, MI.

Locke, B., M. Belore, A. Cook, D. Einhouse, R. Kenyon, R. Knight, K. Newman, P. Ryan, and E. Wright. 2005. *Lake Erie Walleye Management Plan*. Lake Erie Committee, Great Lakes Fishery Commission, Ann Arbor, MI.

Ryan, P., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. Fish community goals and objectives for Lake Erie. Great Lakes Fishery Commission Special Publication 03-02, Ann Arbor, MI.

Links for More Information

GLFC, Lake Erie Committee Walleye Task Group: http://www.glfc.org/lakecom/lec/LEC_WTG.htm

Contact Information

Bob Haas
Michigan DNR, Fisheries Division
E-mail Address: haasrc@michigan.gov

Michael Thomas
Michigan DNR, Fisheries Division
E-mail Address: thomasmv@michigan.gov

INDICATOR: CANVASBACK POPULATION IN LAKE ST. CLAIR/ DETROIT RIVER/WESTERN LAKE ERIE BASIN

Background

More than three million waterfowl are estimated to migrate through the Great Lakes area annually. More than 300,000 diving ducks have been documented at one time during spring migration on the lower Detroit River (Manny et al. 1988). In 1991, retail sales related to waterfowl hunting in Michigan were estimated at \$20.1 million and have most likely increased since that time.

Canvasbacks (*Aythya valisineria*) require large amounts of food to fuel their migration. They can dive as deep as 11 meters (36 ft) for aquatic plants, including wild celery, pondweeds, grasses, and sedges. These omnivores require foods provided by productive marshlands and, in particular, shallow water with dense beds of submergent and emergent vegetation. By mid-October, fall migration for canvasbacks is well under way. However, some flocks overwinter regularly on the lower Great Lakes and in particular Lake St. Clair and along the St. Clair and Detroit rivers. By mid-April, migrating canvasbacks will be moving north to their breeding grounds in central Canada (Cheskey and Wilson 2001).

Extensive beds of aquatic vegetation in the Detroit River ecosystem, particularly wild celery, once attracted large concentrations of divers, primarily canvasbacks. Rafts up to 12-14 km (7-8 miles) long have historically been described on Lake St. Clair (Pearce 1997). However, in the past 100 years, discharges from industrial plants and municipal sewage effluent along with the effects of large, deep draft vessels have degraded the lower Detroit River ecosystem, thus resulting in the substantial decline of wild celery beds. Industrial

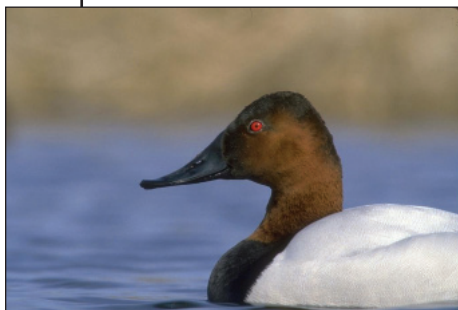


Figure 1. Canvasback (*Aythya valisineria*)
(Photo credit: Ducks Unlimited, Inc.).

and urban development, as well as agricultural reclamation projects, have destroyed wetland breeding, migration stopover, and wintering areas. Periodic droughts have also severely reduced the reproductive success of canvasbacks (Cheskey and Wilson 2001). Remnants of the once vast rafts of migratory waterfowl can still be found in the aquatic vegetative beds surrounding some of the islands in the Detroit River (USFWS 2005).

Canvasbacks have been a game bird of choice among North American hunters with a well-deserved reputation as a fine table bird, and a handsome mount (Figure 1).

During the years of market hunting in the late 1800s and early 1900s, large numbers were shot, putting stress onto the viable population size. Even after the Migratory Bird Convention Act of 1917, which prohibited market hunting, canvasbacks required special protection for many decades (Cheskey and Wilson 2001). Canvasbacks continued to decline between 1955 and 1974 (del Hoyo et al. 1992).

Status and Trends

In 1974, several traditional canvasback migration staging areas were selected in Michigan and other Mississippi Flyway locations for inclusion in a coordinated canvasback survey. Air or ground surveys were scheduled to be conducted on or about November 5 of each year. The important areas in Michigan included Lake St. Clair, the Detroit River, and Lake Erie. These three locations and 6 to 22 additional areas known to have significant canvasback use were inventoried annually between 1974 and 2004 (no survey in 1980). The data collected provide information that can be compared to breeding population estimates and January counts to help ascertain canvasback status.

The number of canvasbacks counted during the Michigan survey ranged from 125 in 1974 to a record high 79,300 in 1999 (Figure 2). The Michigan canvasback inventory along Lake St. Clair, the Detroit River, and Lake Erie exceeded the long-term average (22,000) in 12 of the last 20 years. The 1974-2004 period of record can best be described as high year-to-year variability. Among the three important areas in Michigan, 93% of the canvasbacks were found on Lake St. Clair. The second most heavily used staging area in Michigan is the lower Detroit River/Lake Erie complex.

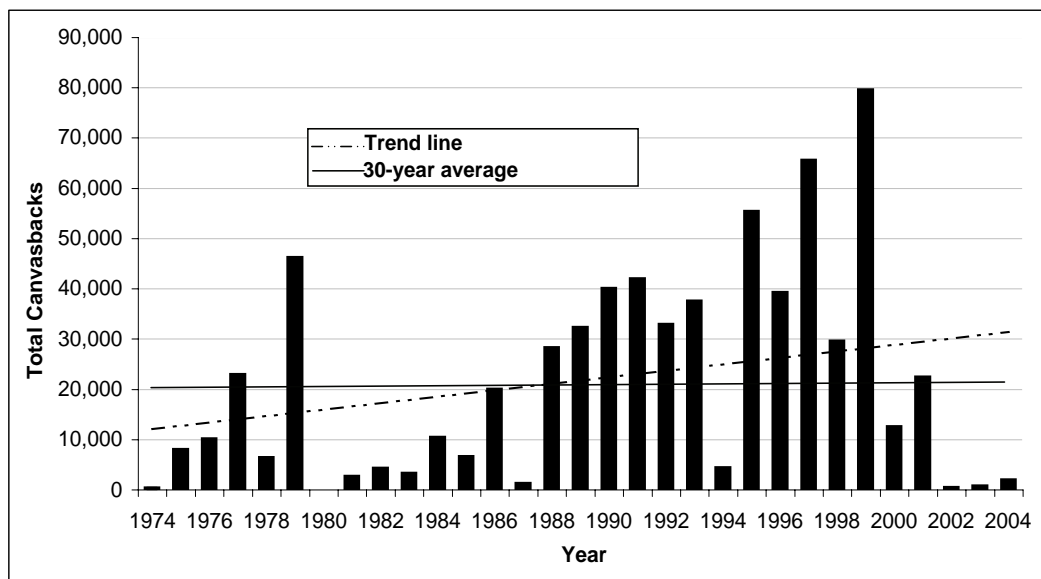


Figure 2. Total canvasbacks counted in the fall on Lake St. Clair, Detroit River and western Lake Erie basin (U.S.), 1974-2004 (data collected by Michigan Department of Natural Resources).

Large numbers of canvasbacks prefer the Canadian side of Lake St. Clair versus the U.S. side for periods of time, and then they move back to the U.S. side. For example, in 2002, Department of Natural Resources Biologists Ernest Kafkas and Joseph Robison witnessed a raft of canvasbacks 14 km (9 miles) long on the Canadian side of Lake St. Clair. The reason for this gradual shift in canvasback distribution in Lake St. Clair is most likely due to human disturbance and other factors, such as a shift in vegetation beds. Also, Ontario has restrictions on how far offshore people are able to hunt while Michigan does not. Human disturbance plays a major role in the distribution of canvasbacks. From 2002-2004 Lake St. Clair in Michigan and Ontario waters had near-record or record low counts of canvasbacks.

The trend of the Michigan canvasback inventory has roughly followed the trend of the total inventory of all survey areas in the Mississippi Flyway since the late 1970s. However, the Lake St. Clair/Erie inventory for the U.S. and Canadian waters combined has been relatively stable compared to the trend of the total Mississippi Flyway inventory. Moreover, these locations appear to have staged a declining proportion of the total canvasbacks observed in the flyway since the early 1990s. From 1974 to 1993, the Lake St. Clair/Erie inventory accounted for 28-65% of the total canvasbacks observed and averaged 45%. That proportion declined to an average of 25% (range 18-38%) of the total canvasbacks observed across the flyway during 1994-1999 (Soulliere et al. 2000).

Surveys have been fairly consistent across the flyway over time. However, this survey only provides an annual “snap shot” of canvasback fall staging activity. The smaller proportion of the population using Lakes St. Clair and Erie may be related to a delayed migration in the late 1990s compared to the 1970s and 1980s. In recent years, canvasbacks using upper Mississippi River pools normally migrate to the East Coast and likely pass over and/or stage on the lower Great Lakes *after* the early November survey (Bellrose 1980). A high number of canvasbacks observed in December and even wintering in southeast Michigan in recent mild-weather years supports this possibility (Soulliere et al. 2000). Southeast Michigan and connecting waters remain one of the most important regions for migrating canvasbacks in North America because of location between prairie breeding grounds and the primary wintering range of the East Coast, as well as its expansive open water and food resources.

Management Next Steps

The lower Detroit River is designated as an Important Bird Area that is globally significant as a site for congregating waterfowl. Continued emphasis should be placed on wetland conservation and management to sustain populations of these waterfowl. Populations have been managed through hunting restrictions and the North American Waterfowl Management Plan, which strives to conserve and develop prime habitat for these diving ducks throughout the continent (Cheskey and Wilson 2001).

Research/Monitoring Needs

The November canvasback survey should be continued to monitor populations of canvasbacks migrating through the Detroit River corridor and Mississippi Flyway. The surveys are important to determine nesting and wintering areas that are of significant importance to canvasbacks. Also, continuation of May Breeding Population Surveys is pertinent to determine reproduction success.

References

- Bellrose, F.C. 1980. *Ducks, Geese and Swans of North America*. 3rd edition. Harrisburg, PA: Stackpole Books.
- Cheskey, E.D., and W.G. Wilson. 2001. *Eastern Lake St. Clair Important Bird Area Conservation Plan*. Canadian Nature Federation, Bird Studies Canada, and Federation of Ontario Naturalists.

del Hoyo, J., A. Elliot, and D.A. Christie, eds. 1992. Canvasback. In *Handbook of the Birds of the World*. Vol. 1, No. 110. Barcelona, Spain: Lynx Edicions.

Manny, B.A., T.A. Edsall, and E. Jaworski. 1988. The Detroit River, Michigan: An ecological profile. U.S. Fish and Wildlife Service Biological Report 85 (7.17).

Pearce, J. 1997. Cleansing wetlands disappeared as country grew up. *Detroit News*, October 6, 1997.

Soulliere, G.J., T.E. Maples, and E.N. Kafcas. 2000. Twenty-five years of canvasback inventory in Michigan, 1974-1999. Wildlife Division Report no. 3332. Michigan Department of Natural Resources.

[USFWS] U.S. Fish and Wildlife Service. 2005. *Detroit River International Wildlife Refuge Comprehensive Conservation Plan and Environmental Assessment*.

Links for More Information

[USGS] Biological and ecotoxicological characteristics of terrestrial vertebrate species residing in estuaries: <http://www.pwrc.usgs.gov/bioeco/canvasback.htm>

Contact Information

Joseph D. Robison
Michigan DNR, Wildlife Biologist
E-mail Address: robisnj@michigan.gov

Ernest N. Kafcas
Michigan DNR, Wildlife Biologist
E-mail Address: kafcase@michigan.gov

INDICATOR: COMMON TERN REPRODUCTION

Background

The common tern (*Sterna hirundo*) is a small colonial waterbird with a distinguishing black cap and a deeply forked tail (Figure 1). The name is actually a paradox because the common tern is not common at all. In 1979, the bird was listed in Michigan as a threatened species and has recently undergone a status assessment by the U.S. Fish and Wildlife Service for possible listing as federally endangered (MDNR 2005).

Common terns that breed in the Great Lakes area overwinter in Florida, the Caribbean, Central America, and as far as the southwestern coast of South America (MDNR 2005). The common tern nested on islands and along the shores of the Detroit River for



Figure 1. Common tern (*Sterna hirundo*)
(Photo credit: Dave Appleton).

hundreds, if not thousands, of years before disturbances led to a devastating population decline (Figure 2). Disturbances such as human encroachment (i.e., development), predation, effects of contaminants, and the explosive growth of ring-billed gulls on traditional common tern breeding grounds pose particularly acute threats to Great Lakes common tern populations. Also, the overgrowth of vegetation on the breeding grounds, especially by nonnative, invasive species such as common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*), has become an increasing concern. Common terns are indicators of the ecological health of the entire ecosystem because they are on the top of the food web, and therefore susceptible to bioaccumulation

of contaminants such as PCBs which cause reproductive failure. Common terns are also an excellent indicator species because they are longtime breeding residents of the Detroit River and their population has greatly fluctuated in response to environmental stressors.

Status and Trends

In the 1960s, the lower Great Lakes had the largest recorded number of common tern nests when approximately 16,000 to 21,000 nesting pairs were observed (Nisbet 2002). But by 1980, only approximately 5,000 pairs were recorded in the same region (Courtney and Blokpoel 1983). This decrease was due to many factors, including the increase of the ring-billed gull population. In the highly urbanized Detroit River watershed, the ring-billed gull population has increased 600-fold during the last quarter century (Weseloh et al. 2001). The ring-billed gull is an earlier spring-arriving species, is opportunistic, and readily adapts to human-altered habitats (Ludwig 1962). This has resulted in the displacement of common terns from formerly mixed gull-tern colonies in the Detroit River, such as on Fighting Island (Figure 2). Although Fighting Island was once a productive tern colony, there have not been terns nesting on the Island since 1998. However, ring-billed gulls continue to successfully nest on the Island.

During years spanning 1960-1980, Courtney and Blokpoel (1983) documented over 4,500 common tern nests on Belle Isle, Mud, Grassy, Bob-Lo, and Fighting Islands in the Detroit River. In 2005, less than 300 common tern nests were found on two man-made bridge protection piers within the Trenton Channel of the Detroit River (Figure 3), representing a 98% decline in the last 25 years. Tern nesting habitat was created on the Grosse Ile Free Bridge protection pier in 2003 and has been utilized by nesting terns in 2004 and 2005.

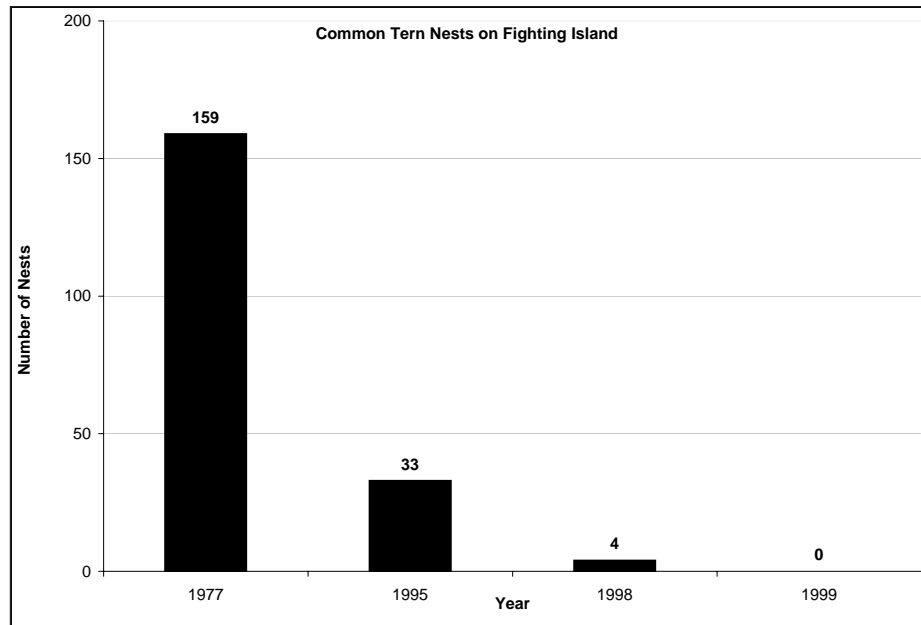


Figure 2. The number of common tern nests on Fighting Island, 1977, 1995, 1998 and 1999. Nests were counted in early to mid-incubation time (data collected by the Canadian Wildlife Service and Bird Studies Canada).

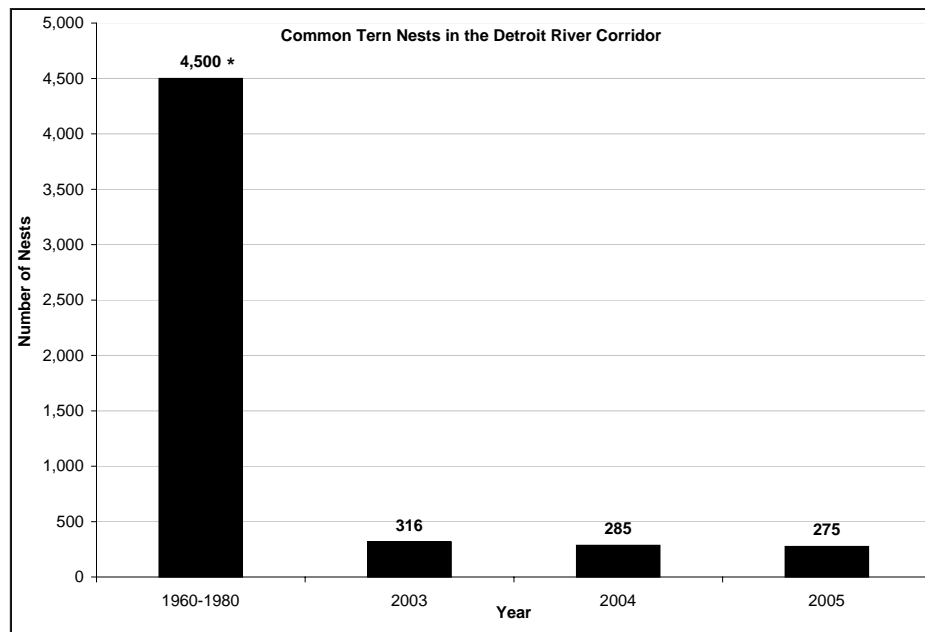


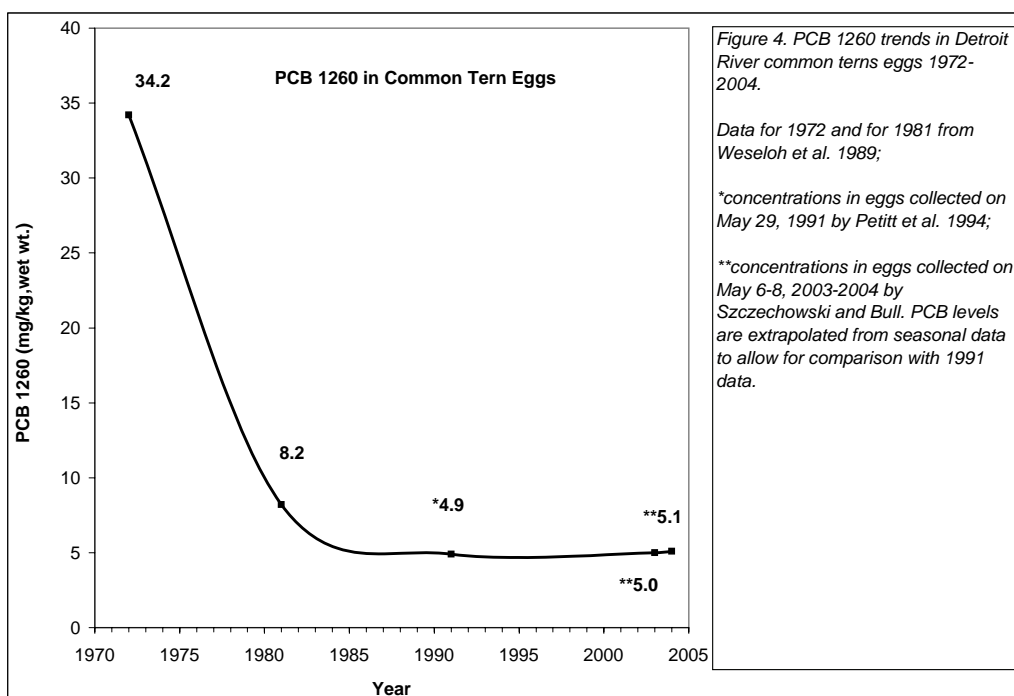
Figure 3. The number of common tern nests in the Detroit River corridor, 1960-1980 and 2003-2005 (1960-1980 population estimate from Courtney and Blokpoel (1983)*; 2003, 2004 and 2005 population estimates from Bull and Szczechowski).

Not only has the nesting population decreased, but it has been estimated in recent years that only about 20% of the chicks are making it to fledgling stage due to environmental factors, contaminant sensitivity, and predation, primarily by black-crowned night herons (Szczechowski and Bull 2005). In the Detroit River, nest and fledging success is quantified before the midpoint of the nesting season (June 18th) because there is a much lower success rate during the second half of the nesting season. In 2005, eggs laid after the midpoint of the nesting season had approximately 24% hatch success compared to 62% before. The number of common tern nests has greatly decreased since the 1980s and terns have had moderate to poor fledge success in 2004 and 2005 (Table 1).

Table 1. Common tern hatch and fledging success (clutches completed on or before the midpoint of the nesting season, June 18th) near the Grosse Ile Free Bridge, 2003-2005 (data collected by B. Szczechowski and J. Bull).

Year	Hatch Success	Fledge Success
2003	0%	0%
2004	76.5%	47-59%
2005	62.1%	12-14%

In 2003 and 2004, common tern eggs were collected at the Grosse Ile Free Bridge nesting site, processed at the U.S. Fish and Wildlife Service lab, and sent to Great Lakes Institute for Environmental Research (University of Windsor, Ontario, Canada) for analysis of contaminants. PCBs found in tern eggs have greatly decreased in the 2003 and 2004 measurements compared to data collected by the Canadian Wildlife Service in 1972. Between 1981 and 2005, however, PCB declines have markedly slowed; there appears to have been a leveling off of PCB concentrations from 1991 to 2005 in common tern eggs from the Detroit River (Figure 4). Common terns are an excellent indicator species for tracking potential problems related to PCB contamination, since common terns are very sensitive to the dioxin-like toxic effects of PCBs (Nisbet 2002). Though common



tern nesting success has been very low in recent years, it appears that the current PCB concentrations may play a secondary role to predation (and other factors) in diminishing common tern reproductive success in the Detroit River and elsewhere in the Great Lakes.

Management Next Steps

Common tern breeding habitat needs to be protected. Additional common tern breeding sites should be located and constructed, similar to the habitat on the Grosse Ile bridges. Terns prefer sandy, well-drained areas away from mammalian predators and human disturbance, with enough space for colonies of 10 to 1,000 nests. Common terns also need an adequate population of small to medium-sized fish, such as shiners and chubs, and insects, such as dragonfly nymphs, as an essential food supply in close proximity to the nesting grounds. To ensure the future of the colony, 67% of eggs must hatch chicks which subsequently reach fledging stage (Szczechowski and Bull 2005). Predator control structures should be built to protect the vulnerable chicks to increase nest success.

Research/Monitoring Needs

Research on the Detroit River common tern colony at the Grosse Ile Free Bridge and Toll Bridge should continue, including monitoring the level of contaminants such as PCBs in common tern eggs. There should be additional research on methods to deter nest predation and other sources of nest failures. Research should also be conducted to determine the feasibility of reestablishing common tern nesting habitat on Fighting Island, Mud Island, and Belle Isle.

References

- Courtney, P.A., and H. Blokpoel. 1983. Distribution and numbers of common terns nesting on the lower Great Lakes during 1900-1980: A review. *Colonial Waterbirds*. 6:107-112.
- Ludwig, J.P. 1962. A survey of the gull and tern populations of lakes Huron, Michigan, and Superior. *Jack-Pine Warbler* 40:104-119.
- [MDNR] Michigan Department of Natural Resources. 2005. Common Terns (*Sterna hirundo*).
- Nisbet, I.C.T. 2002. Common Tern (*Sterna hirundo*). In *The Birds of North America*, No. 618, eds. A. Poole and F. Gill. Philadelphia, PA: The Birds of North America, Inc.
- Pettit, K.E., C.A. Bishop, D.V. Weseloh, and R.J. Norstrom. 1994. An atlas of contaminants in the eggs of fish-eating colonial birds of the Great Lakes (1989-1992) Vols. I and II. Technical Report Series Numbers 193 and 194. Canadian Wildlife Service, Ontario Region.
- Szczechowski, B., and J. Bull. 2005. Personal Communications.
- Weseloh, D.V., T.W. Custer, and B.M. Braune. 1989. Organochlorine contaminants in eggs of common terns from the Canadian Great Lakes, 1981. *Environmental Pollution* 59:141-160.

Weseloh, D.V., T. Havelka, and C. Pekarik. 2001. Biodiversity along the Detroit River corridor: Changes and prospects. *State of the Strait Conference Proceedings*. University of Windsor, Ontario, Canada.

Links for More Information

The Detroit Audubon Society: www.detroitaudubon.org

USGS, Common tern *Sterna hirundo*: <http://www.mbr-pwrc.usgs.gov/id/framlst/i0700id.html>

University of Michigan Museum of Zoology, Animal Diversity Web: http://animaldiversity.ummz.umich.edu/site/accounts/information/Sterna_hirundo.html

Contact Information

Bruce Szczechowski
Downriver Stream Team
E-mail Address: szczecho@sgate.k12.mi.us

James N. Bull
Detroit Audubon Society
E-mail Address: jbull51264@aol.com

INDICATOR: DOUBLE-CRESTED CORMORANT POPULATION CHANGES

Background

The double-crested cormorant (*Phalacrocorax auritus*) is a large black waterbird with a partially orange face and webbed feet. It feeds primarily in littoral zone areas on small fish such as alewife, yellow perch, and round gobies; rainbow smelt, pumpkinseed, crappie, and bass are secondary food choices. Double-crested cormorants are often observed standing on rocks or posts with their wings outstretched (Figure 1). They are also observed swimming low in the water, often with only their head and neck exposed. Cormorants are very sociable birds migrating and often flying between their breeding



Figure 1. Double-crested cormorant (*Phalacrocorax auritus*) (Photo credit: Larry Hamrin).

areas and wintering grounds in V-shaped flocks. They nest in colonies and often gather on the water's surface in gregarious frenzied feeding flocks. Both male and female birds share the responsibility of building the nest, incubating, and feeding the chicks.

Cormorants were first noted breeding on the Great Lakes in the early 1900s. By the early 1970s, the continental population of double-crested cormorants had greatly declined and had been extirpated in several areas due to DDE-induced reproductive failure through eggshell thinning (Weseloh et al. 1983, 1995). DDE is a breakdown product of the pesticide DDT. DDE-

induced eggshell thinning – a serious problem from 1955 until the early- to mid-1970s – caused little to no recruitment into the population. The breeding population eventually crashed from this lack of recruitment and natural adult mortality, which may also have been augmented by a higher death rate among adults who were also contaminated. Subsequently, when the use of DDT was banned, the cormorant population greatly expanded. This expansion was also due to reduced human persecution, and increased forage fish populations (Weseloh et al. 1995). Many people feel that since the early 1980s, the cormorant population has grown to the point of being a nuisance in several areas of the Great Lakes: eastern Lake Ontario, western Lake Erie, northwestern Lake Huron, Georgian Bay, etc. An overabundance of cormorants may impact fish and wildlife populations by:

- impacting vegetation, especially the last natural remnants of Carolinian vegetation on East Sister and Middle Islands in western Lake Erie (Hebert et al. 2005);
- taking over other colonial waterbird nesting habitats (Cuthbert et al. 2002); and
- possibly degrading fisheries by consuming too many forage and sport fish (Lantry et al. 2002; Weseloh et al. 2002; Rudstam et al. 2004).

Status and Trends

The current double-crested cormorant population in North America is estimated at two million birds, with nearly 70% of them in the interior population, which includes the Great Lakes region (USFWS 2006). In the Great Lakes, the cormorant population showed a 30-year colonization period (1920s-1950s), followed by a 20-year decline (1950s-1970s) and, most recently, a 30-year resurgence (1970s-2000s). This resurgence is a result of legislation protecting cormorants, a decrease in commercial fishing, a decrease in human persecution, and a lower level of toxic chemicals, such as PCB and DDT (Environment Canada 1995) in their food. The number of cormorant nests on the five major nesting islands in western Lake Erie increased from 87 in 1979 to 12,973 in 2004 (Figure 2). In 2000, 81% of the Lake Erie breeding population was located on East Sister and Middle Islands, both located in the western basin 16 km (10 miles) north of the north shore of Ohio (Hebert et al. 2005). Western Lake Erie is one of the five major cormorant nesting areas in the Great Lakes (Weseloh et al. 2002).

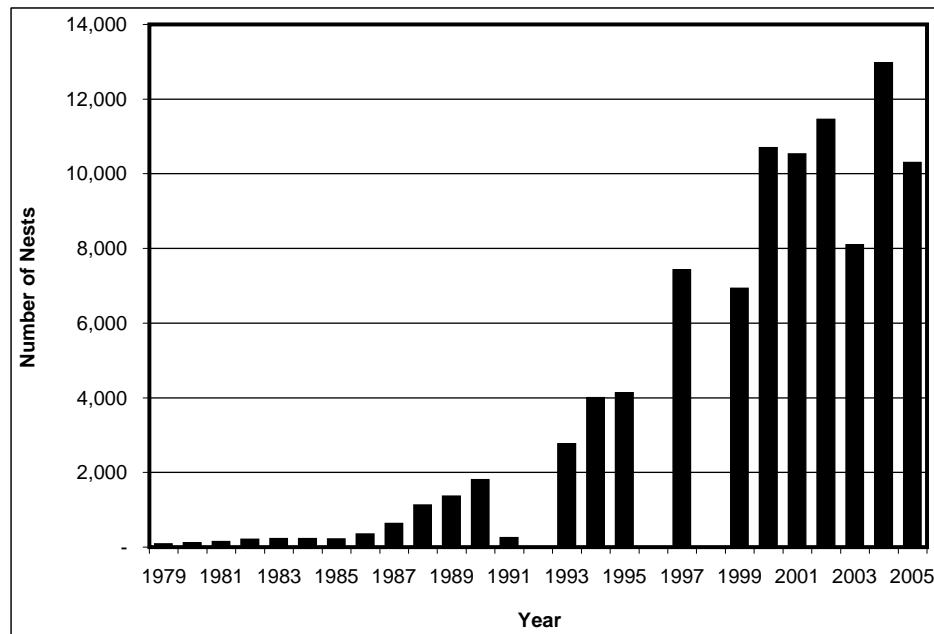


Figure 2. The number of double-crested cormorant nests on Pelee, Middle, Big Chicken, East Sister, and Middle Sister Islands in western Lake Erie, Canada, 1979-2005 (data collected by Canadian Wildlife Service). There were no counts or only partial counts in 1991, 1992, 1996, 1998 and 2003.

