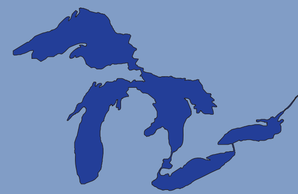
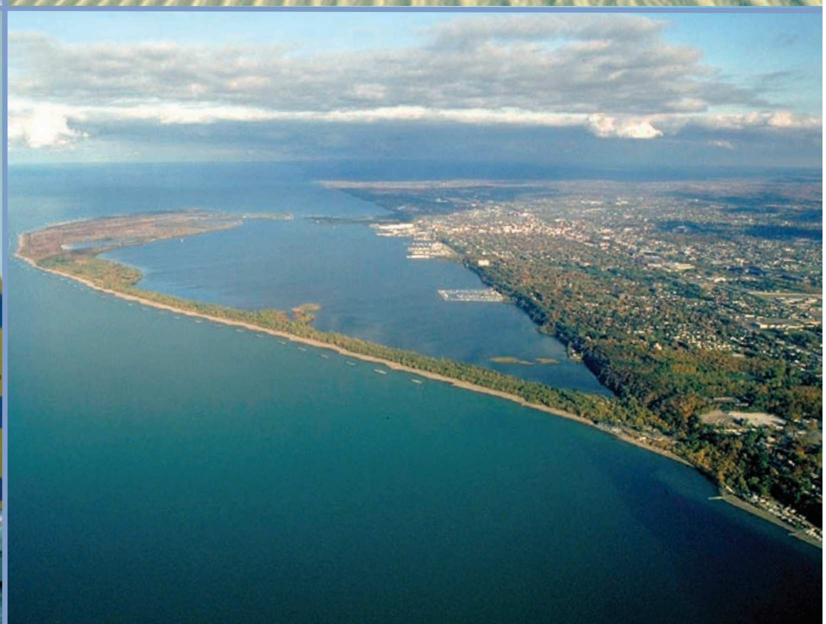
State of the Great Lakes

2011





Indicators to assess the status and trends of the Great Lakes ecosystem

EPA

Canada

Environment Canada

and the

U.S. Environmental Protection Agency

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State of the Great Lakes 2011

By the Governments of

Canada

and the

United States of America

Prepared by

Environment Canada

and the

U.S. Environmental Protection Agency

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Preface

The Governments of Canada and the United States are committed to providing public access to environmental information about the Great Lakes basin ecosystem through the State of the Great Lakes reporting process. The work is undertaken in accordance with the Great Lakes Water Quality Agreement, and is integral to the mission to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes. Knowing the environmental condition of the Great Lakes can allow for effective decision-making by all Great Lakes stakeholders.

The information in this report, **State of the Great Lakes 2011**, has been assembled with involvement from more than 125 scientists and experts from the Great Lakes community within Canada and the United States. The data are based on indicator reports and presentations from the State of the Lakes Ecosystem Conference (SOLEC), held in Erie, Pennsylvania, October 26-27, 2011. Some indicator reports have been augmented with more recent information.

SOLEC and the subsequent indicator reports provide science-based reporting on the state of the health of the Great Lakes basin ecosystem. Four objectives for the SOLEC process include:

- To assess the state of the Great Lakes ecosystem based on accepted indicators
- To strengthen decision-making and environmental management concerning the Great Lakes
- To inform local decision-makers of Great Lakes environmental issues
- To provide a forum for communication and networking amongst all Great Lakes stakeholders

SOLEC provides Great Lakes decision-makers and scientists with the opportunity to receive the most comprehensive, up-to-date, clear and concise information on the state of the Great Lakes, see thought-provoking presentations and network with hundreds of stakeholders. SOLEC enables environmental managers to make better decisions. Although SOLEC is primarily a reporting venue rather than a management program, many SOLEC participants are involved in decision-making processes throughout the Great Lakes basin.

State of the Great Lakes 2011. This technical report contains the full indicator reports as prepared by the primary authors, the indicator category assessments for water quality (chemical integrity), aquatic-dependent life (biological integrity) and landscapes and natural processes (physical integrity) as well as identifies Key Messages and efforts to remediate and protect the ecosystem. It also contains detailed references to data sources.

State of the Great Lakes 2011 Highlights. The Highlights report is a synopsis of the environmental indicator reports prepared for SOLEC 2011. This report provides a snapshot of current conditions in the “Key Indicators” and “Conditions” sections.

For more information about Great Lakes indicators and the State of the Lakes Ecosystem Conference, visit: www.binational.net or www.epa.gov/glnpo/solec or www.ec.gc.ca/greatlakes.

For more information about data quality see Appendix 1.

1. Introduction

The Great Lakes are a global environmental and economic wonder. Lakes Superior, Huron, Michigan, Erie and Ontario contain 84% of North America's fresh surface water, the source of drinking water for more than 24 million people. Millions of jobs are dependent on Great Lakes basin fisheries, forests, farmland, industry and recreation. Ongoing and emerging problems such as invasive species, chemical contaminants, and climate change impact the Great Lakes ecosystem. Understanding ecosystem conditions and knowing whether conditions are getting better or worse are necessary to address these problems. Using status and trend assessments, this report describes the health of the Great Lakes to answer the question, "How are the Great Lakes doing?"

Key Messages

The status for water quality is fair and the trend is deteriorating.

- Harmful and nuisance algae in nearshore areas and coastal bays, particularly in the western Lake Erie basin, Green Bay, Saginaw Bay, and parts of Lake Ontario are impacting human and ecosystem health. Algal trends are worsening.
- Low oxygen levels in the central Lake Erie basin are causing seasonal "dead zones" for aquatic life.
- Increasing water clarity is accelerating the proliferation of nuisance algae along some shorelines and signifies a lack of food for fish offshore.
- Levels of many legacy chemicals are declining in offshore waters; however, while declining, levels in fish and waterbird eggs still exceed guidelines in some areas. Mercury levels in fish have been slowly increasing since 1990.
- New substances of concern are being detected in the environment.

The status for aquatic-dependent life is fair and the trend is deteriorating.

- No new non-native species have been detected in the lakes since 2006, but earlier invaders continue to impact the ecosystem.
- In some areas, native species are struggling to survive in an ecosystem where invasive species have altered the food web and habitats have been lost or degraded.
- Coastal wetland plant and animal communities are diminishing due to loss of habitat; however, protection and restoration of wetland habitats have begun.

The status for landscapes and natural processes that influence the Great Lakes is fair and the trend is improving.

- Dams and other barriers prevent fish access to spawning and nursery habitats, but access is improving through dam removals and riparian restoration.
- Human uses can transform and stress Great Lakes watersheds. However, some positive signs in watersheds include marginal increases in forest cover and better land management.
- Water levels in lakes Superior, Huron and Michigan have been below average since the 1990s, and there are concerns that climate change will cause greater fluctuations and possibly lower water levels.

What Is Being Done

Work to prevent and reduce harmful levels of substances entering the Great Lakes, especially nutrients (specifically phosphorus), legacy chemicals and new substances of concern by:

- Adopting best management practices such as adequate manure storage, proper fertilizer application and installation of vegetative strips along streams and rivers;
- Updating and better maintaining septic systems and investing in wastewater treatment infrastructure;
- Restoring wetlands and riparian zones (the interface between the land and a river or stream) to reduce excess nutrients to waterways;
- Reducing legacy chemicals through a combination of regulations, rehabilitation of contaminated sites, and voluntary actions by industry and citizens; and,
- Researching the impacts of legacy chemicals and substances of emerging concern and conducting long-term monitoring of these substances to show improving or deteriorating trends.

Work to restore and protect native species and habitats, while preventing and controlling invasive species where possible by:

- Researching and monitoring the causes of the changing food web and declining populations of native species;
- Identifying and managing priority habitats at risk and habitats suitable for restoration;
- Supplementing fish stocking programs needed to maintain native fish species by restoring habitats such as reefs;
- Using new information from coastal wetlands monitoring to direct wetland protection and restoration actions and to evaluate restoration success; and,
- Preventing and controlling invasive species through research, vigilant monitoring, major projects such as the electric carp barrier, and individual actions such as cleaning recreational boats of mussels and plants.

Work to implement local land use decisions that plan for the long term, account for cumulative impacts and reflect the value of forests, fields, streams and wetlands by:

- Implementing long-term conservation plans and tracking cumulative impacts of local land use decisions;
- Guiding management decisions to conserve and improve watersheds by providing decision support tools;
- Supporting programs and projects that are economically and environmentally sustainable;
- Removing or mitigating dams and barriers where feasible in order to restore access to critical fish habitats; and,
- Including climate change considerations in all Great Lakes activities, including land use decisions.

2. Indicator Organization

What are Great Lakes indicators?

An indicator is a piece of evidence that helps us to understand the condition of something. Great Lakes indicators can provide insight on how the lakes are doing right now and over time, and whether we are meeting our ecosystem goals. Reporting on a suite of Great Lakes indicators produces a big picture perspective on the condition and trends of the complex ecosystem. Indicators have been used to report on Great Lakes ecosystem components since the first SOLEC in 1994. In 2010, the Great Lakes indicator suite was reviewed. The purpose of the review was to deliver an improved, updated and representative indicator suite that reports on the state of the Great Lakes in a comprehensive, understandable and scientific manner and allows for well-informed decision-making in the Great Lakes basin. The review also aimed to build consensus on indicators among federal, state, provincial and local management organizations, which is necessary to ensure that all related data are being collected, analyzed, and reported in an effective manner as no single organization has the resources or mandate to examine the conditions of the entire Great Lakes ecosystem.

Great Lakes indicators are used to:

- Assess conditions and track changes in the ecosystem;
- Understand existing and emerging issues and solutions;
- Guide programs and policies needed to prevent or address harmful environmental problems; and,
- Provide information to set priorities for research and program implementation.

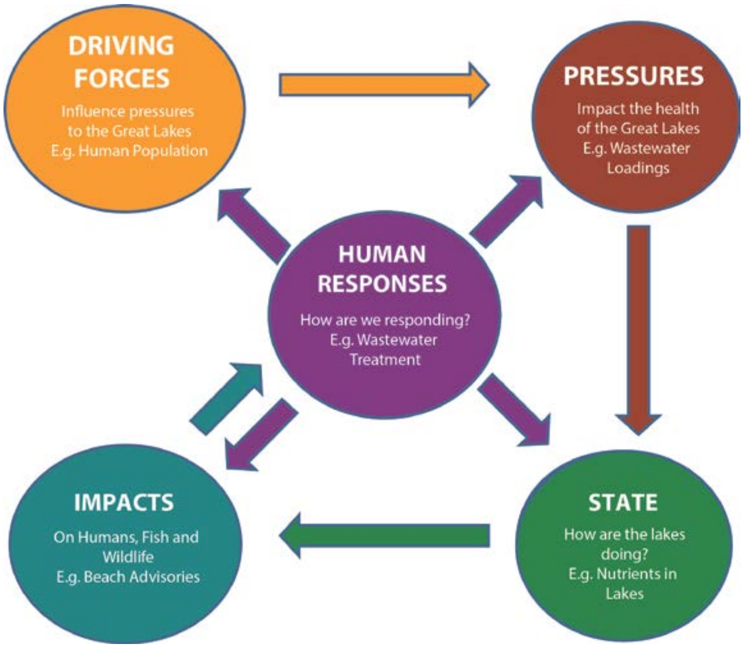
Great Lakes indicators serve the decision-makers working to restore and maintain the largest freshwater ecosystem on the planet. Over 70 complementary indicators have been identified and placed within an organizational framework that provides decision-makers with the maximum use of the information.

What is the geographic scope of the indicator reports?

Indicator reports will provide the status and trend for the Great Lakes overall and, where possible, on an individual lake basin scale. Additionally, status and trends will be reported for certain indicators at the scale of each lake's open and nearshore waters.

How are the indicators organized?

As a result of the 2010 review, the Driving Force – Pressure – State – Impact – Response (DPSIR) framework was adopted with ten top-level reporting categories (see reverse side for DPSIR framework, categories and indicators). The DPSIR framework is an underlying tool to help select, organize and report on indicators. The DPSIR framework allows decision-makers to understand the linkages between the condition of the ecosystem, pressures on the ecosystem, and how human activities are related.



Decision-makers are responsible for the STATE of chemical, physical and biological integrity of the Great Lakes because it IMPACTS the quality of life of humans, fish and wildlife. We are therefore working together on PRESSURES such as invasive species. Together we are asked to RESPOND to ecosystem conditions through restoration and protection efforts.

How are the indicators and the Great Lakes Water Quality Agreement connected?

The Great Lakes Water Quality Agreement (GLWQA) provides the context for selecting appropriate indicators and reporting categories. Ecosystem objectives identified by the GLWQA and supporting programs are the reference values for assessing status and trends within the Great Lakes indicators.

State of the Great Lakes Indicator Reporting Framework

DPSIR Framework Reporting Areas: Driving Forces; Pressures; State; Impacts; Responses

Top Level Categories	Economic/ Social	Pollution & Nutrients	Invasive Species	Resource Use & Physical Stressors	Water Quality	Aquatic-Dependent Life	Landscape & Natural Processes	Human	Fish & Wildlife	Restoration & Protection
Indicators	**Human population** **Economic prosperity** **Energy consumption** *Value of Great Lakes* **Greenhouse gas emissions**	**Contamination in sediment** **Atmospheric deposition** **Inland water quality index** *Nutrients in tributaries* *Pesticides in tributaries* *Bacterial loadings from tributaries* *Municipal wastewater loadings* *Industrial loadings*	**Aquatic non-native species** *including a watch list of high risk species* **Terrestrial non-native species** **Sea lamprey** **Dreissenid mussels**	**Watershed stressor index** *Forest disturbance* *Artificial coastal structures* **Hardened shorelines** **Surface water temperature** **Air temperature** **Precipitation events**	**Toxic chemicals in offshore waters** **Contaminants in whole fish** **Contaminants in waterbirds** **Groundwater quality** **Nutrients in lakes** *Major ions* *Water clarity* **Water chemistry**	**Wetland fish** **Wetland plants** **Wetland birds** **Wetland invertebrates** **Wetland amphibians** **Walleye** **Lake Trout** **Preyfish** **Benthos** ***Diporeia*** *Zooplankton Health* **Zooplankton Biomass** **Phytoplankton** *Threatened species* *Bald eagle* **Lake Sturgeon** *Piping Plover*	**Land cover** **Aquatic habitat connectivity** *Fish habitat* **Base flow due to groundwater** **Water levels** **Ice duration** **Forest cover** *Sediment coastal nourishment* **Tributary flashiness** **Wetland landscape extent and composition**	**Drinking water** **Beach advisories** **Fish consumption restrictions** **Harmful Algal Blooms** ***Cladophora***	**Botulism outbreaks** *Fish disease occurrences* *Endocrine disruption*	**Withdrawing water sustainably** **Conserving and protecting forest land** **Remediating contaminated sediment** **Treating wastewater** *Protection and restoration of habitats and species* **Conserving soil, improving water quality and enhancing wildlife on agricultural lands** *Stocking native fish* *Protecting special lakeshore areas* *Implementing industrial efficiency measures* *Educating Great Lakes basin residents*

Note: **bold denotes existing indicators for which reports can be found in the Indicator Reports section** and *italic denotes indicators under development* Note: indicator report names are shortened in some cases

Indicator status and trend definitions

The status for each indicator is defined as follows:

GOOD - Meeting GLWQA or other ecosystem objectives or otherwise in acceptable condition.

FAIR - Exhibiting minimally acceptable conditions, but not meeting established GLWQA or other ecosystem objectives.

POOR - Severely negatively impacted and not displaying even minimally acceptable conditions.

UNDETERMINED - Data are not available or are insufficient to assess the status of ecosystem components.

The trend for each indicator is defined as follows:

IMPROVING - Metrics show a change toward more acceptable conditions.

DETERIORATING - Metrics show a change away from acceptable conditions.

UNCHANGING - Metrics show no change.

UNDETERMINED - Metrics indicate a balance of both improving and deteriorating conditions, or data are not available to report on a trend.

For more information about Great Lakes indicators, SOLEC and the technical report, visit: www.ec.gc.ca/greatlakes; www.epa.gov/greatlakes/solec; www.binational.net or email: SOLEC@ec.gc.ca.

3. State of the Great Lakes

3.1 Assessment of Water Quality (Chemical Integrity)

Water Quality State Indicators 2011 Assessment (Status and Trend)

Indicators	Lake				
	LS	LM	LH	LE	LO
Contaminants in Waterbirds	Good / Improving	Good / Improving	Good / Improving	Fair / Unchanging	Fair / Unchanging
Contaminants in Whole Fish	Fair / Deteriorating	Fair / Unchanging	Fair / Deteriorating	Fair / Deteriorating	Fair / Unchanging
Groundwater Quality	Under development				
Major Ions	Under development				
Nutrients in Lakes	Good / Unchanging	Fair / Deteriorating	Fair / Deteriorating	Poor / Deteriorating	Fair / Deteriorating
Toxic Chemicals in Offshore Waters	Fair / Undetermined	Fair / Undetermined	Good / Undetermined	Fair / Undetermined	Fair / Undetermined
Water Chemistry	Undetermined / Undetermined				
Water Clarity	Undetermined / increasing	Undetermined / increasing	Undetermined / increasing	Undetermined / Undetermined	Undetermined / increasing

Water Quality Supporting Indicators 2011 Assessment (Status and Trend)

Indicators	Lake				
	LS	LM	LH	LE	LO
Atmospheric Deposition	Fair / Improving				
Beach Advisories – U.S. Beaches	Good / Unchanging	Good / Unchanging	Good / Unchanging	Fair / Deteriorating	Good / Improving
Beach Advisories – Canada Beaches	Good / Deteriorating	Good / Unchanging	Good / Deteriorating	Fair / Deteriorating	Good / Unchanging
Cladophora	Good / Unchanging	Poor / Unchanging	Fair / Undetermined	Poor / Undetermined	Poor / Undetermined
Contamination in Sediment Cores	Unchanging	Not assessed	Improving	Improving	Improving
Dreissenid Mussels – Zebra and Quagga	Undetermined	Deteriorating	Deteriorating	Undetermined	Deteriorating
Drinking Water Quality	Good / Unchanging				
Conserving Soil, Improving Water Quality and Enhancing Wildlife Habitat on Agricultural Lands	Increasing				
Fish Consumption Restrictions Advisories	Fair / Undetermined	Fair / Undetermined	Orange / Undetermined *	Fair / Undetermined	Poor / Undetermined
Harmful Algal Blooms (HABs) Offshore	Good / Unchanging	Fair / Unchanging	Fair / Unchanging	Orange / Deteriorating *	Fair / Unchanging
Harmful Algal Blooms (HABs) Nearshore	Good / Unchanging	Fair / Deteriorating	Fair / Deteriorating	Orange / Deteriorating *	Fair / Deteriorating
Inland Water Quality Index	Good / Undetermined	Undetermined / Undetermined	Good / Undetermined	Fair / Undetermined	Fair / Undetermined
Nutrients in Tributaries	Under development				
Pesticides in Tributaries	Under development				
Protection and Restoration of Habitats and Species	Under development				
Remediating Contaminated Sediment	Increasing				

Good | Fair | Poor | Undetermined

Improving | Deteriorating | Unchanging | Undetermined

* Note: Orange represents Poor to Fair status as assessed by the authors of the Fish Consumption Restrictions Advisories and Harmful Algal Blooms indicators.