In the near future, cormorant population levels will oscillate from a combination of declining food stocks (i.e., alewife populations have declined dramatically in Lakes Ontario and Huron, however, cormorants have begun to feed on the abundant round gobies) and increased lethal management in an attempt to reduce the population.

Management Next Steps

The U.S. Fish and Wildlife Service is conducting a two-year Environmental Impact Study on the growing double-crested cormorant population across the United States. The results of this study will be used to develop a U.S. nationwide Cormorant Management Strategy. A local environmental assessment has been conducted by the U.S. Fish and

Wildlife Service that proposed cooperating agencies reduce double-crested cormorant numbers to a target population of 3,800-4,800 breeding birds in Ohio by 2009 (USFWS 2006). In 2006, there were more than 3,800 pairs of cormorants nesting on West Sister Island alone; management goals call for that number to be reduced to no more than 2,000 breeding pairs (USFWS 2006). Techniques such as physical exclusion, habitat modification, or harassment will be used to reduce the ecological impact to the island from cormorants. In more severe situations, cormorants will be removed by shooting, egg oiling or destruction, nest destruction, or euthanasia following live capture (USFWS 2006).

In Canada, the Ontario Ministry of Natural Resources conducted a cormorant monitoring and research program on several islands in western Lake Erie, Presqu'île area of eastern Lake Ontario, several locations in the Georgian Bay and North Channel area and several inland lakes. This five-year cormorant program:

- included an intensive baseline monitoring program beginning in the spring of 2000;
- tested selected harassment techniques as a means of reducing the impact of cormorant populations; and
- undertook experimental control beginning in spring 2001 (OMNR 2000).

Parks Canada is also evaluating its direction in assessing cormorants on Middle Island.

Research/Monitoring Needs

It is difficult to assess many of the standard biological and chemical parameters associated with using the cormorant as an indicator species in western Lake Erie; since 1987, all nests have been relatively inaccessible in the tops of tall trees. However, further research is needed on the growth potential of the cormorant population in Lake Erie and on the determination of the point at which the population will stabilize. Also, research is needed to further determine if the cormorant population is having an effect on the Lake Erie sport or commercial fishery by studying the consumption by all cormorant colonies individually in the lake and specifically in the western basin (Madenjian and Gabrey 1995; Hebert and Morrison 2003). However, all current findings must be considered in light of the extensive cormorant management actions, including lethal control which is now occurring in western Lake Erie.

References

- Cuthbert, F.J., L.R. Wires, and J.E. McKearnan. 2002. Potential impacts of nesting double-crested cormorants on great blue herons and black-crowned night-herons in the U.S. Great Lakes region. *Journal of Great Lakes Research* 28:145-154.
- Environment Canada. 1995. The rise of the double-crested cormorant on the Great Lakes: Winning the war against contaminants. Published by authority of the Minister of the Environment Public Works and Government Services Canada.
- Hebert, C.E., J. Duffe, D.V.C. Weseloh, E.M.T. Senese, and G.D. Haffner. 2005. Unique island habitats may be threatened by double-crested cormorants. *Journal of Wildlife Management* 69(1):68-76.

Hebert, C.E., and H.A. Morrison. 2003. Consumption of fish and other prey by Lake Erie waterbirds. *Journal of Great Lakes Research* 29:213-227.

Lantry, B.F., T.H. Eckert, C.P. Schneider, and J.R. Chrisman. 2002. The relationship between smallmouth bass and double-crested cormorants in the eastern basin of Lake Ontario. *Journal of Great Lakes Research* 28:193-201.

Madenjian, C.P., and S.W. Gabrey. 1995. Waterbird predation on fish in western Lake Erie: A bioenergetics model application. *Condor* 97:141-153.

[OMNR] Ontario Ministry of Natural Resources. 2000. Cormorant research and monitoring. <http://www.mnr.gov.on.ca/mnr/csb/news/may9fs00.html> (July 2006).

Rudstam, L.G., A.J. VanDeValk, C.M. Adams, J.T.H. Coleman, J.L. Forney, and M.E. Richman. 2004. Cormorant predation and the population dynamics of walleye and yellow perch in Oneida Lake. *Ecological Applications* 14:149-163.

[USFWS] U.S. Fish and Wildlife Service. 2006. Final environmental assessment released on Ohio double-crested cormorant damage management control. Region 3 Midwest.

Weseloh, D.V.C., C. Pekarik, T. Havelka, G. Barrett, and J. Reid. 2002. Population trends and colony locations of double-crested cormorants in the Canadian Great Lakes and immediately adjacent areas, 1990-2000: A manager's guide. *Journal of Great Lakes Research* 28(2):125-144.

Weseloh, D.V., P.J. Ewins, J. Struger, P. Mineau, C.A. Bishop, S. Postupalsky, and J.P. Ludwig. 1995. Double-crested cormorants of the Great Lakes: Changes in population size, breeding distribution and reproductive output between 1913 and 1991. *Colonial Waterbirds* 18:48-59.

Weseloh, D.V., S.M. Teeple, and M. Gilbertson. 1983. Double-crested cormorants of the Great Lakes: Egg-laying parameters, reproductive failure, and contaminant residues in eggs, Lake Huron, 1972-1973. *Canadian Journal of Zoology* 61:427-436.

Links for More Information

Environment Canada. The rise of the double-crested cormorant on the Great Lakes: Winning the war against contaminants: http://www.on.ec.gc.ca/wildlife/factsheets/fs_cormorants-e.html

North American Fishing Club. They're Everywhere! They're Everywhere!: <http://forums.fishingclub.com/eve/forums/a/tpc/f/72010418011/m/92710053521>

U.S. Geological Survey. Predation on walleyes (*Sander vitreus*) by double-crested cormorants (*Phalacrocorax auritus*) at the West Sister Island colony in 2005: http://www.glsc.usgs.gov/_files/reports/2005LakeErieCormorantReport.pdf

Contact Information

D.V. Chip Weseloh
Canadian Wildlife Service
E-mail Address: chip.weseloh@ec.gc.ca

INDICATOR: DETROIT RIVER CHRISTMAS BIRD COUNT

Background

The Christmas Bird Count tradition began Christmas Day, 1900, led by ornithologist Frank Chapman, an early officer for the Audubon Society. This “Christmas Bird Census” was proposed as a new holiday tradition, rather than a Christmas hunt, an earlier tradition. During the first count in 1900, there were 27 participants (Audubon 2005). By 2005 that number had grown to over 50,000 participants in over 2,000 locations nationwide. These volunteer efforts are compiled into the longest-running database in ornithology, representing over a century of unbroken data on trends of early-winter bird populations across the Americas (Audubon 2005).

The Detroit River annual Christmas Bird Count (CBC) was established in 1978 as a binational endeavor to count overwintering birds. The area covered is a circle centered at the intersection of Warren Avenue and Interstate 94 in Detroit, encompassing parts of both Wayne County in Michigan and Essex County in Ontario (Figure 1). The count circle consists of mostly industrial, urban, and residential areas, but includes

some natural areas, such as the Ojibway Prairie in Windsor and wetlands along the Detroit River that are critical for bird populations.

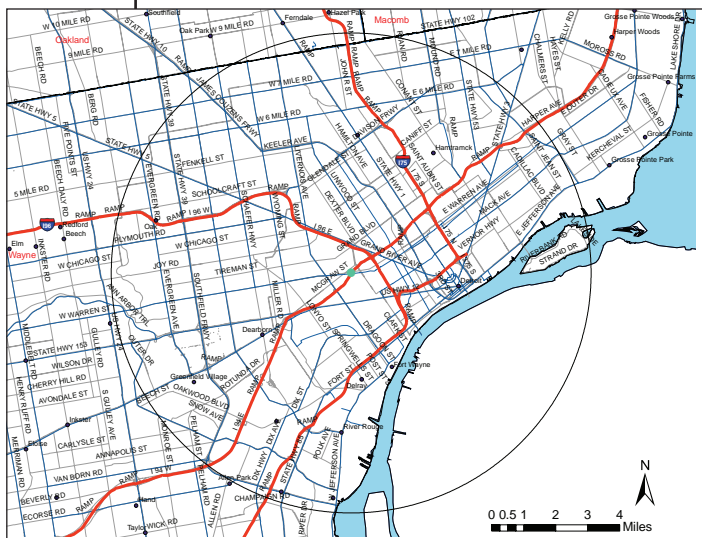


Figure 1. 24.1 km (15 mile) diameter designated count circle centered at Warren Avenue and Interstate 94 in Detroit, MI.

from improper use of pesticides (Audubon 2005). These long-term data can also monitor the presence and increase of introduced species, which often have profound impacts on ecosystem health.

Status and Trends

Because these CBC count data are considered a one-day annual snapshot of the bird community, they may or may not correlate with community status. Though it seems possible to evaluate population changes from these trendlines, caution must be taken because there are annual changes in count effort, varying degrees of skill and diligence of observers, and biases in habitat coverage. The data are not corrected for these variations in observation frequency, observer skill level, or weather conditions.

There have been 35 species consistently counted on all 27 annual Detroit River CBC counts. One of those species is the Canada goose. There are two different populations of Canada geese in southeast Michigan and southwest Ontario, the migratory *Branta canadensis interior* and the resident *Branta canadensis maxima*. Prior to reintroduction efforts in Michigan and Canada in the 1920s and 1930s, the resident population was not present in the region. However, Michigan's Canada goose (*B.c. maxima*) population has grown 14% annually, and continues to increase (MDNR 2001). The Canada goose trend from the Detroit River CBC reflects these increasing numbers (Figure 2). In 2001, the CBC count of Canada geese was the lowest since 1981 due to the fact that the majority of the water bodies were frozen over.

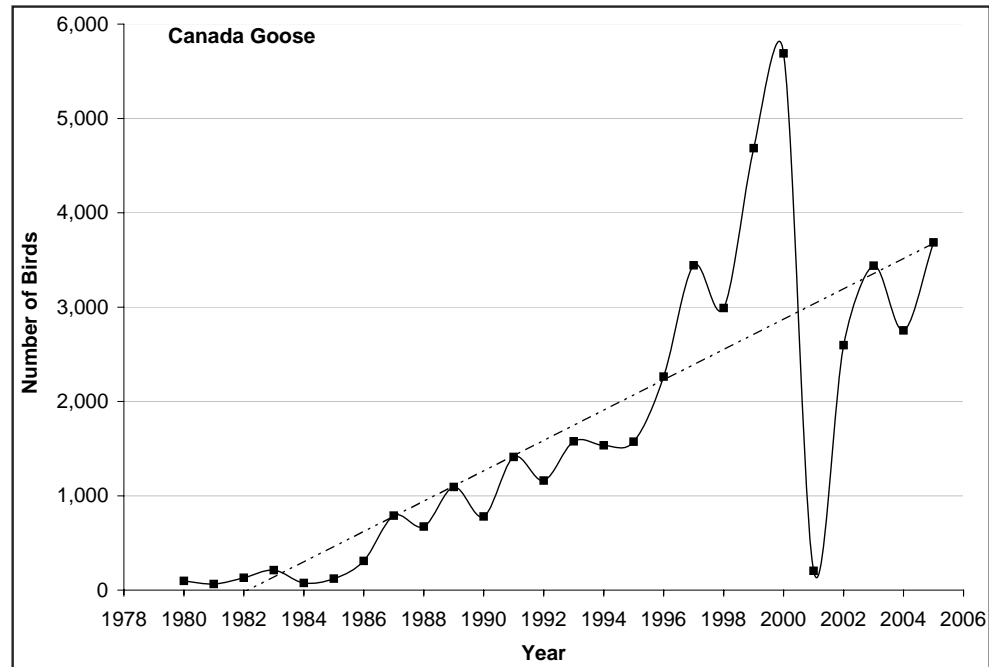


Figure 2. Canada goose Christmas Bird Count trend, 1980-2005.

Mute swans are a nonnative, invasive species introduced from north-central Asia and Europe in the nineteenth century. They are distinguishable from North American swans by the characteristic black knob at the base of their orange bill with a black tip (Figure 3). Mute swans spread throughout the United States from 1920 through the late 1970s when they were reported in all four flyways. In addition to being a nuisance to humans, they are ecologically damaging. They displace native waterfowl by taking over preferred nesting habitat and can seriously damage beds of submerged vegetation, critical to other waterfowl, by their heavy foraging. Mute swan numbers during the Detroit River CBC



Figure 3. Mute swan (*Cygnus olor*)
(Photo credit: Dave Appleton).

fluctuate, but a steady positive trend is evident from 1986 through 2005 (Figure 4). Much of the variability in the data relates to the ability of observers to count the swans from land, which in turn depends on the extent of ice on the water.

Waterfowl as a group also showed a general increasing trend from the late 1970s through 2005 (Figure 5). This yearly count includes waterfowl along the Rouge River as well as parts of the Detroit River. Waterfowl counts vary each year depending on the amount of frozen water; a high percentage of frozen water correlates with a low waterfowl count.

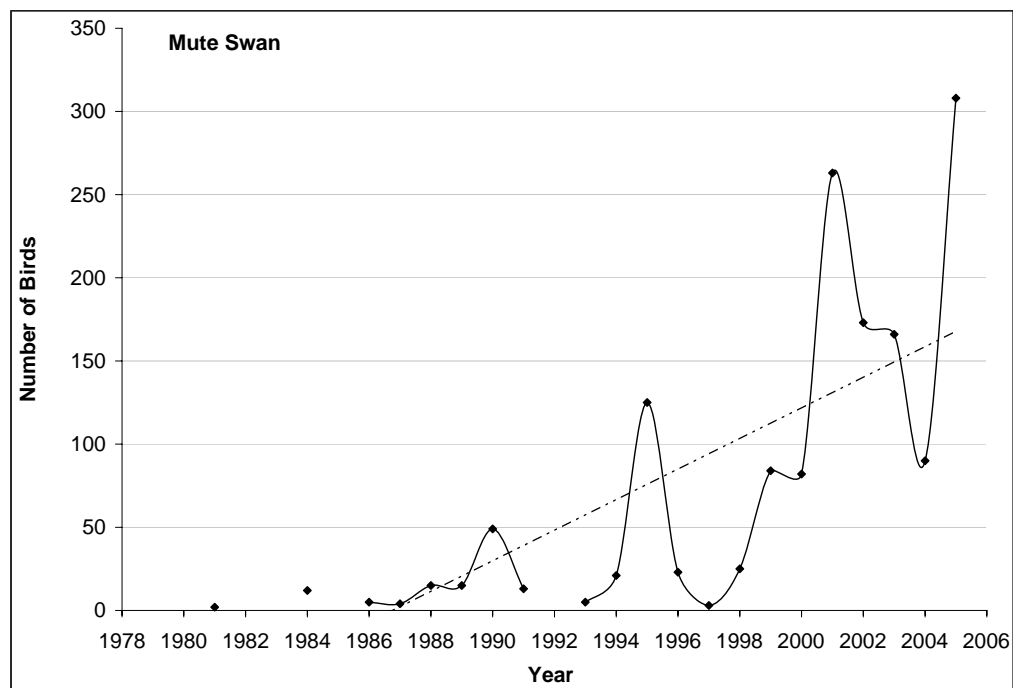


Figure 4. Mute swan Christmas Bird Count trend, 1981, 1984, 1986-2005.

Management Next Steps

It is recommended that management activities continue to monitor mute swan populations and initiate control measures, as necessary. In addition, conservation and restoration of critical waterfowl habitats should be undertaken as a priority.

Research/Monitoring Needs

The annual Detroit River Christmas Bird Count should continue. In the future, counts need to consistently cover the same areas within the count circle yearly, with the same number of count hours expended by volunteers. An increase in volunteer education and participation would be valuable. Research should also be conducted on the environmental effects of the invasive mute swan and methods to control the population.

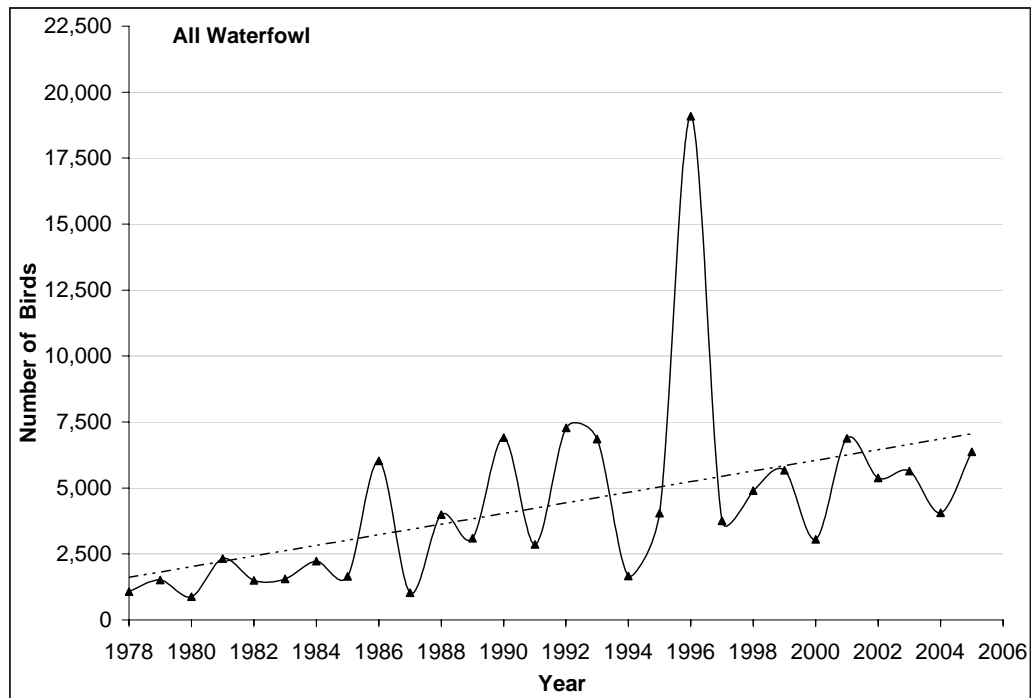


Figure 5. All waterfowl Christmas Bird Count trend, 1978-2005.

References

- Audubon. 2005. The 106th CBC, December 14th 2005 to January 5th 2006, History and Objectives. National Audubon Society.
- Craves, J.A., and J.A. Fowler Jr. December 2003. Twenty-five years of the Detroit River (Michigan-Ontario) Christmas Bird Count. *Ontario Birds* 21(3):110-128.
- Michigan Department of Natural Resources (MDNR). 2001. Waterfowl Status. http://www.michigan.gov/dnr/0,1607,7-153-10363_10859-50168-,00.html (December 2002).

Links for More Information

Rouge River Bird Observatory: www.rrbo.org

Mute swan populations, distribution and management issues in the United States and Canada: http://www.trumpeterswansociety.org/news/publications/16th_conf/24Nelson.pdf

Contact Information

Julie A. Craves
 Rouge River Bird Observatory
 University of Michigan-Dearborn
 E-mail Address: jcraves@umd.umich.edu

INDICATOR: ROCKWOOD, MICHIGAN CHRISTMAS BIRD COUNT– OVERWINTERING BIRD COUNT FLUCTUATIONS

Background

The first Christmas Bird Count (CBC) was held in 1900. Since then, this early winter bird census has grown to nearly 2,000 individual counts across the Western Hemisphere, with over 50,000 participants (Dunn et al. 2005). CBCs tally all birds located within a 24.1 km (15 mile) diameter circle on a single day in early winter around Christmas; dates have now been set during the period December 14th through January 5th. The National Audubon Society (NAS) sponsors the CBC program and has a central repository for the results. The results are published in a quarterly magazine and are also available online (Audubon 2005).

One of these 2,000 nationwide CBCs is centered in Rockwood, Michigan (42°03'35"N, 83°14'15"W) (Figure 1). It covers parts of Wayne and Monroe counties in Michigan and Essex County in Ontario. Approximate boundaries are Sibley Road (north), Amherstburg, Ontario (east), DTE Energy's Fermi 2 Power Plant near Estral Beach (south) and Carleton (west).

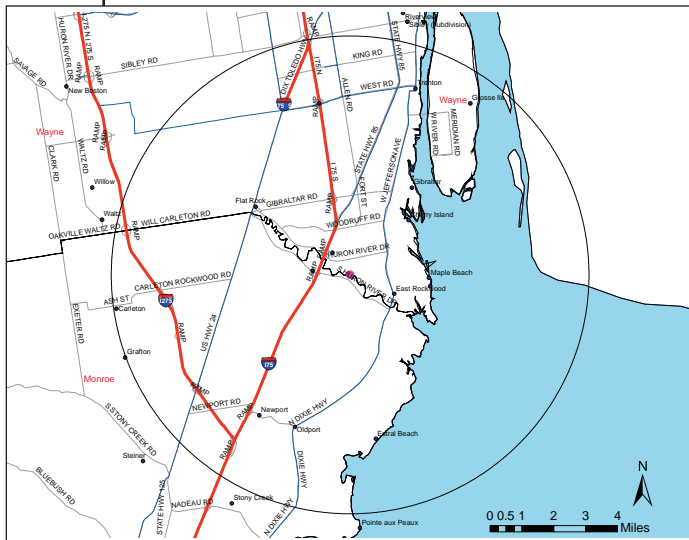


Figure 1. 24.1 km (15 mile) diameter designated count circle centered at Rockwood, Michigan.

The Rockwood CBC was founded in 1974. The first year was considered a test year and the data were not submitted to NAS. However, since 1975, the count has taken place annually and the data have been submitted to NAS and are available to the public for analysis. This document summarizes the Rockwood CBC for the 30-year period from 1975 to 2004, examines count trends for some species of interest, and provides recommendations for improving the count methods to more accurately survey bird populations within the count circle.

Status and Trends

The Rockwood CBC data were examined using actual numbers, not adjusted for survey effort. High year-to-year variability in the number of individuals within each species count is common in CBC data, especially due to variable weather conditions. In order to reduce short-term variability of the data and help evaluate trends, three-year moving averages were calculated (Raynor 1975).

The ten most numerous species observed on the Rockwood CBC (in descending order) are canvasback, European starling, mallard, herring gull, ring-billed gull, common merganser, Canada goose, house sparrow, mourning dove, and tundra swan. There were at least 38 species recorded on every count over the 30-year period.

One species of particular interest found on the Rockwood CBC is the American crow (Figure 2). Crow population trends are of interest because this species is a frequent victim of West Nile virus (WNV), vulnerable to all routes of transmission with extremely high



Figure 2. American crow (*Corvus brachyrhynchos*)
(Photo credit: Jean-Guy Dallaire).

mortality (Caffrey 2003). WNV was first detected in the United States in New York in 1999 and in Michigan in 2001 (SOM 2005) (see “West Nile Virus in Michigan” indicator). Analyses of CBC data and Project FeederWatch data (a winter “citizen science” project sponsored by Cornell Lab of Ornithology) have indicated that crow declines have been geographically patchy (Bonter and Hochachka 2003; Caffrey and Peterson 2003), and that the recent crow declines were within the magnitude of previous fluctuations that have been seen on CBCs over the last 30 years (Bonter and Hochachka 2003). Nonetheless, crow counts decreased 60% in the upper Midwest in a comparison of Project FeederWatch results between the winters of 2001-2002 and 2002-2003, while 79% of CBC circles showed crow declines between those two winters (Bonter and Hochachka 2003).

The mean number of crows per year (636) on the Rockwood CBC during the pre-WNV period, 1975-2001, was substantially higher than the mean for 2002-2004 (35) after WNV was detected in Michigan (Figure 3). This finding is consistent with other studies comparing these periods. Data from within the pre-WNV years (1975-2001) show a significant overall decline. It should be noted

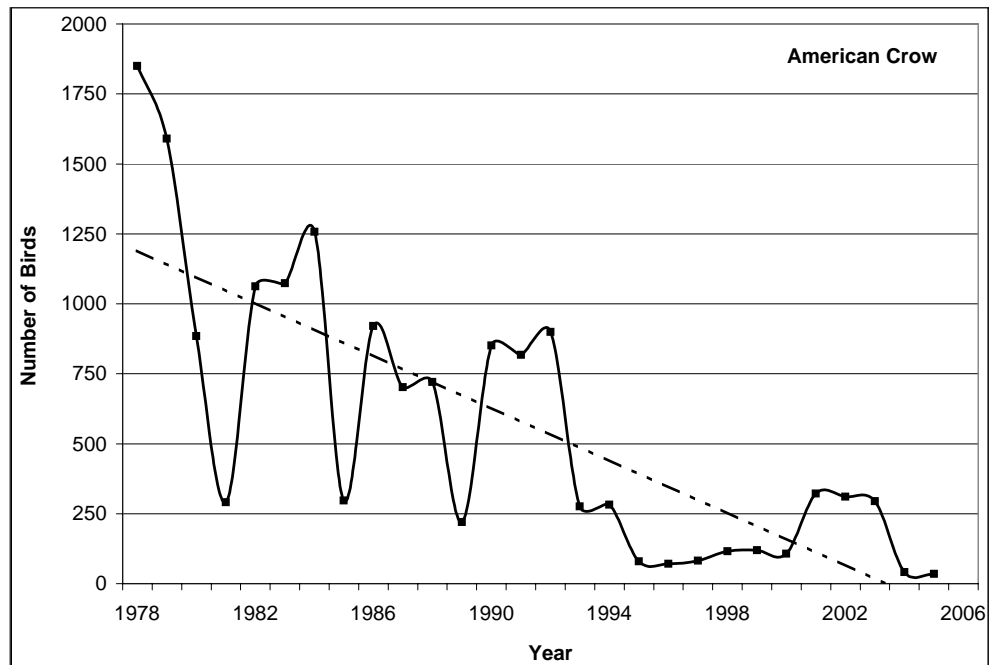


Figure 3. American crow Rockwood Christmas Bird Count trend displaying 3-year moving averages, 1978-2005.

that this is somewhat at odds with the results of other regional CBCs for the pre-WNV period. Analyses of CBC trends from 1959-1988 showed significant increasing annual trends for American crows in Michigan and Ontario count circles (Sauer et al. 1996). The trend for the nearby Detroit River CBC for 1978 (its first year) to 2001 was slightly negative, but not significant (unpublished data).

The crow counts on the Rockwood CBC have varied greatly from year to year, while they were much more consistent on the Detroit River CBC. These differences may reflect the tendency of crows to form large winter flocks and roosts (Caffrey and Peterson 2003), some of which may be very localized or displaced by changing land use. Because many of these flocks contain migratory birds, CBC data may not accurately sample resident birds (Caffrey and Peterson 2003).

The American black duck is also a species of particular interest on the Rockwood CBC. Black duck populations have shown a long-term (1970-2003) decreasing trend in North America (NAWMP 2004), and for the Mississippi Flyway (1955-2004) (USFWS 2004). This decline has been attributed to habitat loss, hunting, and competition and hybridization with the mallard (LePage and Bordage 1998; USGS 1998). Being much more adaptable to urbanization, mallards occupy territory being vacated by black ducks (due to hunting or habitat changes), which increases hybridization opportunities. This appears to be especially prevalent in southern Ontario (Longcore et al. 2000).

There was no significant trend for American black ducks based on the Rockwood CBC period of record (1978-2004; Figure 4). In general, however, there was a decreasing trend between the late 1970s and the late 1980s, followed by an increasing trend between the late 1980s and early 2000s. The recent increase may coincide with harvest restrictions that were implemented in the U.S. in 1983 (Longcore et al. 2000).

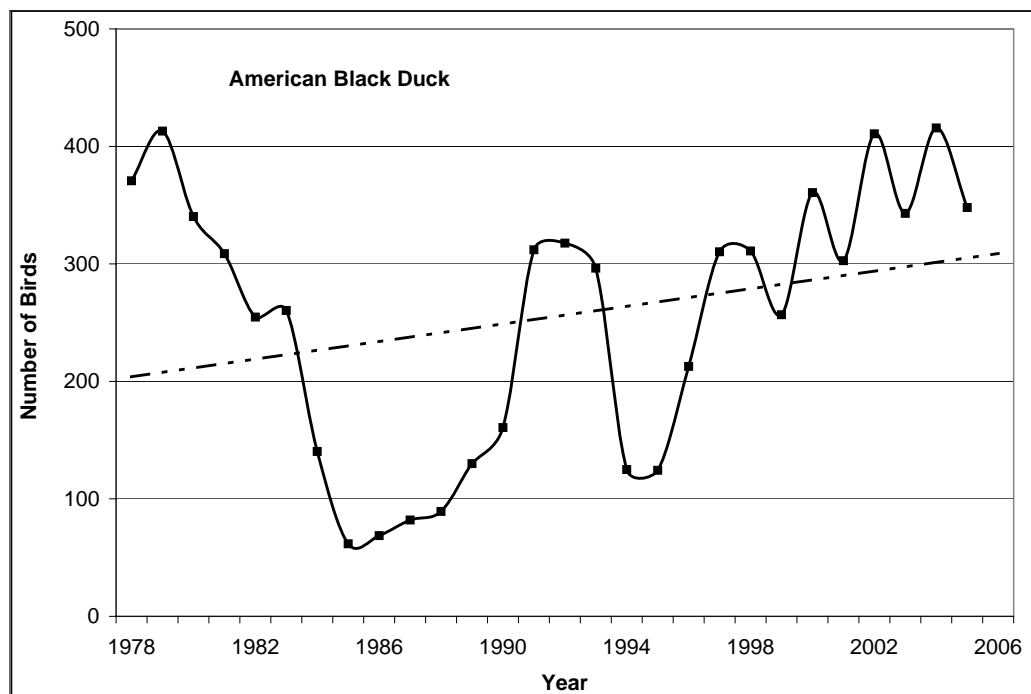


Figure 4. American black duck Rockwood Christmas Bird Count trend displaying 3-year moving averages, 1978-2005.

Since competition with mallards has been implicated in black duck declines, a comparison of relative abundance between black ducks and mallards was examined (Figure 5), a technique suggested by Bock and Root (1981). For nearly the last 20 years, the ratio has remained fairly stable, at roughly 1:17, despite a significantly positive trend in the numbers of mallards. Confounding evaluation of these two species, however, is the difficulty of distinguishing many of the hybrids (Figure 6). It has been estimated that 5 to over 13 percent of birds that look like black ducks in North America are actually hybrids (Longcore et al. 2000; Wright and Wyndham 2005), although this is not reflected in the Rockwood CBC numbers where virtually no hybrids are ever reported. Thus, these numbers should be viewed with caution.

The mute swan and Canada goose population data from the Detroit River CBC (see “Detroit River Christmas Bird Count” indicator) is very similar to the Rockwood CBC, in that both have increased by approximately 16% and 14%, respectively (Petrie and Francis 2003; MDNR 2001).

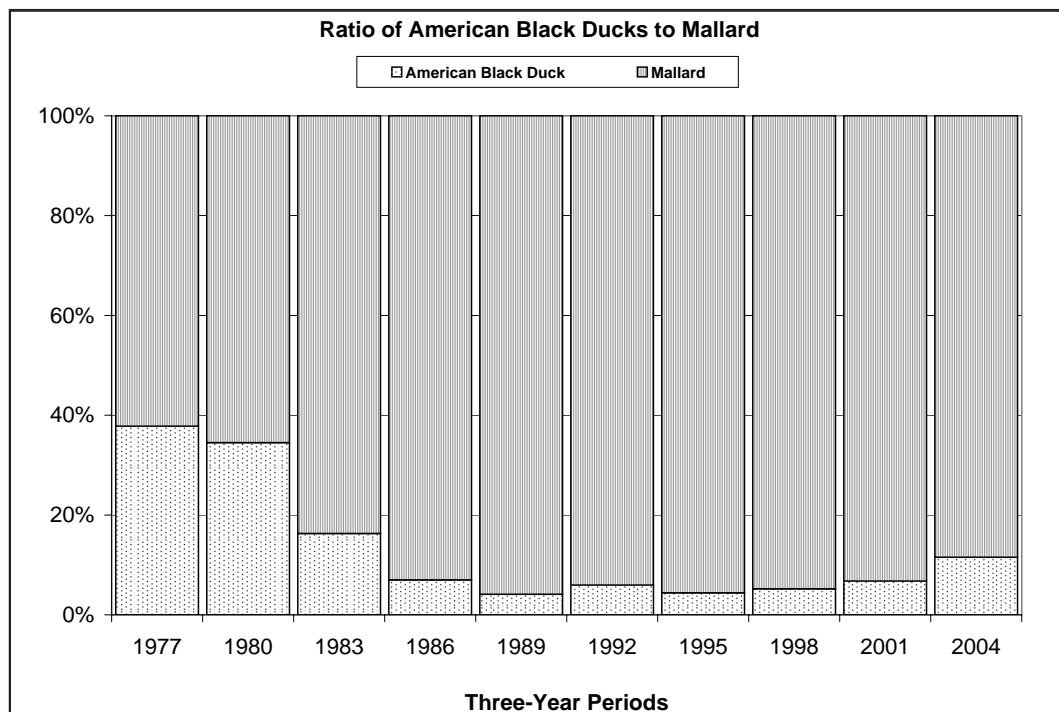


Figure 5. Ratio of American black ducks to mallards in the Rockwood Christmas Bird Count, 1977-2004.

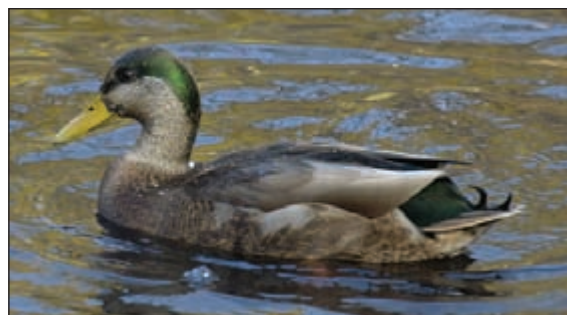


Figure 6. A hybrid mallard and American black duck (Photo credit: Jack Illingworth).

Management Next Steps

Managers should continue to use CBC data to improve management strategies of American crow, American black duck, mallard, Canada goose, and mute swan populations. Control measures could be initiated as necessary with aggressive “nuisance” species, such as the mute swan. Waterfowl hunting limits must correlate with reproductive success and management of breeding habitats to ensure increasing reproductive success of native species.

Research/Monitoring Needs

The annual Rockwood Christmas Bird Count should be continued. In the future, counts need to consistently cover the same areas within the count circle yearly, with the same number of count hours expended by volunteers for consistency. Increased volunteer education and participation will be essential.

It is important to keep accurate count records, using GPS units to determine accurate observation locations, as well as accurately logged time and distance traveled. Feeder-watching efforts and waterfowl survey efforts and counts should be recorded separately. Feeder-watchers should also be given literature and training to aid in identifying species. Habitat changes in the circle over time should be recorded. Average weather conditions for the week and month proceeding the count day should also be recorded because of factors that may affect waterfowl counts. Clearly, more participants need to be recruited to improve accuracy and utility of these CBC data.

References

- Audubon. 2005. The 106th CBC, December 14th 2005 to January 5th 2006, History and Objectives. National Audubon Society.
- Bock, C.E., and T.L. Root. 1981. The Christmas Bird Count and avian ecology. In *Estimating Numbers of Terrestrial Birds*, eds. C.J. Ralph and J.M. Scott. *Studies in Avian Biology* 6:17-23.
- Bonter, D.N., and W.M. Hochachka. 2003. Declines of chickadees and corvids: Possible impacts of West Nile virus. *American Birds* 57:22-25.
- Caffrey, C. 2003. Determining impacts of West Nile virus on crows and other birds. *American Birds* 57:12-13.
- Caffrey, C., and C.C. Peterson. 2003. West Nile virus may not be a conservation issue in northeastern United States. *American Birds* 57:14-21.
- Dunn, E.H., C.M. Francis, P.J. Blancher, S.R. Drennan, M.A. Howe, D. Lepage, C.S. Robbins, K.V. Rosenberg, J.R. Sauer, and K.G. Smith. 2005. Enhancing the scientific value of the Christmas Bird Count. *Auk* 122:338-346.
- LePage, C., and D. Bordage. 1998. The American black duck web site. Environment Canada, Québec Region. Version 31. http://www.qc.ec.gc.ca/faune/sauvagine/html/black_duck.html (February 2006).

Longcore, J.R., D.G. McAuley, G.R. Hepp, and J.M. Rhymer. 2000. American black duck (*Anas rubripes*). In *The Birds of North America*, No. 481, eds. A. Poole and F. Gill. Philadelphia, PA: The Birds of North America, Inc.

[MDNR] Michigan Department of Natural Resources. 2001. Waterfowl status. http://www.michigan.gov/dnr/0,1607,7-153-10363_10859-50168-,00.html (December 2006).

[NAWMP] North American Waterfowl Management Plan, Plan Committee. 2004. *North American Waterfowl Management Plan 2004. Strategic Guidance: Strengthening the Biological Foundation*. Canadian Wildlife Service, U.S. Fish and Wildlife Service, Secretaria de Medio Ambiente y Recursos Naturales.

Petrie, S.A., and C.M. Francis. 2003. Rapid increase in the lower Great Lakes population of feral mute swans: A review and recommendation. *Wildlife Society Bulletin* 31:407-416.

Raynor, G.S. 1975. Techniques for evaluating and analyzing Christmas Bird Count data. *American Birds* 29:626-633.

Sauer, J.R., S. Schwartz, and B. Hoover. 1996. The Christmas Bird Count home page. Version 95.1 Patuxent Wildlife Research Center, Laurel, MD. <http://www.mbr-pwrc.usgs.gov/bbs/cbc.html> (February 2006).

[SOM] State of Michigan. 2005. History of West Nile virus. Emerging diseases web site. <http://www.michigan.gov/emergingdiseases/0,1607,7-186-25805-75265-,00.html> (August 2006).

[USFWS] U.S. Fish and Wildlife Service. 2004. Waterfowl population status, 2004. U.S. Department of the Interior, Washington, DC.

[USGS] U.S. Geological Survey. 1998. Variables affecting the black duck decline and current status of black ducks and mallards in southern Ontario. Patuxent Wildlife Research Center, Laurel, MD. <http://www.pwrc.usgs.gov/research/sis98/longco4s.htm> (February 2006).

Wright, B.S., and M. Wyndham. 2005. American black duck. Hinterland who's who bird fact sheets. Canadian Wildlife Service and Canadian Wildlife Federation. <http://www.hww.ca/hww2.asp?id=14> (August 2006).

Links for More Information

Rouge River Bird Observatory: www.rrbo.org

University of Michigan, Animal Diversity Web, American crow: http://animaldiversity.ummz.umich.edu/site/accounts/information/Corvus_brachyrhynchos.html

Contact Information

Julie A. Craves
Rouge River Bird Observatory
University of Michigan-Dearborn
E-mail Address: jcraves@umd.umich.edu

INDICATOR: FALL RAPTOR MIGRATION AT HOLIDAY BEACH CONSERVATION AREA, AMHERSTBURG, ONTARIO

Background

Fall migrating birds have used the north shore of Lake Erie since the last ice sheet retreated over ten thousand years ago. Since the 1950s casual observers have recorded large numbers of hawks at Holiday Beach Conservation Area (HBCA) east of Amherstburg, Ontario, and nearby sites. More systematic observations began in the 1970s, when evidence indicated that hawks and other birds were experiencing dramatic population declines. Over two million raptors have been counted at this site during the past 35 years.

Since 1974, from September through November, qualified volunteer observers and members of Holiday Beach Migration Observatory (HBMO) have worked enthusiastically (averaging 600 hours in a season) toward a goal of identifying and recording all migrant raptors passing the count site. The information collected is analyzed locally in cooperation with Hawk Migration Association of North America (HMANA) (Chartier and Stimac 2002). HMANA was organized to help standardize count procedures and identification, and to educate the public. Currently, HMANA is assessing the well-being of raptor populations with data collected at several well-established raptor sites, including HBCA. These sites will be included in their Raptor Population Index project.

Since birds of prey are indicators of ecosystem health due to their terminal position in the food web, any decline in their numbers may indicate unfavorable environmental conditions. Because raptors are top carnivores in short food webs, they are usually the first wild species to show ill effects of bioaccumulated contaminants in the watersheds. Historically, these contaminants included heavy metals and chlorine-based pesticides (DDT, aldrin, dieldrin, and heptachlor). In several species of raptors these accumulated materials have contributed to reproductive failure, eggshell thinning, bill malformations, nesting failure, and death.

Raptors depend on updrafts of warm air, primarily over land, for gliding and soaring. As the raptors move south from their eastern Canadian breeding areas, the north shores of Lakes Erie and Ontario become migration barriers. The birds are forced to follow the Lake Erie shoreline westward and are funneled into a narrow migration avenue with Lakes St. Clair and Huron bordering to the north. After passing HBMO and crossing the Detroit River, many birds are recounted by observers (Southeastern Michigan Raptor Research, SMRR) located at Lake Erie Metropark and the Pointe Mouillee State Game Area Headquarters (Figure 1). However, while many birds are recounted at SMRR, there are significant numbers that were not first seen at HBMO. Therefore, SMRR is certainly not a complete reflection of the migration of the same birds at HBMO, but similar trends between the two sites can be found.

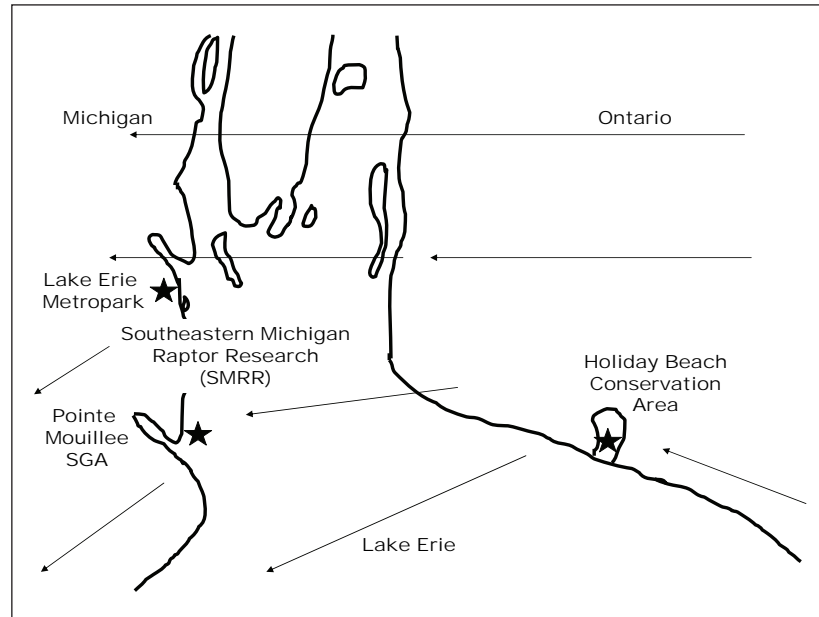


Figure 1. Count site locations at Holiday Beach Migration Observatory (HBMO) and Southeastern Michigan Raptor Research (SMRR). The arrows indicate the general flyway and their precise route is variable.

Status and Trends

Each fall at HBCA, observers tally between 600,000 and 750,000 migrant birds, from ducks to warblers, with an average of 75,000 of these being hawks. Because of these large numbers of fall migrants using this region for their trek southward, HBCA has received the status of an Important Bird Area (IBA). Hawks in the area generally start flying after sunrise and continue throughout the day. The most significant factor influencing whether a bird is counted or not is wind direction. North component winds (NNW, NW, N, NE, NNE) force the birds to follow more closely to the north shore of the lake, and therefore, within range of being counted. South component winds tend to move the birds more north of the count site out of range of viewing and therefore are not counted. Consequently, there may be large variations in total numbers within a species from year to year, however, over a long period these differences are minimal. Analysis of population trends must take into account this wind-influencing factor.

Figure 2 illustrates an upward trend of red-shouldered hawks from the mid-1970s through the early 1990s, followed by a decline through 2004. The low numbers observed in recent years are due to the decreased percentage of immature birds. The cause or causes of this very poor recruitment is unknown and likely requires research on their nesting grounds.

Figure 3 shows a dramatic increase in turkey vulture numbers. A similar increase was also observed at the U.S. sites operated by SMRR. In recent years, this species has continuously had record numbers each season. In 2004, the turkey vulture count was 86% higher than the 1974 count at HBCA and in 2005 a record number of 41,500 vultures were sighted (not indicated on graph). All but one hawk watch site within the Central Continental Flyway have recorded increases in turkey vulture sightings (Berardi 2004).

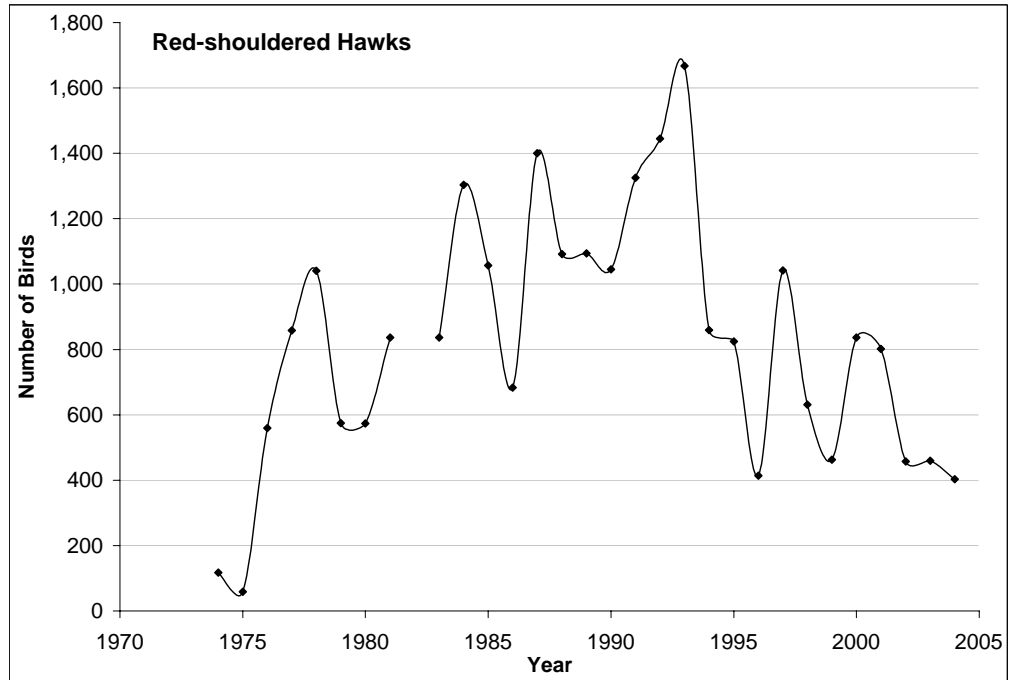


Figure 2. Red-shouldered hawk trend data from Holiday Beach, 1974-2004 (no data available for 1982).

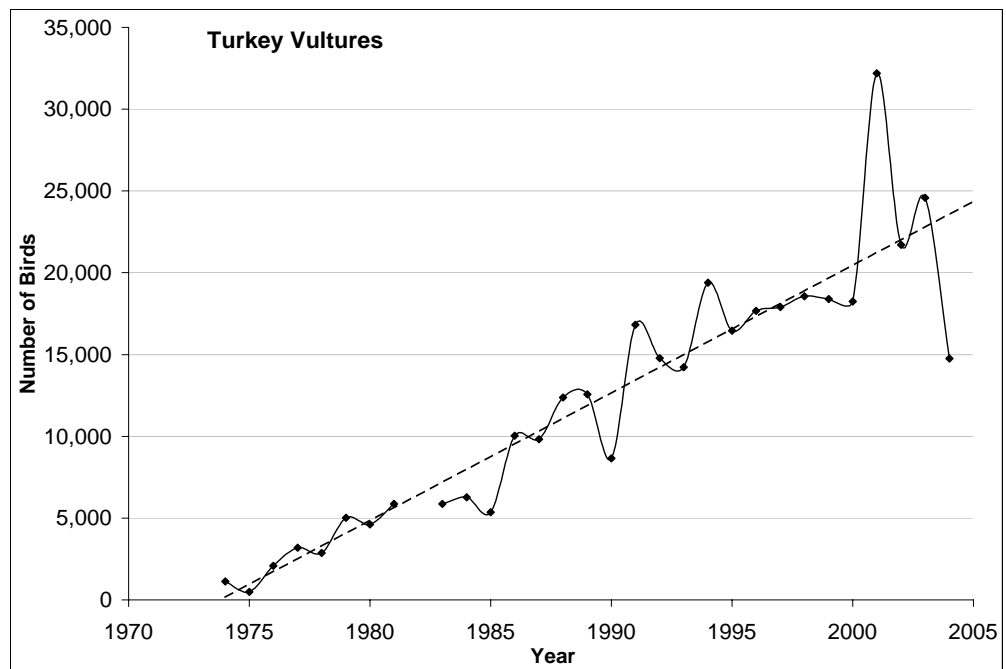


Figure 3. Turkey vulture trend data from Holiday Beach, 1974-2004 (no data available for 1982).

Figure 4 illustrates increases in numbers of peregrine falcons, ospreys, and bald eagles during the 30-year period, 1974-2004 (HBMO). Hawk watches throughout the Central Continental Flyway have also noted a similar increase (Berardi 2004). Ospreys and peregrine falcons were below their 10-year averages in 2004 (unlike SMRR's 2004 tally) by 27% and 30%, respectively. That same year, the bald eagle totals were approximately equal to their 10-year average.

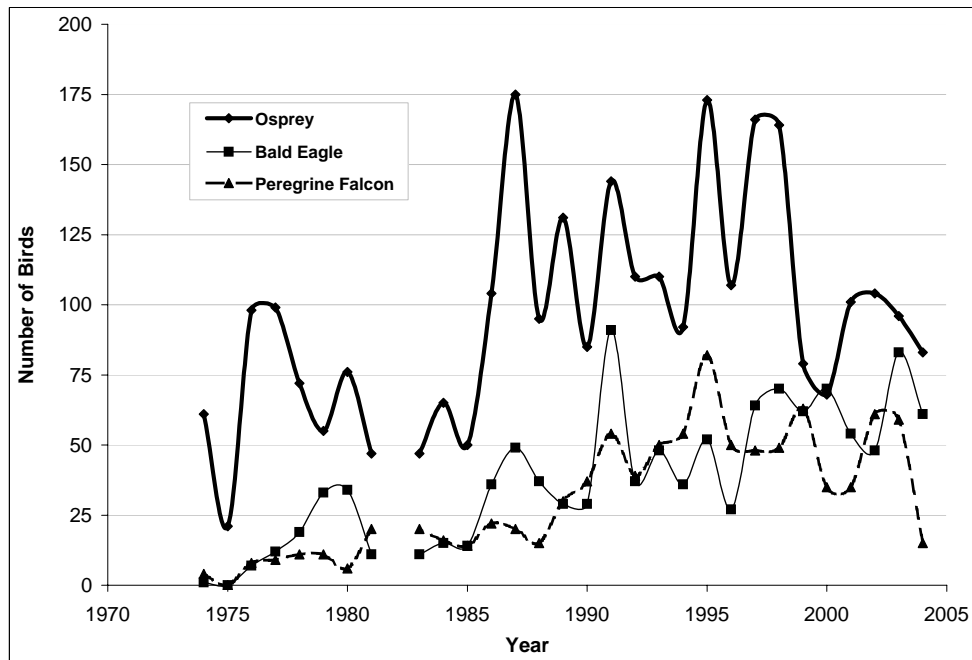


Figure 4. Osprey, bald eagle, and peregrine falcon trend data from Holiday Beach, 1974-2004 (no data available for 1982).

The sharp-shinned hawk is the most consistently observed raptor during the 92 days of the fall count season (Figure 5). Excluding days with severe weather (very high winds, thunderstorms, or driving rain), sharp-shinned hawks are recorded on 98% of the remaining count days. Figure 6 demonstrates that the yearly totals for this species are dramatically decreasing with 2004 being a record low count year. Even though wind direction does influence count totals, there is a real declining trend in sharp-shinned hawk numbers. This trend is recorded at many of the eastern count sites. Two factors



Figure 5. Sharp-shinned hawk (*Accipiter striatus*) (Photo credit: John Longhenry).

are thought to contribute to this decline. One is the possible reduction in prey species in their breeding range, since fall numbers reflect nesting success. The second factor may be that pesticide usage on their wintering areas in Central America is altering their reproductive success.

Management Next Steps

Reaching a goal of sustainable raptor populations will require increasing the carrying capacity in North America by improving the amount of foraging and nesting habitat through conservation and restoration. Because of the migratory nature of these birds, the populations will benefit most through an international conservation vision that includes both the breeding and wintering areas. Red-shouldered hawk management may require conservation and restoration of their preferred breeding habitats of damp woods, river bottomlands, and swamps with tall trees where birds can nest 6-20 meters (approximately 20-60 ft) above ground. Perches with a wide field of view could be constructed to assist the birds to hunt prey such as rodents, birds, frogs, and snakes (Fergus 2004).

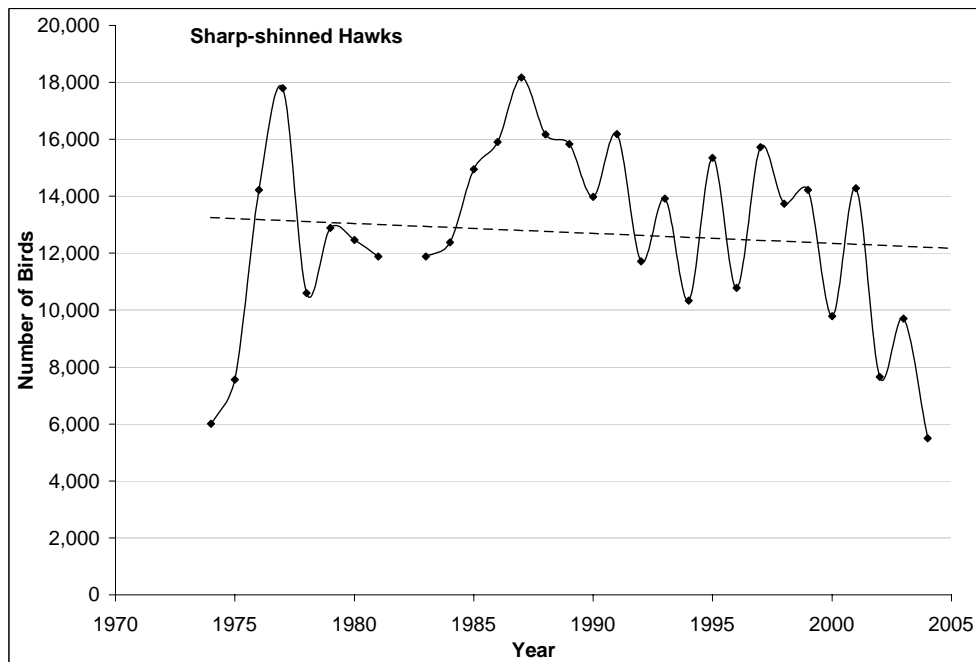


Figure 6. Sharp-shinned hawk trend data from Holiday Beach, 1974-2004 (no data available for 1982).

Research/Monitoring Needs

Monitoring consistently during fall migration should continue. Procedures and guidelines should be reviewed and updated each year. Improvements to the existing program should include more funding for paid staff (counters and banders), more educational opportunities for volunteers to maintain high standards of data collection, and more public outreach. Additional research efforts during the breeding season in north and northeastern Ontario could explain trends in population fluctuations (in particular, the red-shouldered hawk adult/immature ratios). Using radio-tagged birds would broaden our knowledge of the migration habits of each species. Increasing the number of raptor count sites would also help paint a broader picture of the scope of raptor migration and ultimately give us a more realistic view of their numbers.

Well-funded studies of the blood chemistry of migrating sharp-shinned hawks during their fall and spring passage need to be conducted to determine what foreign chemicals might be influencing reproductive success. Obtaining samples at both times of the year could show differences in the period of accumulation of any foreign material.

References

- Berardi, V. 2004. Fall 2003 Central continental flyway report. *HMANA Hawk Migration Studies* Vol. 29: No. 1.
- Chartier, A., and David Stimac. 2002. *Hawks of Holiday Beach: A Guide to Their Identification, Occurrence, and Habits at Holiday Beach Conservation Area, Ontario, Canada*. Second edition. Holiday Beach Migration Observatory.
- Fergus, C. 2004. Pennsylvania Game Commission. *Wildlife Notes*. <http://www.pgc.state.pa.us/pgc/cwp/view.asp?a=458&q=150468> (January 2006).

Links for More Information

Holiday Beach Migration Observatory (HBMO): <http://www.hbmo.org>

Southeastern Michigan Raptor Research (SMRR): <http://www.smrr.net/>

Hawk Migration Association of North America (HMANA): www.hmana.org

Contact Information

Bob Hall-Brooks, President
Holiday Beach Migration Observatory
E-mail Address: Bhall-brooks@cogeco.ca

Bob Pettit, Vice President and Raptor Co-Chair
Holiday Beach Migration Observatory
E-mail Address: redknot@earthlink.net

Jason Sodergren, Secretary and Raptor Co-Chair
Holiday Beach Migration Observatory
E-mail Address: Jason@taiga.com

INDICATOR: FALL RAPTOR MIGRATION OVER LAKE ERIE METROPARK

Background

The geography of the eastern Great Lakes, combined with the migratory preferences of North American birds of prey, provide unique opportunities to monitor the status and trends of raptor populations at the mouth of the Detroit River. The Detroit River is at the intersection of the Atlantic and Mississippi Flyways making it a unique area to survey migrating birds, especially raptors. As the raptors move south from their eastern Canadian breeding grounds, they are blocked by the north shore of Lakes Erie and Ontario. Thermals (rising columns of warm air) do not form over water so the birds are forced in one of two directions: east around Lake Ontario or west around Lake Erie. Those that move west follow the north shore of Lake Erie, until they reach the mouth of the Detroit River. Turning back is not an option so the birds fly over a 6-km (4-mile) span of water to southeast Michigan, specifically near Lake Erie Metropark and Pointe Mouillee State Game Area. They lose altitude as they cross, making it easier for them to be observed (Figure 1). Volunteer monitoring programs such as Southeastern Michigan Raptor Research (SMRR) and Holiday Beach Migration Observatory (HBMO) have proven invaluable in monitoring fall raptor migrations. Hawk watches are conducted yearly during the months of September, October, and November at specific places where raptors avoid the expansive lakes. A total of 23 raptor species have been observed (16 regularly occurring species).



Figure 1. Red-tailed hawk (*Buteo jamaicensis*) (Photo credit: Donald Metzner).

Status and Trends

The early seasons of hawk migration studies by SMRR were exploratory and the hours and count locations were not consistent. However, by 1991 they were more standardized, thus trend analysis begins with the 1992 season. All 16 regularly occurring species have increased since 1992 (though more detailed analysis to test for statistical significance is needed). Figure 2 illustrates a general upward trend of the red-shouldered hawk sightings (SMRR). While the trend is encouraging, the percentage of immature birds for 2001, 2002, and 2003 was 20%, 11%, and 21%, respectively (SMRR). These percentages of immature birds are low compared to other monitoring areas. The cause or causes of this lower than expected recruitment is unknown and likely requires research on their nesting grounds.

Figure 3 shows a significant increase in turkey vulture numbers (SMRR). In recent years this species has continuously broken records with every season that passes. In 2004, the count was 63% above the 10-year average with a high of 12,131 vultures seen in one day (Figure 4). Most hawk watches (all but one) throughout the Central Continental Flyway recorded increases as well (Berardi 2004).