Water quality status is fair and the trend is deteriorating.

The overall status for water quality in the Great Lakes is fair. There are currently low concentrations of toxic chemicals in offshore waters, and a decreased concentration of some legacy chemicals, such as PCBs and DDT, in fish. However, not all water quality guidelines are being met. Despite a mix of trends for the various monitored contaminants, the overall water quality trend is deteriorating. Nearshore symptoms of nutrient enrichment persist and algal trends are worsening in some areas of the Great Lakes. Phosphorus concentrations in offshore waters are becoming too low in some lakes to support productive food webs. Increasing mercury concentrations in fish are being observed in some areas of the lakes, after years of steady decline.

The following four indicators were used to justify the water quality status and trend determination. A short summary of each follows and the full indicator reports can be found in the Indicator Reports section.

Contaminants in Waterbirds*

Concentrations of contaminants that have been managed and monitored since the 1970s and 1980s have decreased in herring gull eggs, including significant declines in DDE (a breakdown product of DDT) and other banned pesticide-related compounds. However, over the last decade there has been a mixture of chemical concentration trends in herring gull eggs, with some contaminant trends showing continuing improvements but other contaminant trends showing no significant change. The overall assessment is good with an improving trend.

Contaminants in Whole Fish*

Total mercury concentrations in fish are below the 1987 GLWQA guidelines in all lakes. However, concentrations appear to be increasing in lakes Superior, Huron and Erie. Concentrations of pentaPBDEs are currently above the Federal Environmental Quality Guidelines developed by Environment Canada in lake trout and walleye in all the Great Lakes, but are declining in most monitored fish. Total PCB concentrations in fish are above 1987 GLWQA guidelines in all lakes.

* These indicators are in the Water Quality assessment because long-term trends of contaminants in aquatic biota provide valuable insight into how chemicals get into and move throughout the food web.

Nutrients in Lakes

In lakes Michigan, Huron and Ontario, offshore total phosphorus concentrations are currently below 1987 GLWQA targets but may be too low to support healthy levels of lake productivity. In Lake Erie, targets are frequently exceeded and conditions are deteriorating. Only in Lake Superior are offshore targets being met and conditions acceptable. The assessment for nutrients in lakes in offshore waters is fair and deteriorating. Nearshore symptoms of nutrient enrichment persist and are getting worse in some areas of the Great Lakes resulting in greater extent and duration of nuisance and harmful algal blooms.

Toxic Chemicals in Offshore Waters

Concentrations of many compounds are still detected in offshore waters, although they are at very low concentrations, so the status of this indicator is considered fair. Overall, the trends of toxic chemicals in offshore waters are undetermined because there is a mixture of trends observed. Trends for the majority of organochlorine compounds are improving, while trends for PAHs and in-use pesticides vary. The highest concentrations of total mercury in Great Lakes surface waters are observed in the western basin of Lake Erie; however, there have been no observed exceedances of the Canadian Council of Ministers of the Environment water quality guideline.

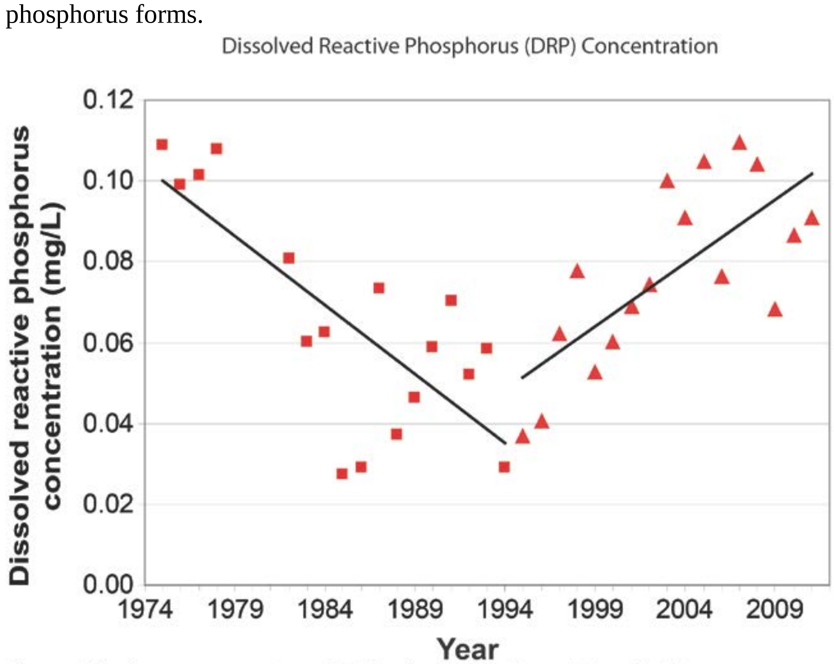
Integrating Indicators: Using Indicators to Describe Water Quality Issues

Building from the water quality assessment, four important stories are explained below to answer questions such as "Are the increasing amounts of nutrients and algae in the lakes dangerous to people?", "Doesn't clearer water mean cleaner water?", and "Where are the chemical substances still coming from?" Understanding the Great Lakes conditions requires information not just on the **state** of the ecosystem but also includes information on the **pressures** on the environment, the **impact** of conditions on humans, aquatic species and wildlife, and how society can **respond**.

Harmful and Nuisance Algae

Despite early successes in reducing phosphorus loads to the lakes after the 1972 Great Lakes Water Quality Agreement was implemented, algae have reappeared in recent years in nearshore areas. The resurgence of excessive algal growth in the Great Lakes is stressing ecosystem health and posing threats to human well-being and the tourism and recreational fishing industries.

Increased nutrients in water stimulate unwanted algal growth. In particular, too much phosphorus is entering rivers and lakes from land runoff and point sources. In 2011, delivery of a record-breaking amount of dissolved reactive phosphorus from the Maumee River in the spring preceded one of the worst harmful algal blooms ever observed in Lake Erie. Dissolved reactive phosphorus is a form of phosphorus that algae can use more easily compared to other phosphorus forms.



Flow-weighted mean concentrations of DRP for the Maumee River at Waterville, Ohio, 1975 - 2011. Squares represent data from 1975 - 1994 and triangles represent data from 1995 - 2011. Source: Heidelberg University, Ohio Tributary Loading Program.

Compounding this problem, in-lake nutrient cycling has changed due to the spread of invasive zebra and quagga mussels that became established in the 1990s. Invasive mussels retain and recycle nutrients in nearshore areas through their filtering and excretion activities. This alteration of nutrient flow is resulting in greater nuisance algal growth in the nearshore regions, closer to where humans interact with the lakes, while deeper offshore waters are deprived of nutrients. As they comprise the base of the food chain, some algae are desirable and necessary to promote fish production. However, harmful and nuisance algae are having a negative impact on ecosystem conditions.

Harmful algal blooms are highly noticeable growths of cyanobacteria, also known as blue-green algae. After largely being absent in the 1980s, blooms have reappeared in parts of the Great Lakes. Lake Erie is the most severely impacted with blooms becoming more widespread in the 1990s and 2000s. In 2011, Lake Erie's algal bloom consisted mostly of *Microcystis aeruginosa*, which produces a liver toxin (called microcystin) that is harmful to humans. In the summer of 2011, measurements of microcystin in Lake Erie were 50 times higher than the World Health Organization (WHO) recommendation for safe recreation, and 1,200 times higher than the WHO safe drinking water limit. Fortunately, microcystin is removed by municipal water treatment. In addition to the western basin of Lake Erie, algal blooms are prevalent in Green Bay, Saginaw Bay, and parts of Lake Ontario. Note that a regional drought in the spring of 2012 resulted in reduced nutrient runoff into the lakes, and as a result there was a marked reduction in Lake Erie harmful algal blooms.

Cladophora is a form of nuisance green algae that grows on hard surfaces. Excessive *Cladophora* can clog water intake pipes, decay and foul beaches and promote bacterial growth that may pose a risk to human health. The total amount of *Cladophora* varies from year to year, but observations and modeling indicate that the amount and resulting shoreline fouling have increased since the mid-1990s. Since that time, incidences of nuisance *Cladophora* growth have been recorded in each Great Lake, with the exception of Lake Superior.

Other changes contributing to the resurgence of algae include the loss of wetlands and riparian vegetation that once trapped nutrients. Shifting communities of phytoplankton, increased water clarity and climate issues such as warmer waters and extreme precipitation events also play a role.

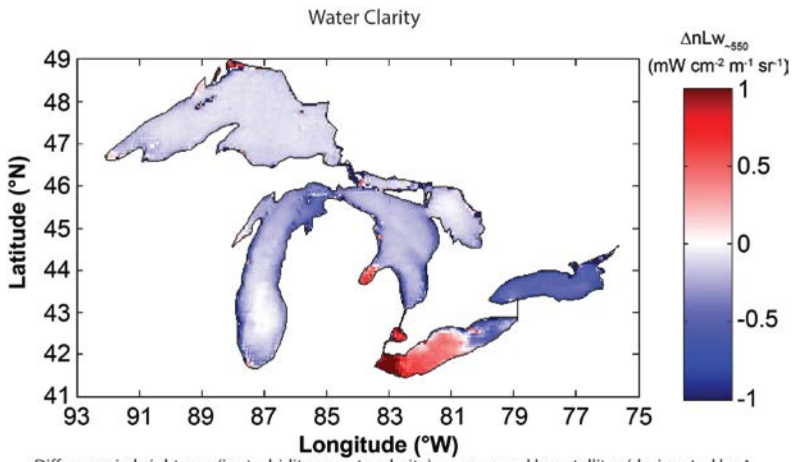
Low Oxygen Levels

Closely related to the excess nutrients and algae problem is the issue of low dissolved oxygen levels in Lake Erie. Since 2003, the total extent and duration of low oxygen levels have increased, particularly in the central basin. These areas are sometimes called "dead zones", as few animal species can survive under such conditions. Note that the dead zone impact was evident in September 2012, when tens of thousands of fish washed onto the shores of Lake Erie after being exposed to waters with low levels of oxygen that were brought to the surface during an upwelling event.

Seasonal declines of oxygen in the deep parts of all of the Great Lakes are a natural occurrence. However, in Lake Erie the natural declines are aggravated by increased nutrient inputs that stimulate excessive algal growth. When large quantities of algae die and sink to the bottom, they are decomposed by bacteria which deplete the supply of oxygen in the deeper waters. To improve dissolved oxygen levels in Lake Erie, levels of algae need to be reduced.

Clear Water

With a few exceptions, including the central and western basins of Lake Erie, all offshore areas of the lakes are clearer now than compared to 30 years ago. Offshore Lake Ontario water clarity doubled from a depth of approximately 3-4 meters to a depth of 6-8 meters during this period. Water clarity is determined by the amount of phytoplankton, dissolved organic materials and suspended materials in the water. Increased water clarity allows sunlight to penetrate to greater depths, which allows algae and rooted plants to grow in deeper areas of the lakes. It is also a significant factor in the resurgence of nearshore *Cladophora* blooms.



Difference in brightness (i.e. turbidity or water clarity) as measured by satellites (designated by Δ nLw~550) between the 1979 - 1985 time period and the 1998 - 2005 time period. Blue indicates clearer conditions, white indicates no change, and red indicates more turbid conditions.
Source: Environment Canada.

The increase in offshore water clarity is attributed to two factors. First, the zebra and quagga mussel invasion coincides with increasing water clarity and declining concentrations of calcium. The invasive mussels filter algae and calcium out of the water, leaving fewer particles in the water to absorb light. Reductions in offshore phosphorus loadings as a result of invasive mussel filtration and excretion have also limited algal productivity in the open waters, which further increases water clarity.

The reduction of nutrients and plankton in the offshore waters of Lakes Huron, Michigan and Ontario has led to significant changes in the ecosystem, including alterations to the food web as discussed in the “Fish Struggle to Survive” section of this report on page 23.

Chemical Substances

Chemical substances that have been the focus of management actions for decades are known as legacy chemicals and include PCBs and mercury. Legacy chemicals are now present in much lower concentrations in water, air and sediment than the peak concentration period in the 1970s and their levels generally continue to decline at very slow rates. In most colonial-nesting fish-eating birds, such as herring gulls, toxic chemical levels have decreased to where ecological effects, such as eggshell thinning, hatching failures, and population declines are no longer apparent.

The manufacture of PCBs was banned in North America in the 1970s, and levels in lake trout and walleye have been declining since that time. However, concentrations in these fish still exceed 1987 GLWQA guidelines and the rate of decline has slowed or in some cases halted since the early 2000s. Many transformers, capacitors, electric motors and other products built before the 1980s can still contain PCBs and thereby serve as sources of PCBs to the lakes. The concentration of PCBs and other contaminants in sediments are substantially lower than the peak levels that occurred in the mid-1950s through the early 1970s. However even with declines, contaminated sediments remain a source of harmful pollutants to the Great Lakes.

Mercury is found throughout the Great Lakes, with the highest concentrations in surface waters of the western basin of Lake Erie and nearshore areas of Lake Ontario, although levels in all lakes have dropped significantly over the past four decades. Levels of mercury in the offshore surface waters are low and are declining. Mercury levels in fish have been slowly increasing since 1990, reaching levels seen in the 1980s. Although mercury levels in fish are below 1987 GLWQA guideline levels, fish consumption advisories for mercury are in place for many fish caught in the Great Lakes. World-wide, the largest remaining source of mercury emissions to the atmosphere is coal-fired power plants. Regionally, many sources are reducing emissions; however, additional local and global actions may be needed to reduce the transport and deposition of mercury to the Great Lakes. Atmospheric deposition is also a significant route by which other persistent toxic chemicals, such as PCBs, currently enter the Great Lakes. Overall, the atmospheric deposition of toxic chemicals appears to be decreasing although different chemicals have different decline rates.

Many chemical substances of emerging concern are being assessed for environmental impact, and a broad basin-wide determination of their status and trend is not yet possible. Both the U.S. and Canadian governments are incorporating the monitoring of many chemical substances of emerging concern, including perfluorooctane sulfonate (PFOS) and flame retardants, into their routine monitoring programs. PFOS has been used in non-stick cookware, water-repellent clothing and stain-resistant carpets, as well as in a wide range of industrial applications. Concentrations of many PBDEs, a group of flame retardants, found in lake trout and walleye have been decreasing over the past 10 years; however, concentrations are still above the Federal Environmental Quality Guidelines developed by Environment Canada. These reductions are likely due to a voluntary North American manufacturing phase-out of penta-BDE and octa-BDE flame retardant formulations. However, concentrations of some of the other chemicals that are replacing the PBDEs are beginning to increase in the environment.

3.2 Assessment of Aquatic-Dependent Life (Biological Integrity)

Aquatic-Dependent Life State Indicators 2011 Assessment (Status and Trend)

Indicators	Lake: LS	LM	LH	LE	LO
Bald Eagle	Under development				
Benthos Diversity and Abundance	Good, Unchanging	Good, Unchanging	Undetermined, Undetermined	Poor, Unchanging	Fair, Deteriorating
Coastal Wetland Amphibians	Undetermined, Undetermined	Poor, Unchanging	Poor, Unchanging	Poor, Unchanging	Poor, Unchanging
Coastal Wetland Birds	Undetermined, Undetermined	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating
Coastal Wetland Fish Communities	Undetermined, Undetermined (all lakes)				
Coastal Wetland Invertebrate Communities	Undetermined, Undetermined (all lakes)				
Coastal Wetland Plants	Fair, Undetermined	Fair, Undetermined	Fair, Undetermined	Fair, Deteriorating	Poor, Unchanging
Diporeia	Good, Unchanging	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating
Lake Sturgeon	Fair, Improving	Fair, Improving	Fair, Improving	Fair, Improving	Fair, Improving
Lake Trout	Good, Improving	Poor, Unchanging	Fair, Improving	Poor, Deteriorating	Fair, Improving
Phytoplankton Populations	Good, Unchanging	Fair, Undetermined	Fair, Undetermined	Poor, Deteriorating	Fair, Undetermined
Piping Plover	Under development				
Preyfish Populations	Undetermined, Improving	Undetermined, Deteriorating	Undetermined, Deteriorating	Undetermined, Deteriorating	Undetermined, Deteriorating
Threatened Species	Under development				
Walleye	Fair, Undetermined	Good, Improving	Good, Improving	Fair, Unchanging	Fair, Unchanging
Zooplankton Biomass	Good, Unchanging	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined
Zooplankton Health	Under development				

Aquatic-Dependent Life Supporting Indicators 2011 Assessment (Status and Trend)

Indicators	Lake: LS	LM	LH	LE	LO
Aquatic Non-Native Species	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating	Poor, Deteriorating
Botulism Outbreaks	Unchanging	Undetermined	Undetermined	Undetermined	Undetermined
Dreissenid Mussels – Zebra and Quagga	Good, Undetermined	Good, Deteriorating	Good, Deteriorating	Good, Undetermined	Good, Deteriorating
Hardened Shorelines	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	Poor, Deteriorating
Sea Lamprey	Fair, Improving	Poor, Unchanging	Poor, Unchanging	Poor, Deteriorating	Good, Unchanging
Surface Water Temperature	Increasing	Increasing	Increasing	Undetermined	Undetermined
Terrestrial Non-Native Species	Undetermined, Undetermined (all lakes)				
Water Levels	Undetermined, Undetermined (all lakes)				

Good | Fair | Poor | Undetermined

Improving | Deteriorating | Unchanging | Undetermined

Aquatic-dependent life status is fair and the trend is deteriorating.