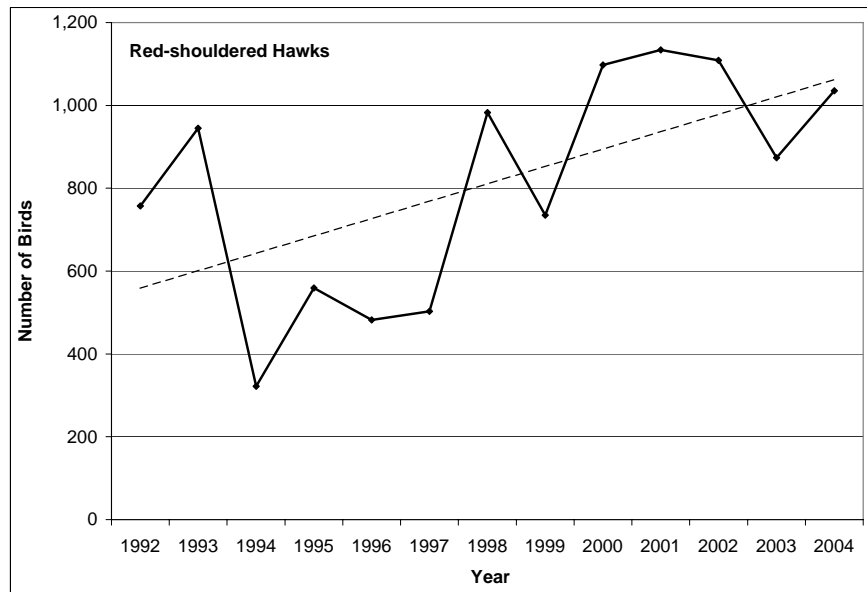


Figure 2. Red-shouldered hawk trend (1992-2004).

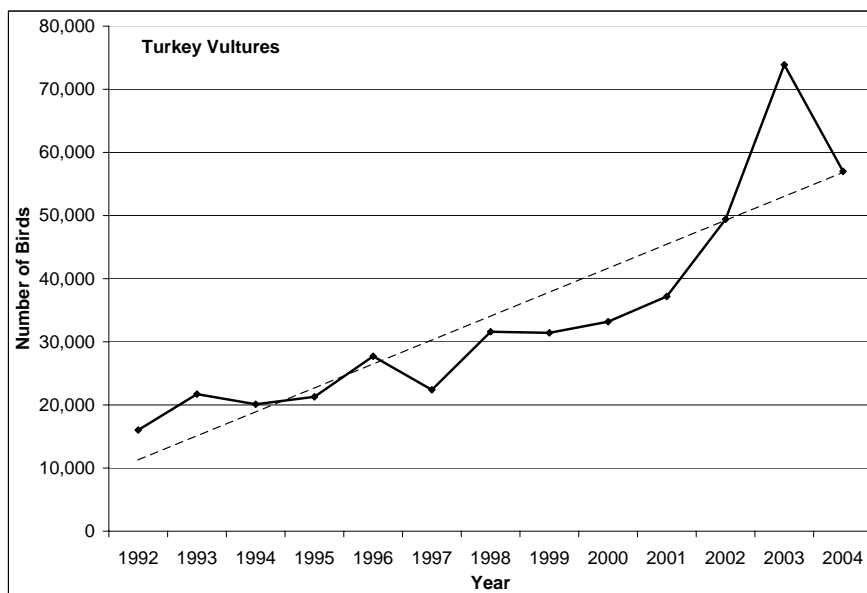


Figure 3. Turkey vulture trend (1992-2004).

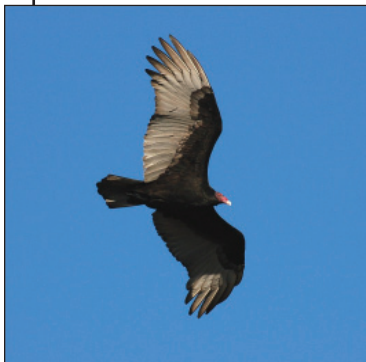


Figure 4. Turkey vulture (*Cathartes aura*) (Photo credit: Donald Metzner).

Figure 5 shows the substantial increases of peregrine falcons, ospreys, and bald eagles during the 13-year period on record (SMRR). Hawk watches throughout the Central Continental Flyway have noted this increase as well (Berardi 2004). Ospreys and bald eagles will spend considerable time in the study area; however, only migrating birds are counted because count protocols prevent the inclusion of nonmigrating and nesting birds. In 2004, ospreys and bald eagles were 65% and 69%, respectively, above their 10-year averages. In 2004, only 36 peregrine falcons were observed – this was 36% below the 10-year average.

The red-tailed hawk has shown a very stable population size since 1992 (Figure 6). Counts have fluctuated up and down, with no clear increasing or decreasing trend.

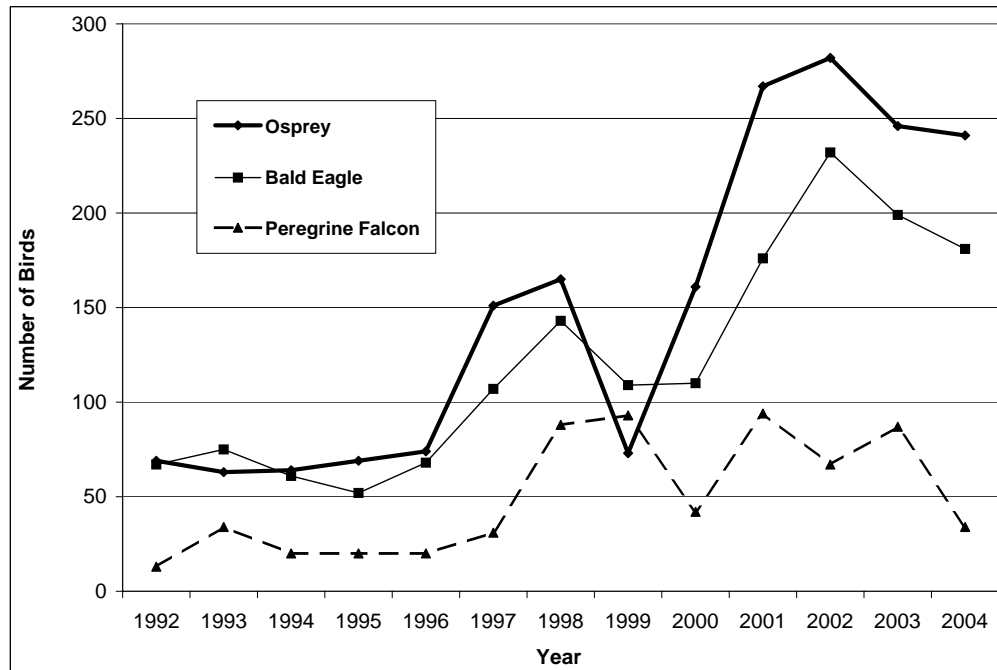


Figure 5. Osprey, bald eagle, and peregrine falcon trends (1992-2004).

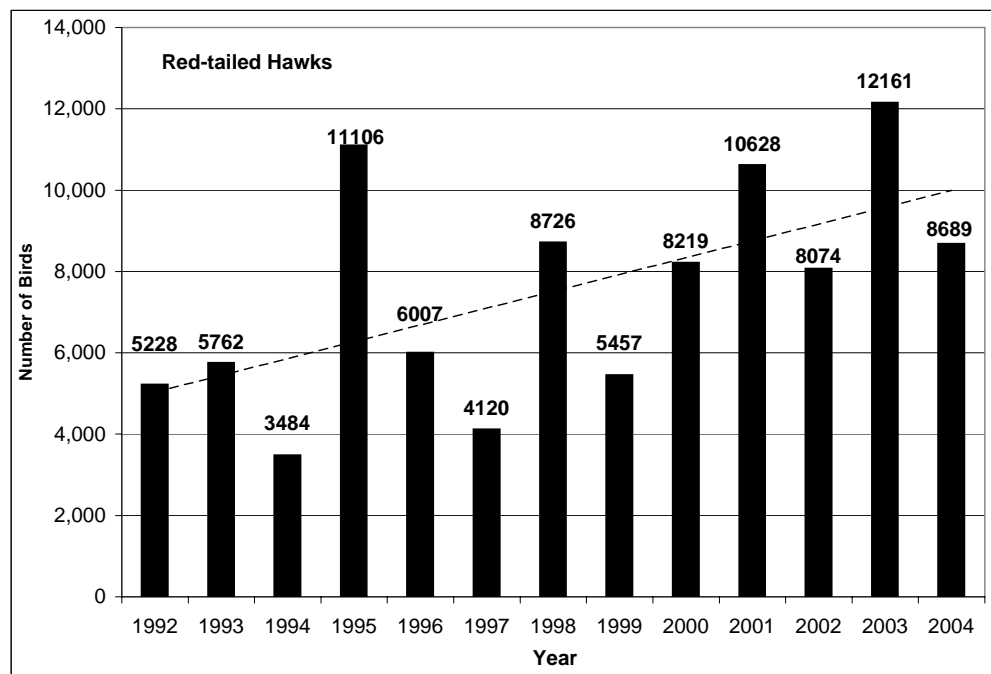


Figure 6. Red-tailed hawk trend (1992-2004).

Management Next Steps

Management for sustainable populations or healthy population sizes of these species must come from maintaining habitat for them in their breeding and wintering areas. This must be done and assessed specifically for each species because, although their populations are monitored altogether at these count sites, each species has unique habitat requirements, reproductive rates and sensitivities to environmental stressors. Management of the habitat in which these species spend the most time should include responding to issues involving habitat fragmentation, contaminants (both in habitat areas and adjacent lands), invasive species, and other disturbances both in the breeding and wintering areas.

Research/Monitoring Needs

Consistent SMRR monitoring should continue during fall migration. As at Holiday Beach Migration Observatory, improvements to the already existing program would include continued recruitment of volunteers, more funding to secure counters and banders, and more public outreach. Despite the “limited” size of the database, preliminary research efforts in eastern Canada might explain some trends that have already been noted (in particular, the red-shouldered hawk adult/immature ratios). Studies should be done to determine which raptor species are nesting in southeast Michigan, including identification of nest locations. More research needs to be undertaken to determine what environmental factors may be contributing to fluctuations in observed numbers. Input of data from all of the hawk watches across North America will aid in statistically defensible population indices so that we have knowledge of the health of these species both for their protection and for their contribution to our understanding of the many ecosystems they represent. This is currently being done by the Raptor Population Index – a project undertaken through a partnership between HMANA, Hawk Mountain Sanctuary, and HawkWatch International, and this research should continue.

References

Berardi, V. 2004. Fall 2003 Central continental flyway report. *HMANA Hawk Migration Studies* Vol. 29: No. 1.

[SMRR] Southeastern Michigan Raptor Research. 2005. Hawk migration studies by Southeastern Michigan Raptor Research at the Detroit River (Unpublished).

Fergus, C. 2004. Pennsylvania Game Commission. *Wildlife Notes*. <http://www.pgc.state.pa.us/pgc/cwp/view.asp?a=458&q=150468>

Links for More Information

Southeastern Michigan Raptor Research: <http://www.smrr.net/>

Holiday Beach Migration Observatory: <http://www.hbmo.org>

The Hawk Migration Association of North America (HMANA): www.hmana.org

Contact Information

Paul Cypher, President
Southeastern Michigan Raptor Research
E-mail Address: paulcypher@comcast.net

INDICATOR: PEREGRINE FALCON REPRODUCTION IN SOUTHEAST MICHIGAN

Background

Peregrine falcons (*Falco peregrinus*), known for their swift flight, have never been very abundant anywhere in the world due to very specific nest site requirements and their position at the top of the food web. A 1940 survey of eyries (nesting sites) estimated that the eastern U.S. population consisted of only 350 pairs. The upper Midwest population was estimated to be 109 pairs before a dramatic decline in the 1950s. Historically, there were 13 known eyries in Michigan, all located on cliffs in the Upper Peninsula (Huron Mountains, Pictured Rocks, Mackinac Island), except for some found in steep sand dunes on the Fox Islands in northern Lake Michigan. The last documented successful nesting in Michigan before restoration began was in 1957 at Burnt Bluff, a cliff on the Garden Peninsula in Delta County (Michigan Department of Natural Resources 2001).

During the 1950s, the world population of peregrines was decimated, mostly due to the use of pesticides like DDT. When DDE, the breakdown product of DDT, accumulates in the bodies of many birds, it causes them to lay thin-shelled eggs which break during incubation (Michigan Department of Natural Resources 2001). Studies show the peregrine falcon retains the highest DDT residue of all vertebrates, causing reproductive problems (Appel et al. 2002). A repeat of the 1940 survey of historically known eyries, conducted in 1964, found no breeding pairs or even a single adult peregrine falcon east of the Mississippi River. As a result, the peregrine falcon was listed as an endangered species by the U.S. Fish and Wildlife Service in 1970. The peregrine falcon was also included in the first list of endangered species promulgated under Michigan's Endangered Species Act in 1974 (Michigan Department of Natural Resources 2001).

By the 1970s, DDT had been banned in both Europe and the U.S., partially due to data linking it to the decline of the peregrine falcon. In 1981, the Midwest Peregrine Falcon Restoration Team was created and charged with the task of developing a management plan to restore peregrine falcons as a nesting bird population in the upper Midwest.

A highly successful program for Midwest reintroductions into urban environments was started in 1982. Peregrine chicks of captive adults were raised in artificial structures and subsequently released into their new urban environment. These new homes, including buildings of all shapes and sizes, bridges, and power plant stacks, were so successful that in 2005, over 90 Midwest cities had peregrine falcon nesting effort. Peregrines feed exclusively on other birds which are abundant in urban areas, such as rock pigeons, mourning doves, European starlings, northern flickers and American woodcocks (Appel et al. 2002). It is also thought that, as these "urban" raised peregrines expanded their territories, they would naturally seek out some of the natural, more traditional sites, such as cliffs in the Upper Peninsula of Michigan.

By 1991, over 3,000 captive-bred peregrines had been released throughout the U.S., including 400 in the upper Midwest and 139 in Michigan (108 in the Upper Peninsula and 31 in Grand Rapids and Detroit; Michigan Department of Natural Resources



Figure 1. Peregrine falcon (Falco peregrinus) (Photo credit: Paul Buxton).

2001). As of 2005 more than 20 peregrines have been observed either nesting or attempting to nest in southeast Michigan (Figure 1). Birds released from Sudbury, Ontario and Pittsburgh, Pennsylvania formed a pair that became the first to successfully nest in Michigan at the Book Building in downtown Detroit in 1993 (Yerkey 2004.)

The year 1999 will be recognized as a milestone year for the restoration of endangered species. On August 20th, the peregrine falcon was taken off the list of federally endangered species. This triumph is significant, due to the fact that the eastern population of peregrine falcons had been completely eliminated by the mid-1960s. At the time restoration began, the population of peregrines in the U.S. was probably down to approximately 10% of its original size (Michigan Department of Natural Resources 2001). Reintroducing captive-bred falcons into the wild has proven to be successful in restoring a population of peregrines that were produced in the wild.

Status and Trends

Michigan started the introduction program with a goal of establishing ten successful nesting pairs by 2000. The first release site was in 1986 at a Grand Rapids location. In 1987, five peregrine falcon young were released in downtown Detroit. In 1988, one sub-adult pair was present when the five chicks were released; however, this pair did not successfully nest. For the next four years, various pairs continued to “visit” each year with no nesting success. In 1993, two young peregrines were successfully raised, documented for the first time in Detroit’s history and the first in the Lower Peninsula in 37 years. The number of young produced in southeast Michigan increased from none in 1992 to a peak of 10 in 2005 (Figure 2).

From 1997 through 2004, there have consistently been four territories defended by peregrine pairs in southeast Michigan. In 2005, two new nesting sites were added totaling six territories. These six territories produced a total of 10 peregrine young that subsequently fledged. In 2001, surveys found 10 territorial pairs in Michigan fledging 13 young, while in 2005 there were 17 territorial pairs fledging 33 young (Tordoff et al. 2005). Southeast Michigan, especially for peregrines nesting along the Detroit River and its connecting waterways, is a significant part of the species’ habitat in Michigan. They have also begun nesting in Canadian urban centers such as London, Ontario (USFWS 2005).

Management Next Steps

In 1999, the U.S. Fish and Wildlife Service delisted the peregrine falcon as a federally endangered species. However, it remains protected federally under the Migratory Bird Treaty Act. In Michigan, peregrine falcons remain listed as an endangered species under state law.

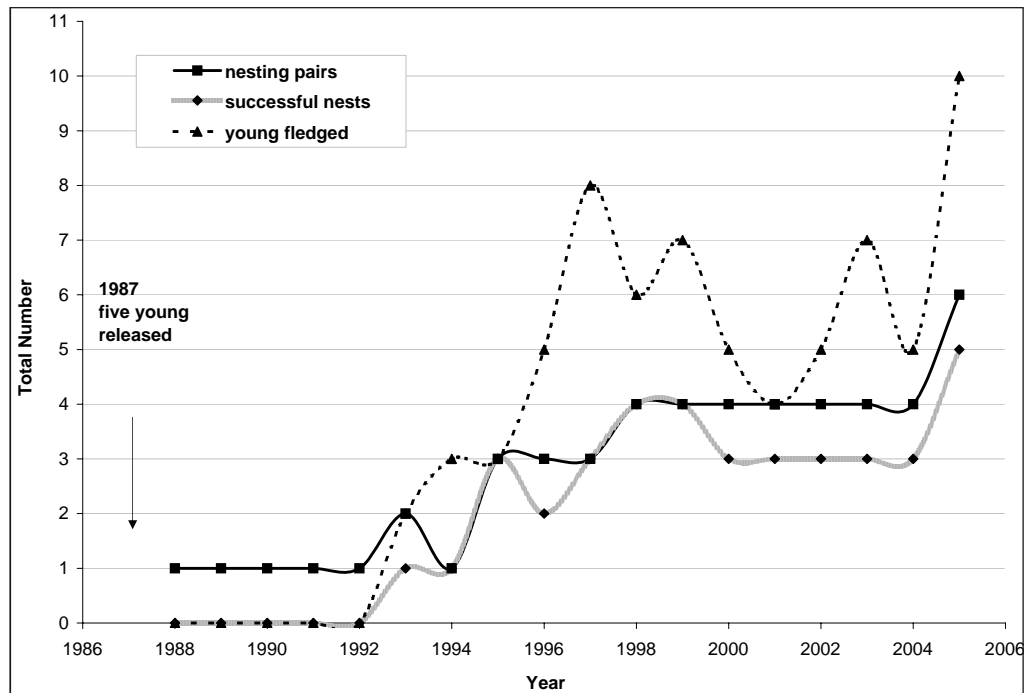


Figure 2. Southeast Michigan peregrine falcons' presence and reproduction success, 1988-2005. Reproductive success trends for nesting pairs, successful nests, and young fledged increased overall (data compiled by Judith M. Yerkey).

The goal of the Michigan Department of Natural Resources' Natural Heritage Program (nongame wildlife) is to maintain a population of at least 10 nesting pairs of peregrine falcons in Michigan.

The peregrine falcon is also identified as a Species of Greatest Conservation Need by the Michigan Wildlife Conservation Strategy (Eagle et al. 2005). Management strategies include:

- protecting and enhancing habitat (including artificial nests in the Detroit metropolitan area);
- minimizing disturbance and falcon mortality;
- monitoring contaminants, nesting success, and productivity; and
- continuing to protect peregrines through law enforcement, education, and public information.

Research/Monitoring Needs

The Michigan Department of Natural Resources has provided funding through its Natural Heritage Program to monitor falcon populations in the Detroit area and gain a better understanding of this species. With this funding and additional support, the current monitoring of the Detroit population should continue.

There have been cases of high mortality, likely caused by bad weather, incidental death, or predators, such as great horned owls, that put stress on the local population. More

research on the causes of mortality and the most effective means to decrease that mortality rate is required. Also, continued research of peregrine falcons throughout their current range could aid in a better understanding of nationwide environmental stressors and mortality. Additional research should be conducted on fledglings that are produced in Detroit and leave the area to determine the location of their nests and if they are reproducing successfully.

References

Appel, L.M., J.A. Craves, M.K. Smith, B. Weir, and J.M. Zawiskie. 2004. *Explore Our Natural World: A Biodiversity Atlas of the Lake Huron to Lake Erie Corridor*. Wildlife Habitat Council, Great Lakes Regional Office. Detroit, MI.

Eagle, A.C., E.M. Hay-Chmielewski, K.T. Cleveland, A.L. Derosier, M.E. Herbert, and R.A. Rustem. 2005. *Michigan's Wildlife Action Plan*. Michigan Department of Natural Resources. Lansing, MI.

Michigan Department of Natural Resources. 2001. Peregrine Falcon (*Falco peregrinus*) http://www.michigan.gov/dnr/1,1607,7-153-10370_12145_12202-32592~CI,00.html#Michigan%20History (February 2006).

Tordoff, H.B., J.A. Goggin, and J.S. Castrale. 2005. Midwest peregrine falcon restoration, 2005 report. <http://www.midwestperegrine.umn.edu/> (February 2006).

[USFWS] U.S. Fish & Wildlife Service. 2005. *Detroit River International Wildlife Refuge: Comprehensive Conservation Plan and Environmental Assessment*.

Yerkey, J.M. 2004. Southeast Michigan peregrines 1987-2004 ("An Overview"). Unpublished Report.

Links for More Information

U.S. Fish and Wildlife Service. American Peregrine Falcon: <http://www.fws.gov/endangered/i/B22.html>

University of Michigan Museum of Zoology: http://animaldiversity.ummz.umich.edu/site/accounts/information/Falco_peregrinus.html

Detroit Falcons, 2005: http://www.geocities.com/macomb_audubon/Falcon_Page_2005.htm

Contact Information

Judith M. Yerkey
Southeastern Michigan Peregrine Consultant
E-mail Address: anatumfalcon@nemichigan.com

Timothy Payne
Michigan Department of Natural Resources
E-mail Address: paynet@michigan.gov

INDICATOR: BALD EAGLE REPRODUCTIVE SUCCESS

Background

Bald eagles (*Haliaeetus leucocephalus*) are large fish-eating raptors, averaging 4.5-6.4 kg (10-14 lbs) for females and 3.6-4.1 kg (8-9 lbs) for males, with an approximate 2.1 meter (seven-foot) wingspan. They are classified and protected as provincially endangered in southern Ontario, state endangered in Ohio, and state threatened in Michigan. Recently (June 28, 2007) the bald eagle was removed from the federal list of threatened and endangered species in the U.S. The bald eagle continues to be federally protected in the U.S. under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act. The species has been identified as an indicator of aquatic ecosystem health in the Lake Erie Lakewide Management Plan and is under review for indicator status by the State of the Lakes Ecosystem Conference (Environment Canada and the U.S. Environmental Protection Agency 2003).

Bald eagles were documented in the early 1900s as being “evenly distributed” throughout Michigan. The population then declined through the mid-1900s due to loss of nesting habitat and persecution by humans (shooting, poisoning, trapping and electrocution). In the 1950s, the decline of eagles in Michigan accelerated until they were on the brink of extinction in the 1970s. This trend was similar throughout the lower 48 states and southern Canada. This decrease was a result of several factors, most influential being the increasing widespread use of organochlorine compounds such as DDT and PCBs following World War II (Colborn 1991; Bowerman et al. 1995; Bowerman et al. 1998; Bowerman et al. 2003). Exposure to these contaminants in avian species can cause effects in early developmental stages, including embryonic mortality, egg shell thinning, wasting syndrome in hatchlings, and life-threatening deformities such as crossed bills and embryonic edema to the head and neck. Several of these effects are considered the Great Lakes embryo mortality, edema, and deformities syndrome (GLEMEDS) found in colonial fish-eating birds (Gilbertson et al. 1991). Post-fledging effects may manifest as sterility, altered behaviors such as impaired foraging abilities, and increased susceptibility to disease through immune system dysfunction. Death can also result from acute poisoning.

Reproductive impairments were greatly evident in the mid-1970s and early 1980s, when bald eagles nesting along the Lake Erie shoreline experienced near complete reproductive failure. The foundation for the recovery of the species in the U.S. and throughout North America was initiated in 1972 with the banning of DDT usage in the U.S. by the U.S. Environmental Protection Agency, and in 1973 with the passage of the Endangered Species Act and its implementation by the U.S. Fish and Wildlife Service. In 1973, the bald eagle was declared an endangered species in Ontario. With these protections and ensuing management, the bald eagle population along the Detroit River and Lake Erie shoreline has shown continual growth and improvement in reproductive performance.

Geographic Area of Coverage

For the purpose of this indicator report, the geographic area of coverage includes the Detroit River corridor and the western basin of Lake Erie, extending on the north shore to Point Pelee, Ontario, on the south shore to Vermillion, Ohio, and including all islands within the western basin (Figure 1). The results of long-term reproductive monitoring are summarized below for all bald eagles nesting within 8 km (5 miles) of all shorelines and embayments within this geographic area. It does not include eagles nesting greater than 8 km (5 miles) from the shorelines, where exposure to Great Lakes contaminants occurs through their being situated along water courses that support spawning runs of Great Lakes fishes.

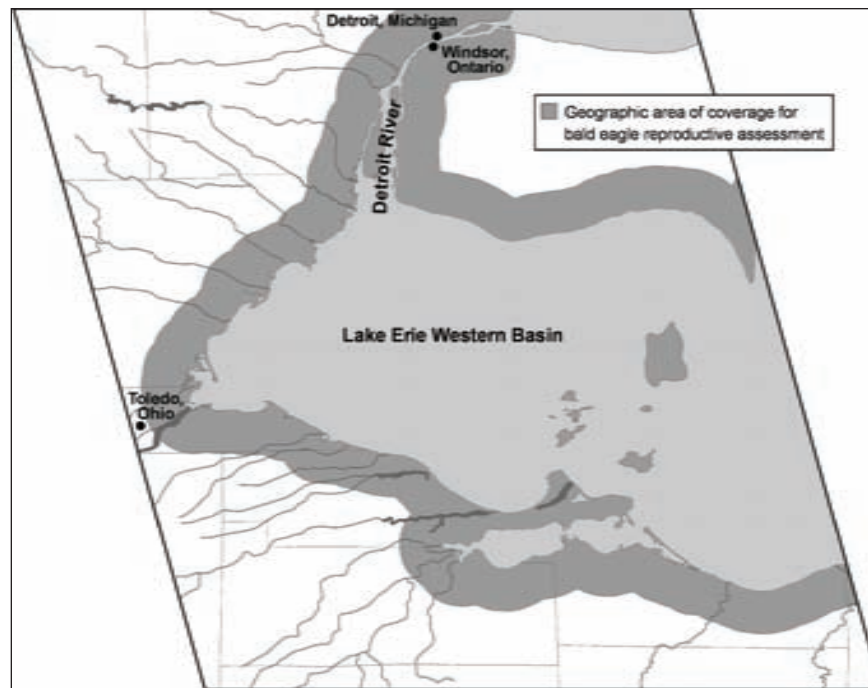


Figure 1. Geographic area of coverage for bald eagle reproductive assessment.

Nomenclature

For the purpose of this report, a breeding area is the territory maintained by a pair of adult eagles during the breeding season, and contains one or more alternative nests. A breeding area is deemed occupied when behaviors and/or activities associated with reproduction are observed. These observations may include the presence of fresh lining in a nest, the construction of a new nest, the detection of eggs, incubation, or young, the observation of courtship flights or copulation, or the presence of two adults in close proximity to a nest. A breeding area is deemed inactive if no signs of reproductive efforts are noted, despite the presence of one or two adults in the general area. A successful breeding area is one that is known or suspected to have fledged one or more eaglets.

Status and Trends

Bird Studies Canada (BSC), in partnership with the Ontario Ministry of Natural Resources and Canadian Wildlife Service, coordinates a research and monitoring program in southern Ontario which monitors the health of the southern Ontario bald eagle population. The status and productivity of every bald eagle nest on the north shores

of Lakes Erie, Ontario, and Huron are monitored annually using a network of volunteer nest monitors and landowners. While most nests are monitored from the ground, special aerial surveys occasionally have been conducted in Essex County to assess nests that are difficult to view from the ground. Presently, nests are accessed every five years to obtain blood and feather samples.

In Michigan, the Michigan Departments of Natural Resources and Environmental Quality and the U.S. Fish and Wildlife Service coordinate a monitoring program aimed at assessing the health of bald eagles. In Ohio, the Ohio Department of Natural Resources conducts annual reproductive assessments of bald eagles. Data are compiled from a combination of fixed-wing aircraft and helicopter surveys, and citizen reports.

The data collected by these monitoring programs show that the number of occupied breeding areas in southern Ontario, Ohio, and Michigan within 8 km (5 miles) of the Detroit River and western Lake Erie basin has increased over the last two decades (Figure 2). The increase has been most apparent in Ohio, where the number of occupied breeding areas has increased from zero in 1974 to 44 in 2006. Increases in occupation have also occurred in Michigan and Ontario, but to a lesser extent. The Sandusky Bay area in Ohio served as an eagle “refugia” in the lower Great Lakes during the 1970s, and thus helped fuel the later reoccupation and expansion of the shorelines in these other areas.

From 1961 to 1987 there were no bald eaglets produced in Michigan primarily due to the absence of breeding pairs (Figure 3). Since the mid-1980s, there has been a steady increase in the number of fledgling bald eaglets throughout the geographic area of coverage, with Ohio fledging over 60 young in 2006. The fledging of eaglets in Michigan and Ontario has also increased, but to a lesser extent than in Ohio, and appears to have leveled off.

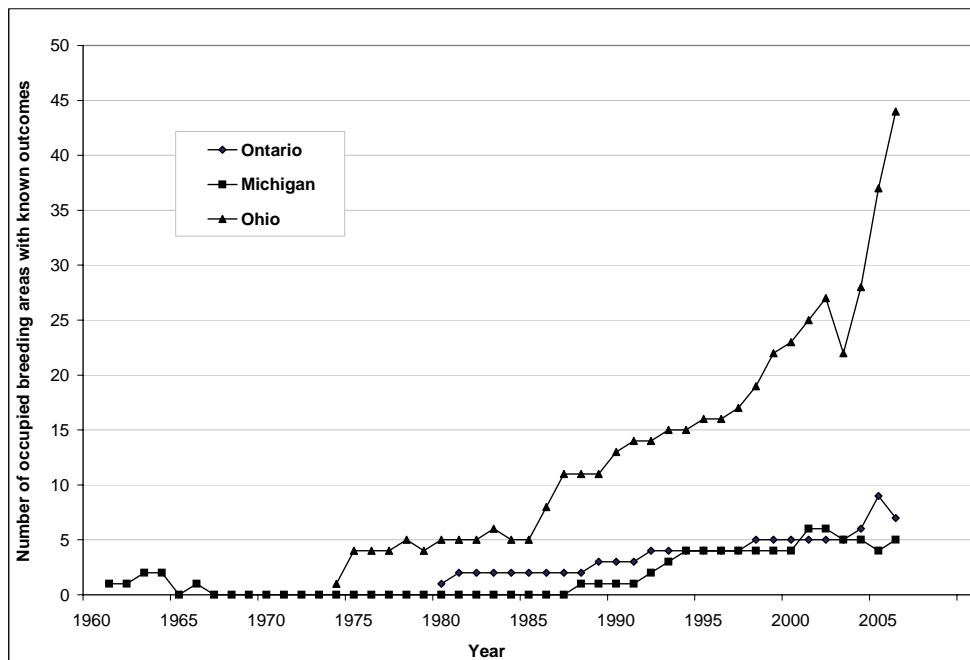


Figure 2. The number of occupied bald eagle breeding areas within 8 km (5 miles) of the Detroit River and western basin of Lake Erie, 1961-2006 (data collected by Bird Studies Canada, U.S. Fish and Wildlife Service, Michigan Departments of Natural Resources and Environmental Quality, and Ohio Department of Natural Resources; data compiled by D. Best, U.S. Fish and Wildlife Service).