The overall status of aquatic-dependent life in the Great Lakes is fair because many locations support self-sustaining fish populations and a healthy food web; however, other areas are degraded. Predatory fish populations are being fairly well maintained through stocking programs, and in some cases natural reproduction, but most populations do not meet target levels. The overall deteriorating trend for aquatic-dependent life is a result of decreasing preyfish populations, the declining population of *Diporeia* (a source of food for small fish), and the declining populations of many coastal wetland species. The food web has been drastically altered. No new non-native species have been detected since 2006; however, the impacts of established invasive species continue to harm the ecosystem.

The following nine indicators were used to justify the aquatic-dependent life status and trend determination. A short summary of each follows and the full indicator reports can be found in the Indicator Reports section.

Benthos Diversity and Abundance

Changes in the benthic (or bottom-dwelling) community, as measured by the tolerance of certain freshwater benthic worm communities to nutrient enrichment, are indicating that some nearshore sites in Lake Ontario and Lake Michigan have become more rich in nutrients. This nutrient enrichment promotes the proliferation of plant life (i.e. more eutrophic). The majority of offshore sites in Lake Huron have seen a reduction in nutrient levels (i.e. increasingly oligotrophic), potentially causing problems for the aquatic ecosystem since there is a lack of food. Lake Erie is consistently and significantly more eutrophic than the other lakes while Lake Superior is oligotrophic.

Coastal Wetland Amphibians

Between 1995 and 2010, the occurrence of five species was stable, two species increased and one decreased. Indices of relative occurrence for these eight species are below proposed targets established by the Marsh Monitoring Program.

Coastal Wetland Bird Communities

The abundance of half the species that regularly or always nest in Great Lakes wetlands declined significantly between 1995 and 2010 and is below proposed targets established by the Marsh Monitoring Program. However, the abundance of trumpeter swan, sandhill crane and common yellowthroat increased.

Coastal Wetland Plant Communities

The conditions of the plant community in coastal wetlands naturally differ across the Great Lakes basin due to differences in underlying geomorphic and climatic conditions. Some individual wetlands have healthy plant communities, as indicated by their conservatism index score and other measures. The conservatism index score measures the specificity of a particular plant species to a specific habitat. Overall, the status for Lake Ontario coastal wetland plant communities is poor, and the other lakes are in fair condition. Note that the overall lake assessments can mask the good, fair, or poor conditions observed in individual wetland marsh types within a lake basin.

Diporeia

Populations of the small, native, shrimp-like *Diporeia* have declined for more than a decade and are almost completely gone in lakes Michigan, Ontario and Huron, while Lake Erie populations have been virtually gone since 1998. The population in Lake Superior, although highly variable, remains good and unchanging.

Lake Sturgeon

Once an important commercial species, only remnant populations of lake sturgeon remain in each of the Great Lakes. Populations have been considered fair and slowly increasing in all lakes over the last decade, with stocking programs and habitat restoration contributing to the increased abundance.

Lake Trout

Lake trout, historically the top predator fish of the Great Lakes, now only have self-reproducing populations throughout Lake Superior and many smaller populations in Lake Huron. Populations in lakes Michigan, Erie and Ontario are mostly below Great Lakes Fishery Commission Lake Committee target levels for relative abundance and natural reproduction is low. Although populations remain low in Lake Ontario, there was a sharp recovery in adult lake trout numbers in 2010. Some population increases are being observed with support of stocking and other restoration efforts.

Preyfish Populations

Basinwide, preyfish biomass (total weight) has been decreasing since 1988. A combination of pressures is causing the decline including salmonid predation and the compounding impacts resulting from the expansion of zebra and quagga mussels and other invasive species. However, the Lake Superior preyfish community is considered improving because of an increase in the proportion of native species comprising the assemblage and the preybase's ability to support the recovery of the wild lake trout population.

Walleye

Walleye populations in lakes Huron and Michigan are good, with improving trends since approximately 2003 and 2007, respectively. Populations in Lake Ontario have stabilized or increased slightly compared to declines observed in the 1990s. Lake Erie populations are lower than the highs experienced in the 1990s and early 2000s. Lake Superior populations are lower than historical levels, with healthy self-sustaining populations only in the St. Louis and Kaministiquia rivers.

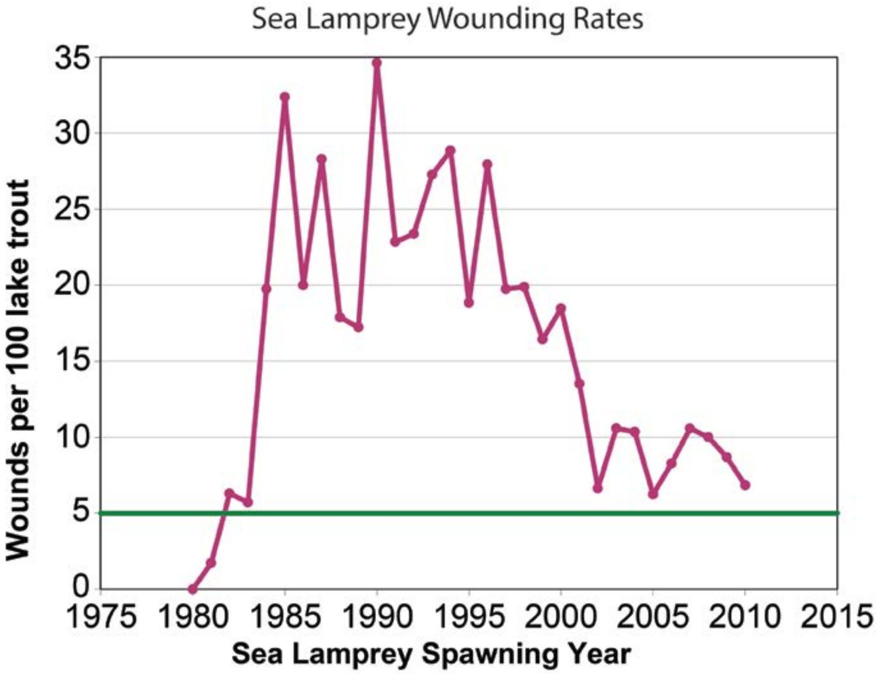
Integrating Indicators: Using Indicators to Describe Aquatic-Dependent Life Issues

Building on the state of aquatic-dependent life assessment, three important stories are explained below to answer questions such as "What problems are invasives causing and how are they getting into the Great Lakes?", "Why are there fewer sport fish?", and "Why is it important to restore wetlands?" Understanding the Great Lakes conditions requires information not just on the **state** of the ecosystem but also includes information on the **pressures** on the environment, the **impact** of conditions on humans, aquatic species and wildlife, and how society can **respond**.

Invasive Species

Since the 1830s, non-native aquatic species have significantly changed the Great Lakes ecosystem by altering aquatic food webs and degrading water quality and physical habitats. Although introductions have slowed, the 184 established non-native aquatic species continue to persist and expand their ranges within the Great Lakes. While the majority of non-native aquatic species have no known negative impact on the overall health of the Great Lakes, approximately 10 percent are considered invasive and harmful to the Great Lakes ecosystem.

One well-known invader is the sea lamprey, which has preyed on fish in the Great Lakes such as lake trout for decades. Control efforts have reduced the abundance of this invasive species by about 90 percent from peak levels, but the number of sea lamprey still currently exceeds Great Lakes Fishery Commission target ranges for lakes Huron, Michigan and Erie. Another invader, the quagga mussel, continues to expand its range into offshore habitats. The presence of quagga mussel contributes to or is implicated in a number of issues such as harmful and nuisance algal growth, food-web alterations, and Type E botulism which can cause large-scale mortalities in fish and waterbirds.



Yearly sea lamprey wounding rates on lake trout in Lake Huron. The green horizontal line represents the fishery management wounding rate target. Source: Great Lakes Fishery Commission.

A lack of new aquatic invasive species being detected in recent years is likely the result of effective ballast water and solid ballast management in ocean-going ships. While the primary risk of invasion from transoceanic shipping has been reduced, other potential pathways such as canals and the trade of live organisms for bait, food and pets need to continue to be addressed. The Chicago Sanitary and Ship Canal, in particular, has been the focus of much attention regarding the potential migration of Asian carp from the Mississippi River into the Great Lakes basin. Further, rising lake temperatures associated with climate change may increase the range of existing aquatic non-native species and provide favorable conditions for new introductions. The prevention of new and the control of existing aquatic non-native invasive species is a necessary, expensive and ongoing management challenge for the foreseeable future.

Terrestrial invasive species are pervasive and some pose direct threats to the Great Lakes. The emerald ash borer, for example, is an invasive insect that has killed millions of trees in the basin. *Phragmites australis* is an invasive grass that creates monoculture stands that replace complex wetland plant communities. Prevention, detection, rapid response, and management have been limited to local programs such as the Lake Superior Invasive Free Zone, where priority is given to removing non-native species in targeted areas. Degradation, fragmentation, and loss of habitats can render the Great Lakes basin even more vulnerable to further invasions.

Fish Struggle to Survive

Great Lakes fishes are struggling to survive due to food web changes. Historically, the food web of the Great Lakes was relatively simple. Microscopic plant life, called phytoplankton, and green algae in particular, served as the base of the food web. Phytoplankton was consumed by *Diporeia* and zooplankton. In turn, these organisms were eaten by a host of small and important preyfish species. In general, lake trout was the top predator; except in Lake Erie and some of the other shallow embayments of the upper Great Lakes where walleye was the top predator.

Diporeia
Credit: NOAA

Changes to the food web are ongoing. The phytoplankton communities of lakes Michigan and Huron in particular have seen a notable reduction in size and extent in the spring. Zooplankton communities are changing and declining throughout much of the basin. Larger-sized zooplankton species, typically located in waters of low biotic productivity, are making up an increasing proportion of the community during the summer in most of the upper lakes while smaller zooplankton decline. *Diporeia,* once the main food source for small fish in the Great Lakes is now almost gone, except in Lake Superior. The *Diporeia* decline has resulted in a change in the diets of small fish as well as reductions in small fish weight and energy. The causes of the *Diporeia* decline are not clear and a better understanding of this significant loss to the food web is essential in order to identify additional areas of the lakes that may be at risk.

The overall decline of zooplankton has strong implications for the food web because these organisms are an important link between phytoplankton and healthy fish populations. Preyfish population numbers are near historic lows in lakes Michigan and Huron for several species, such as alewife, rainbow smelt, and deepwater sculpin. In Lake Erie, preyfish populations have increased since the early 1990s, but are fluctuating considerably.

Historically, lake trout were the keystone predator fish for most of the Great Lakes. Today, self-reproducing populations of lake trout are only present in Lake Superior, and in some areas of Lake Huron. Stocked mature lake trout have been observed basinwide in Lake Huron and abundant young wild lake trout are now entering the adult portion of the population. In lakes Michigan, Erie and Ontario, lake trout populations are mostly below the Great Lakes Fishery Commission target levels. Walleye are present in fair to good numbers throughout the nearshore areas of the Great Lakes. However, in Lake Erie, walleye recruitment (survival) has been below average since 2003. Habitat restoration and supplemental stocking programs continue to be necessary to re-establish and maintain native fish species.

Juvenile Lake Sturgeon
Credit: US Fish and Wildlife Service

Lake sturgeon is the largest fish in the Great Lakes, and can live to be well over a hundred years old. These prehistoric fish were once estimated to number in the millions, but are now considered rare or endangered. Despite many hurdles, and with the support of dedicated and long-term restoration and protection efforts such as reef construction in the St. Clair and Detroit rivers and stream-side rearing programs, sturgeon populations are slowly increasing. In 2011, lake sturgeon successfully reproduced in the St. Louis River in Minnesota for the first time in over a century.

One illustration of the complex changes and challenges facing the food web today is the history of the non-native invasive preyfish, called the alewife. Alewives entered the upper Great Lakes through the Welland Canal in the 1940s. The alewife thrived because it had very few predators. Alewife populations grew to incredibly high numbers by the 1950s, and winter die-offs became a nuisance on the beaches of many metropolitan areas. New top predators, non-native Chinook and coho salmon, were intentionally introduced to the Great Lakes through a large, cooperative stocking program, in part to control alewife populations. Today, alewives remain part of the Great Lakes food web, and continue to challenge the survival of some other species by eating juvenile lake trout and creating conditions that can lead to a lethal vitamin deficiency in newly hatched lake trout and Atlantic salmon.

Coastal Wetland Communities

Great Lakes coastal wetlands are found throughout the entire basin and span a diversity of types, from freshwater estuaries to lagoons and marshes. They provide valuable ecosystem services, such as storing and cycling nutrients from the land to the lake, cleansing impurities in the water, and providing habitat for fish to spawn and migratory birds to feed. People also benefit from the flood control, erosion protection and recreational opportunities provided by coastal wetlands. Despite providing significant ecosystem and societal benefits, in many areas 50 to 90 percent of coastal wetlands have been lost due to development, pollution, invasive species, unnatural water level fluctuations and climate change impacts. Conservation of remaining coastal wetlands and restoration of those previously destroyed are a necessary component to restoring and maintaining the integrity of the Great Lakes.

Common Yellowthroat
Credit: US Fish and Wildlife Service

Recently, coastal wetland experts from universities, agencies and organizations developed a binational Great Lakes coastal wetland classification system and monitoring program. A five-year program to establish a baseline of coastal wetland conditions is progressing. By 2015, 100 percent of remaining Great Lakes coastal wetlands that are greater than 4 hectares in size will be assessed using established indicators that include marsh birds, amphibian populations, invertebrates, fish, wetland plants, and water chemistry. Once this baseline has been completed, protection and restoration actions will be targeted to coastal wetlands most in need of conservation.

3.3 Assessment of Landscapes and Natural Processes (Physical Integrity)

Landscapes and Natural Processes State Indicators 2011 Assessment (Status and Trend)

Indicators	Lake				
	LS	LM	LH	LE	LO
Aquatic Habitat Connectivity	Good, Improving	Good, Improving	Good, Improving	Fair, Unchanging	Fair, Unchanging
Base Flow Due to Groundwater Discharge	Fair, Deteriorating	Fair, Unchanging	Fair, Deteriorating	Fair, Deteriorating	Fair, Unchanging
Fish Habitat	Under development				
Forest Cover – Watershed	Good, Improving	Fair, Improving	Good, Improving	Poor, Deteriorating	Fair, Deteriorating
Forest Cover – Riparian Zones	Good, Undetermined	Fair, Undetermined	Fair, Undetermined	Poor, Undetermined	Fair, Undetermined
Ice Duration on the Great Lakes	Fair, Deteriorating				
Land Cover	Good, Undetermined	Undetermined, Undetermined	Fair, Undetermined	Poor, Undetermined	Undetermined, Undetermined
Sediment Coastal Nourishment	Under development				
Tributary Flashiness	Undetermined, Undetermined				
Water Levels	Undetermined, Undetermined				
Coastal Wetland Landscape Extent and Composition	Fair, Deteriorating				

Landscapes and Natural Processes Supporting Indicators 2011 Assessment (Status and Trend)

Indicators	Lake				
	LS	LM	LH	LE	LO
Air Temperature	Increasing				
Conserving Soil, Improving Water Quality and Enhancing Wildlife Habitat on Agricultural Lands	Increasing				
Extreme Precipitation Events	Increasing				
Economic Prosperity	Undetermined				
Energy Consumption	Increasing				
Greenhouse Gas Emissions	Undetermined				
Hardened Shorelines	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	Poor, Deteriorating
Human Population	Decreasing	Increasing	Increasing	Increasing	Increasing
Sea Lamprey	Fair, Improving	Poor, Unchanging	Poor, Unchanging	Poor, Deteriorating	Good, Unchanging
Surface Water Temperature	Increasing	Increasing	Increasing	Undetermined	Undetermined
Watershed Stressor Index	Good, Undetermined	Poor, Undetermined	Fair, Undetermined	Poor, Undetermined	Poor, Undetermined
Withdrawing Water Sustainability	Under development				

Good	Fair	Poor	Undetermined	Improving	Deteriorating	Unchanging	Undetermined

Landscapes and natural processes status is fair and the trend is improving.

The overall status of landscapes and natural processes of the Great Lakes is fair. Despite degradation in some areas, many watersheds and tributaries continue to serve as important spawning or nursery habitat for Great Lakes fish and continue to provide important functions such as water purification. The overall trend is improving because dam mitigation and barrier removal projects are increasing habitat connectivity for fish; forested lands in lakes Superior, Huron, and Michigan basins are increasing slightly; and some rivers and streams are exhibiting more stable streamflow conditions. Climate change impacts on natural processes of the Great Lakes, such as water level fluctuations and ice cover, are being observed.

The following three indicators were used to justify the status and trend of landscapes and natural processes. A short summary of each follows and the full indicator reports can be found in the Indicator Reports section.

Aquatic Habitat Connectivity

Thousands of dams are found on Great Lakes tributaries and are a key factor in the decline of several species of fishes. Many dams are near the end of their functional life. Several dam mitigation projects occurring throughout the basin are restoring connectivity between aquatic habitats.

Forest Cover

Percentage of Forested Lands within a Watershed by Lake Basin

Forested lands, as measured by satellite imagery, cover a large percentage of land area within the Lake Superior and Lake Huron basins, a moderate amount in the Lake Michigan and Lake Ontario basins and a low percentage in the Lake Erie basin. Recent data for basin-wide trends indicate that forest cover for lakes Superior, Michigan and Huron are increasing, but are decreasing overall for lakes Erie and Ontario. However, it is important to note that the forest cover trends being seen in the Great Lakes basin are quite small. Changes in forest types, composition and localized decreases in forest cover remain a concern.

Percentage of Forested Lands within Riparian Zones by Watershed

Forested cover in the riparian zone of water bodies is high in the Lake Superior basin, moderate in the Lake Michigan, Lake Huron and Lake Ontario basins and low in the Lake Erie basin. Trends are undetermined as data are not available.

Tributary Flashiness

Tributary flashiness is a measure that reflects the frequency of short-term changes in streamflow; the flow of a flashy stream increases and decreases dramatically in hours or a few days in response to rainfall. On average, tributary flashiness has significantly decreased in five out of 11 selected tributaries over a ten-year period, meaning flow conditions are becoming more stable. Flashiness in one of the tributaries (the Maumee River) has significantly increased, while flashiness in the remaining five tributaries studied did not exhibit significant trends. Periodic changes in flow rates are natural in streams and rivers and organisms that live in these systems adapt to them. However, changes in hydrologic regimes, either reductions or increases in flashiness, can lead to displacement of native biotic communities. Status and trends in tributary flashiness have not been analyzed for each lake basin.

Integrating Indicators: Using Indicators to Describe Landscapes and Natural Process Issues

Building from the landscapes and natural processes assessment, three important stories are explained below to answer questions such as “Why do lake levels change and what are the impacts?”, “How does land use relate to water condition?”, and “Why does dam removal benefit fish in streams?” Understanding the Great Lakes conditions requires information not just on the **state** of the ecosystem but also includes information on the **pressures** on the environment, the **impact** of conditions on humans, aquatic species and wildlife, and how society can **respond**.

Lake Levels

Since the late 1990s, water levels in lakes Superior, Huron and Michigan have been below average. This pattern follows nearly three decades of higher levels. Lake levels in the basin fluctuate on time scales that vary from hours to millennia; therefore, the extent of the water level record is insufficient to capture a complete understanding of trends in lake level variability. However, short- and long-term lake level fluctuations are critical to maintain healthy coastal habitats, especially coastal wetlands. Lake level fluctuations are the result of both natural and anthropogenic changes to water supply and storage.

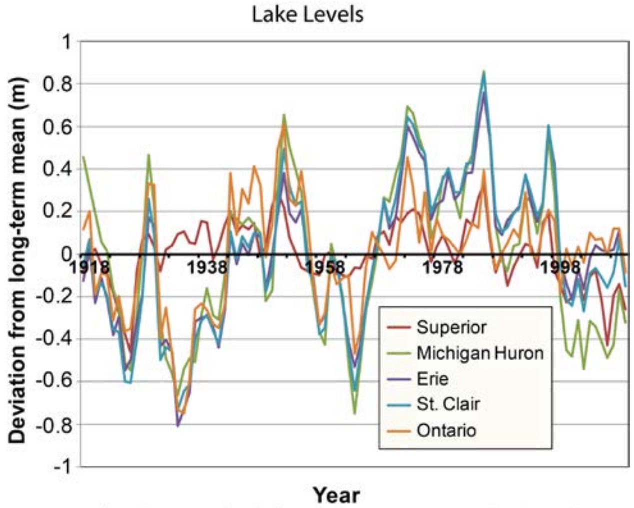
Low Lake Levels
Credit: Mark Breederlan, Michigan Sea Grant

Natural causes of long-term water level changes include overlake precipitation, runoff, evaporation, groundwater inflow/outflow and movements of the earth's crust. Human influences, such as water level regulation, diversions into and out of the Great Lakes, changes in land use affecting runoff, consumptive uses, and dredging in connecting channels, have different impacts in each lake. Of all the anthropogenic factors, control structures and dredging in channels have had the largest impact on water levels.

Lake levels can impact the economy. For example, a drop in lake level can reduce the cargo capacity of ships, increase dredging needs and reduce hydropower production. Lake level increases can cause flooding and erosion and worsen the impacts of storm damage.

Multi-lake level regulation through the building of new dams in connecting channels could help mitigate water level changes in currently unregulated lakes Michigan, Huron and Erie. However, this regulation will not fully eliminate the risk of extreme lake level fluctuations, and could take decades to implement, cost billions of dollars, and possibly come with significant ecological effects.

It is predicted climate change will affect lake levels. Projections vary, with some climate models predicting that water levels will decrease by 30 to 90 centimeters, depending on the lake, while more recent studies suggest that both extremely high and low water levels are possible. High or low lake levels should be of concern, though the magnitude and timing of these changes remain highly unpredictable. Despite this unpredictability, records show physical changes are occurring. For example, surface waters are warming earlier in the season and ice cover is decreasing, with freeze-up occurring later in the fall and ice-out occurring earlier in the spring.



Deviations of yearly average levels from the long-term mean in the Great Lakes.
Source: U.S. Army Corps of Engineers

Dams and Other Barriers

Streams and rivers provide spawning and nursery habitats for over one-third of Great Lakes fishes. However, fish access to these habitats has been significantly limited by thousands of dams, culverts and other barriers. For example, only 13 percent of the original stream passages in the Lake Huron basin are accessible to fishes. This loss of access to habitat has been a key factor in the historic decline of walleye, lake sturgeon and coaster brook trout populations.

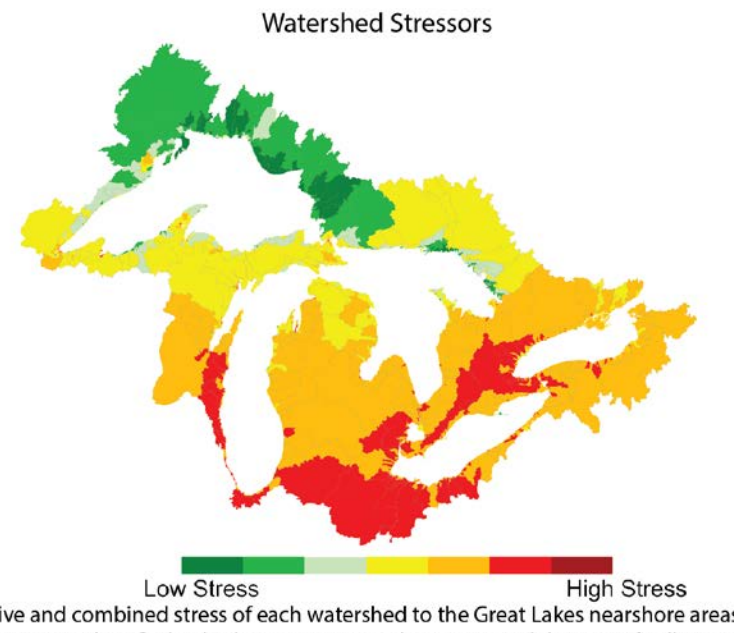

Lake Sturgeon Fish Passage
Credit: U.S. Fish and Wildlife Service

Several restoration projects are underway throughout the Great Lakes basin to remove or bypass dams. These projects provide an opportunity to restore aquatic habitat connectivity which will promote healthy fish populations. Other benefits include lower water temperatures, higher nutrient transport, natural flood cycles, and increased riparian and coastal wetland cover. Historical fishing grounds and culturally significant species such as coaster brook trout benefit from these restoration activities.

Transforming Watersheds

The watersheds of the Great Lakes have been and continue to be transformed to benefit the communities within the Great Lakes region. The region boasts prime agricultural lands, world-class cities and transportation corridors, renewable energy sources and more. However, these changes to the watersheds also impact the Great Lakes. Rivers and streams, which are conduits for fish passage and sediment nourishment to the lakes, have been straightened and dammed, disrupting natural flow regimes and hydrology. Coastal areas are dynamic, productive and rich in natural resources but some have been altered by development and hardened shorelines. The uplands furthest from the lakes—where groundwater is recharged, soils are productive, habitats sustain numerous species and water is naturally regulated and stored—are being converted to hard surfaces or used for other human purposes.

Recent research has identified five human-related stressors from the watersheds that can be particularly disruptive to Great Lakes. They are population density, road density, agricultural activity, area of non-natural land cover and number of point source discharges. When the five variables are combined, watersheds exerting the most stress on nearshore areas can be identified, and areas for protection and restoration can be prioritized.



Relative and combined stress of each watershed to the Great Lakes nearshore areas. Red areas are identified as high stress, green as low stress and degrees of yellow as moderate stress. Source: University of Windsor and University of Minnesota - Duluth.

Many changes are taking place to benefit or protect natural conditions in watersheds. Agricultural producers are improving field productivity while minimizing impacts to the Great Lakes. The number of best management practices adopted to conserve soil, improve water quality and enhance wildlife habitat has increased since 2005. Adoption of practices including the establishment of permanent vegetative filter strips at field edges, construction of manure storage structures, fencing livestock out of riparian areas, erosion control structures, and practicing integrated pest and nutrient management are helping to sustainably produce food while better managing environmental risks. Over the past 30 years, forest cover has increased overall in the U.S. Great Lakes basin, although there is concern that original forest types, such as boreal, are changing in some local and regional areas.

Cities and communities are also working to manage infrastructure renewal and growth with respect to established environmental goals. While restoration to pre-settlement conditions is unrealistic, an ecosystem that supports a balance between healthy environments and use by people is achievable.

4. Indicator Reports

4.1 Indicator Assessments (Status and Trend) Summary Table

Indicators	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	Top Level Reporting Category
Air Temperature (No status or individual lake assessment)	Increasing					**Pressure** – Resource Use and Physical Stressors
Aquatic Habitat Connectivity	Fair – Improving	Fair – Improving	Fair – Improving	Fair – Improving	Fair – Improving	**State** – Landscapes and Natural Processes
Aquatic Non-Native Species	Poor – Deteriorating	Poor – Deteriorating	Poor – Deteriorating	Poor – Deteriorating	Poor – Deteriorating	**Pressure** - Invasive Species
Atmospheric Deposition (no individual lake assessment)	Fair – Improving					**Pressure –** Pollution and Nutrients
Baseflow due to Groundwater Discharge (no individual lake assessment)	Fair – Undetermined					**State –** Landscape and Natural Processes
Beach Advisories – U.S. Beaches	Good – Unchanging	Good – Unchanging	Good – Unchanging	Fair – Deteriorating	Good – Improving	**Impacts -** Human
Beach Advisories – Canada Beaches	Good – Deteriorating	Good – Unchanging	Good – Deteriorating	Fair – Deteriorating	Good – Unchanging	**Impacts - Human**
Benthos (Freshwater Oligochaete) Diversity & Abundance	Good – Unchanging	Good – Unchanging	Undetermined – Undetermined	Poor – Unchanging	Fair – Deteriorating	**State –** Aquatic-dependent Life
Botulism Outbreaks	Unchanging	Undetermined	Undetermined	Undetermined	Undetermined	**Impacts –** Fish and Wildlife
Cladophora	Good – Unchanging	Poor – Unchanging	Fair – Undetermined	Poor – Undetermined	Poor – Undetermined	**Impacts -** Human
Coastal Wetland Amphibians	Undetermined – Undetermined	Poor – Unchanging	Poor – Unchanging	Poor – Unchanging	Poor – Unchanging	**State –** Aquatic-dependent Life
Coastal Wetland Birds	Undetermined – Undetermined	Poor – Deteriorating	Poor – Deteriorating	Poor – Deteriorating	Poor – Deteriorating	**State –** Aquatic-dependent Life
Coastal Wetland Fish Communities (no individual lake assessment)	Undetermined – Undetermined					**State –** Aquatic-dependent Life
Coastal Wetland Invertebrates (no individual lake assessment)	Undetermined – Undetermined					**State –** Aquatic-dependent Life
Coastal Wetland Extent and Composition (No individual lake assessment)	Fair – Deteriorating					**State –** Landscape and Natural Processes
Coastal Wetland Plants	Fair – Undetermined	Fair – Undetermined	Fair – Undetermined	Fair – Deteriorating	Poor – Unchanging	**State –** Aquatic-dependent Life
Conserving and Protecting Forest Land (no status or individual lake assessment)	Undetermined					**Response –** Restoration & Protection
Conserving Soil, Improving Water Quality and Enhancing Wildlife Habitat on Agricultural Lands	Increasing					**Response –** Restoration & Protection
Contaminants in Waterbirds	Good – Improving	Good – Improving	Good – Improving	Fair – Unchanging	Fair – Unchanging	**State –** Water Quality
Contaminants in Whole Fish	Fair – Deteriorating	Fair – Unchanging	Fair – Deteriorating	Fair – Deteriorating	Fair – Unchanging	**State –** Water Quality
Contamination in Sediment Cores	Good – Unchanging	Not assessed	Good – Improving	Fair – Improving	Fair – Improving	**Pressures –** Pollution and Nutrients

Status: Good | Fair | Poor | Undetermined

Trend: Improving | Deteriorating | Unchanging | Undetermined

Indicators	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	Top Level Reporting Category
Diporeia	Good / Unchanging	Poor / Deteriorating	Poor / Deteriorating	Poor / Deteriorating	Poor / Deteriorating	**State –** Aquatic – Dependent Life
Dreissenid Mussels	Good / Undetermined	Poor / Deteriorating	Poor / Deteriorating	Fair / Undetermined	Fair / Deteriorating	**Pressures** – Invasive Species
Drinking Water Quality (no individual lake assessment)	Good / Unchanging (all lakes)					**Impacts** – Human
Economic Prosperity (No status or individual lake assessment)	Undetermined (all lakes)					**Driving Forces –** Economic / Social
Energy Consumption (No status or individual lake assessment)	Increasing					**Driving Forces** – Economic / Social
Extreme Precipitation Events (No status or individual lake assessment)	Increasing					**Pressure** – Resource Use and Physical Stressors
Fish Consumption Restrictions	Fair / Undetermined	Fair / Undetermined	Poor to Fair* / Undetermined	Fair / Undetermined	Poor / Undetermined	**Impacts** – Human
Forest Cover % of forested lands within a watershed	Good / Improving	Fair / Improving	Good / Improving	Poor / Deteriorating	Fair / Deteriorating	**State** – Landscapes and Natural Resources
Forest Cover % of forested lands within riparian zones	Good / Undetermined	Fair / Undetermined	Fair / Undetermined	Poor / Undetermined	Fair / Undetermined	**State** – Landscapes and Natural Resources
Greenhouse Gas Emissions (No status or individual lake assessment)	Undetermined (all lakes)					**Driving Forces -** Economic / Social
Hardened Shorelines	Undetermined / Undetermined	Undetermined / Undetermined	Undetermined / Undetermined	Undetermined / Undetermined	Poor / Deteriorating	**Pressures** – Resource Use and Physical Stressors
Harmful Algal Blooms (HABs) Offshore	Good / Unchanging	Fair / Unchanging	Fair / Unchanging	Poor to Fair* / Deteriorating	Fair / Unchanging	**Impacts** – Human
Harmful Algal Blooms (HABs) Nearshore	Good / Unchanging	Fair / Deteriorating	Fair / Deteriorating	Poor to Fair* / Deteriorating	Fair / Deteriorating	
Human Population	decreasing	increasing	increasing	increasing	increasing	**Driving Forces** – Economic / Social
Ice Duration (No individual lake assessment)	Fair / Deteriorating (all lakes)					**State** – Landscapes and Natural Processes
Inland Water Quality Index	Good / Undetermined	Undetermined / Undetermined	Good / Undetermined	Fair / Undetermined	Fair / Undetermined	**Pressures** – Pollution and Nutrients
Land Cover	Good / Undetermined	Undetermined / Undetermined	Fair / Undetermined	Poor / Undetermined	Undetermined / Undetermined	**State –** Landscape and Natural Processes
Lake Sturgeon	Fair / Improving	Fair / Improving	Fair / Improving	Fair / Improving	Fair / Improving	**State** – Aquatic – Dependent Life
Lake Trout	Good / Improving	Poor / Unchanging	Fair / Improving	Poor / Deteriorating	Fair / Improving	**State** – Aquatic – Dependent Life
Nutrients in Lakes	Good / Unchanging	Fair / Deteriorating	Fair / Deteriorating	Poor / Deteriorating	Fair / Deteriorating	**State** - Water Quality
Phytoplankton	Good / Unchanging	Fair / Undetermined	Fair / Undetermined	Poor / Deteriorating	Fair / Undetermined	**State** – Aquatic – Dependent Life
Preyfish Populations	Undetermined / Improving	Undetermined / Deteriorating	Undetermined / Deteriorating	Undetermined / Deteriorating	Undetermined / Deteriorating	**State –** Aquatic – Dependent Life

* Orange represents Poor to Fair status as assessed by the authors of the Fish Consumption Restrictions Advisories and Harmful Algal Blooms indicators.