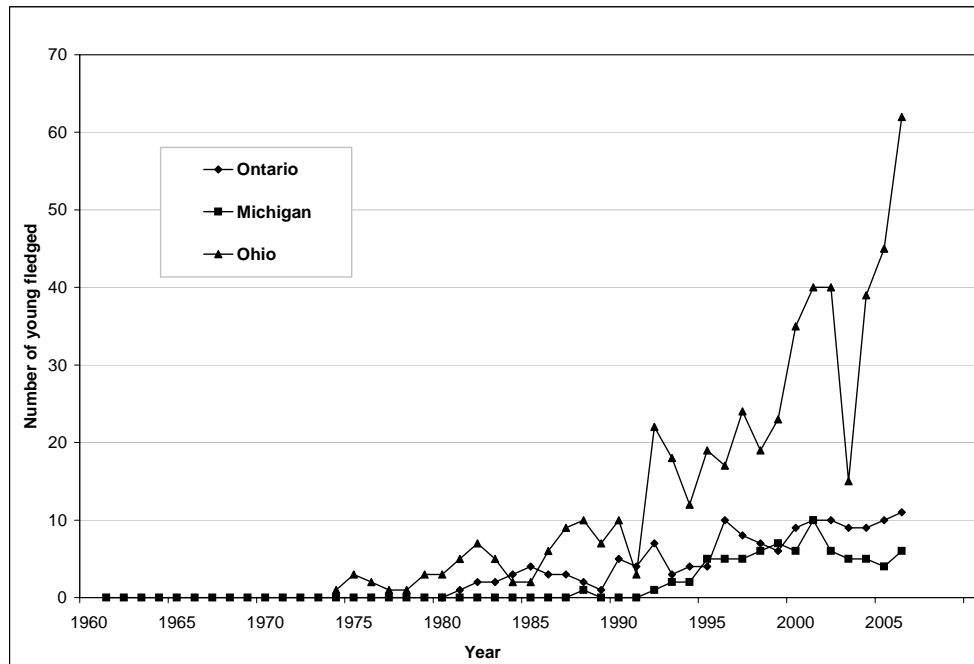


Figure 3. The number of eaglets fledged within 8 km (5 miles) of the Detroit River and western basin of Lake Erie, 1961-2006 (data collected by Bird Studies Canada, U.S. Fish and Wildlife Service, Michigan Departments of Natural Resources and Environmental Quality, and Ohio Department of Natural Resources; data compiled by D. Best, U.S. Fish and Wildlife Service).

In 2004, there were six occupied breeding areas in the geographic area of coverage in Ontario. This included four bald eagle nests found on the Canadian side of the Detroit River and an additional two nests along the north shore of the western basin of Lake Erie (i.e., Essex County). Two of these nests have been active since the early 1980s and two have been active since the early 1990s (Laing and Badzinski 2006). In 2005, the number of occupied breeding areas in the area of coverage rose to ten.

While these trends are suggestive of an improving situation, they can be misleading since they do not measure actual reproductive rates of performance. For a long-lived species like the bald eagle, repeated failures over time may not result in the abandonment of breeding areas. In addition, if the number of breeding areas over a period of time is growing faster than the number of eaglets fledged, then the rate of fledging young per nesting effort is actually declining. Therefore, true measures of reproductive performance need to be calculated from three monitoring outcomes: the number of occupied breeding areas, the number of eaglets fledged, and the number of successful breeding areas.

Within the geographic area of coverage, the number of eaglets fledged per occupied breeding area has increased over time (Figure 4) with Michigan lagging slightly behind Ontario and Ohio. For purposes of comparison, Sprunt et al. (1973) considered a rate of reproduction equal to 0.7 young fledged per occupied breeding area as representing a stable population. As a population exhibits increasing rates of reproduction above this level, the population will show expansion and improved health. The U.S. recovery goal for the northern states geographic area is 1.0 young fledged per occupied breeding area (Grier et al. 1983) and is generally considered to represent a healthy expanding population. Whereas eagles once reproduced poorly within the area of coverage, they now seem to be reproducing at healthy levels and promoting further expansion.

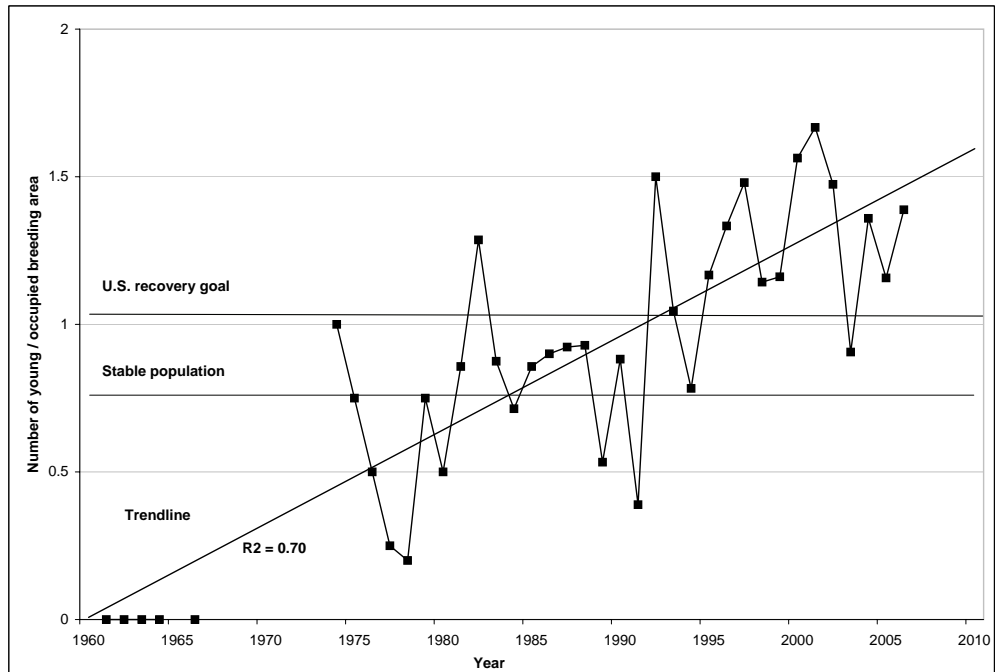


Figure 4. The number of eaglets fledged per occupied breeding area within 8 km (5 miles) of the Detroit River and western basin of Lake Erie, 1961-2006 (data collected by Bird Studies Canada, U.S. Fish and Wildlife Service, Michigan Departments of Natural Resources and Environmental Quality, and Ohio Department of Natural Resources; data compiled by D. Best, U.S. Fish and Wildlife Service).

Similar trends are exhibited by eagles within the geographic area of coverage in the number of eaglets fledged per successful breeding area, i.e., brood size (Figure 5) and in the success rate of occupied breeding areas (Figure 6). Sprunt et al. (1973) considered a success rate of 50% as representing a stable population.

Eagles within the area of coverage have exceeded this success rate for the past 12 years. All three measures of reproduction show considerable year-to-year variability, which may be attributable to differences in winter/spring weather, storm events, prey abundance and availability, human recreational activities, and other episodic factors.

The increase in the bald eagle reproductive parameters and the concurrent decline of organochlorine contaminants suggest the population is recovering in many parts of the lower Great Lakes (Bowerman et al. 2002). While the reoccupation of breeding habitat by bald eagles and the improved reproductive performance along the western basin of Lake Erie and the Detroit River corridor are positive signs, there are several factors which may confound the true situation. Since the mid-1980s, a large number of uncontaminated eaglets have been introduced to the Lake Erie watershed through hacking and fostering projects in both Ontario and Ohio. The apparent increase in nesting success in the period that followed may be associated more with the sexual maturation of this relatively clean, introduced cohort than with the eaglets locally reared and exposed to in-place contaminants.

Secondly, there are concerns about the viability and long-term stability of the bald eagle population along the Great Lakes shorelines. The large increase in the population of eagles across North America, and especially in inland areas adjacent to the Great Lakes,

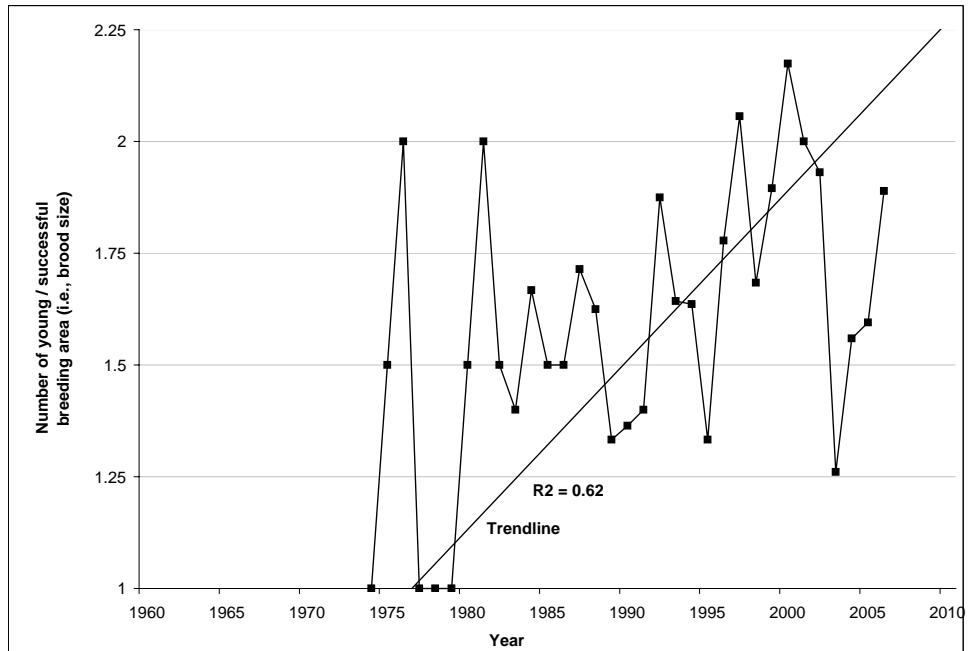


Figure 5. The number of eaglets fledged per successful breeding area, or brood size, within 8 km (5 miles) of the Detroit River and western basin of Lake Erie, 1961-2006 (data collected by Bird Studies Canada, U.S. Fish and Wildlife Service, Michigan Departments of Natural Resources and Environmental Quality, and Ohio Department of Natural Resources; data compiled by D. Best, U.S. Fish and Wildlife Service).

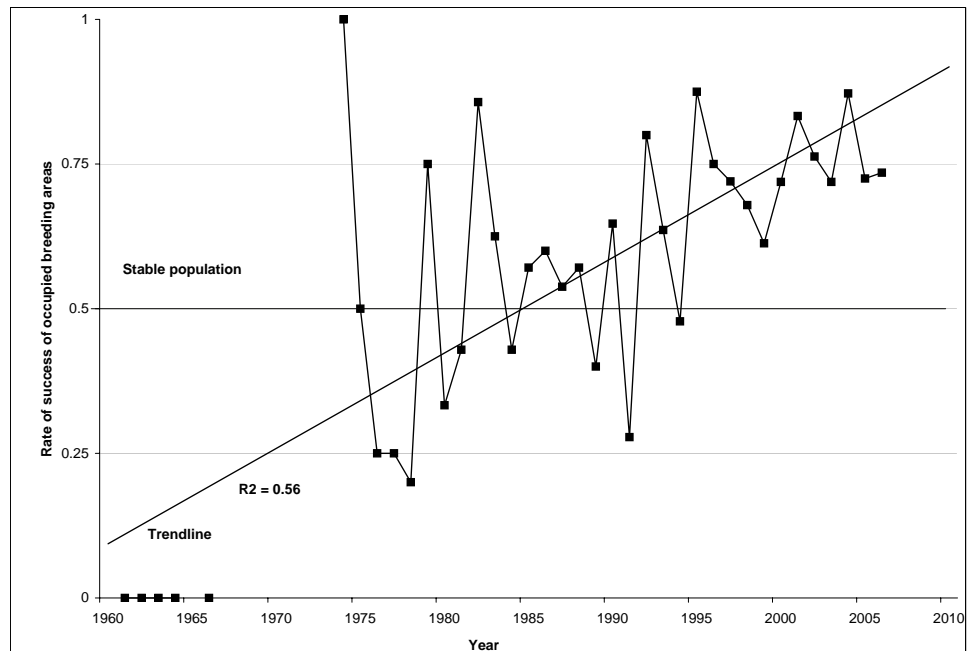


Figure 6. The rate of success of occupied breeding areas within 8 km (5 miles) of the Detroit River and western basin of Lake Erie, 1961-2006 (data collected by Bird Studies Canada, U.S. Fish and Wildlife Service, Michigan Departments of Natural Resources and Environmental Quality, and Ohio Department of Natural Resources; data compiled by D. Best, U.S. Fish and Wildlife Service).

has created a large pool of young eagles dispersing to find suitable and unclaimed nesting habitat. The possibility exists that the growth of the eagle population within the geographic area of coverage is dominated by immigration from clean, nearby inland areas. Observations of nest turnover rates, collected by volunteer nest monitors, suggest that bald eagles in southern Ontario have shortened life spans (Laing and Badzinski 2006). This is also suspected for the eagles located throughout the coastal areas of Ohio and Michigan (Grasman et al. 2000). Therefore, these shorelines may serve as a sink for excess eagles, rather than a source for expansion. In addition to these confounding factors, eagles continue to be vulnerable to human disturbance, in-place and new-generation contaminants, and ongoing habitat loss.

The potentially long life span of bald eagles and their upper trophic-level status within aquatic ecosystems make the species a good indicator of exposure to bioaccumulative contaminants. Grasman et al. (2000) suggest that reproductive impairments to bald eagles on Lake Erie continue to occur as a result of current exposure to organochlorine compounds within the aquatic ecosystem. The analysis of addled bald eagle eggs from Ontario and Ohio shows that criteria for adverse effects are consistently exceeded by total PCB and dieldrin concentrations, and often exceeded by *p,p'*-DDE concentrations. Roe (2004) found spatial differences in exposure to various organochlorine compounds in bald eaglet blood plasma, with lower concentrations detected in eaglets from Sandusky Bay than in eaglets from other areas along the Lake Erie shoreline of Ohio. Bald eaglets from Lake Erie exhibit rates of hard-tissue deformity, such as crossed bills, greatly above background levels in birds (Grasman et al. 2000). Future versions of this indicator report will present and discuss these and current exposure data in more detail relative to ecosystem health.

Management Next Steps

Agencies and organizations with land management responsibilities should identify, enhance and protect bald eagle habitat where feasible within the Detroit River-Lake Erie basin. In addition, the placement of nesting platforms in suitable and secure habitat may provide stability over time to existing breeding pairs, as well as induce additional breeding pairs to establish within the river corridor. Efforts should be undertaken to identify and protect suitable nesting and foraging habitats.

Provincial, state and federal agencies should continue to place a priority on control of contaminants at the source and on the remediation of contaminated sediment “hot spots,” to ultimately ensure that contaminant levels in fish and other aquatic prey do not result in reproductive impairment of bald eagles. Further, bald eagles should continue to be protected through federal, state and provincial law enforcement efforts, in light of delisting of the species from endangered species protections as progress toward recovery continues. The species will also benefit from increased public outreach and awareness of the threats to the health of the species and the ecosystem.

Research/Monitoring Needs

Grasman et al. (2000) identified the need to continue studies along Lake Erie on reproductive success, deformities, and contaminant concentrations in blood and addled eggs. Yearly monitoring of the bald eagle population for reproductive outcomes should continue throughout the Detroit River and western Lake Erie watersheds in Ontario,

Ohio, and Michigan. Eaglets should continue to be banded and have representative samples taken to monitor exposure to contaminants, so as to determine the health status of individual eagles and the ecosystems in which they reside. Contaminants of concern include organochlorine compounds and heavy metals, as well as emerging new-generation compounds. Furthermore, additional laboratory and field studies may be necessary to further clarify the role of environmental endocrine disruptors on reproduction in avian populations (Bowerman et al. 2000).

Grasman et al. (2000) identified the need for dispersal/recruitment studies along Lake Erie to address issues regarding the perceived high turnover rate of adult eagles, the survival and reproductive success of eagles exposed to developmental toxins, and the rates of immigration from inland to shoreline areas. In 2004, BSC in partnership with the Ontario Ministry of Natural Resources and Canadian Wildlife Service launched a new program called *Destination Eagle* to address the question of where juvenile eagles are becoming exposed to heavy metals. This was based on elevated levels of mercury and lead detected in tissues derived from necropsied eagles from southern Ontario. This program uses satellite telemetry to follow the movements of juvenile eagles for a five-year period. The goal is to identify areas where juvenile birds fledged from southern Ontario nests are spending the majority of their time, and perhaps becoming exposed to harmful contaminants. Between 2004 and 2006, a total of ten nestling bald eagles have been equipped with satellite telemetry. However, only three of these eaglets were fledged from within the geographic area of coverage. Preliminary results have shown that fledgling eaglets often wander great distances, but have used coastal marshes and embayments within the geographic area of coverage. This project aims to reveal important information on the movements of juvenile eagles and to increase public awareness of the importance of aquatic ecosystem health (Laing and Badzinski 2006).

References

- Bowerman, W.W., J.P. Giesy, D.A. Best, and V.J. Kramer. 1995. A review of factors affecting productivity of bald eagles in the Great Lakes region: Implications for recovery. *Environmental Health Perspectives* 103 (Suppl. 4):51-59.
- Bowerman, W.W., D.A. Best, T.G. Grubb, G.M. Zimmerman, and J.P. Giesy. 1998. Trends of contaminants and effects in bald eagles of the Great Lakes Basin. *Environmental Monitoring and Assessment* 53:197-212.
- Bowerman, W.W., D.A. Best, T.G. Grubb, J.G. Sikarskie, and J.P. Giesy. 2000. Assessment of environmental endocrine disruptors in bald eagles of the Great Lakes. *Chemosphere* 41:1569-1574.
- Bowerman, W.W., A.S. Roe, M.J. Gilbertson, D.A. Best, J.G. Sikarskie, R.S. Mitchell, and C.L. Summer. 2002. Using bald eagles to indicate the health of the Great Lakes' environment. *Lakes and Reservoirs: Research and Management* 7:183-187.
- Bowerman, W.W., D.A. Best, J.P. Giesy, M. Shieldcastle, M.W. Meyer, S. Postupalsky, and J.G. Sikarskie. 2003. Associations between regional differences in polychlorinated biphenyls and dichlorodiphenyldichloroethylene in blood of nesting bald eagles and reproductive productivity. *Environmental Toxicology and Chemistry* 22:371-376.
- Colborn, T. 1991. Epidemiology of Great Lakes bald eagles. *Journal of Toxicology and Environmental Health* 33:395-453.

Environment Canada and the U.S. Environmental Protection Agency. 2003. *State of the Lakes 2003*. Environment Canada and the U.S. Environmental Protection Agency, En40-11/35-2003E.

Gilbertson, M., T. Kubiak, J. Ludwig, and G. Fox. 1991. Great Lakes embryo mortality, edema, and deformities syndrome in colonial fish-eating birds: Similarity to chick-edema disease. *Journal of Toxicology and Environmental Health* 33:455-520.

Grasman, K., C. Bishop, W. Bowerman, J. Ludwig, and P. Martin. 2000. Executive summary: Animal deformities or reproductive problems. Lake Erie Lakewide Management Plan, Technical Report No. 7.

Grier, J.W., J.B. Elder, F.J. Gramlich, N.F. Green, J.B. Kussman, J.E. Mathisen, and J.P. Mattsson. 1983. *Northern States Bald Eagle Recovery Plan*. U.S. Department of the Interior-Fish and Wildlife Service, Washington DC.

Laing, D.K., and D.S. Badzinski. 2006. Southern Ontario bald eagle monitoring program, 2005 final report. Bird Studies Canada. Unpublished Report.

Roe, A.S. 2004. Spatial and temporal analyses of environmental contaminants and trophic status of bald eagles in the Great Lakes region. Unpubl. Ph.D. Dissertation, Clemson University, SC.

Sprunt, A., W.B. Robertson, S. Postupalsky, R.J. Hensel, C.E. Knoder, and F.J. Ligas. 1973. Comparative productivity of six bald eagle populations. *Transcontinental North American Wildlife Conference* 38:96-106.

Links for More Information

Bird Studies Canada: <http://www.bsc-eoc.org/regional/ondesteagle.html>

U.S. Fish and Wildlife Service: http://ecos.fws.gov/species_profile/servlet/gov.doi.species_profile.servlets.SpeciesProfile?spcode=B008

Michigan Department of Natural Resources: <http://www.michigan.gov/dnr/0,1607,7-153-10319-32581~,00.html>

Ohio Department of Natural Resources: <http://www.dnr.state.oh.us/wildlife/Resources/Eagle/default.htm>

Contact Information

Dave Best
U.S. Fish and Wildlife Service
Environmental Contaminants Program
E-mail Address: dave_best@fws.gov

Report written by:

D.A. Best, U.S. Fish and Wildlife Service, Environmental Contaminants Program,
East Lansing Ecological Services Field Office, MI.

E. Wilke, U.S. Fish and Wildlife Service, Detroit River International Wildlife Refuge,
MI.

INDICATOR: ASTHMA HOSPITALIZATION RATES IN WAYNE COUNTY, MICHIGAN

Background

Asthma is a chronic lung condition characterized by inflammation in the airways. Chronically inflamed airways are hyperresponsive; they become obstructed and airflow is limited when airways are exposed to various risk factors. This is caused by constriction of bronchial tissue, mucus plugs, and increased inflammation. Episodes or “attacks” of asthma are attributed to exposure to triggers that lead to constriction of the bronchial tissue, resulting in wheezing, breathlessness, chest tightness, and coughing, particularly at night or in the early morning. Asthma cannot be cured, but it can be controlled through avoidance of triggers, monitoring lung function, and appropriate use of medications (National Heart, Lung, and Blood Institute 2006).

Environmental factors that can affect asthma are present in both indoor and outdoor environments. Indoor factors can be irritants (e.g., gases like nitrogen dioxide, volatile and chemical compounds, small particles, tobacco smoke, and household dust) and allergens (e.g., primarily biological material such as pet dander, insect particles, pollen, bacteria, and mold) that cause an immune reaction in people who are sensitive. Outdoor factors are air pollutants that can be separated into two main groups: criteria pollutants and hazardous air pollutants. Criteria pollutants include six compounds (ozone, particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead) of which ozone and particulate matter (or particle pollution) are most commonly linked with triggering symptoms of asthma in patients (Centers for Disease Control and Prevention 2005). Other asthma triggers include weather conditions, certain medications, exercise, strong emotions, foods, respiratory infection and other non-environmental triggers.

Routine air quality monitoring for particulate matter and ozone is performed in southeast Michigan. An American Lung Association (ALA) “State of the Air 2005” report (ALA 2005) showed that Detroit is one of the 25 most polluted U.S. cities by year-round fine particulate matter (particulate matter that is equal to or less than 2.5 μm in diameter [$\text{PM}_{2.5}$]). Furthermore, according to the ALA (ALA 2005), Detroit is also one of the 25 most ozone-polluted cities in the U.S. Clearly, much needs to be done in the Detroit Metropolitan Area to identify environmental factors that contribute to asthma attacks in this region and to reduce exposure to people. Based on asthma research, the U.S. Environmental Protection Agency (2006) has concluded the following:

- Exposure to air pollutants such as ground-level ozone can put both children and adults at greater risk of developing asthma;
- People with asthma are more severely affected by ozone and particulate matter than people without the disease;

- Children may develop allergies that are strongly associated with asthma due to exposure to metals (such as copper and zinc found in particulate matter) and to pollutants such as ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead at levels below the National Ambient Air Quality Standards; and
- There is greater prevalence and severity of asthma in the poorer socioeconomic groups, which is at least partially attributed to indoor air quality, and possibly to lack of proper nutrition.

Status and Trends

Asthma affects 20 million people in the United States (National Center for Health Statistics 2006). Over 701,000 adults and over 230,000 children currently have asthma in Michigan (Michigan Department of Community Health 2005). On average, rates for hospitalization due to asthma in Wayne County are over 75% higher than in the state of Michigan as a whole (Figure 1). In addition, rates of asthma hospitalization in Wayne County show no appreciable change since 1990, while the asthma rates of hospitalization statewide show an overall decline since 1990 (Figure 1).

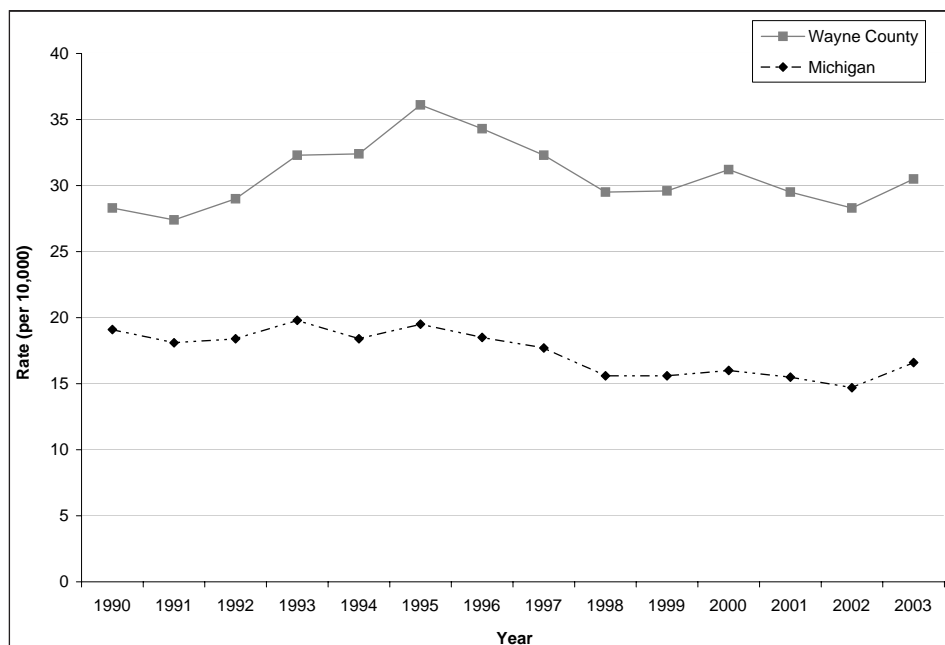


Figure 1. Annual hospitalization rates (age-adjusted) due to asthma (per 10,000 population) for Wayne County and the state of Michigan (all ages) from 1990 to 2003 (data from Michigan Inpatient Database, Bureau of Epidemiology, Michigan Department of Community Health [2005]). Note that asthma hospitalization was defined as a primary discharge diagnosis.

The U.S. Department of Health and Human Services (2000) has developed Healthy People 2010 — a set of disease prevention and health promotion objectives for the nation to achieve by the year 2010. Objective 24-2 of Healthy People 2010 gives the following target rates of asthma hospitalization by age group:

- Age 0-4 years: 25 per 10,000 people

- Age 5-64 years: 7.7 per 10,000 people
- Age ≥ 65 years: 11 per 10,000 people

Based on asthma hospitalization rates for 2000-2002, both Wayne County and the state of Michigan are significantly higher than the Healthy People 2010 targets established for all age groups (Figure 2; Michigan Department of Community Health 2005).

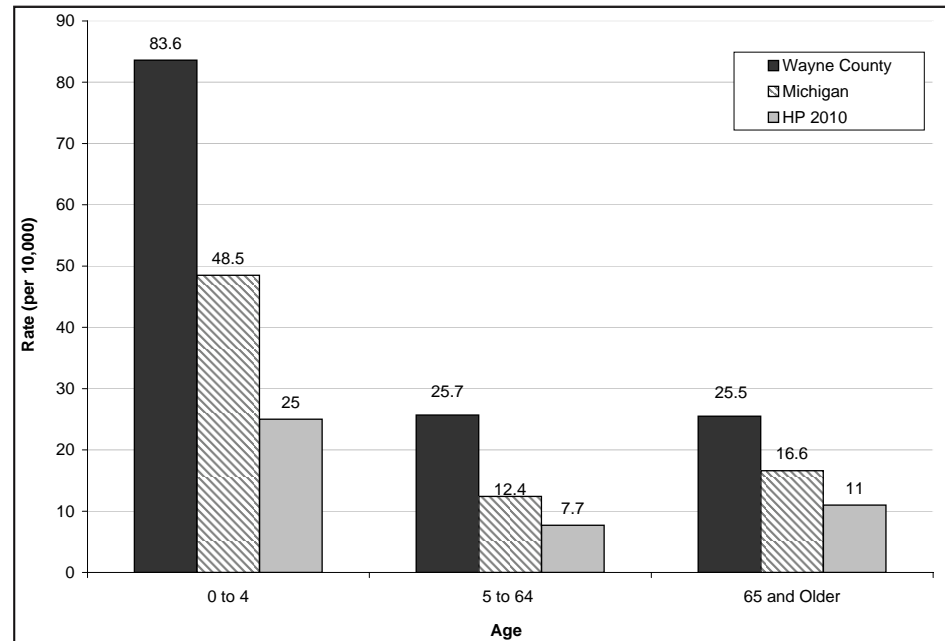


Figure 2. A comparison of asthma hospitalization rates (age-adjusted) in Wayne County and the state of Michigan from 2000-2002 with Healthy People 2010 targets by age group (data from Michigan Inpatient Database, Bureau of Epidemiology, Michigan Department of Community Health [2005]). Note that asthma hospitalization was defined as a primary discharge diagnosis.

Management Next Steps

Rates of asthma hospitalization continue to disproportionately impact Wayne County populations. The initial onset of asthma cannot be cured (Centers for Disease Control and Prevention 2005). However, asthma can be controlled, and people who have asthma can live symptom-free lives. Asthma can be controlled by following a medical management plan and by avoiding contact with known triggers.