Status: Good | Fair | Poor | Undetermined

Trends: Improving | Deteriorating | Unchanging | Undetermined

Indicators	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario	Top Level Reporting Category
Remediating Contaminated Sediment (No status or individual lake assessment)	Increasing					**Response** – Restoration and Protection
Sea Lamprey	Fair, Improving	Poor, Unchanging	Poor, Unchanging	Poor, Deteriorating	Good, Unchanging	**Pressures** – Invasive Species
Surface Water Temperature (No status assessment)	increasing	increasing	increasing	Undetermined	Undetermined	**Pressures** – Resource Use and Physical Stressors
Terrestrial Non-Native Species (No individual lake assessment)	Undetermined, Undetermined					**Pressures** – Invasive Species
Toxic Chemicals in Offshore Waters	Fair, Undetermined	Fair, Undetermined	Good, Undetermined	Fair, Undetermined	Fair, Undetermined	**State** – Water Quality
Treating Wastewater (No status assessment)	increasing	Undetermined	Undetermined	increasing	increasing	**Response** – Restoration and Protection
Tributary Flashiness (no individual lake assessment)	Undetermined, Undetermined					**State** – Landscape and Natural Processes
Walleye	Fair, Undetermined	Good, Improving	Good, Improving	Fair, Unchanging	Fair, Unchanging	**State** – Aquatic – Dependent Life
Water Chemistry (No individual lake assessment)	Undetermined, Undetermined					**State –** Water Quality
Water Clarity	Undetermined, increasing	Undetermined, increasing	Undetermined, increasing	Undetermined, Undetermined	Undetermined, increasing	**State –** Water Quality
Water Levels (No individual lake assessment)	Undetermined, Undetermined					**State –** Landscape and Natural Processes
Watershed Stressor Index (no tend assessment possible at this time)	Good	Poor	Fair	Poor	Poor	**Pressure –** Resource Use and Physical Stressors
Zooplankton Biomass	Good, Unchanging	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	Undetermined, Undetermined	**State** – Aquatic – Dependent Life

Good | Fair | Poor | Undetermined

Improving | Deteriorating | Unchanging | Undetermined

4.2 Full Indicator Reports

Air Temperature

Overall Assessment
Trend: **Increasing**
Rationale: Unavailable

Purpose
- To assess trends in air temperature and to examine the observed evidence and effects of climate changes in and on the Great Lakes region.
- The Air Temperature indicator is used in the Great Lakes indicator suite as a Pressure indicator in the Resource Use and Physical Stressor top level reporting category.

Ecosystem Objective
The Great Lakes Water Quality Agreement Act's General Objectives (1987) state, "these water should be free from materials and heat directly or indirectly entering the water as a result of human activity that...produces conditions that are toxic or harmful to human, animal, or aquatic life." Furthermore, this indicator relates to Annex 1 of the Great Lakes Water Quality Agreement which states, "there should be no change in temperature that would adversely affect any local or general use of the waters."

Ecological Condition
Trends
According to the Intergovernmental Panel on Climate Change's (IPCC) 2007 Synthesis report, "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." This finding is supported in part by global temperature data showing that of the last twelve years (1995-2007), eleven were among the warmest in the instrumental record of global surface temperature dating back to 1850 *(Bernstein et al., 2007)*. At the local and regional scale climate data can be naturally quite variable *(Kling et al., 2003)*. As a result, the identification of the contribution of anthropogenic warming within long-term trends on this scale can be problematic. As most changes in the Great Lakes region are still within the bounds of natural variability, it can be difficult to definitively attribute observed trends to human induced climate change. Nevertheless, the similarity between regionally and globally observed trends supports a connection between observed changes in the basin and climatic shifts *(Hayhoe et al., 2009)*.

Based on the analysis of data from the National Climate Data Center (1985-2001) and the Midwest Climate Center (1900-2000) of the Great Lakes region, over the last thirty years, temperatures have hovered near or slightly above long-term averages. The data also suggests a recent shift in temperature. In the last four years the annual average temperatures have ranged from 2 to 4˚F (1 to 2˚C) warmer than the long-term average with up to a 7˚F (4˚C) increase above average in the winter. It is important to note, however, that this warming is comparable in magnitude to warm periods experienced during the 1930s and 1950s. Furthermore, the hottest months in history have occurred in the past two decades and most years have been characterized by a decrease in cold waves *(Kling et al., 2003)*.
Based on the predictions of climate models, temperature in the region are expected to warm by 5 to 12 ˚F (3 to 7˚C) in the winter months and by 5 to 20 ˚F (3 to 11˚C) in the summer months. Examining the data at a finer resolution, models also suggest a larger increase in night-time temperatures than daytime temperatures and an increase in extreme heat events (Kling et al., 2003).

Data Source
Data from this report was generated using climate data from the NOAA climate divisions found in Table 1. These divisions were chosen based on an approximation of the boundaries of the Great Lakes basin.

Linkages
According to findings from the IPCC, "there is high confidence that recent regional changes in temperature have had discernible impacts on physical and biological systems." In this report, the term 'high confidence' is characterized by an 8 out of 10 chance of being correct. Furthermore, there is 'very high confidence' (characterized by at least a 9 out of 10 chance of being correct) that species within terrestrial biological systems have already been strongly affected by earlier timing of spring events, bird migrations, and egg-laying, and poleward and upward range shifts in plant and animal species. With regard to freshwater systems, there is 'high confidence' that observed changes in aquatic biological systems are associated with increases in water temperature and, subsequently, related to alterations in ice cover, oxygen levels, and circulation. Observed changes include increases in algal and zooplankton abundance in high latitude lakes and range changes and temporal shifts in fish migration patterns *(Bernstein et al., 2007)*. This assessment is reflected in the Great Lakes region through trends indicating an earlier occurrence of the last spring freeze, to the magnitude of one week earlier than was experienced at the beginning of the 1990s, and a lengthening of the growing season over the past two decades (Kling et al., 2003).

Additional <u>observed</u> changes include:

- Declines in the duration of winter ice (see *Ice Duration Report*)
- Increases in surface water temperatures and a corresponding increase in the duration of the period of summer stratification (see *Surface Water Temperature Report*)(Kling et al., 2003)
- Alterations of patterns of precipitation (see *Extreme Precipitation Indicator Report*)
- The time in which plants bloom has been altered on the magnitude of two weeks earlier than in the early- to mid- 1900s (Glick, 2011)

Additional <u>expected</u> changes include:

- Reduction in coldwater species such as lake trout, brook trout, and whitefish and cool-water species such as northern pike and walleye in southern parts of the basin. Conversely, the distribution of warm water fish such as smallmouth bass and bluegill are likely to expand northward
- Increased likelihood of invasions from warm-water non-native species
- Altered timing of hydrologic flows characterized by increased variability in timing, frequency, and duration of events
- Altered distribution of plant distribution likely characterized by a northward shift in forest communities
- Range shifts in insect species including such forest and agricultural pests as gypsy moths and bean leaf beetles (Kling et al., 2003)

Management Challenges/Opportunities
The realm of response options to address climate change is classified into two categories, the first of which is adaptation, or "initiatives and measures designed to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (Koslow, 2010). Although a wide range of adaptation strategies exist, there are significant financial, technological, cognitive, behavioral, political, social, institutional, and cultural constraints resulting in limited implementation and effectiveness of adaptive strategies. Such limitations are apparent even in countries with high adaptive capacity as was showcased by the 2003 heat wave in Europe that resulted in significant human mortality, especially among the elderly population (Bernstein et al., 2007).
In the Great Lakes basin there has been significant progress in defining what adaptation means for conservation and restoration efforts in the region. For example, tools to help managers incorporate adaptation strategies into planning efforts have been developed by such organizations as the National Wildlife Federation, the Climate Adaptation Knowledge Exchange, regional Sea Grant offices, NOAA, and Natural Resources Canada to name a few (Koslow,

2010 and Natural Resources Canada). A few examples of projects or programs which have integrated adaptive strategies into management processes include the following:

- The Great Lakes-St Lawrence River Basin Water Resources Compact: The Compact is a law that required withdrawal standards be reviewed to, "give substantive consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty, and appropriate measures to exercise cause in cases of uncertainty if serious damage may result" (Koslow, 2010).
- City of Grand Rapids, Michigan: In the City, in order to adapt to changes in temperature, there is a plan to increase the percentage of tree canopy to reduce the urban heat island effect and thus the impact on human and ecological health from heat events (Koslow, 2010).

Despite relatively recent advances in the field of climate adaptation, there exist several limitations which present barriers to progress. In 2011, the National Wildlife Federation and the National Council for Science and the Environment convened a meeting of 80 natural resource and climate change experts. These respondents included representation from federal agencies, state agencies, tribes, and non-profit organizations. Findings from this summit highlighted the current need for funding, downscaled climate information, planning guidance for adaptation projects, guidance on project implementation, and case studies of on-the-ground adaptation efforts (Inkley, 2011). These findings mirror those of the 2010 workshop, organized by the National Wildlife Federation, the Great Lakes Commission, and the Council of Great Lakes Industries which drew representation from states and cities, federal agencies, Canada, the International Joint Commission, industry, environmental non-governmental groups, First Nations, Tribes, and academic institutions titled Climate Change in the Great Lakes: Advancing the Regional Discussion (Hinderer, 2010). Findings from this meeting suggest the need for the following actions to overcome barriers to success:

- Increased application of climate science in on-the-ground restoration and protection efforts such as wildlife management, habitation restoration, and urban planning.
- Increased focus on building cross-sector partnerships to increase knowledge sharing
- Place increased emphasis quality of life improvement from climate change adaptation in order to better inform the public of the need and benefits of such actions
- Increased use of economic incentives to increase the use of adaptive strategies (Hinderer, 2010)

The other way in which climate change can be addressed is through mitigation, or technological change and substitution that reduce resource inputs and emissions per unit of output (Koslow, 2010).

Both mitigation and adaptation strategies are necessary to lessen the future impacts of climate change. However, there is 'high confidence' that neither adaptation nor mitigation can eliminate all threats. Furthermore, in a scenario of unmitigated climate change, in the long-term it is likely that the capacity of the world's natural, managed, and human systems to adapt will be severely limited. In other words, sole reliance on adaptation to address the impacts of climate change may result in the creation of a world in which the magnitude of the effects of climate change grow to the extent in which human and natural populations are either unable to adapt or confronted with solutions with very high social, environmental, and economic costs (Bernstein et al., 2007).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Table 1. Climate Divisions
Source: National Oceanic and Atmospheric Administration

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Figure 1. Trends in Air Temperature in the Great Lakes Basin.
Source: National Climate Data Center (1985-2001) and the Midwest Climate Center (1900-2000)

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State	Climate Division
Minnesota	3,6
Wisconsin	1,2,3,6,9
Illinois	2
Indiana	1,2,3
Michigan	1,2,3,4,5,6,7,8,9,10
Ohio	1,2,3,4
Pennsylvania	10
New York	1,9,10

Table 1. Climate Divisions
Source: National Oceanic and Atmospheric Administration

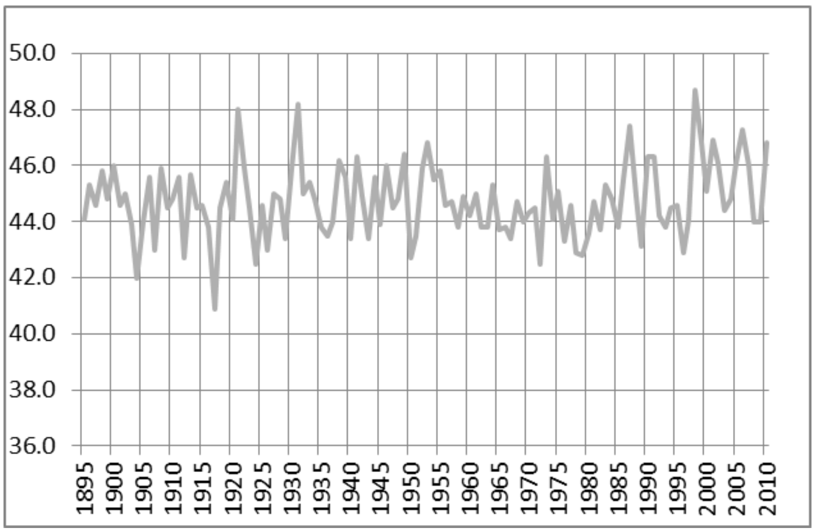

Figure 1. Trends in Air Temperature in the Great Lakes Basin.
Source: National Climate Data Center (1985-2001) and the Midwest Climate Center (1900-2000)

Aquatic Habitat Connectivity

Overall Assessment
Status: Fair
Trend: Improving
Rationale: Dams and barriers have been significantly impacting the health of aquatic ecosystems in the Great Lakes for over a century and are a key factor in the decline of several species of fishes. In addition to limiting access of fishes to spawning and nursery habitats, loss of aquatic connectivity impacts nutrient flows and riparian and coastal processes. There are thousands of dams and barriers (road-stream, crossings) on Great Lakes tributaries. Many dams are near the end of their functional life and will need to be replaced or decommissioned in the next decade. Several dam mitigation projects are occurring throughout the basin, which are restoring aquatic connectivity. An increase interest in micro-hydro projects could result in additional dams, but in most cases these new projects include measures to provide for the passage of fish.

Lake-by-Lake Assessment
Lake Superior
Status: Fair
Trend: Improving
Rationale: A comprehensive assessment of barriers to aquatic connectivity has not been completed for Lake Superior. The Lakewide Management Plan reports that a binational dataset has been created that includes dams and barriers to fish passage (Environment Canada and Environmental Protection Agency, 2011). Several dam mitigation projects have been proposed.

Lake Michigan
Status: Fair
Trend: Improving
Rationale: Aquatic habitat connectivity is being examined in the Biodiversity Conservation Strategy that was initiated in 2010. Several dam removal and mitigation projects have been initiated in the last few years through the Great Lakes Restoration Initiative (e.g. Boardman River dam removal will connect over 250 km of stream habitat back to Lake Michigan - the dam closest to the river mouth will be modified to allow for fish passage while blocking access for sea lamprey.)

Lake Huron
Status: Fair
Trend: Improving
Rationale: Status is based on the Lake Huron Biodiversity Conservation Strategy (Franks Taylor et al., 2010). Expert review and opinion was used to determine that access to spawning areas is limiting the population size of migratory fishes. This report notes that one sub-basin (Eastern Georgian Bay) has a status of “good” (sufficient spawning habitat to maintain population) while another (Saginaw Bay) has a status of “poor” (spawning habitat is severely limiting population size).

Lake Erie
Status: Fair
Trend: Improving
Rationale: Aquatic habitat connectivity is being examined in the Biodiversity Conservation Strategy that was initiated in 2010. Several dam removal and mitigation projects have been initiated in the last few years through the Great Lakes Restoration Initiative (e.g. Ballville Dam on the Sandusky River will open up 35 km of river habitat for walleye).

Lake Ontario
Status: Fair
Trend: Improving
Rationale: Status is based on the Lake Ontario Biodiversity Conservation Strategy (Lake Ontario Biodiversity Conservation Strategy Working Group, 2009). Expert review of maps developed for the migratory fishes target used to provide an assessment. Several dam mitigation projects have been initiated (e.g. dam removal in the Duffins Creek watershed by the Toronto Region Conservation Authority to improve access for Atlantic salmon).

Purpose
- To determine the amount of accessible tributary habitat for Great Lakes fishes.
- To summarize initiatives to improve connectivity of aquatic habitat.
- To highlight some of the issues related to barrier removal.
- The Aquatic Habitat Connectivity indicator is used in the Great Lakes indicator suite as a State indicator in the Landscapes and Natural Processes top level reporting category.

Ecosystem Objective
To reduce the impacts of barriers to aquatic connectivity on fish populations and nearshore/coastal health.

Dams and barriers have been identified as a significant threat in the Lake Ontario and Huron biodiversity conservation strategies (Franks Taylor et al., 2010) and have been identified as recovery actions for at risk Great Lakes fishes such as for lake sturgeon (Golder Associates Ltd., 2011) and American eel (MacGregor, 2010). Mitigation of this pressure will need to be assessed on case-by-case basis to ensure that barrier mitigation does not impact efforts to reduce the spread on aquatic invasive species and sea lamprey.

Ecological Condition
Background
Streams and rivers provide critical spawning and nursery habitat for over one-third of Great Lakes fishes. This includes walleye, lake sturgeon, (coaster) brook trout, suckers and native lamprey. Dams and barriers have been having a significant impact on the aquatic ecosystems of the Great Lakes for over a century and are a key factor in the decline of several species of fishes. As early as 1861, southern Ontario alone had over 2,000 mills reported in the annual census (Fischer & Harris, 2007). Accessibility to streams has been reduced by a variety of anthropogenic barriers such as dams, culverts at road-stream crossings and dikes. In addition to improvements for migratory fishes, improving aquatic connectivity can also have a number of benefits for restoring aquatic systems. These include: reducing water temperatures, increasing levels of oxygen, transport of nutrients and woody debris, restoring natural flood cycles and increasing the amount of riparian and coastal wetland cover.

Measure
Aquatic habitat connectivity can be measured at a landscape level though Geographical Information Systems by intersecting the hydrology network with dams. The distance between the Great Lake and the first barrier can be measured to provide an assessment of the amount of accessible riverine habitat that is available. Information on the distribution of dams can be obtained from the National Inventory of Dams (U.S. Army Corps of Engineers) and the Ontario Dam Registry (Ontario Ministry of Natural Resources). More detailed spatial information on dams occurs for some lake basins and watersheds (e.g. Great Lakes Fisheries Commission, Conservation Authorities).

Road-stream crossings can also reduce aquatic habitat connectivity. While road-stream crossing can be easily identified by intersecting the hydrology network with roads (Figure 3), field verification is required to determine if the crossing do actually cause a disruption to connectivity (such as a “perched” culvert). In general, road-stream crossings are only an issue on small tributaries where culverts are installed.

Aquatic habitat connectivity is a pressure measure (i.e. it measures a threat). Other potential measures would include a direct measure of the population of key migratory fishes that will benefit from access to tributaries (e.g. SOLEC has indicators for lake sturgeon and walleye). The number of barrier mitigation projects could also be measured as a response indicator.

Linkages
Sea Lamprey: Barrier mitigation must be coordinated with efforts to limit the access of seam lamprey to spawning areas.
Walleye and Sturgeon: Loss of aquatic connectivity has contributed to the decline of the species.
Watershed Stressor Index: The number of dams and barriers is an important factor in assessing watershed stress.

Management Challenges/Opportunities
There has been an increase in dam and barrier removal projects over the last few years. This activity has been initiated because of an increase in funding availability (e.g. Great Lakes Restoration Initiative) and because many dams are deteriorating. Most dams in the basin are 50 years+ will require repair or removal in the next decade to avoid failure. This presents a significant opportunity to restore aquatic habitat connectivity.

With the increase in interest in dam removal, there are now several Best Management Practices and assistance programs available in the U.S. and Ontario. While a comprehensive bi-national database of the dams in the basin, describing current use and ownership, does not exist, efforts in both countries may combine to produce this important source of information. For example, in Ontario an on-going province-wide inventory of dams will include a registration program by 2012.

Improvements in aquatic connectivity must be coordinated with efforts to limit the spread of aquatic invasive species, sea lamprey and VHS. Some dams and barriers may be a key management tool for mitigating these other pressures. Decisions about fish passage or dam removal need to be assessed on the basis of local conditions.

Comments from the author(s)
Improving access to spawning habitats is one of the key strategies to restoring populations of Great Lakes fishes. While other pressures that had a major impact on fish populations in the past have had significant success, such as overfishing and water quality, basin-wide mitigation actions to restore the historic riverine spawning and nursery habitats is just beginning.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				

Clarifying Notes: Information on barriers to aquatic connectivity is available, but not complete. Not all dams are included in the database, and current databases do not include information on fish passages.

Acknowledgments
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Source: The Nature Conservancy of Canada (2011)

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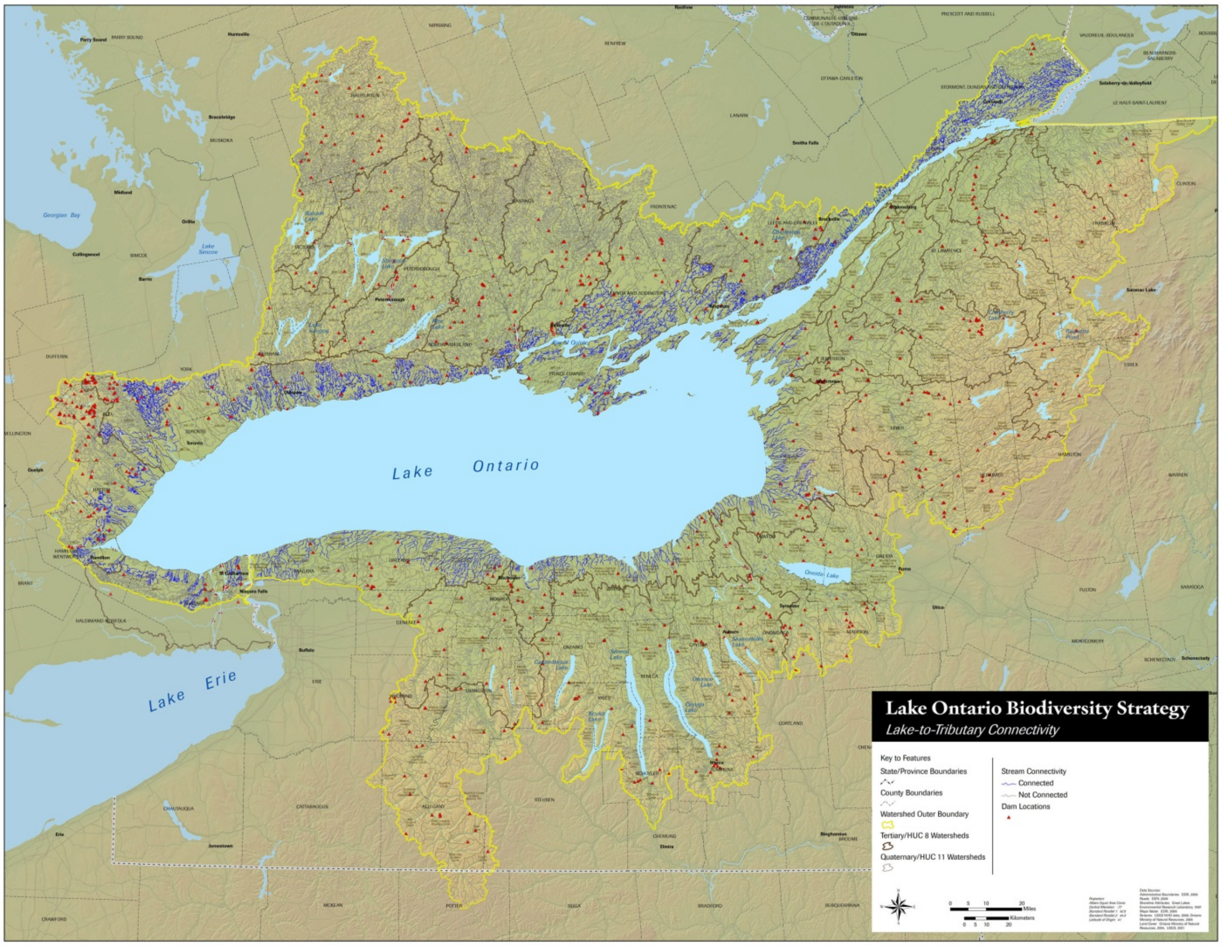

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Source: Lake Ontario Biodiversity Conservation Strategy Working Group (2009)

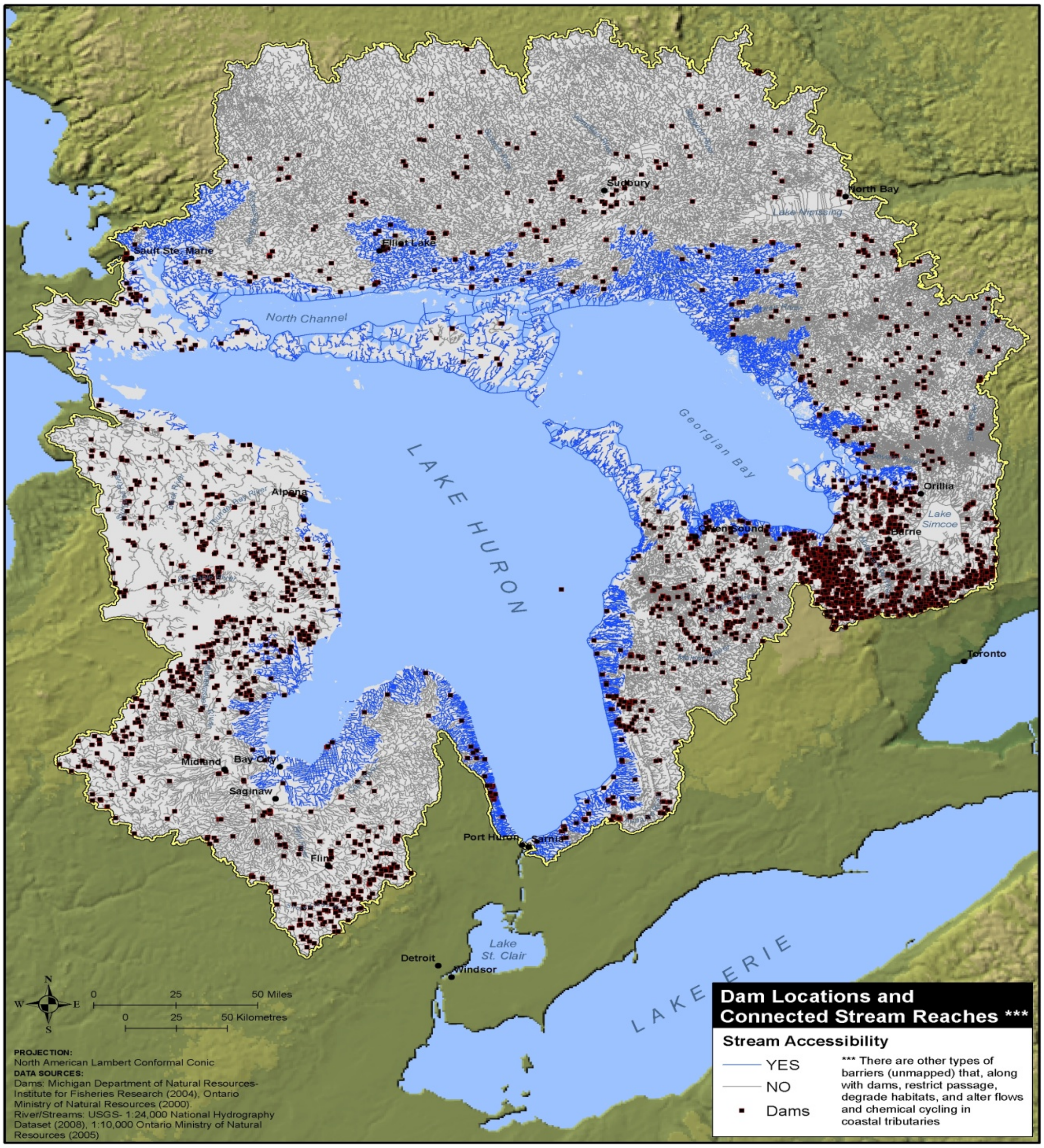

Figure 2. Location of dams and accessible tributaries in Lake Huron
Source: Franks Taylor et al. (2010)

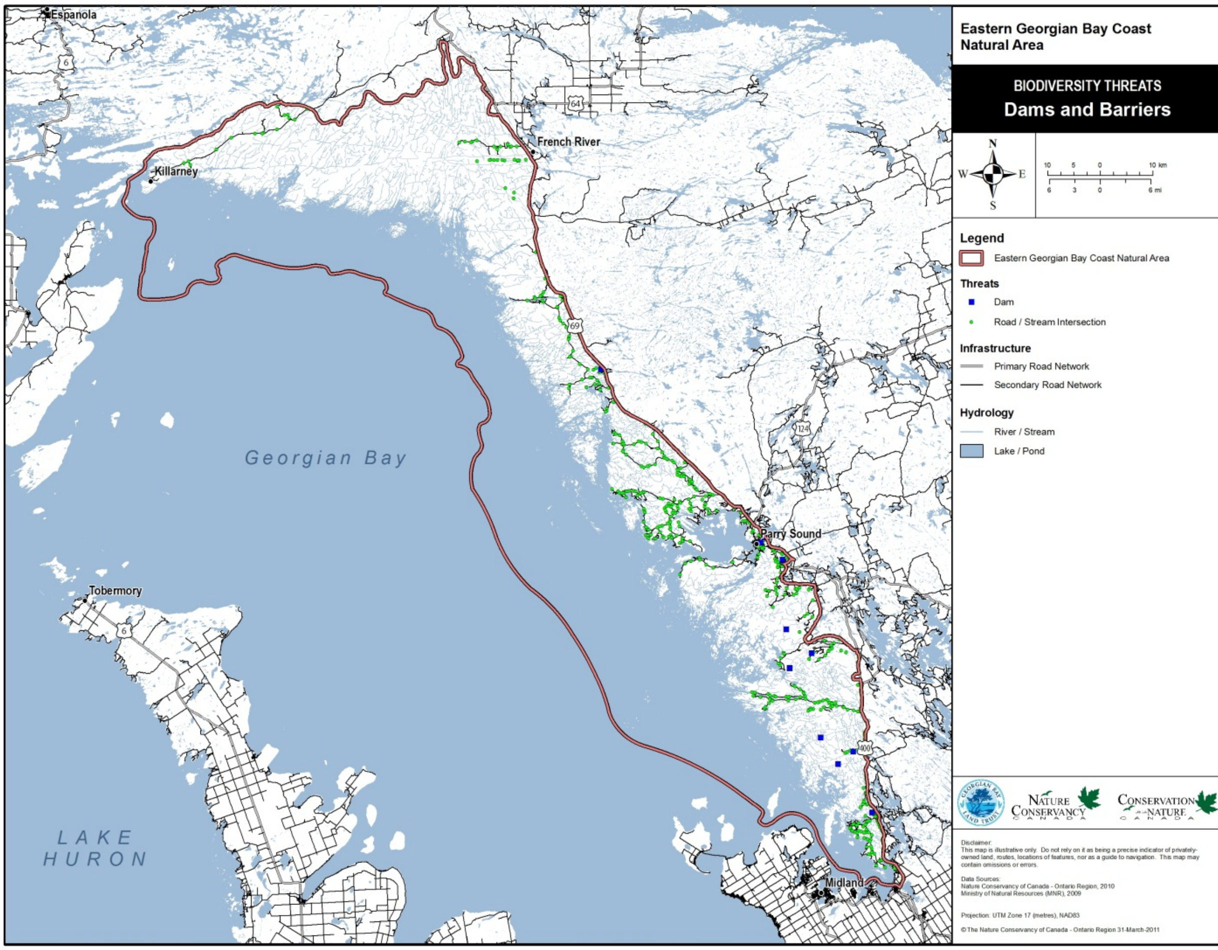

Figure 3. Example of Road-Stream Crossing Analysis for Eastern Georgian Bay
Source: The Nature Conservancy of Canada (2011)

Aquatic Non-Native Species

Overall Assessment
Status: Poor
Trend: Deteriorating
Rationale: Although no new aquatic nonindigenous species (ANS) have been discovered in the Great Lakes over the past five years, the impacts of established invaders persist and the ranges of ANS within the lakes are expanding. New negative impacts, including synergistic disruptions, are becoming evident.

Lake-by-Lake Assessment
Lake Superior
Status: Poor
Trend: Deteriorating
Rationale: Lake Superior is the site of greatest ballast water discharge in the Great Lakes, but this pathway has led to comparatively fewer ANS establishments. Intrabasin movement of ANS is likely to be of greater consequence, as in the case of recent establishment of Viral Hemorrhagic Septicemia (VHS).

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations continue to decline and are rarely found at shallow sites. Viral Hemorrhagic Septicemia (VHS) has recently become established in this lake.

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations continue to decline and are rarely found at shallow sites.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: Established invaders continue to exert negative impacts on native species. A possible link exists between waterfowl deaths due to botulism and established ANS (i.e. round goby and dreissenids). Viral Hemorrhagic Septicemia has caused mass die-offs of fish. *Diporeia* has been extirpated.

Lake Ontario
Status: Poor
Trend: Deteriorating
Rationale: Native *Diporeia* populations, and the condition and growth of lake whitefish, continue to decline. At shallow sites, *Diporeia* is now absent. A possible link exists between waterfowl deaths due to botulism and established ANS. Viral Hemorrhagic Septicemia has caused mass die-offs of fish.

Purpose
- To assess the presence, number, and distribution of aquatic nonindigenous species (ANS) in the Laurentian Great Lakes, and to understand the means by which these species are introduced

- To aid in the assessment of the status of biotic communities, as ANS alter both the structure and function of ecosystems thereby compromising the biological integrity of these systems

Ecosystem Objective

The goal of the United States and Canadian Great Lakes Water Quality Agreement (GLWQA) of 1987 is, in part, to restore and maintain the biological integrity of the Great Lakes ecosystem. Fundamental to this goal is to control existing, and prevent further introduction of, aquatic nonindigenous species through tracking the number of invasions and pathways of introduction. Note: the renewed GLWQA of 2012 includes an Annex on Aquatic Invasive Species.

Ecological Condition

Background

The National Oceanic and Atmospheric Administration (NOAA) currently reports a total of 184 Great Lakes ANS. At least 10% of all ANS introduced to the Great Lakes have had significant impacts on ecosystem health, a percentage consistent with findings in the United Kingdom (Williamson and Brown 1986) and in the Hudson River of North America (Mills et al. 1997). However, considering socioeconomic as well as environmental impacts, this percentage appears to be considerably higher (18%). In the Great Lakes, transoceanic ships have been the primary invasion vector. Other vectors, such as canals, intrabasin transport, and private sector activities (e.g., aquarium and bait industries), however, may play increasingly important roles. Considering the high costs of ANS control, prevention of new introductions continues to be the most effective and economically viable strategy mitigating this ecosystem pressure.

Status of ANS

The total number of ANS introduced and established in the Great Lakes has increased steadily since the 1830s, with some indication of stabilization over the last five years (Fig. 1a). Although there have been 34 invasions since the GLWQA was signed in 1987, no new species have been discovered since 2006. Furthermore, more invasions occurred in the decades from 1950 to 2000 than the preceding or most recent decades. Release of contaminated ballast water by transoceanic ships has been implicated in 65% of faunal ANS introductions to the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Grigorovich et al. 2003; Ricciardi 2006), although this trend may also be slowing (Fig. 1b).

NOAA-developed impact assessment tool (GLANSIS in prep.) has been applied to 147 of the Great Lakes' 184 established ANS. Briefly, this questionnaire-style assessment considered three main categories of impact: environmental, socio-economic, and beneficial. Scores under criteria for each impact category were determined based on literature review and expert evaluation, with the results assigned a qualitative score of High, Moderate, Low, or Unknown. Of the species assessed to date, 16% have had high environmental impacts, 6% have had high socioeconomic impacts (all but 2 all also had high environmental impact), and 6% have had high beneficial effects (7 of which also had high environmental impact) (Table 1).

The overall economic impact of ANS on the Great Lakes region—spanning direct operating costs, decreased productivity, and reduced demand within sport and commercial fishing, power generation, industrial facilities, tourism and recreation, water treatment, and households—is estimated at well over $100 million annually (Rosaen et al. 2012). This figure includes both basinwide efforts such as that of Great Lakes Fishery Commission's sea lamprey control program, with an annual budget of about $18 million, and local responses, such as the $1,040-$26,000 cost per acre of Eurasian watermilfoil removal (Rosaen et al. 2012). Economic impacts from dreissenid mussel control and monitoring are estimated at $1.2 million annually per power plant, $1.97 million for removal of 400 yd^3 at a paper plant, and $480,000-$540,000 annually at a water treatment plant (Rosaen et al. 2012).

Recent studies suggest that each of the Great Lakes may differ in vulnerability to invasion. Lake Superior receives a disproportionately high number of discharges by both BOB and NOBOB ships, yet it has sustained surprisingly few initial invasions (Fig. 2). Conversely, the corridor connecting Lake Huron and Lake Erie is an invasion 'hotspot' despite receiving disproportionately few ballast discharges (Grigorovich et al. 2003). The greatest number of ANS range expansion species (native or cryptogenic to a portion of the basin but introduced to other areas of the basin) have become established in Lake Superior and Lake Huron, suggesting that intrabasin movement of species should not be ignored. Other vectors, including canals and the private sector, continue to deliver ANS to the Great Lakes and may increase in relative importance in the future.