The Centers for Disease Control and Prevention created the National Asthma Control Program in 1999. The program supports the goals and objectives of Healthy People 2010 for asthma and is based on the following three public health principles:

1. Surveillance: collecting and analyzing data on an ongoing basis to understand the “who, what, and where” of asthma;
2. Interventions: ensuring that scientific information is translated into public health practices and programs to reduce the burden of asthma; and
3. Partnerships: ensuring that all stakeholders have the opportunity to be involved in developing, implementing, and evaluating local asthma control programs.

Strong research programs in support of management are needed to reach Healthy People 2010 targets for asthma hospitalization. Wayne County needs to decrease hospitalization rates by 70% for age groups 0-4 and 5-64, and by 57% for age group ≥ 65 from 2005 data to reach Healthy People 2010 targets (Figure 2). This requires effective, continuous action on the part of government and public health officials, health care providers, and commitment of people living with asthma who are the ultimate managers of this chronic disease.

Further, to continue management of asthma in Wayne County, it is equally important to acknowledge that quality primary health care and personalized patient education (i.e., instruction on key steps in managing asthma: correct use of medication, avoidance of triggers, and identification and removal of specific environmental factors) are critical milestones to effectively treat, manage and control asthma symptoms, which could greatly improve the quality of life.

Research/Monitoring Needs

To better understand the prevalence of asthma and its consequences, Michigan must continue to improve its ability to collect data on the number of people with asthma for all age groups and populations (e.g., young children and racial/ethnic groups such as Arab American and Hispanic American communities). Michigan must also increase the amount of geographical detail in its data collection, so that effective interventions can be targeted to areas of high asthma burden (Michigan Department of Community Health 2004). Focused monitoring and research in Wayne County neighborhoods that have higher rates of asthma hospitalization are a priority and are currently being conducted by state and local public health officials. Assessing these communities and investigating reasons for higher rates of asthma hospitalization will lead to the development of intervention strategies, targeting of funds, and increasing awareness, education and outreach to not only the communities, but also to primary care providers who have critical contact with patients. These activities will contribute to reducing racial, ethnic, geographic and economic disparities in asthma hospitalization rates.

The U.S. Environmental Protection Agency (2006) published a report highlighting results from current asthma research and describing three high priority research areas that are currently being addressed by federal, state, and local health agencies:

- study certain types of air pollutants and their effects believed to play a greater role in inducing and exacerbating asthma (e.g., fuel combustion and bioaerosols such as indoor molds, and particles from dust mites and cockroaches);
- study factors that increase susceptibility to asthma or factors that increase risk of subgroups of Americans, focusing on genetic factors that could interact with environmental exposure; and
- intervention (e.g., reducing risks from environmental factors, improving indoor air quality, and providing education to affected communities).

References

[ALA] American Lung Association. 2005. *State of the Air Report*. http://www.lungaction.org/reports/sota05_full.html (June 2006).

Centers for Disease Control and Prevention, Department of Health and Human Services. 2005. Environmental hazards and health effects. <http://www.cdc.gov/asthma/faqs.htm> (June 2006).

Michigan Department of Community Health. 2004. Epidemiology of asthma in Michigan: 2004 Surveillance Report. Lansing, MI.

Michigan Department of Community Health. 2005. Epidemiology of asthma in Wayne County, Michigan. Lansing, MI.

National Center for Health Statistics. 2006. <http://www.cdc.gov/nchs/> (June 2006).

National Heart, Lung, and Blood Institute. 2006. Asthma. http://www.nhlbi.nih.gov/health/dci/Diseases/Asthma/Asthma_WhatIs.html (June 2006).

U.S. Department of Health and Human Services. 2000. Healthy People 2010 <http://www.healthypeople.gov/> (October 2006).

U.S. Environmental Protection Agency. 2006. Report highlighting results of asthma research released. <http://www.epa.gov/ord/articles/2005/asthma.htm> (June 2006).

Links for More Information

Asthma Initiative of Michigan: <http://www.getastmahelp.org/>

Epidemiology of Asthma in Michigan: Surveillance Report 2004: <http://www.bhsj.org/healthdata/StateReports/AsthmaSurveillance%20report%202004.pdf>

Global Initiative for Asthma: <http://www.ginasthma.com>

Michigan Department of Community Health: <http://www.michigan.gov/mdch>

Contact Information

Robert Wahl
Michigan Department of Community Health
E-mail Address: wahlr@michigan.gov

Guadalupe Cummins
Department of Biology
Wayne State University
E-mail Address: aq4983@wayne.edu

INDICATOR: LEAD POISONING IN DETROIT, MICHIGAN

Background

Lead is a highly toxic metal that is soft, malleable and resistant to corrosion. Despite lead's toxic characteristics, it has been used for centuries in paint, gasoline, ceramics, acid-lead batteries, and other products (Lewis 1985). The use of lead in the past and its persistence in the environment creates a problem that is a major public health concern. The National Health and Nutrition Examination Survey (NHANES) conducted by the Centers for Disease Control and Prevention's (CDC) National Center for Health Statistics reported that 2.2% of children younger than five years of age (434,000 children nationwide) had elevated blood lead levels (EBLLs) of 10 micrograms per deciliter (10 µg/dL) or higher, the level of concern established by the CDC (WSU 2003).

In the city of Detroit, 6% of all children six years of age and younger tested in 2004 were identified to have lead poisoning (Detroit Department of Health and Wellness Promotion 2005a). In response to this, the city of Detroit and the State of Michigan have committed to the goal of reducing the incidence rate of new lead-poisoned children (age six and under) to 3.2% or less by 2010. Exposure to lead has serious neurological and behavioral effects on children. According to the American Academy of Pediatrics: Committee on Environmental Health (2005), the best studied effects of lead poisoning are cognitive impairments measured by IQ tests, but other aspects of brain and nerve function, especially behavior, may also be affected. This organization also reports that students with elevated lead levels are less attentive, hyperactive, disorganized, and less able to follow directions. Other consequences of lead poisoning are motor development delays, impaired growth, and hearing dysfunction. According to the Center for Urban Studies at Wayne State University (WSU), health consequences of lead poisoning have few physical symptoms (e.g., headaches, stomachaches, sleeping or eating disorders, attention deficit disorders, and weakness or clumsiness), but significant damage to intellectual functioning is evident even at blood lead levels lower than 10 micrograms per deciliter.

Status and Trends

Several sources of lead have contributed to contamination in Detroit and to lead poisoning of children. These sources include:

- lead-based paint that is deteriorated or poorly maintained (Figure 1);
- contaminated soil around former smelters located at or near residential areas that have released lead into the air during operations, which has been deposited into the soil;
- lead dust that has been washed into the soil from houses during rainfall;

- food and liquids stored in lead crystal or lead-glazed pottery;
- water that runs in old lead plumbing; and
- automotive emissions from leaded gasoline in use before 1986.

Lead was used in paint from 1884 to 1978 because it improved durability and adhesive qualities. Although the use of lead-based paint was banned in 1978, it is the primary source of lead poisoning in children today because it is still present in older cities like



Figure 1. Deteriorated lead-based paint is one of the leading causes of lead poisoning in Detroit children (Photo credit: Emily Wilke).

Detroit where approximately 56% of all housing stock was built prior to 1950 (Detroit Department of Health and Wellness Promotion 2005a). As it is easily found inside and outside of houses, apartments, and public housing in the city, young children are at greater risk of swallowing paint chips and inhaling lead dust. Children under three years of age are even more susceptible to being exposed to lead because they crawl and play on floors where paint chips and dust are deposited, ingesting them orally. Given that lead-based paint was used outdoors as well as indoors, lead dust can also wash off into the soil surrounding a home and poison a child during play.

Other important sources of lead contamination in Detroit are former smelter sites in certain residential areas. It is at such former smelter sites where both adults and children have been exposed to long-term emissions

of lead dust that has settled into the soil around the industrial site, as well as outside its boundaries. Sixteen potentially harmful former lead smelters, foundries, and alloy makers were identified in Detroit (Lam and Wendlandbowyer 2003a and b). Many of these smelter sites have either been abandoned or sold and are currently performing different operations, which makes tracking responsible parties difficult. Testing has been done in some of them showing high levels of contamination, prompting further testing and analysis for lead and other heavy metals by the U.S. Environmental Protection Agency and the Michigan Department of Environmental Quality (e.g., former Master Metals, Inc., located at 4700 East Nevada Street in the Krainzwood neighborhood).

Although exposure to lead from ceramics and the use of leaded gasoline in the past are not considered major sources of lead poisoning in Detroit, they are factors that must be considered. Lead was added to gasoline as a fuel additive to improve engine performance and octane ratings in the 1920s. It was phased out for public health reasons by government order starting in 1975 and concluding in 1986, resulting in a direct correlation with drops in elevated blood lead levels nationwide (Kovarik 2003).

Water that runs through old pipes that contain lead is considered another potential source of lead in homes. However, this should be considered the least harmful source of lead poisoning for Detroit children. Plumbing systems that may contribute lead to the household water supply have been tested since 1992. In 2002, testing showed that only two of the 51 homes tested had lead levels over the action level (Detroit Water and Sewerage Department 2004). The action level is specified by the U.S. Environmental Protection Agency as 0.015 milligrams per liter (U.S. Environmental Protection Agency 2005).

An issue of concern in southwest Detroit is the use of bean pots among residents of this community because some dishes and clay cookware contain high levels of lead in their glaze or decoration. Their use provides a direct and dangerous source of lead poisoning.

Given the various sources of lead which contribute greatly to the number of children with lead poisoning, substantial efforts are being made by health, government, nonprofit, and community development organizations to increase screening and testing in the city of Detroit. For instance, the Center for Urban Studies at Wayne State University not only tracks the extent of lead poisoning in Detroit, but it also evaluates effectiveness of existing prevention programs, targets new prevention activities, and evaluates programs and policies.

In conjunction with universal screening which was approved by the CDC in 2000 and implemented in 2001, there has also been a shift towards targeted screening (CDC 2000). In Detroit, to improve surveillance and targeted intervention programs, the Department of Health and Wellness Promotion has identified “at risk” neighborhoods within the city of Detroit. These communities, according to the 2005 Surveillance Report, are evaluated every year to identify specific areas at high risk. Results from these analyses identified six communities that had a 23% higher rate of lead poisoning among children than the rest of the city; furthermore, these communities accounted for 30% of all cases of lead poisoning in 2004 (Detroit Department of Health and Wellness Promotion 2005b). The neighborhoods identified as high-risk target areas are Belle Isle, Chene, Kettering-Butzel, Rosa Parks, St. Jean, and Tireman. Some of the former smelter locations mentioned above are located in these targeted communities. Federal-Mogul Corporation was located in St. Jean. Aetna Smelting & Refining Company and Federal Alloys Corporation were located in Kettering-Butzel. Federated Metals Division of ASARCO was located in Chene, and City Metals Refining Company was located in Tireman.

There has been a major effort to measure the extent of lead poisoning in Detroit children since 1998 and more children have been tested since universal testing began in 2001. Based on the available data, the number and percent of children with blood lead levels of 10 micrograms per deciliter or more have decreased by at least 60% from 1998 to 2004 (Figures 2 and 3).

Management Next Steps

Proximity to residential areas should be taken into account when industrial sites are considered for cleanup. In fact, officials should target industrial cleanups to areas where traces of lead could explain higher rates of lead poisoning.

According to the Center for Urban Studies at Wayne State University, it is also important to focus on primary prevention by abatements (i.e., measures designed to permanently eliminate lead-based paint or lead dust hazards). Abatements include:

- removal of lead-based paint and lead dust hazards, permanent enclosure or encapsulation of lead-based paint, replacement of components or fixtures painted with lead-based paint, and removal or permanent covering of soil with lead hazards; and
- all preparation, cleanup, disposal, and post-abatement clearance testing activities associated with such measures.

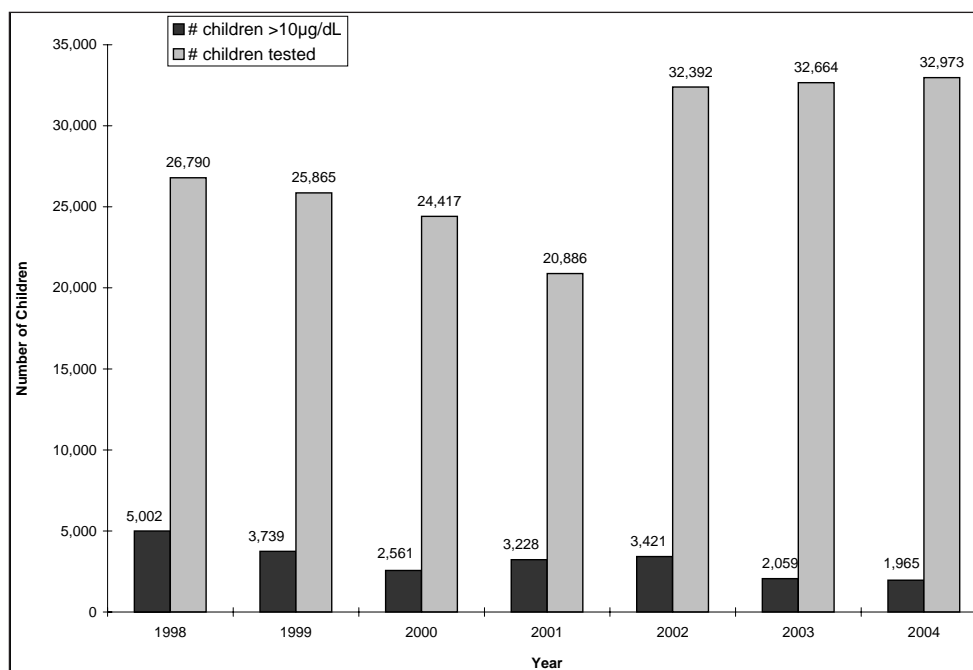


Figure 2. Extent of lead poisoning in the city of Detroit, 1998-2004 – total number of tested children with blood lead levels of 10 micrograms per deciliter or above and number of children tested for lead poisoning (data from Wayne State University's Center for Urban Studies).

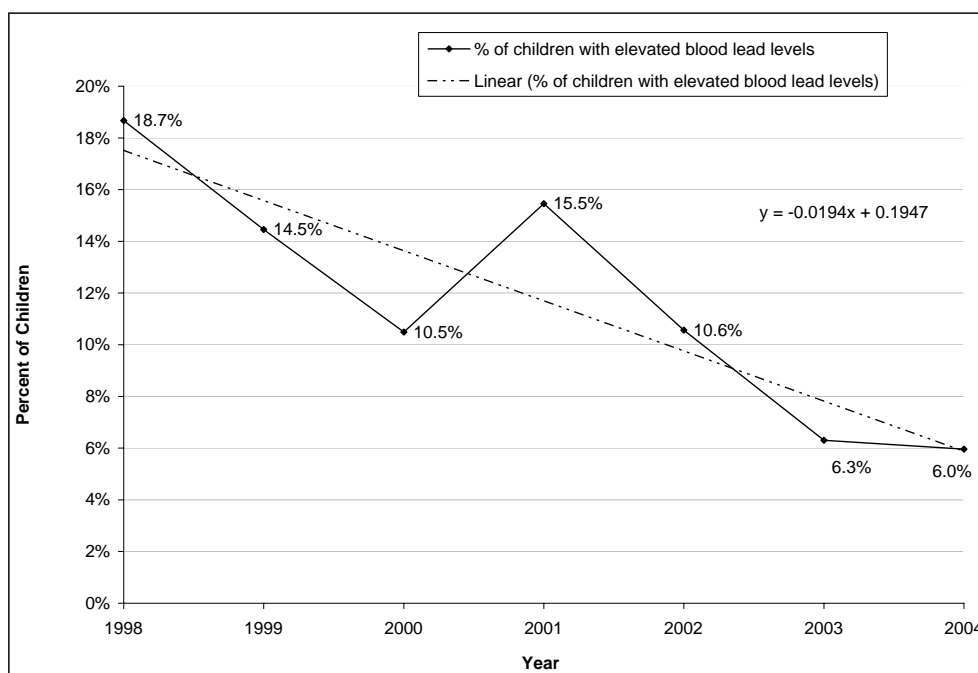


Figure 3. Linear decline of the percentage of children with elevated blood lead levels from 1998 to 2004. Linear correlation was used to statistically elucidate the rate of decrease.

In order to control children's exposure to lead, it is necessary to have a timely and effective management plan. The goal of health and government officials in the city of Detroit is to reduce the lead poisoning incidence rate to 3.2% or less for children age six or younger by 2010 (Detroit Department of Health and Wellness Promotion 2005a).

To help reach this goal, two important reports were published in 2005 by the Detroit Department of Health and Wellness Promotion's Childhood Lead Poisoning Prevention and Control Program in collaboration with 70 partners composed of community-based and governmental agencies: a 2004 Annual Childhood Lead Poisoning Report (Detroit Department of Health and Wellness Promotion 2004) and a Strategic Lead Elimination Work Plan for the city of Detroit (Detroit Department of Health and Wellness Promotion 2005a). A coordinating body has now been established to assure accountability to the public and to monitor the implementation and evaluation of the Strategic Lead Elimination Work Plan.

The Strategic Lead Elimination Work Plan outlines activities that must be executed in order to accomplish the lead poisoning reduction goal in Detroit by 2010; it also establishes time frames and identifies responsible or involved parties. The progress of this Strategic Lead Elimination Work Plan will depend on the implementation and close evaluation of each objective below:

- reduce childhood lead poisoning cases (confirmed greater than or equal to 10 micrograms per deciliter) by 1% annually through education and outreach;
- increase the number of children tested annually by 5% (baseline 35% in 2003);
- target lead testing to high-risk populations living in Detroit: Medicaid enrolled children, children 0-3 years old, and ethnic groups;
- prevent lead exposure among Detroit children by increasing primary prevention activities targeted to pregnant women, newborns, and children ages 1-2 with blood lead levels of 4 to 9 micrograms per deciliter in high-risk areas;
- create lead-safe housing in Detroit by 2010;
- enhance legislation regarding the control of environmental lead hazards and the lead code enforcement in Detroit; and
- acquire funding and resources to adequately fund and support lead poisoning prevention, remediation, and treatment intervention.

Having this Strategic Lead Elimination Work Plan in place is important, but it is also necessary to monitor the effects of new legislation and ordinances since it will take time to actually see the results.

Research/Monitoring Needs

Wayne State University's Center for Urban Studies pointed out that new research should focus on ways to target funding for abatement and prevention, and also to identify which programs will eliminate the problem of lead poisoning more efficiently and effectively.

A concrete example relates to one of the Strategic Lead Elimination Work Plan's objectives that anticipates the creation of lead-free housing by 2010. Abatement of a house can cost as much as \$20,000, with an average of \$10,000. Dividing the available funding by this average, Detroit can abate approximately 200 homes per year. However, this is clearly not enough given that 90% of Detroit housing stock was built before

1978. Even though this is a problem that needs to be addressed in the near future, its complexity highlights the importance of continuous interim controls or measures designed to temporarily reduce likely exposure to lead and lead hazards (e.g., repairs, painting, temporary containment, specialized cleaning, and lead-based paint maintenance activities). According to the Center for Urban Studies at Wayne State University, interim controls are currently considered a major way to address the housing problem in the city of Detroit; therefore, research should be conducted not only to monitor the effects of interim controls, but also to improve and expand such measures.

Continued research is also warranted on human health effects of lead poisoning. It will take coordinated work, focused management of each factor regarding lead poisoning in children, and a comprehensive approach to addressing all sources of lead in the environment to reach the goal of reducing the incidence rate of new lead-poisoned children.

References

American Academy of Pediatrics: Committee on Environmental Health. 2005. Lead exposure in children: Prevention, detection and management. *Pediatrics* 116(4):1036-1046. <http://aappolicy.aappublications.org/cgi/content/full/pediatrics;116/4/1036>

[CDC] Centers for Disease Control. 2000. Childhood Lead Poisoning Prevention Program: Children's blood lead levels in the United States. <http://www.cdc.gov/nceh/lead/research/kidsBLL.htm> (December 2005).

Detroit Department of Health and Wellness Promotion. 2004. Childhood Lead Poisoning Prevention and Control Program. 2004 Annual Report.

Detroit Department of Health and Wellness Promotion. 2005a. Childhood Lead Poisoning Prevention and Control Program. Strategic Lead Elimination Work Plan for the City of Detroit.

Detroit Department of Health and Wellness Promotion. 2005b. Childhood Lead Poisoning in Detroit, Michigan: Surveillance Report 2005 Edition. Detroit, MI.

Detroit Water and Sewerage Department. 2004. 2004 Water Quality Report. http://www.dwsd.org/cust/wqr_2004.pdf (December 2005).

Kovarik, W. 2003. The Ethyl War, Forbidden Fuel and Public Poison; The Ethyl War Summary: Leaded Gasoline History and Current Situation. <http://www.runet.edu/~wkovarik/ethylwar/overview.html>

Lam, T., and W. Wendlandbowyer. 2003a. Potential of danger at 16 sites brings little action. *Detroit Free Press*.

Lam, T., and W. Wendlandbowyer. 2003b. Old Sites Forgotten, Ignored. *Detroit Free Press*.

Lewis, J. 1985. Lead Poisoning: A historical perspective. U.S. Environmental Protection Agency. Washington, DC. <http://www.epa.gov/history/topics/perspect/lead.htm>

U.S. Environmental Protection Agency. 2005. Drinking Water Contaminants and Maximum Contaminant Levels. <http://www.epa.gov/safewater/contaminants/index.html#listmcl>

[WSU] Wayne State University. 2003. Lead Poisoning Research at the Center for Urban Studies. Detroit, MI. <http://detroitleaddata.cus.wayne.edu/>

Links for More Information

Center for Urban Studies, Wayne State University: <http://detroitleaddata.cus.wayne.edu/>

Final Report of the Task Force to Eliminate Childhood Lead Poisoning: http://www.michigan.gov/documents/lead_108767_7.pdf

Michigan Department of Community Health: <http://www.michigan.gov/mdch>

Michigan State University's Annual Reports on Blood Lead Levels 1998-2004: <http://oem.msu.edu/annualreports.asp>

Contact Information

Valerie Monet
Center for Urban Studies
Wayne State University
E-mail Address: V.Monet@wayne.edu

Guadalupe Cummins
Department of Biology
Wayne State University
E-mail Address: aq4983@wayne.edu

INDICATOR: WEST NILE VIRUS IN MICHIGAN

Background

West Nile virus is a mosquito-transmitted disease that was first discovered in the African country of Uganda in 1937 (Michigan Department of Community Health 2006a). It is considered an “emerging infectious disease” because of the spread beyond its traditional geographic range. In recent years West Nile virus has caused illness in birds, horses, and humans in Europe and now in the United States. It was first discovered in the U.S. in 1999 in New York City. Since that time, West Nile virus has been detected in humans, animals, and mosquitoes in 47 states from coast to coast.

West Nile virus is a disease of birds that can cause illness in humans when they are bitten by an infected mosquito. Most humans infected with West Nile virus develop no symptoms of illness; however, about 20% may become sick with a fever, headache and body aches three to 14 days after receiving a bite from an infected mosquito. Rarely, persons infected with West Nile virus may develop more severe disease, including encephalitis and sometimes death.

Individuals with fever and signs of encephalitis and/or meningitis should be tested for West Nile virus during the mosquito season. Symptoms of encephalitis (inflammation of the brain) and meningitis (inflammation of the spinal cord and brain linings) include severe headache, high fever, neck stiffness, stupor, disorientation, coma, tremors, muscle weakness, convulsions and paralysis. West Nile virus is spread almost exclusively to humans by mosquitoes of the genus *Culex*, which are commonly found in urban environments and lay their eggs in stagnant water that is rich in organic matter.

West Nile virus also causes severe morbidity and mortality in horses. However, an effective vaccine has been developed for West Nile virus in horses.

Status and Trends

The West Nile Virus Working Group, a multi-agency working group that emerged from the Arbovirus Core Group in 2000, was formed in response to the threat of West Nile virus in Michigan (Michigan Department of Community Health 2006b). In 2001, a toll-free hotline was established for citizens to report dead crows, as monitoring death among these birds can be an early indicator of virus activity in an area. Cases of West Nile virus in birds may also be an early indicator of human disease in a geographic area. As a result of the initial monitoring effort in 2001, West Nile virus was first detected in Michigan in August of that year in dead crows. There were 65 West Nile virus-positive birds detected in 10 counties including Wayne, Oakland, Macomb, Washtenaw, Jackson, Calhoun, Ingham, Barry, Ottawa, and Muskegon. In addition, two West Nile virus-positive mosquito pools were detected in Oakland County and one in Macomb County.

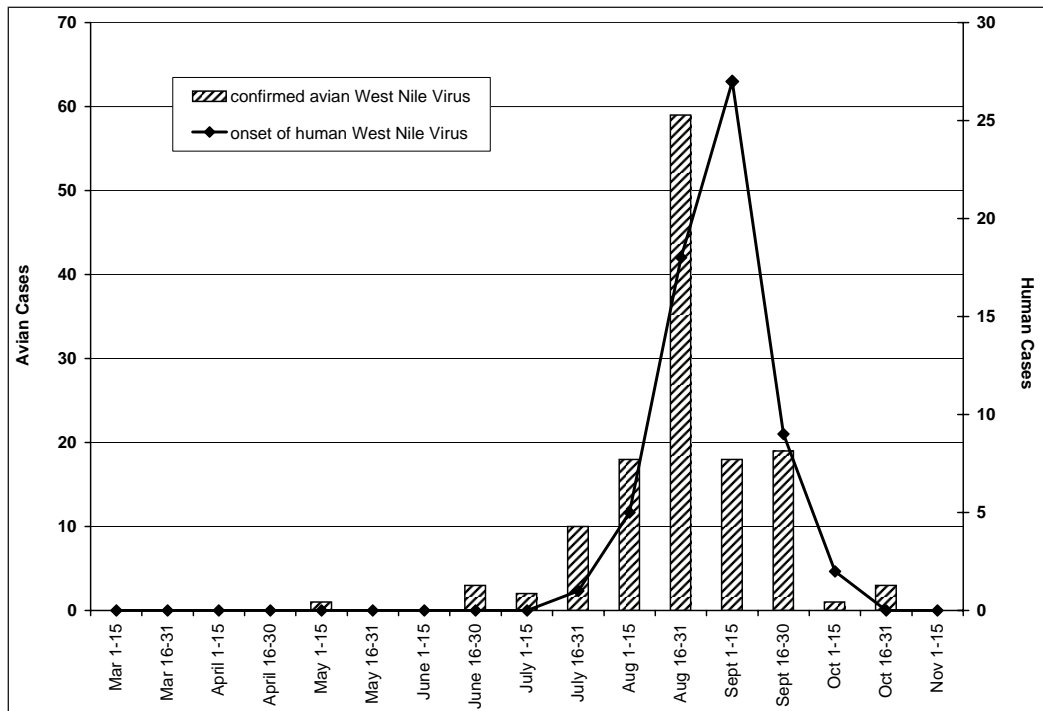


Figure 1. West Nile virus in people and birds in Michigan, 2005 (data collected by Michigan Department of Community Health). Avian infection peaked during the second half of August, followed by the human infection peak in early September. Human and avian infections drop off quickly and are 0 by early November.

The Michigan Department of Community Health continues to collect corvid (American crows, blue jays, common ravens) samples from interested jurisdictions conducting surveillance. Figure 1 represents positive avian samples (bars) and confirmed human case onset (line) from March to November 2005 in the state of Michigan showing human infection peaks just after avian infection.

Human illness due to West Nile virus in Michigan was first documented in 2002 when a large-scale outbreak occurred in the Upper Midwest. Human cases were heralded by a massive die-off in resident corvid populations. From early May to late October 2002, the Michigan Department of Community Health received over 10,000 reports of dead birds from the public. Southeast Michigan (including Wayne, Macomb, and Oakland counties) was particularly hard-hit, accounting for 531 of 644 statewide human West Nile virus illnesses confirmed by public health authorities. Wayne County confirmed 203 human cases and 15 deaths due to West Nile virus in 2002.

Table 1 presents data on West Nile virus-positive corvids, human cases (positive for West Nile virus), and human deaths from West Nile virus in Wayne County. As noted below, the first West Nile virus-positive corvid was reported in Wayne County in 2001 and the first human death attributed to West Nile virus in Wayne County was reported in 2002; another three deaths were reported in 2005.

Table 1. Incidence of West Nile virus-positive corvids, human cases (positive for West Nile virus), and human deaths attributed to West Nile virus in Wayne County.

Year	West Nile Virus-Positive Corvids	Human Cases Wayne County (Statewide)	Human Deaths (Statewide)
2001	15	0	0
2002	2	203 (644)	15 (51)
2003	3	10 (19)	0 (2)
2004	5	8 (16)	0
2005	7	28 (62)	3 (4)

Mosquito Management

Mosquito surveillance for West Nile virus has been conducted in Michigan since 2001. In 2005, over 5,000 mosquito pools were tested for the virus, and 55 pools were found to be positive. Virus activity within the mosquito population peaked quickly in early August, although the mosquitoes were active prior to this peak (Figure 2). It is likely that by controlling the early breeding populations of these mosquitoes, they can be kept at a level at which the virus will not “amplify” to critical levels, thereby reducing the risk to humans.

Culex species mosquitoes are tested for West Nile virus when local jurisdictions conduct mosquito surveillance. In southeast Michigan, mosquito infection with West Nile (bars) was documented in late July with human cases (line) following 1-3 weeks later (Figure 2).

There are many species of mosquito in Michigan and some are more “competent” at transmitting West Nile virus than others. In the eastern United States, the primary vectors are within the genus *Culex*. These mosquitoes are active in the summer, with peak biting times at dusk and dawn. These mosquitoes are also more common in urban environments where they reproduce readily in man-made containers containing nutrient-rich water. These habitats may include: sewer catch-basins, bird feeders, unused swimming pools, scrap tires, or practically any other man-made container.

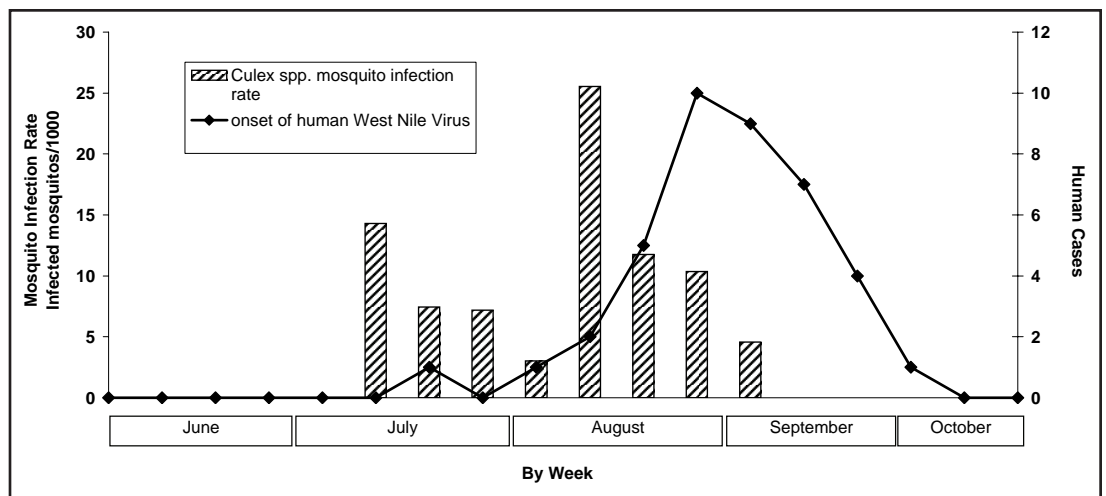


Figure 2. *Culex* species mosquito infection rate versus human West Nile virus onset in southeast Michigan, 2005. Human onset and peak follows the mosquito infection onset and peak by 1 to 3 weeks. Mosquito infection peaked early in August and dropped off in mid-September; human infection peaked at the end of August and dropped to 0 by early October.

Since it is not feasible to control the virus within wild bird populations, our best target for control is the mosquito. The use of licensed “larvicides” which kill the immature mosquitoes in the water have been shown to reduce mosquito populations and disease risk when used within an integrated mosquito management program. It is unlikely that individual treatment by citizens in a piecemeal fashion will reduce the risk because mosquitoes can breed nearby in areas that are untreated.

The mosquito management program would include: source reduction, personal protection education, and surveillance for mosquito density and virus activity.

Management Next Steps

No human vaccine against West Nile virus is currently available. The Michigan Department of Community Health considers West Nile virus an emerging disease issue and has devoted considerable resources to surveillance, management, and public education. The Centers for Disease Control and Prevention (2006) recommend the following:

- Education about reducing the risk of infection is important for all persons in transmission areas, but especially in the higher-risk populations (persons more than 50 years old and persons who are immunocompromised);
- The primary prevention step recommended is the use of mosquito repellent when outdoors. Mosquitoes may bite through thin clothing, so spraying clothes with repellent containing permethrin or another U.S. Environmental Protection Agency-registered repellent will give extra protection. These repellents are the most effective and the most studied;
- Repellents containing permethrin are not approved for direct application on the skin. Repellent should not be sprayed on the skin under clothing. Other options include wearing protective clothing (long sleeves, socks, and long pants) when outdoors;
- The primary mosquito-biting hours for many of the species that are important vectors of West Nile virus are dusk and dawn. It is advisable to either stay indoors during these hours or use protective clothing and repellent;
- Household mosquito-source reduction is also important. Standing water should be removed from outdoor receptacles; and
- Integrated mosquito management can be another important factor in controlling mosquito populations.

Research/Monitoring Needs

Testing will continue to be conducted in order to provide community-based information about West Nile virus activity in birds and mosquitoes. The State of Michigan compiles surveillance information on the “Emerging Diseases” website, which can be viewed at: www.michigan.gov/westnilevirus

The public can also report sick or dead birds with feedback as to whether the bird is needed for surveillance purposes. Communities can use this information to target their intervention and prevention strategies to areas where West Nile virus activity has been detected. Michigan health workers are implementing a system of animal and human disease surveillance that utilizes geographic information system mapping capabilities to detect outbreaks more rapidly. Research continues on a possible human vaccine and health treatment options.

References

Centers for Disease Control and Prevention. 2006. Division of Vector-Borne Infectious Diseases: West Nile Virus. <http://www.cdc.gov/ncidod/dvbid/westnile/qa/prevention.htm>. (May 2006).

Michigan Department of Community Health. 2006a. Emerging disease issues: History of West Nile virus. <http://www.michigan.gov/emergingdiseases/0,1607,7-186-25805-75265~,00.html>. (May 2006).

Michigan Department of Community Health. 2006b. Emerging disease issues: West Nile virus working group. <http://www.michigan.gov/emergingdiseases/0,1607,7-186-25805-75046~,00.html>. (May 2006).

Links for More Information

Michigan Department of Community Health: www.michigan.gov/westnilevirus

Centers for Disease Control and Prevention: <http://www.cdc.gov/ncidod/dvbid/westnile/index.htm>

Contact Information

Erik S. Foster
Wildlife and Vector Ecologist/Biologist
Michigan Department of Community Health
Division of Communicable Disease
E-mail Address: fostere@michigan.gov

6.0 APPENDIX B

RESPONSE INDICATORS

INDICATOR: PHOSPHORUS DISCHARGES FROM DETROIT WASTEWATER TREATMENT PLANT

Background

Lake Erie has a long history of accelerated eutrophication. During the 1960s, Lake Erie was on the front cover of several national magazines because phosphorus-induced algal blooms and oxygen depletion of deeper waters caused fish kills. In general, phosphorus is the most scarce and readily controllable nutrient relative to plant needs. Therefore, U.S.

and Canadian governments worked through the Great Lakes Water Quality Agreement to set phosphorus target loads to control water quality problems associated with phosphorus enrichment. This phosphorus control program called for controlling inputs from municipal wastewater treatment plants, controlling inputs from agricultural and urban runoff, and restricting the phosphorus content of cleaning agents and laundry detergents.



Figure 1. An aerial photograph of the Detroit Wastewater Treatment Plant ~ one of the largest in North America (Photo credit: Detroit Water and Sewerage Department).

The Detroit Wastewater Treatment Plant was the single largest contributor of phosphorus to Lake Erie. This regional wastewater treatment plant was constructed in 1940 and treats the waste of over three million people in 76 communities. It handles over 2,600 million liters (700 million gallons) of wastewater per day (Figure 1).

Status and Trends

In 1970, the Detroit Wastewater Treatment Plant began removing phosphorus from its effluent using pickle liquor and polymer to meet the 1 mg/L phosphorus standard for all major plants (3.8 million liters; one million gallons

per day or greater). Pickle liquor (ferrous chloride) was obtained from local steel mills and pumped or fed by gravity into interceptor sewers, while polymer was injected into channels leading to the primary clarifiers. Aeration facilities for secondary treatment were constructed during 1973-1976. Through this process, ferrous chloride is converted to ferric chloride, which has been found to more effectively precipitate phosphorus. During 1979-1980, staff at the plant implemented an alternative sludge removal process, which increased sludge handling capability and indirectly increased the plant's ability to remove phosphorus.

Two statewide phosphorus control initiatives were also implemented. In 1971, Michigan enacted a phosphorus limitation of 8.7% by weight on all cleaning agents. Michigan's phosphorus detergent ban was implemented in 1977, restricting the phosphorus content of household laundry detergents to no greater than 0.5% by weight.

The combined influence of these phosphorus control efforts can be seen in Figure 2a and 2b below. The result was a greater than 90% reduction in phosphorus concentration and loading from the Detroit Wastewater Treatment Plant. Similar reductions occurred in other wastewater treatment plants; however, because of the Detroit plant's 2,600 million liter (700 million gallon) per day flow, the impact on Lake Erie was substantial. The Detroit Wastewater Treatment Plant would become the single largest cause of the reversal of cultural eutrophication of Lake Erie during the 1970s and 1980s. Lake Erie responded with dramatic improvements in water quality.

It should also be noted that as the Detroit plant expanded its municipal customers and service area, there were a number of problems in consistent and adequate operation of the plant. These problems climaxed in a 1977 Federal Consent Judgment, which outlined the specific deficiencies, areas requiring improvement, and target dates for achieving compliance. A full-scale evaluation of the plant was performed in 1979 to help ensure adequate operation of the plant. It was not until 1981, when the construction and modification of secondary settling tanks were completed, that the plant would achieve consistent operation sufficient for secondary treatment standards (Figure 2).

The story of reductions in phosphorus loadings and the subsequent reversal of cultural eutrophication of Lake Erie is one of the greatest success stories of water resource management. Indeed, the U.S.-Canada phosphorus control program is heralded as an international model. It should be noted that by the early 1990s zebra and quagga mussels invaded Lake Erie causing major changes in the food web. In recent years, blooms of blue-green algae have occurred in Lake Erie raising new concerns. The exact reasons for these blooms are uncertain. Did increased discharge of nutrients occur? Did zebra

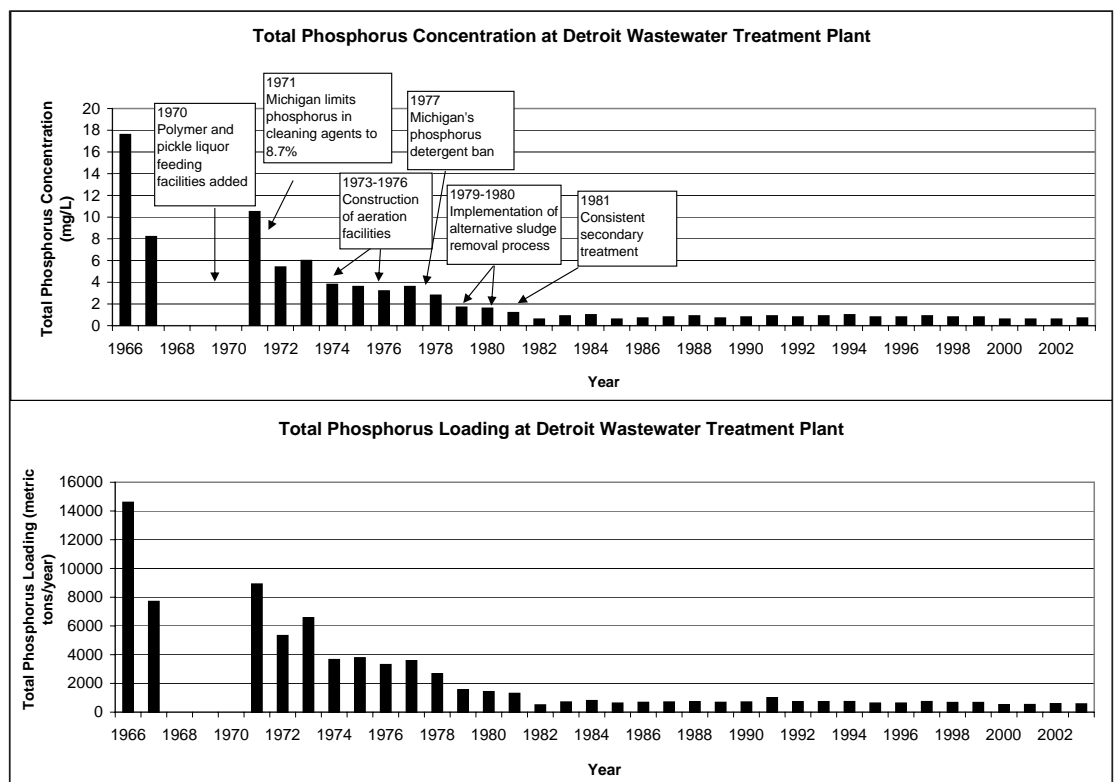


Figure 2a and 2b. Total phosphorus concentration (a) and loading (b) from Detroit Wastewater Treatment Plant, 1966-2003.

mussels change the water quality and favor productivity of blue-green algae? Will this lead to more taste and odor problems in drinking water supplies? Research needs to be focused on answering such questions.

Management Next Steps

Efforts must be sustained to control phosphorus inputs from the Detroit Wastewater Treatment Plant and others. Current management efforts are focused on addressing combined sewer overflows from Detroit and other communities. For example, Detroit is in the middle of a ten-year, \$4 billion capital improvement program that began in 2000. This includes over \$1 billion for controlling combined sewer overflows.

The major changes that have occurred in Lake Erie in recent years are poorly understood, but it is clear that management programs, research, and monitoring must be sustained and closely coupled in order to achieve management goals for the Detroit River and Lake Erie. The Lake Erie Committee of the Great Lakes Fishery Commission has recommended a “hold the line on phosphorus levels” until there is clear scientific evidence that suggests otherwise.

Research/Monitoring Needs

Major cuts have occurred in monitoring and research for both the Detroit River and Lake Erie. Effluent monitoring of the Detroit Wastewater Treatment Plant and other plants must be sustained for calculating reliable loading estimates, evaluating impacts of remedial efforts, understanding short- and long-term ecosystem trends, and refining modeling frameworks applied for management and decision making. Coordinated, comprehensive research will be needed to understand cause-and-effect relationships relative to the recent changes in Lake Erie and to ensure ecosystem-based management.

References

Panek, J., D.M. Dolan, and J.H. Hartig. 2003. Detroit's role in reversing cultural eutrophication of Lake Erie. In *Honoring Our Detroit River: Caring for Our Home*, ed. John H. Hartig, pp. 79-90. Bloomfield Hills, MI: Cranbrook Institute of Science.

Links for More Information

Detroit Water and Sewerage Department: <http://www.dwsd.org/>

Contact Information

Gary Fujita, Deputy Director
Detroit Water and Sewerage Department
E-mail Address: fujita@dwsd.org

INDICATOR: COMBINED SEWER OVERFLOW CONTROLS IN SOUTHEAST MICHIGAN

Background

Most large, older cities in the Great Lakes basin were located on the banks of rivers or lakes to meet the needs for transportation and commerce. Detroit was no exception. During the 1700s and 1800s, the streets were primarily dirt or gravel and they frequently remained muddy after rainfall. Citizens of Detroit and similar cities grew tired of muddy streets and urged the government to do something about this inconvenience.

The immediate solution was to build sewers to drain storm water off the streets during wet weather so that they would not remain muddy for long periods of time. These sewers were either open ditches or pipes buried underground. As communities grew, these sewers needed to be quite substantial in size to carry away the storm water. Remember, of course, that the vehicles on these roads were horses and carriages, and that the horses left behind more than footprints. At that time, domestic water use was relatively low, but the domestic wastewater was simply dumped in the gutter where it would be flushed away during the next rain. During these rains, both domestic wastewater and manure from the streets were flushed into the sewers, where they were transported directly to the nearest waterway. This created both odor problems and pollution of waterways.

A new kind of sewer, called an interceptor sewer, was built to address these problems. They were primarily built parallel to waterways to carry wastewater further downstream. It was common and acceptable up to the late 1800s and early 1900s to move this wastewater further downstream where there were fewer or no people to complain. In the early 1900s, domestic use of water increased rapidly with human population growth and resulted in increased domestic wastewater discharges. Since the sewers at that time were originally designed to carry away storm water, the increased domestic wastewater from the growing population could exceed sewer capacity during heavy rains and snow melt. However, because of budget constraints, the sewers at that time were sized to intercept only the domestic waste during dry weather conditions. Therefore, one of two things had to happen during a rainstorm. Either the sewers would exceed their capacity and flood the streets or there needed to be a relief discharge directly into a waterway near these populated areas. Structures, called regulators, were constructed to provide this relief. They operate when the flow rises above the height of the overflow weir, allowing the combined storm and sanitary sewer flow to overflow into the receiving waterway – thus causing what has come to be called a combined sewer overflow (CSO).

As time went by, the idea of building sewers that handled both the sanitary wastewater and the storm water gave way to the concept of building a separate system just for sanitary wastes. These separate sewers came to be called sanitary sewers and the original type of sewer came to be called combined sewers. Today, these combined sewers are

found only in older, larger cities where combined storm water and wastewater are treated during dry weather, but it overflows directly into rivers during and after wet weather events. When many of these combined sewers were constructed, they were simply called “sewers.” Later on, in the 1930s and 1940s, the distinction between storm sewers, sanitary sewers, and combined sewers became well accepted.

Status and Trends

In 1972, the U.S. Congress passed the Clean Water Act which launched a major effort to control pollution from industrial and municipal sources. The law required each state to issue discharge permits to regulate the quantity and concentration of pollutants from municipal and industrial treatment facilities to meet state water quality standards.

By the mid-1980s virtually all of the over 400 municipal wastewater treatment plants in Michigan had achieved compliance with the Clean Water Act requirement to provide secondary treatment of all flows. Michigan’s treatment plants were also required to disinfect the wastewater prior to discharge and reduce phosphorus loadings to control nutrient impacts in the Great Lakes basin.

As the discharges from wastewater treatment plants came under control, attention began to focus on water quality problems attributable to intermittent wet weather discharges from combined sewer systems. CSO discharges can be a significant source of pollution to receiving waters since they consist of a diluted mixture of untreated sanitary wastewater and storm water runoff. Water quality problems attributable to uncontrolled CSOs include public health threats from bacteria contamination and pathogenic organisms, dissolved oxygen depletion, aesthetic problems, and residues from sanitary trash and floatable materials.

CSOs are a particularly significant problem in southeast Michigan because of the high population and the fact that CSO discharges were impacting small urban waterways such as the Rouge River and its tributaries. Within the service area of the Detroit wastewater treatment plant, more than 25% of the service area utilizes combined sewer systems. Within the city of Detroit there are 35,924 hectares (88,770 acres) served by combined sewers and an additional 24,186 hectares (59,764 acres) in suburban communities in Wayne, Oakland and Macomb counties (Figure 1). Uncontrolled CSO discharges were identified as a major source of pollution throughout much of the Rouge River basin, the Clinton River basin, and portions of the Lake St. Clair and Detroit River shoreline.

In 1985, work began on the development of Remedial Action Plans for these watersheds to define alternatives for improving water quality and protecting public health. The Rouge River Remedial Action Plan was adopted in 1988 and called for substantial investment in facilities to control CSOs in Detroit, Wayne County and Oakland County. Similar control efforts were initiated along the Clinton River and Red Run Drain basin, and the shoreline areas of Lake St. Clair and the Detroit River.

The recommendations of the Remedial Action Plans were the basis for new permit requirements to eliminate or adequately treat CSO discharges throughout southeast Michigan. The southeast Michigan CSO control program received support from the federal government when Congress approved the Rouge River National Wet Weather Demonstration Project in 1992. Under this program, municipalities in the Rouge

River watershed served as a pilot program to demonstrate the effectiveness of various CSO control measures. The program also instituted a variety of other pollution control activities related to storm water discharges, streambank erosion control, wetland preservation, public education, and other measures.

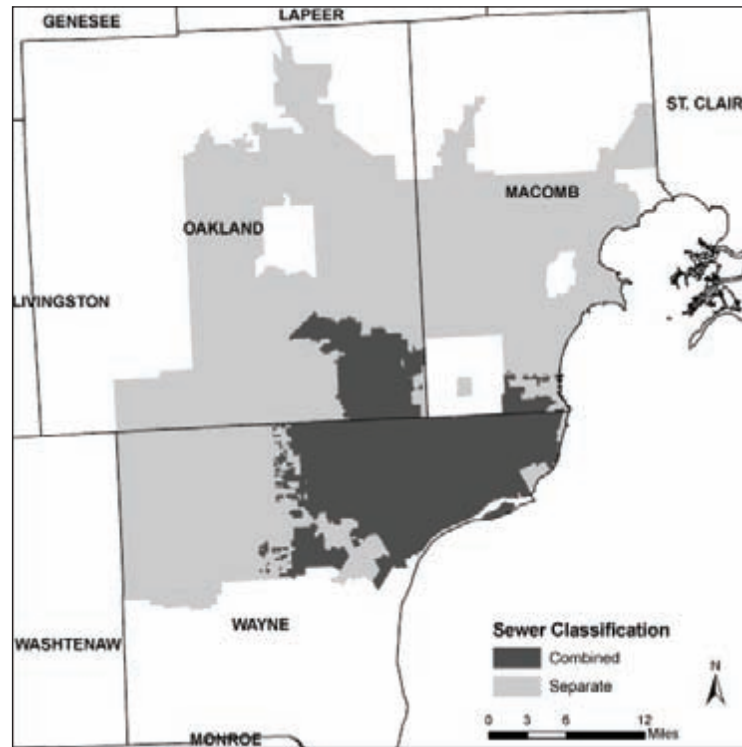


Figure 1. Areas of Wayne, Oakland, and Macomb counties that have combined and separate sewer systems.

Prior to 1990, there were more than 170 uncontrolled CSOs in existence in 35 municipalities in southeast Michigan. The quantity of untreated combined sewage discharged annually at that time is estimated at more than 119 billion liters per year (over 31 billion gallons per year), although the actual quantity of the discharge varies in response to climatic conditions and rainfall patterns. CSO discharges typically occurred about 50 times per year throughout the region and the pollutant load from these discharges was significant. Numerous water quality studies in the area documented serious impairments and water quality standards violations during and after wet weather events when CSO discharges occurred. Dissolved oxygen levels in some areas were depleted, making it difficult for the watersheds to support aquatic life and fish.

In response to the regulatory initiative to control CSOs, southeast Michigan communities in the Detroit Water and Sewerage Department service area have committed to the construction of projects totaling nearly \$2.2 billion to eliminate, capture, or treat combined sewage. A list of the CSO control projects is included in Table 1. The debt obligation to pay for these capital improvements has had a significant impact on local sewer rates, even though many facilities were financed with low interest loan assistance from the State Revolving Loan Fund, and the initial projects received grant support through the National Wet Weather Demonstration Project.

Table 1. CSO investment of southeast Michigan as of May 2007 ^a. DWSD = Detroit Water and Sewerage Department.

Name of the Facility	Ownership	Status	Storage Volume: million liters (million gallons)	Construction Cost ^b
Detention Basins				
Belle Isle	DWSD	In Construction	1.14 (0.30)	Est. \$13,866,000
Conner Creek	DWSD	Operational	119.24 (31.50)	\$186,512,000
Hubbell-Southfield	DWSD	Operational	83.28 (22.00)	\$54,884,000
Oakwood Pump Station	DWSD	In Construction	34.07 (9.00)	Est. \$131,437,000
Puritan – Fenkell	DWSD	Operational	15.52 (4.10)	\$18,194,000
Seven Mile	DWSD	Operational	11.73 (3.10)	\$29,948,000
Acacia Park	Oakland County	Operational	15.14 (4.00)	\$10,681,000
Bloomfield Village	Oakland County	Operational	37.85 (10.00)	\$21,994,000
Birmingham	Oakland County	Operational	20.82 (5.50)	\$26,252,000
GWK	Oakland County	Operational	350.91 (92.70)	\$165,068,000
Chapaton	Macomb County	Operational	105.99 (28.00)	\$25,817,000
Martin	Macomb County	Operational	32.55 (8.60)	\$7,471,000
Milk River	Wayne County	Operational	71.92 (19.00)	\$31,200,000
Dearborn Heights	Dearborn Heights	Operational	10.22 (2.70)	\$18,678,000
Inkster	Inkster	Operational	11.73 (3.10)	\$18,592,000
Redford Township	Redford	Operational	7.19 (1.90)	\$14,300,000
SUBTOTAL			929.32 (245.50)	\$774,894,000
Treatment/Capture Shafts				
Capture Shaft 013	Dearborn	In Construction	27.25 (7.20)	\$28,895,000
Capture Shaft 014	Dearborn	In Construction	38.23 (10.10)	\$33,097,000
Disinfection Facility for Capture Shaft 013 and 014	Dearborn	In Construction	Included Above	\$4,397,000
Capture Shaft 015	Dearborn	In Construction	9.08 (2.40)	\$10,528,000
Original CSO Shafts	Dearborn	Constructed	Included Above	\$26,000,000
Treatment Shafts 1 – 5	Dearborn	In Design	98.80 (26.1)	\$170,000,000
Treatment Shaft 016	Dearborn	In Construction	12.49 (3.30)	\$25,997,000
Treatment Shaft 017	Dearborn	In Construction	24.61 (6.50)	\$36,791,000
SUBTOTAL			210.47 (55.60)	\$335,705,000
Screening & Disinfection Facilities				
Baby Creek (Including VR-7)	DWSD	Operational	115.08 (30.4)	\$73,107,000
Leib	DWSD	Operational	31.42 (8.3)	\$31,438,000
St. Aubin	DWSD	Operational	9.20 (2.43)	\$19,821,000
SUBTOTAL			155.69 (41.13)	\$124,366,000
Tunnels				
Upper Rouge Tunnels	DWSD	In Design	760.87 (201.00)	\$640,000,000
SUBTOTAL			760.87 (201.00)	\$640,000,000

Name of the Facility	Ownership	Status	Storage Volume: million liters (million gallons)	Construction Cost
In-System Storage Facilities (Dams and Gates)				
Conner Creek Influent Storage Gates	DWSD	Operational	152.93 (40.40)	\$4,392,000
Wyoming Relief (ISD001)	DWSD	Operational	23.24 (6.14)	\$26,469,000
Weatherby (ISD002)	DWSD	Operational	11.92 (3.15)	
Upper Livernois Relief (ISD003)	DWSD	Operational	9.24 (2.44)	
Joy (ISD004)	DWSD	Operational	13.55 (3.58)	
Clark Summit (ISD005)	DWSD	Operational	15.06 (3.98)	
First Hamilton (ISD006)	DWSD	Operational	34.14 (9.02)	
First Hamilton (ISD007)	DWSD	Operational	16.77 (4.43)	
First Hamilton (ISD008)	DWSD	Operational	14.99 (3.96)	
First Hamilton (ISD009)	DWSD	Operational	16.20 (4.28)	
First Hamilton (ISD010)	DWSD	Operational	5.38 (1.42)	
Conant Mt. Elliott (ISD011)	DWSD	Operational	34.18 (9.03)	
Six Mile Rd. (ISD012)	DWSD	Operational	8.86 (2.34)	
Seven Mile Rd. (ISD013)	DWSD	Operational	13.51 (3.57)	
6 Mile & 6 Mile Relief Outfall Gates	DWSD	Operational	26.12 (6.90)	\$7,708,000
Puritan Outfall Gates	DWSD	Operational	1.14 (.30)	
Lyndon Outfall Gates	DWSD	Operational	6.44 (1.7)	
Lahser Outfall Gates	DWSD	Operational	5.30 (1.4)	
W. Chicago Outfall Gates	DWSD	Operational	19.68 (5.2)	
Tireman Outfall Gates	DWSD	Operational	21.58 (5.7)	
Bloomfield Hills, Birmingham, Acacia Park	Oakland County	Operational	18.17 (4.8)	\$1,552,000
GWK Influent Weir Storage	Oakland County	Operational	124.92 (33.00)	Included w/GWK Basin
Frisbee Sewer	City of Detroit	Operational	7.19 (1.9)	\$2,043,000
SUBTOTAL			600.52 (158.64)	\$42,164,000
Equalization Basins (as part of CSO Elimination Program)				
Farmington	Farmington	Operational	12.11 (3.20)	\$5,000,000
City of Wayne	Wayne County	Operational	8.71 (2.30)	\$3,827,000
Livonia	Livonia	Operational	8.33 (2.20)	\$1,029,000
SUBTOTAL			29.15 (7.70)	\$9,856,000
Sewer Separations/Relief Sewers and Collection System Upgrades				
Area 25	City of Wayne	Operational		\$221,000
Areas 19, 20, 23	City of Wayne	Operational		\$2,454,000
Area 18	City of Wayne	Operational		\$82,000
Farmington	Farmington	Operational		\$9,000,000
Midtown West	Garden City	Operational		\$9,727,000
Midtown East	Garden City	Operational		\$6,435,000
South Venoy	Garden City	Operational		\$1,228,000
Merriman	Garden City	Operational		\$459,000

Name of the Facility	Ownership	Status	Storage Volume: million liters (million gallons)	Construction Cost
Sewer Separations/Relief Sewers and Collection System Upgrades				
Perrin & Middlebelt	Garden City	Operational		\$10,848,000
Robinson Subdivision	Plymouth Township	Operational		\$557,000
Districts 30, 31, & 32	Plymouth Township	Operational		\$341,000
Area 42	Westland	Operational		\$346,000
Area 38	Westland	Operational		\$1,364,000
Area 10 (Contract 1 & 2)	Westland	Operational		\$4,010,000
Area 10 (Contract 3)	Westland	Operational		\$1,874,000
Area 10 (Contract 4)	Westland	Operational		\$768,000
Grosse Pointe Farms	Grosse Pointe Farms	Operational		\$10,000,000
Grosse Pointe Park	Grosse Pointe Park	Operational		\$18,600,000
Eastpointe Roseville Separation	Macomb County	Operational		\$4,184,000
So. Macomb Relief Sewers	Macomb County	Operational		\$15,269,000
So. Macomb Pump Station/Bypass Structure	Macomb County	Operational		\$22,827,000
Area Tributary to CSO 016	Dearborn	In Construction		\$6,380,000
Miller Rd. Pump Station Renovation	Dearborn	Operational		\$8,000,000
SUBTOTAL				\$134,974,000
Operational Elements				
Fairview Pump Station	DWSD	Operational		\$6,072,000
VR-15 (Conant Mt. Elliott)	DWSD	Operational		\$6,902,000
VR-17 (Shiawassee Gate)	DWSD	Operational		\$198,000
VR-8 (Hubbell-Southfield)	DWSD	Operational		\$202,000
SUBTOTAL				\$13,374,000
Detroit WWTP				
Primary Clarifiers No. 17, 18	DWSD	Operational		\$89,018,000
PS-2A (Additional Pump)	DWSD	Operational		\$2,048,000
SUBTOTAL				\$91,066,000
TOTAL EXPENDITURE				\$2,166,399,000

^a Listing does not include facilities to control sanitary sewer overflows (SSOs) from separated sewer systems except for equalization basins which were built to retain excess wet weather flows in newly separated combined sewer systems.

^b Construction cost reflects the cost to build the facility (as-bid contractor's cost plus or minus change orders) and has not been adjusted to account for inflation since the project was built. Costs do not include engineering, administrative, land acquisition or legal expenses.

The benefits of this massive CSO expenditure have become apparent as water quality throughout southeast Michigan continues to improve. The volume of uncontrolled CSOs has decreased substantially, and further improvements will be achieved as projects currently in design and construction are completed and placed into service. As shown in Figure 2, the quantity of uncontrolled CSO discharges will be reduced by 85% when all of the facilities are completed and placed in service.