Human activities associated with transoceanic shipping are responsible for over one-third of ANS introductions to the Great Lakes (Fig. 3). During the 1980s, the importance of ship ballast water as a vector for ANS introductions was recognized, prompting ballast management measures in the Great Lakes. In the wake of Eurasian ruffe and zebra mussel introductions, Canada introduced voluntary ballast exchange guidelines in 1989 for ships declaring "ballast on board" (BOB) following transoceanic voyages; this action followed recommendations by the Great Lakes Fishery Commission and the International Joint Commission. In 1990, the United States Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act, producing the Great Lakes' first ballast exchange and management regulations in May of 1993. The National Invasive Species Act (NISA) followed in 1996, but this act expired in 2002. A stronger version of NISA entitled the Nonindigenous Aquatic Invasive Species Act has been drafted and awaits Congressional reauthorization. In September 2009, the U.S. Coast Guard proposed a two-phase standard for the allowable concentration of living organisms in ballast water discharge within U.S. waters. If proven practical, this rule would be implemented by 2016 and include discharge standards that are 1000x more restrictive than the International Maritime Organization standards (less than 10 viable organisms per cubic meter) ratified by Canada and 24 other countries.

Following initiation of voluntary guidelines in 1989 and mandated regulations in 1993, the overall rate of Great Lakes invasion did not decline until recently (Grigorovich et al. 2003; Holeck et al. 2004; Ricciardi 2006). However, more than 90% of transoceanic ships that entered the Great Lakes during the 1990s declared "no ballast on board" (NOBOB; Colautti et al. 2003; Grigorovich et al. 2003; Holeck et al. 2004; Fig. 4) and were not required to exchange ballast, despite their tanks containing residual sediments and water that could be discharged in the Great Lakes. Residual water and sediment in these ships have been found to contain several species previously unrecorded in the basin; such species could be discharged after the ship undergoes sequential ballasting operations as it travels between ports within the Great Lakes to offload and take on cargo (Duggan et al. 2005, Ricciardi and MacIsaac 2008). In June 2006, Canada implemented new regulations for the management of residuals contained within NOBOB tanks and requires the salinity of all incoming ballast water to be at least 30 ppt (Government of Canada 2006). In the decade since, we have seen no new ballast water ANS introductions (the last being *Hemimysis anomala*, collected in May 2006) despite a fairly steady number of NOBOB transits.

Second only to shipping, unauthorized release, transfer, and escape have introduced ANS into the Great Lakes. Of particular concern are private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets. Silver and bighead carp escapees from southern United States fish farms have developed large populations in the middle and lower segments of the Illinois River, which connects the Mississippi River to Lake Michigan via the Chicago Sanitary and Ship Canal (CSSC). A prototype electric barrier on the CSSC was activated in April 2002 to block the transmigration of species between the Mississippi River system and the Great Lakes basin. The U.S. Army Corps of Engineers (partnered by the State of Illinois) completed construction of second and third permanent barriers in 2005 and 2011, respectively. Since 2009, environmental DNA (eDNA) surveillance has been used to complement the use of traditional monitoring and suppression tools. Between 2009 and 2010, DNA of both bighead and silver carp was detected past the electric barriers; however, only a single bighead carp was subsequently found (Lake Calumet, June 2010). As of August of the 2011 monitoring year, only silver carp DNA had been detected on the lake side of these barriers for that year; despite an intensive sampling effort in response to three consecutive rounds of positive eDNA tests in the Lake Calumet area, no Asian carp were seen or captured.

Nearly a million Asian carp, including bighead and black carp, are sold annually at fish markets within the Great Lakes basin. Until recently, most of these fish were sold live. All eight Great Lakes states and the province of Ontario now have some restriction on the sale of live Asian carp. Enforcement of many private transactions, however, remains a challenge. The U.S. Fish and Wildlife Service published a final rule in March 2011, officially adding the bighead carp to the federal injurious wildlife list and codifing the Asian Carp Prevention and Control Act. Bighead, silver, and black carp are now listed as nuisance species under the Lacey Act, prohibiting interstate transport. There are currently numerous shortcomings in legal safeguards relating to commerce in exotic live fish in Great Lakes and Mississippi River states, Quebec, and Ontario, as identified by Alexander (2003). These include: express and de facto exemptions for the aquarium pet trade; de facto exemptions for the live food fish trade; inability to proactively enforce import bans; lack of inspections at aquaculture facilities; allowing aquaculture in public waters; inadequate triploidy (sterilization) requirements; failure to regulate species of concern (e.g., Asian carp); regulation through "dirty lists" only (e.g., banning known nuisance species); and failure to regulate transportation.

Linkages

Invasion Meltdown: Evidence indicates that newly invading species may benefit from the presence of previously established invaders. That is, the presence of one ANS may facilitate the establishment or population growth of another (Ricciardi 2001). For example, the sea lamprey (*Petromyzon marinus*) may have created enemy-free space that facilitated the alewife's (*Alosa pseudoharengus*) invasion, and the round goby (*Neogobius melanostomus*) and *Echinogammarus ischnus* (amphipod) have thrived in the presence of previously established zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*). In effect, dreissenids have set the stage to increase the number of successful invasions, particularly those of co-evolved species in the Ponto-Caspian assemblage. [Indicators: Sea Lamprey, Dreissenid Mussels]

Multi-stressors: Changes in water quality, global climate change, and land use also may make the Great Lakes more hospitable for the arrival of new invaders. [Indicators: Nutrients in Lakes, Dissolved Oxygen, Water Clarity]

Secondary Shifts in Native Populations: ANS may exert significant direct and indirect pressures upon native species, including facilitation of parasitism, transmission of viral/bacterial infections, magnification of toxins, competition, food-web alteration, genetic introgression, degradation of water quality, and degradation of physical habitat. ANS have promoted the proliferation of native nuisance species, including cyanobacteria (Skubinna et al. 1995; Vanderploeg et al. 2001). [Indicators: Wetland Species, Lake Trout, Walleye, Preyfish, Benthos, *Diporeia*, Zooplankton Biomass and Health, Threatened Species, Sturgeon, Botulism Outbreaks, Fish Disease Occurrences, Harmful Algal Blooms, *Cladophora*]

Aquatic Habitat Connectivity: The potential for ANS to colonize new locations is increased with removal of dams. In contrast, ecological separation of the Great Lakes from the Mississippi River basin is currently being discussed as a way to limit transfer of ANS between these basins.

Fish Habitat: Many nonindigenous plants are capable of forming dense mats that may exclude fish from nearshore habitats. Colonization of lakebed areas by dreissenid mussels and the consequent filling of remaining interstitial spaces with pseudofeces and fine-grained sediments led to the exclusion of lake trout from their native spawning grounds (S. Mackey, Habitat Solutions NA, pers. comm.).

Management Challenges/Opportunities

ANS have invaded the Great Lakes basin from regions around the globe (Fig. 5). Increasing world trade and travel elevates the risk that additional species (Table 2) will continue to gain access to the Great Lakes. Indeed, the arrival of *Hemimysis anomala* was predicted (Ricciardi and Rasmussen 1998). Existing connections between the Great

Lakes watershed and systems outside the watershed, such as the Chicago Sanitary and Ship Canal, and growth of industries such as aquaculture, live food markets, and aquarium retail stores will also increase the risk that new ANS will be introduced.

Researchers are seeking to better understand links between vectors and donor regions, the receptivity of the Great Lakes ecosystem, and the biology of new invaders in order to make recommendations to reduce the risk of future invasion. To protect the biological integrity of the Great Lakes, it is essential to closely monitor routes of entry for ANS, to introduce effective safeguards, and to quickly adjust safeguards as needed. The rate of invasion may increase if positive interactions involving established ANS or native species facilitate the establishment of new ANS. Ricciardi (2001) suggested that such a scenario of "invasional meltdown" is occurring in the Great Lakes, although Simberloff (2006) cautioned that most of these cases have not been well substantiated. Moreover, each new invader can interact in unpredictable ways with previously established invaders, potentially creating synergistic impacts (Ricciardi 2001, 2005). For example, recurring outbreaks of avian botulism in the lower Great Lakes are thought to result from the effects of dreissenid mussels and round gobies, in which the mussels create environmental conditions that promote the pathogenic bacterium and the gobies transfer bacterial toxin from the mussels to higher levels of the food web.

To be effective in preventing new invasions, management strategies must focus on linkages between ANS, vectors, and donor and receiving regions, and have available to them resources in support of early detection and rapid response. However, without measures that effectively eliminate or minimize the role of ship-borne and other emerging vectors (such as live trade and recreational boating, see Mandrak and Cudmore 2010), we can expect the number of ANS in the Great Lakes to continue to rise, with an associated loss of native biodiversity and an increase in unforeseen ecological disruptions. Furthermore, increasing lake temperatures associated with climate change will lead to increased potential for ANS introduced from warmer climates to establish overwintering populations (see Adebayo et al. 2011; Mandrak 1989).

Comments from the author(s)

Lake-by-lake assessments should include Lake St. Clair and connecting channels (Detroit River, St. Clair River). Species first discovered in these waters were assigned to Lake Erie for the purposes of this report. Moreover, range expansion ANS (those native or cryptogenic to a portion of the basin but introduced to other areas of the basin) should be included in lake-by-lake assessments and perhaps incorporated into future figures. Environmental and socioeconomic impacts, as well as beneficial effects of ANS should also receive additional treatment (e.g., Table 1).

In preliminary reviews of this report, it was suggested that there also be a discussion of prevention, spread, and control options for ANS. However, that sort of information would shift the focus from a Great Lakes ecosystem pressure indicator to one of response. The National Oceanic and Atmospheric Administration (NOAA) Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) is already in the process of compiling management options for each introduced and high risk "watchlist" species and could help support future integration of that information into one of the existing response indicator reports (e.g., "Protecting and Restoring Habitat and Species").

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				

Clarifying Notes: Assessment data in Tables 1 and 2 are currently in the process of being collected and reviewed; completion is expected in 2013.

Acknowledgments

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List of Tables

Table 1. Nonindigenous species assessed to have the greatest environmental, socioeconomic, and/or beneficial

impacts in the Great Lakes. This list represents an update to Mills (1993) categorization of invasive species in the Great Lakes. (Note: As of report preparation, 147 of 184 established species had been assessed. The remaining assessments are targeted for completion by NOAA/GLANSIS in 2013.)
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html (in prep.)

Table 2. Nonindigenous species predicted in the scientific literature to have a high probability of introduction to the Great Lakes. Probability of introduction, establishment, and predicted level of impact (Environmental, Socioeconomic, Beneficial) are given as High, Moderate, Low, or Unknown. (Note: As of report preparation, detailed risk assessments on each species were incomplete. Missing assessments are targeted for completion by NOAA/GLANSIS in 2013.)
Source: Adebayo et al. 2011; Bailey et al. 2005; Cole 2001; Cudmore and Mandrak 2005; Cudmore-Vokey and Crossman 2000; Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html (in prep.); Grigorovich et al. 2003; Herborg et al. 2007; Johengen et al. 2005; Kipp et al. 2010; Kolar and Lodge 2002; Kolar et al. 2005; Mandrak 1989; Mendoza-Alfaro et al. 2009; A. Ricciardi, McGill University; Ricciardi and Rasmussen 1998; Rixon et al. 2005; Stepien and Tumeo 2006; U.S. EPA 2008.

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Figure 1. Cumulative number of aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s attributed to (a) all vectors and (b) only the ship vector.
Source: Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

Figure 2. Release mechanisms for aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s. Unintentional release encompasses ornamental plant escape, research escape, and parasites/pathogens through fish stocking.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

Figure 3. Lake of first discovery for ANS established in the Great Lakes basin since the 1830s.
Discoveries in connecting waters between Lakes Huron, Erie, and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html.

Figure 4. Numbers of upbound transoceanic ballasted (BOB) and cargo laden (NOBOB) vessels entering the Great Lakes from 1959 to 2010.
Source: Colautti et al. 2003; Grigorovich et al. 2003; Holeck et al. 2004; Saint Lawrence Seaway Development Corporation Annual Traffic Reports, http://www.greatlakes-seaway.com/en/seaway/facts/traffic/index.html.

Figure 5. Regions of origin for aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

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Table 1. Nonindigenous species assessed to have the greatest environmental, socioeconomic, and/or beneficial impacts in the Great Lakes.

Species	Common Name	Environmental Impact	Socio-Economic Impact	Beneficial Effect
Alosa pseudoharengus	alewife	High	High	High
Bithynia tentaculata	faucet snail	High	Moderate	Low
Bythotrephes longimanus	spiny waterflea	High	Low	Low
Cercopagis pengoi	fishhook waterflea	High	Low	Low
Cyprinus carpio	common carp	High	Unknown	High
Dreissena polymorpha	zebra mussel	High	High	Low
Dreissena rostriformis bugensis	quagga mussel	High	High	Low
Echinochloa crus-galli	barnyard grass	Moderate	High	Moderate
Frangula alnus	glossy buckthorn	High	Low	Moderate
Heterosporis sp.	microsporidian parasite	High	Low	Low
Ichthyocotylurus pileatus	digenean fluke	High	Low	Low
Iris pseudacorus	yellow iris	High	Moderate	Moderate
Morone americana	white perch	High	Moderate	High
Myxobolus cerebralis	salmonid whirling disease	High	Low	Low
Neogobius melanostomus	round goby	High	High	Low
Nitellopsis obtusa	starry stonewort	Moderate	High	Low
Novirhabdovirus sp. VHSV-IVb	viral hemorrhagic septicemia virus	High	High	Low
Oncorhynchus kisutch	coho salmon	Moderate	Low	High
Oncorhynchus mykiss	rainbow trout	High	Low	High
Oncorhynchus tshawytscha	Chinook salmon	Moderate	Low	High
Osmerus mordax	rainbow smelt	High	Unknown	High
Petromyzon marinus	sea lamprey	High	High	Low
Ranavirus sp.	largemouth bass virus	High	Low	Low
Rhabdovirus carpio	spring viremia of carp	High	Low	Low
Renibacterium salmoninarum	bacterial kidney disease	High	High	Low
Salmo trutta	brown trout	High	Low	High
Typha angustifolia	narrow-leaved cattail	High	Low	High

This list represents an update to Mills (1993) categorization of invasive species in the Great Lakes. (Note: As of report preparation, 147 of 184 established species had been assessed. The remaining assessments are targeted for completion by NOAA/GLANSIS in 2013.)

Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html (in prep.)

Table 2 Nonindigenous species predicted in the scientific literature to have a high probability of introduction to the Great Lakes.

2.1 Non-indigenous Fish Species

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Alburnus alburnus	ballast water (Eurasia)			High/Low/High	Kolar and Lodge 2002
Atherina boyeri	ballast water (Eurasia)				Kolar and Lodge 2002
Babka gymnotrachelus	ballast water (Eurasia)				Kolar and Lodge 2002; Stepien and Tumeo 2006
Benthophilus stellatus	ballast water (Eurasia)				Kolar and Lodge 2002; Ricciardi and Rasmussen 1998
Channa argus	unintentional release (Asia)	Low	High	Unk./Mod./High	Cudmore and Mandrak 2005; Herborg et al. 2007; Mendoza-Alfaro et al. 2009; Rixon et al. 2005
Clupeonella cultriventris	ballast water (Eurasia)				Kolar and Lodge 2002; Ricciardi and Rasmussen 1998
Cottus gobio	ballast water (Eurasia)				Kolar and Lodge 2002
Ctenopharyngodon idella	canal (Mississippi basin)			High/Low/High	Herborg et al. 2007; Mandrak and Cudmore 2005; Rixon et al. 2005
Cyprinella whipplei	canal (Mississippi basin)				Cudmore-Vokey and Crossman 2000; Mandrak 1989
Hypophthalmichthys molitrix	canal (Mississippi basin)			High/High/High	Herborg et al. 2007; Kolar and Lodge 2002; Kolar et al. 2005; Mandrak and Cudmore 2005
Hypophthalmichthys nobilis	canal (Mississippi basin)			High/High/High	Herborg et al. 2007; Kolar et al. 2005; Mandrak and Cudmore 2005; Rixon et al. 2005
Knipowitschia caucasica	ballast water (Eurasia)				Kolar and Lodge 2002
Leuciscus leuciscus	ballast water (Eurasia)				Kolar and Lodge 2002
Neogobius fluviatilis	ballast water (Eurasia)			High/Low/Mod.	Kolar and Lodge 2002; Ricciardi and Rasmussen 1998
Oncorhynchus keta	deliberate release (Pacifique)				Kolar and Lodge 2002
Perca fluviatilis	ballast water (Eurasia)				Kolar and Lodge 2002
Perccottus glenii	ballast water (Eurasia)				A. Ricciardi pers. comm.
Phoxinus phoxinus	ballast water (Eurasia)				Kolar and Lodge 2002
Rutilus rutilus	ballast water (Eurasia)				Kolar and Lodge 2002

2.2 Non-indigenous Cladocerans

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Cornigerius maeoticus maeoticus	ballast water (Eurasia)				Grigorovich et al. 2003
Daphnia cristata	ballast water (Eurasia)				Grigorovich et al. 2003
Podonevadne trigona ovum	ballast water (Eurasia)				Grigorovich et al. 2003

2.3 Non-indigenous Copepods

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Calanipeda aquaedulcis	ballast water (Eurasia)				Grigorovich et al. 2003
Cyclops kolensis	ballast water (Eurasia)				Grigorovich et al. 2003
Ectinosoma abrau	ballast water (Eurasia)				Grigorovich et al. 2003
Heterocope appendiculata	ballast water (Eurasia)				Grigorovich et al. 2003
Heterocope caspia	ballast water (Eurasia)				Grigorovich et al. 2003
Paraleptastacus spinicaudus triseta	ballast water (Eurasia)				Grigorovich et al. 2003