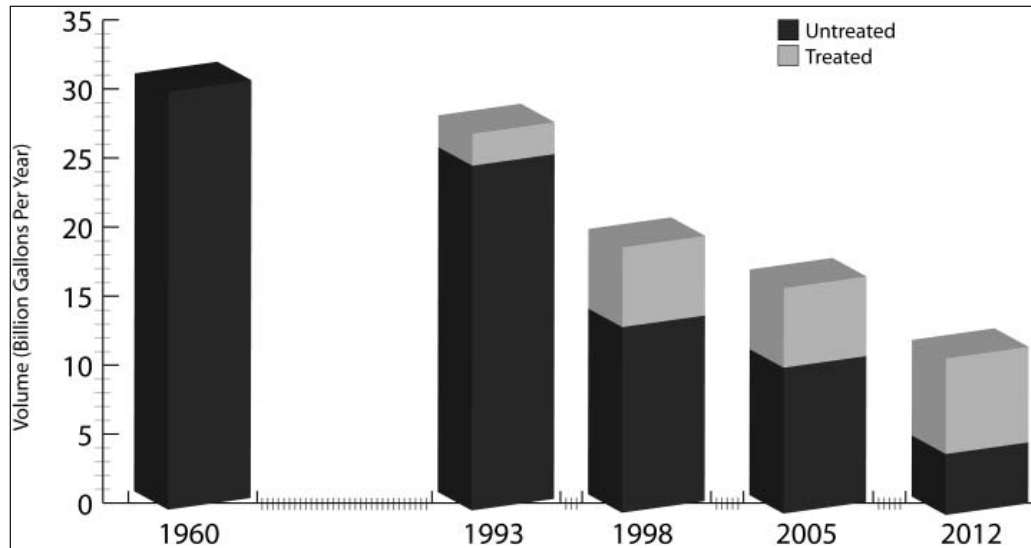


Figure 2. Historical and projected effects of Detroit Water and Sewerage Department's and customers' efforts to reduce and treat CSOs.

Dissolved oxygen levels in receiving waters throughout southeast Michigan have shown steady improvement, and fish and aquatic life surveys document that area waterways are markedly improved. Because the CSO control projects typically include disinfection to control bacteria, recreational users benefit from improved public health protection practices, and beach closures in response to wet weather events have become increasingly infrequent.

While the effort to control wet weather pollution from CSOs is not yet complete, the progress achieved to date demonstrates that significant water quality improvements are achievable in urban areas when CSO controls are constructed. The overall health of the watersheds in southeast Michigan is continuing to improve, and in large measure this is a result of the work by local government to control pollution from combined sewer systems throughout the area.

Management Next Steps

Key management actions for southeastern Michigan watersheds include:

- Complete Phase 2 CSO control projects (planned CSO controls on all remaining combined sewer areas);
- Continue sanitary sewer capacity improvements;
- Promote the economic importance of the region's "Green" (plants) and "Blue" (waters) infrastructure to encourage adequate public investment in continued restoration and protection efforts;

- Ensure sufficient collaboration among all watershed communities, all watershed counties, Michigan Department of Environmental Quality, and the U.S. Environmental Protection Agency to secure adequate funding to sustain and expand a collaborative illicit discharge elimination effort and a public education and watershed monitoring program; and
- Expand the voluntary storm water permit efforts of the Rouge River to all southeastern Michigan watersheds, consistent with Michigan's Watershed-Based Storm Water Permit (MIG619000).

Research/Monitoring Needs

Monitoring is essential for proper watershed management. Priority must be given to ensuring sufficient monitoring to be able to adequately evaluate effectiveness of programs and to make midcourse corrections. Further, research is needed on innovative funding mechanisms for storm water, CSOs, and watershed management in order to maintain the momentum for restoration and protection efforts.

Links for More Information

Detroit Water and Sewerage Department
www.dwsd.org

Rouge River National Wet Weather Demonstration Project
www.rougeriver.com

Contact Information

Gary Fujita
 Deputy Director of Detroit Water and Sewerage Department
 E-mail Address: fujita@dwsd.org

James Sherrill
 Wade Trim
 E-mail Address: jsherrill@wadetrim.com

Dick Hinshon
 Hinshon Environmental Consulting
 E-mail Address: hinshonr@aol.com

INDICATOR: CONTAMINATED SEDIMENT REMEDIATION

Background

Although contaminant loads to the Detroit River and Lake Erie from fixed sources have substantially decreased since the 1970s, the atmosphere and sediments continue to contribute contaminants to the ecosystem (Zarull et al. 2001). Since all Areas of Concern around Lake Erie (i.e., the Detroit River, Rouge River, River Raisin, and Maumee River) have contaminated sediment, it is viewed as a universal obstacle in restoring beneficial uses in the Detroit River and Lake Erie (Sediment Priority Action Committee, International Joint Commission 1999).

The Detroit River and western Lake Erie have contaminants, such as mercury and PCBs, in sediment that exceed chemical guidelines; the effects these contaminants are having on the ecosystem are only partially known. However, there is evidence linking these contaminants to restrictions on fish and wildlife consumption, fish tumors or other deformities, loss of fish and wildlife habitat, degraded invertebrate communities, and other beneficial use impairments identified in the U.S.-Canada Great Lakes Water Quality Agreement.



Figure 1. Black Lagoon sediment remediation project
(Photo credit: Robert Burns, Detroit Riverkeeper).

In general, reductions in contaminant loadings have resulted in a 50-70% decline in contamination of fish. However, consumption advisories on certain fishes remain in effect in the Detroit River and western Lake Erie. Since the mid-1980s, levels of contaminants in the environment appear to have generally leveled off or their rate of decrease has slowed substantially.

Status and Trends

Considerable progress has been made in sediment remediation in the watershed of the Detroit River and western Lake Erie over the last 13 years. For example, during 1993-2006 over 989,000 cubic

meters of contaminated sediment has been remediated as a result of 12 projects which include: Elizabeth Park Marina on Trenton Channel, Carter Industrial Site in Detroit, Lower River Raisin in Monroe, Evan's Ditch on Rouge River, Monguagon Creek in Riverview, Lower River Raisin floodplain in Monroe, Newburgh Lake impoundment on Rouge River, Willow Run Creek on Huron River, Fraleigh Creek on Ottawa River, Conners Creek on upper Detroit River, Black Lagoon on Trenton Channel, and Trenton Channel in Riverview (Figure 2). Examples of the magnitude and benefits of contaminated sediment remediation projects completed include:

- in 1998 approximately 306,000 cubic meters of contaminated sediment were removed from the Newburgh Lake impoundment on the Rouge River at a cost of \$11 million, resulting in a tenfold decline in PCB contamination of fish and a lifting of the health advisory on fish from Newburgh Lake;
- in 2003 approximately 122,300 cubic meters of contaminated sediment were removed from Conner Creek at the upstream end of the Detroit River at a cost of \$9 million, resulting in substantial environmental, aesthetic, and economic benefits; and
- in 2005 approximately 87,900 cubic meters of contaminated sediment were removed from Black Lagoon (Figure 1) on the Detroit River at a cost of \$9.3 million, furthering economic revitalization of the adjacent area.

The cumulative cost of these 12 sediment remediation projects undertaken in the Detroit River-western Lake Erie watershed during 1993-2006 was over \$154 million (Figure 3).

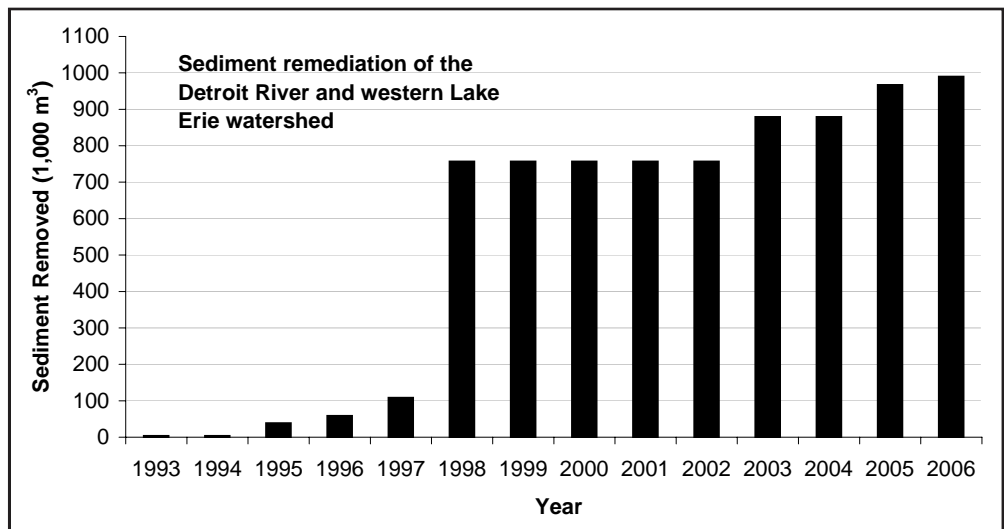


Figure 2. The cumulative volume of sediment remediated from the Detroit River and western Lake Erie watershed, 1993-2006.

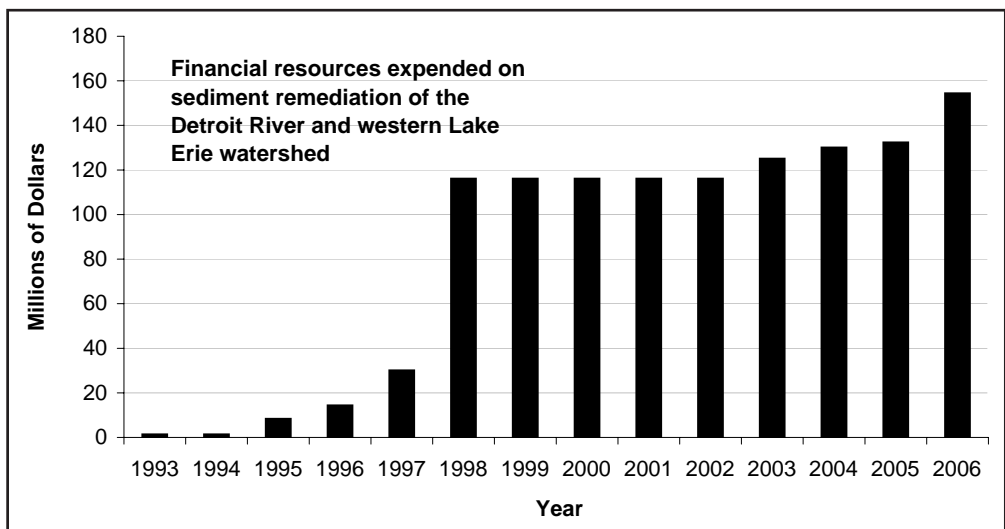


Figure 3. The cumulative financial resources expended on sediment remediation from the Detroit River and western Lake Erie watershed, 1993-2006.

Management Next Steps

Control of contaminants at source remains the primary imperative for action, but a higher priority must be given to measuring and monitoring both loadings and system responses. Remediation of contaminated sediment is growing in importance as greater levels of source control are achieved. Sediment depositional zones have been delineated and thoroughly assessed in the Detroit River-western Lake Erie basin. The Michigan Department of Environmental Quality (Ostaszewski 2003) has concluded that there remains approximately 2.3 million cubic meters (3 million cubic yards) of sediments that impact beneficial use impairments in the Detroit River (in particular the Trenton Channel), Rouge River (from the turning basin downstream), and River Raisin (lower river) combined. In addition, the U.S. Environmental Protection Agency (Czeczule 2003) has concluded that additional sediment remediation is essential in the lower Ottawa River for the removal of fish consumption advisories.

Research/Monitoring Needs

There are gaps in our understanding of the relationship between contaminated sediment and the 11 beneficial use impairments identified in the Great Lakes Water Quality Agreement. As a result of these critical knowledge gaps, the International Joint Commission's Sediment Priority Action Committee (1999) recommended additional research to quantify the relationships between contaminated sediment and known use impairments, and to forecast ecological benefits. It was also recommended that ecological recovery and beneficial use restoration be monitored in a scientifically defensible and cost-effective fashion. In particular, much greater emphasis should be placed on post-project monitoring of effectiveness of sediment remediation (i.e., assessment of effectiveness relative to restoration of beneficial uses, with appropriate quality assurance/quality control).

References

- Czeczule, M. 2003. A summary of Ottawa River PCB investigations and cleanup of Fraleigh Creek. In Heidtke, T.M., J.H. Hartig, and B. Yu. *Evaluating Ecosystem Results of PCB Control Measures within the Detroit River/Western Lake Erie Basin*. U.S. Environmental Protection Agency, EPA-905-R-03-001, Chicago, Illinois.
- Ostaszewski, A. 2003. PCBs in sediments: A Remedial Action Plan perspective. In Heidtke, T.M., J.H. Hartig, and B. Yu. *Evaluating Ecosystem Results of PCB Control Measures within the Detroit River/Western Lake Erie Basin*. U.S. Environmental Protection Agency, EPA-905-R-03-001, Chicago, Illinois.
- Sediment Priority Action Committee. 1999. Ecological benefits of contaminated sediment remediation in the Great Lakes Basin. Great Lakes Water Quality Board, International Joint Commission, Windsor, Ontario, Canada.
- Zarull, M.A., J.H. Hartig, and G. Krantzberg. 2001. Contaminated sediment remediation in the Laurentian Great Lakes: An overview. *Water Qual. Res. J. Canada* 36(2):347-365.

Links for More Information

Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin: <http://www.ijc.org/php/publications/html/ecolsed/index.html>

Overcoming Obstacles to Sediment Remediation in the Great Lakes Basin: <http://www.ijc.org/php/publications/html/sedrem.html>

Identifying and Assessing the Economic Benefits of Contaminated Aquatic Sediment Cleanup: <http://www.ijc.org/rel/pdf/ecben.pdf>

U.S. Environmental Protection Agency's Contaminated Sediment Program: <http://www.epa.gov/glnpo/sediments.html>

Contact Information

Michael A. Zarull
Environment Canada
E-mail Address: Michael.Zarull@ec.gc.ca

John H. Hartig, Refuge Manager
U.S. Fish and Wildlife Service
E-mail Address: John_Hartig@fws.gov

INDICATOR: LAND CONSERVATION FOR WILDLIFE IN THE DETROIT RIVER INTERNATIONAL WILDLIFE REFUGE

Background

The Detroit River International Wildlife Refuge (DRIWR) was established by an Act of Congress (Public Law 107-91) on December 21, 2001 (USFWS 2005). It is the only International Wildlife Refuge in North America and includes islands, coastal wetlands, marshes, shoals, and waterfront lands along 48 miles of Detroit River and western Lake Erie shoreline. Its location, situated in a major metropolitan area, is highly unique. The authorized acquisition boundary of the DRIWR extends from the confluence of the Rouge and Detroit rivers to the Michigan-Ohio border in the western basin of Lake Erie.

This area has made great progress since the major pollution problems in the 1970s. Over 35 years of pollution prevention and cleanup programs, and conservation initiatives, have resulted in dramatic improvements in environmental quality of the Detroit River and western Lake Erie. These environmental improvements have resulted in one of the most remarkable ecological recoveries in North America. The U.S. Fish and Wildlife Service recognizes the ecological importance of the area and is conserving valuable wildlife habitats within the DRIWR.

Status and Trends

Conserving the remaining sensitive wildlife habitats in the Refuge is a high priority of the U.S. Fish and Wildlife Service and its many partners. To guide this conservation work, the Service developed a Comprehensive Conservation Plan (CCP) for the DRIWR in 2001. This CCP articulates management goals, objectives, and strategies to guide management for the next 15 years. The preferred management approach is to focus on cooperative management—where the Refuge would grow primarily through management agreements with industries, government agencies, and other organizations. Partnerships at all levels will be essential to achieve the mission of the U.S. Fish and Wildlife Service and the goals of the CCP for the DRIWR. Indeed, the Refuge is rapidly gaining a national reputation for its public-private partnerships for conservation.

The DRIWR began in 2001 with 123 hectares (304 acres) that included Grassy Island and Mamajuda Shoal. That same year Mud Island was donated to the Refuge by National Steel Corporation (now U. S. Steel Corporation). In 2002 the Refuge expanded to include Calf Island. In 2003 the Refuge signed its first cooperative management agreement with DTE Energy to add the Lagoon Beach Unit at Fermi Power Plant. Also added in 2003 was the Brancheau Unit in Monroe, Michigan. In 2004, a milestone year for the Refuge, Humbug Marsh (the last remaining mile of natural shoreline along the U.S. mainland of the Detroit River) was acquired by the U.S. Fish and Wildlife Service and protected in perpetuity as part of the Refuge. Also in 2004 the U.S. Army Corps of Engineers donated the Strong Unit in Monroe, Michigan. In 2005, cooperative

management agreements were signed with Automotive Components Holdings for Eagle Island Marsh Unit and with the University of Toledo for Gard Island. In 2006, the Refuge nearly doubled in size with the signing of a cooperative management agreement with The Nature Conservancy for Erie Marsh along the lower portion of western Lake Erie. Late in 2006, 316 hectares (780 acres) at Lake Erie Metropark were put into the Refuge by cooperative agreement. In total, the Detroit River International Wildlife Refuge has grown from an initial 123 hectares (304 acres) in 2001 to 2,042 hectares (5,047 acres) in 2007 (Figure 1). The CCP for the DRIWR has set a land conservation target of 4,856 hectares (12,000 acres) (i.e., the Service has identified 4,856 hectares [12,000 acres] of marshes, wetlands, islands, shoals, and uplands that could potentially be conserved through acquisitions, easements, and cooperative agreements).

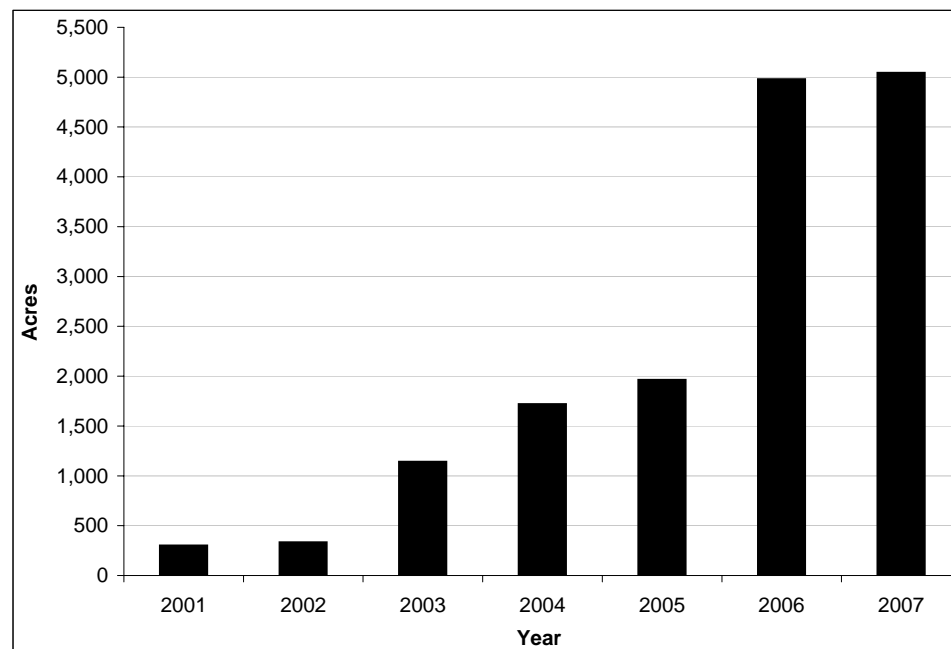


Figure 1. The cumulative growth of acreage in the Detroit River International Wildlife Refuge, 2001-2007. Note: One acre = 0.40 hectares.

Management Next Steps

Conserving as many remaining high quality habitats as possible is the top priority of the Refuge. This is particularly important to recognize in a relatively new Refuge with limited staff. Managers are placing substantial emphasis on conservation of unique wildlife habitats while these opportunities still exist.

Managers will also be placing a high priority on further developing public-private partnerships and building a network of volunteers with the help of the International Wildlife Refuge Alliance, an independent 501(c)(3) nonprofit organization, whose mission is to: “support the first International Wildlife Refuge in North America by working through partnerships to protect, conserve and manage the Refuge’s wildlife and habitats, and to create exceptional conservation, recreational and educational experiences to develop the next generation of conservation stewards.” Priority emphasis is also being placed on establishing a similar cooperative management agreement process in Canada to simultaneously grow the Refuge on the Canadian side.

Research/Monitoring Needs

The DRIWR recognizes the need to have strong linkages between science and management. The Refuge is currently being managed in an adaptive management context, where assessment, priority setting, and management action are followed in an iterative fashion for continuous improvement. The Detroit River-Western Lake Erie Indicator Project is a good example of ecosystem assessment. However, much more needs to be done, particularly in establishing a systematic and comprehensive biological program. This biological program should include standardized vegetation surveys, waterfowl surveys, colonial waterbird nesting counts, and others, and be complementary to the current research being conducted in the Detroit River-Western Lake Erie watershed. In addition, Refuge monitoring and management must be integrated with the Lake Erie Millennium Network, the Lake Erie Lakewide Management Plan, the Detroit River Remedial Action Plan, the Lake Erie Committee of the Great Lakes Fishery Commission, and others.

References

[USFWS] U.S. Fish and Wildlife Service. 2005. *Detroit River International Wildlife Refuge Comprehensive Conservation Plan and Environmental Assessment*.

Links for More Information

Detroit River International Wildlife Refuge: <http://www.fws.gov/midwest/DetroitRiver/>

Michigan Sea Grant, Detroit River International Wildlife Refuge, Birdwatching Eco-tourism & Education Project, and the International Wildlife Refuge Alliance: <http://www.miseagrant.umich.edu/coastal/ecotourism.html>

Midwest Natural Resources Group: <http://www.mnrg.gov/accomplishments/detroit-river.htm>

Contact Information

John Hartig, Refuge Manager
Detroit River International Wildlife Refuge
E-mail Address: John_Hartig@fws.gov

Steve Dushane, Assistant Refuge Manager
Detroit River International Wildlife Refuge
E-mail Address: Steve_Dushane@fws.gov

INDICATOR: SOUTHEAST MICHIGAN GREENWAY TRAILS

Background

Greenways are linear open spaces, including habitats and trails that link parks, nature reserves, cultural features or historic sites for recreation and conservation purposes. Throughout North America, greenways promote outdoor recreation, catalyze economic development, increase adjacent property values, celebrate historical and cultural assets, promote conservation and environmental education, and improve quality of life (Figure 1). Greenways can provide exceptional outdoor recreational experiences that reconnect children and families to natural resources which build a stewardship ethic. It should not be surprising that greenways are an enormous source of community pride. In many major urban areas, greenway trails provide an alternative mode of transportation.

Such greenway trails connect communities through a green infrastructure for biking, skiing, hiking, jogging and rollerblading; they serve as fishing piers, kayak landings, and wildlife corridors. Greenways promote sustainable communities and are considered an essential element in a sought-after community.



Figure 1. Greenway in Flat Rock, MI
(Photo credit: Melissa Prowse).

Status and Trends

Early greenway efforts were initiated in Detroit in the 1970s with the development of a linked riverfront parks plan (Table 1). Although visionary in its design, the plan was not implemented. In the 1980s, greenways received a national champion with the creation of the Rails-to-Trails Conservancy. The Michigan Rails-to-Trails Field Office was established in 1989.

The 1990s brought growing emphasis on regional planning for greenway trails. In 1994, the City of Detroit developed

a land use master plan that included greenways as one of the five key components of redevelopment in the city. The Southeast Michigan Greenways Initiative, established in 1990 as a project of the Michigan Chapter of the Rails-to-Trails Conservancy, and the Rivers, Trails and Conservation Office of the National Park Service published *A Vision for Southeast Michigan Greenways* in 1998. The Greater Detroit American Heritage River Initiative, established under the Metropolitan Affairs Coalition in 1998, championed linked greenways as one of its five priorities. In 1999 the Southwest Detroit Riverfront Greenway Project published a report titled "Detroit's New Front Porch." Later that year the Downriver Linked Greenways Initiative (DLGI) was established when a concerned group of citizens joined business representatives and state, local, and federal officials to champion linked greenways among the 21 Downriver communities south of Detroit. To

date, over 16 km (10 miles) of new trails have been constructed to link with 16 km (10 miles) of existing trails and over 2,835 hectares (7,000 acres) of natural areas and parks meandering through cultural, historic, community and business sites. Over \$10 million of greenway trail investment has been made Downriver since 1999. In 2003, DLGI created *Downriver Linked Greenways Wayside Companion*, in cooperation with the National Park Service, to help develop community stories and provide consistency for trail users.

Table 1. History of greenways development in southeast Michigan.

Time Period	Greenways Activities
1970s	Limited emphasis on greenways; City of Detroit prepared a conceptual plan of linked riverfront parks.
1980s	Emphasis on maintaining and improving existing parks; Rails-to-Trails Conservancy founded to catalyze greenways across the country; Michigan Rails-to-Trails Field Office established in 1989.
1990s	Growing emphasis on regional planning for greenway trails; Southeast Michigan Greenways Initiative established in 1990 to champion greenways; City of Detroit land use plan includes greenways as one of five keys to city redevelopment in 1994; Rails-to-Trails Conservancy and National Park Service release <i>A Vision for Southeast Michigan Greenways</i> in 1998; Greater Detroit American Heritage River Initiative, established under Metropolitan Affairs Coalition in 1998, championed linked greenways as one of its five priorities; Southwest Detroit Riverfront Greenway Project published "Detroit's New Front Porch" in 1999; DLGI established in 1999 to champion linked greenways between 21 Downriver communities.
2000s	In 2001, the Community Foundation for Southeast Michigan launched its GreenWays Initiative to help build a regional network of greenway trails. The GreenWays Initiative raised \$25 million from foundations and private contributions to help communities build greenway trails. It awarded over \$15 million in grants that leveraged \$90 million for greenway trails in southeast Michigan. The City of Detroit created a riverfront vision in 2002 using a multi-stakeholder process. The Detroit Riverfront Conservancy was established in 2003 to build the Detroit RiverWalk from the Belle Isle Bridge to the Ambassador Bridge. The Detroit Riverfront Conservancy has raised nearly \$100 million to build the Detroit RiverWalk, much of which will be completed in 2007. An endowment was also created through the Detroit Riverfront Conservancy to operate and maintain the Detroit RiverWalk in perpetuity. In 2003, DLGI created <i>Downriver Linked Greenways Wayside Companion</i> , in cooperation with the National Park Service, to develop community stories and provide consistency for trail users.

In 2002, the City of Detroit created a riverfront vision using a multi-stakeholder process. The Detroit Riverfront Conservancy was established in 2003 to realize that vision and build the Detroit RiverWalk from the Belle Isle Bridge to the Ambassador Bridge. The Detroit Riverfront Conservancy has raised nearly \$100 million to build the Detroit RiverWalk, much of which will be completed in 2007. The Conservancy created an endowment to operate and maintain the Detroit RiverWalk in perpetuity.

A significant resource for recent greenway development in the region is the GreenWays Initiative, launched in 2001 by the Community Foundation for Southeast Michigan. This Initiative raised more than \$25 million from foundations and private contributions to help communities build and connect a regional network of greenway trails. This effort was the first of its kind in the nation and created an unprecedented momentum for greenway development in southeast Michigan. To date, the GreenWays Initiative has

awarded \$15 million in grants to local units of government and nonprofit organizations for greenways planning and construction throughout southeast Michigan. Those grants have leveraged an additional \$90 million in public money to support those greenways projects. This Initiative significantly jump-started greenway development by providing capital for greenway planning and construction, identifying previously untapped funding resources, raising awareness about the issue, and by facilitating a regional master planning process that resulted in a consistent plan that will help prioritize and unify greenway development efforts at both a regional and local level.

In 2006, the GreenWays Initiative supported a public involvement process that engaged literally every municipality in the seven counties in southeast Michigan to develop greenways' visions for each of the counties and for the region as a whole.

Greenway planning and development increased significantly over the past five years due, in great part, to the increased availability of funding through previously untapped sources within the governmental, foundation, and business sectors. In total, over 145 km (90 miles) of greenways have been built at a cost of over \$75 million in the last five years. An additional 56 km (35 miles) are slated for construction over the next two to three years. Although much remains to be done to complete a regional greenways system, considerable progress has been made in a relatively short period of time.

Management Next Steps

The greenways vision for southeast Michigan is an interconnected trail system that stretches from the southern tip of Lake Huron to the southwestern corner of Lake Erie, up tributaries like the Clinton, Rouge, Huron, and Raisin rivers, and across to Canada to preserve or create natural beauty and to provide nonmotorized transportation options in rural and urban areas. The GreenWays Initiative and Downriver Linked Greenways Initiative will continue to play a role facilitating greenway planning and development to follow through with the regional vision. DLGI will update its master plan to include new trail locations, mapping, a marketing piece, website development and next action steps. Individual communities and counties will address their projects locally while working in the context of the regional plan. Recently completed projects have helped to build momentum for the next set of priority greenway projects.

Research/Monitoring Needs

Identifying creative financing options for greenways, as well as a provision for long-term maintenance and security, is a continuous challenge for greenway systems. Research should address these issues to work toward solutions to greenway management and construction. In addition, more applied research is needed on benefits assessment for greenways. Promoting the integration of greenways and trail development into community master planning processes to promote sustainable community development should also be a priority. There is no doubt that considerable benefits are accrued, but the benefits need to be better quantified and used as the rationale for completing the regional greenways vision.

Links for More Information

Rails-to-Trails Conservancy: <http://www.railtrails.org/index.html>

Detroit Riverfront Conservancy: www.detroitriverfront.org

Michigan Trails and Greenways Alliance: www.michigantrails.org

Downriver Linked Greenways Initiative: <http://www.miseagrant.umich.edu/coastal/revitalization.html#greenways>

Contact Information

Nancy Krupiarz, Executive Director
Michigan Trails and Greenways Alliance
E-mail Address: nancy@michigantrails.org

Thomas M. Woiwode, Director, GreenWays Initiative
Community Foundation for Southeast Michigan
E-mail Address: twoiwode@cfsem.org

Susanna M. Weckerle, Program Associate
Community Foundation for Southeast Michigan
E-mail Address: sweckerle@cfsem.org

Mary Bohling and Anita Twardesky, Co-Chairs
Downriver Linked Greenways Initiative
E-mail Addresses: bohling@msu.edu, anita@riversidekayak.com

John H. Hartig, Refuge Manager
Detroit River International Wildlife Refuge
E-mail Address: John_Hartig@fws.gov