2.4 Non-indigenous Amphipods

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Chelicorophium curvispinum	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
Dikerogammarus haemobaphes	ballast water (Eurasia)				Grigorovich et al. 2003; Ricciardi and Rasmussen 1998
Dikerogammarus villosus	ballast water (Eurasia)	High	High	High/Low/Low	Grigorovich et al. 2003; Ricciardi and Rasmussen 1998
Echinogammarus warpachowskyi	ballast water (Eurasia)				Grigorovich et al. 2003
Obesogammarus aralensis	ballast water (Eurasia)				Grigorovich et al. 2003
Obesogammarus crassus	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
Obesogammarus obesus	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
Pontogammarus robustoides	ballast water (Eurasia)				Grigorovich et al. 2003; Ricciardi and Rasmussen 1998

2.5 Non-indigenous Mysids

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Limnomysis benedeni	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
Paramysis (Mesomysis) intermedia	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
Paramysis (Serrapalpisis) lacustris	ballast water (Eurasia)			Mod./Low/Unk.	Ricciardi and Rasmussen 1998
Paramysis (Metamysis) ullskyi	ballast water (Eurasia)				Ricciardi and Rasmussen 1998

2.6 Non-indigenous Bivalves

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Monodacna colorata	ballast water (Eurasia)				Ricciardi and Rasmussen 1998

2.7 Non-indigenous Polychaetes

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Hypania invalida	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
Leyogonimus polyoon	canal (Mississippi basin)	Moderate	High		Cole 2001

2.8 Non-indigenous Bryozoans

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Fredericella sultana	ballast water (Europe)			High/High/Unk.	Kipp et al. 2010

2.9 Non-indigenous Rotifers

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Brachionus leydigii	ballast water (widespread)				Bailey et al. 2005; Johengen et al. 2005
Filinia cornuta	ballast water (widespread)				Bailey et al. 2005; Johengen et al. 2005
Filinia passa	ballast water (widespread)				Bailey et al. 2005; Johengen et al. 2005

2.10 Non-indigenous Plants

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Egeria densa	unintentional release (S. America)				Rixon et al. 2005
Eichhornia crassipes	unintentional release (S. America)				Adebayo et al. 2011
Hydrilla verticillata	unintentional release (widespread)				U.S. EPA 2008

Species	Predicted pathway (source)	Probability of Introduction	Probability of Establishment	Probability of Impact (E/S/B)	Reference
Hygrophila polysperma	unintentional release (Asia)			Mod./Mod./Low	Rixon et al. 2005
Myriophyllum aquaticum	unintentional release (S. America)	High	High	High/Mod./Low	Rixon et al. 2005
Pistia stratiotes	unintentional release (S. America)				Adebayo et al. 2011

Table 2 Probability of introduction, establishment, and predicted level of impact (Environmental, Socioeconomic, Beneficial) are given as High, Moderate, Low, or Unknown. (Note: As of report preparation, detailed risk assessments on each species were incomplete. Missing assessments are targeted for completion by NOAA/GLANSIS in 2013.)
Source: Adebayo et al. 2011; Bailey et al. 2005; Cole 2001; Cudmore and Mandrak 2005; Cudmore-Vokey and Crossman 2000; Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html (in prep.); Grigorovich et al. 2003; Herborg et al. 2007; Johengen et al. 2005; Kipp et al. 2010; Kolar and Lodge 2002; Kolar et al. 2005; Mandrak 1989; Mendoza-Alfaro et al. 2009; A. Ricciardi, McGill University; Ricciardi and Rasmussen 1998; Rixon et al. 2005; Stepien and Tumeo 2006; U.S. EPA 2008.

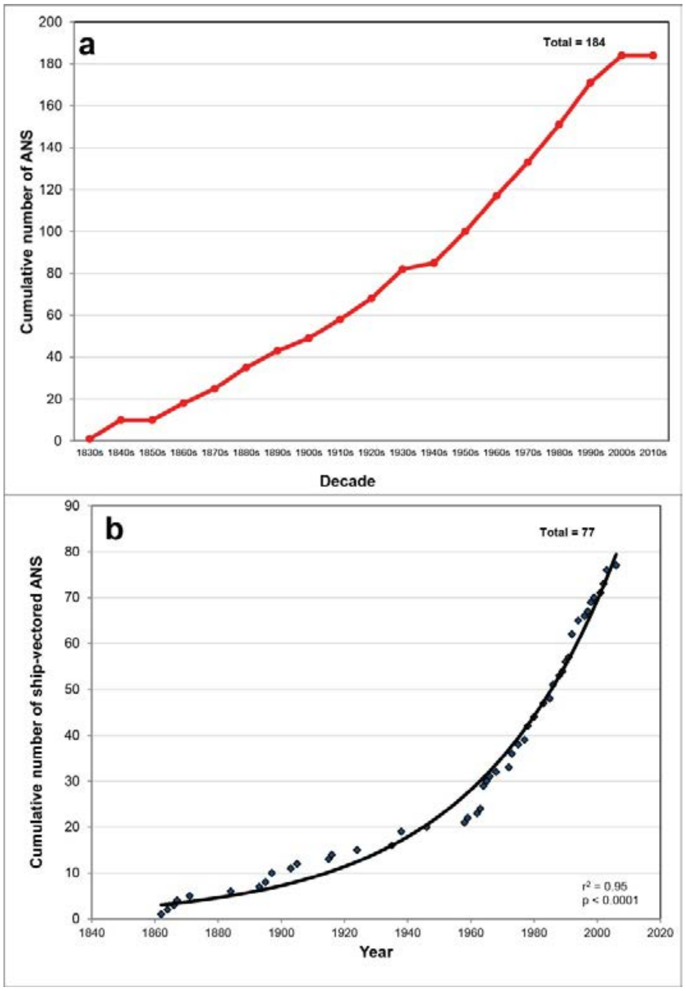

Figure 1. Cumulative number of aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s attributed to (a) all vectors and (b) only the ship vector.
Source: Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

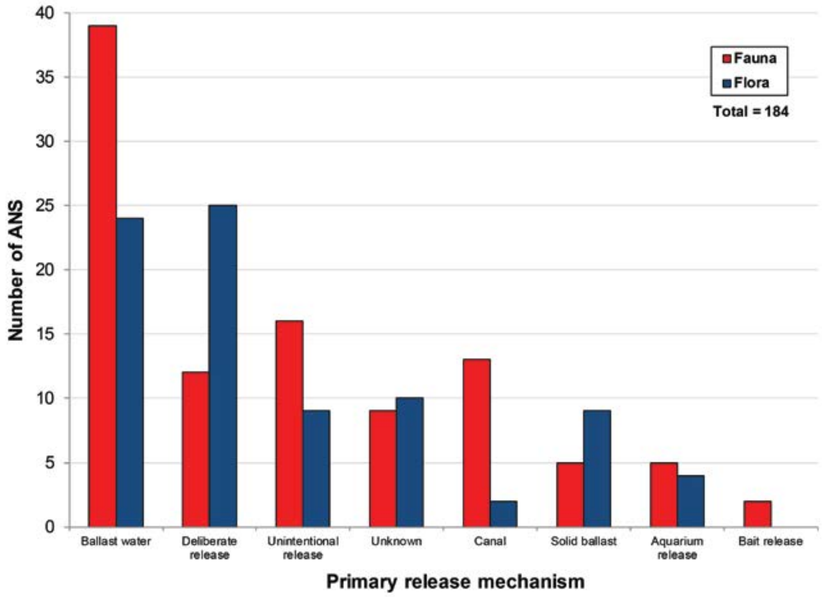

Figure 2. Release mechanisms for aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s. Unintentional release encompasses ornamental plant escape, research escape, and parasites/pathogens through fish stocking.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

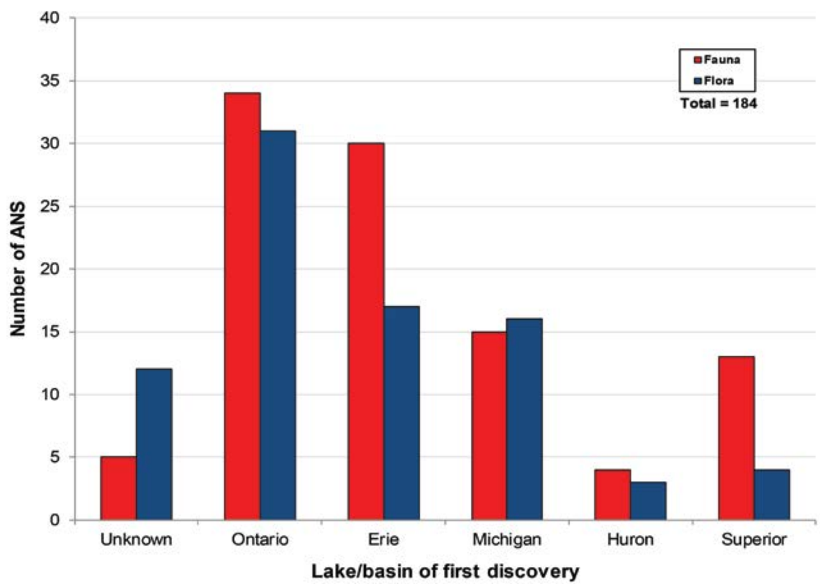

Figure 3. Lake of first discovery for ANS established in the Great Lakes basin since the 1830s. Discoveries in connecting waters between Lakes Huron, Erie, and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

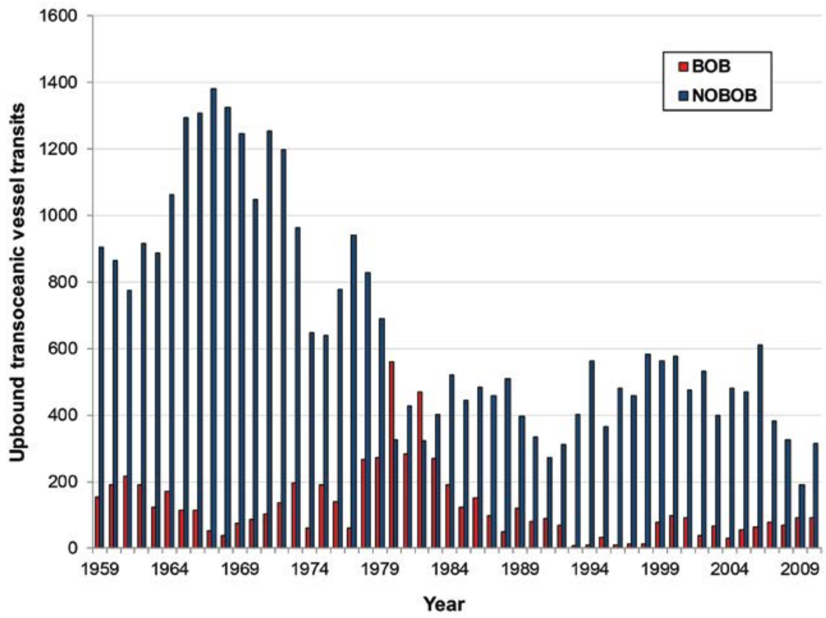

Figure 4. Numbers of upbound transoceanic ballasted (BOB) and cargo laden (NOBOB) vessels entering the Great Lakes from 1959 to 2010.
Source: Colautti et al. 2003; Grigorovich et al. 2003; Holeck et al. 2004; Saint Lawrence Seaway Development Corporation Annual Traffic Reports, http://www.greatlakes-seaway.com/en/seaway/facts/traffic/index.html

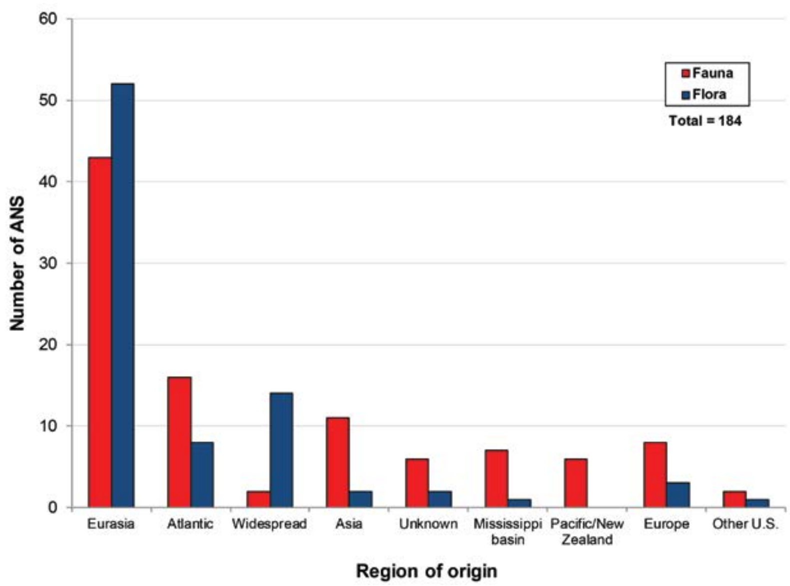

Figure 5. Regions of origin for aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s.
Source: Great Lakes Aquatic Nonindigenous Species Information System, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

Atmospheric Deposition of Toxic Chemicals

Overall Assessment

Status: **Fair**

Trend: **Improving (for PAHs, organochlorine pesticides, dioxins and furans) / Unchanging or slightly improving (for mercury and PCBs)**

Rationale: **Fair because different chemical groups have different trends and rates of decline over time. Levels of toxic chemicals in urban areas can be much higher than in rural areas.**

Levels of persistent bioaccumulative toxic (PBT) chemicals in air tend to be lowest over Lake Superior, Lake Huron, and northern Lake Michigan, but their surface area is larger, resulting in a greater importance of atmospheric inputs (Strachan and Eisenreich 1990; Kreis 2005). Connecting channels inputs dominate for Lake Erie and Lake Ontario, which have smaller surface areas.

While concentrations of some toxic chemicals are very low at rural sites, they may be much higher in "hotspots" such as urban areas. Lake Michigan, Lake Erie, and Lake Ontario have greater inputs from urban areas. The Lake Erie station tends to have higher levels than the other remote master stations, most likely since it is located closer to an urban area (Buffalo, NY) than the other master stations. It may also receive some influence from the East Coast of the U.S.

Atmospheric deposition of chemicals of emerging concern, such as brominated flame retardants and other compounds that may currently be under the radar, could be future stressors to the Great Lakes. Efforts are being made to screen for other chemicals of potential concern.

Lake-by-Lake Assessment

Each lake was not specifically categorized for status and trend. Site specific trends for some chemicals are available (Venier and Hites 2010a). Calculated loadings for each lake, including trends over time, are also available (U.S. EPA and Environment Canada 2008).

Purpose

- To determine temporal trends in concentrations of PBT chemicals in the atmosphere over the Great Lakes
- To estimate the annual average loadings of PBT chemicals from the atmosphere to the Great Lakes
- To track the progress of various Great Lakes programs toward virtual elimination of toxic chemicals to the Great Lakes

Ecosystem Objective

The Great Lakes Water Quality Agreement (GLWQA, United States and Canada 1987) and the Binational Toxics Strategy (Environment Canada and U.S. Environmental Protection Agency 1997) both state the virtual elimination of toxic substances in the Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic to human, animal, or aquatic life. The amended GLWQA of 1987 included a separate Annex (Annex 15) which provided the mandate for both Parties (US and Canada) to establish the Integrated Atmospheric Deposition Network (IADN) to conduct surveillance and monitoring of toxic contaminants.

Ecological Condition

The Integrated Atmospheric Deposition Network (IADN) consists of five master monitoring stations, one near each of the Great Lakes, and several satellite stations. This joint United States-Canada monitoring network has been in operation since 1990. Since that time, over a million measurements of the concentrations of PCBs, pesticides, PAHs, flame retardants, and trace metals have been made at these sites. Concentrations of PBT chemicals are measured in the atmospheric gas and particle phases and in precipitation. Spatial and temporal trends of these concentrations and atmospheric loadings to the Great Lakes can be examined using these data. Data from other networks are used here to supplement the IADN data for mercury, dioxins and furans.

PCBs

Total PCBs (ΣPCBs) is a suite of congeners that make up most of the PCB mass and that represent the full range of PCBs. Concentrations of gas-phase ΣPCBs have generally decreased over time at the master stations (Figure 1, Sun *et al*. 2007, Venier and Hites 2010a, Venier and Hites 2010b), but the rate of change is remarkably slow considering that the manufacture of PCBs was banned in North America over 30 years ago. Some increases are seen during the late 1990s and early 2000s that remain unexplained. There is some evidence of connections with atmospheric circulation phenomena such as North Atlantic Oscillations (NAO) or El Nino events (Ma *et al*. 2004); however, similar increases were not seen for other compounds making this perhaps an unlikely explanation (Venier and Hites 2010b). PCB measurements in precipitation samples were stopped at the rural master stations after 2005 because concentrations were nearing levels of detection.

The Lake Erie site consistently shows relatively elevated ΣPCB concentrations compared to the other master stations. Back-trajectory analyses have shown that this is due to possible influences from upstate New York and the East Coast (Hafner and Hites 2003). Figure 2 shows that ΣPCB concentrations at urban satellite stations in Chicago and Cleveland are about fifteen and ten times higher, respectively, than the remote master stations at Eagle Harbor (Lake Superior), Sleeping Bear Dunes (Lake Michigan) and Burnt Island (Lake Huron) and the rural master station at Point Petre (Lake Ontario).

In comparison to other PBT chemicals measured by IADN, PCBs have a long halving time (13 to 17 years) and are generally showing the slowest rate of decline (Venier and Hites 2010a, Venier and Hites 2010b). The slow rate of decline, despite PCBs being banned in the US in 1976, is likely due to large amounts of PCBs still in transformers, capacitors, and other electrical equipment and in storage and disposal facilities (Venier and Hites 2010a, Hsu et al. 2003). It is assumed that PCB concentrations will continue this slow decline in the future.

Organochlorine Pesticides

In general, concentrations of banned or restricted pesticides measured by IADN are decreasing over time in air and precipitation (Sun *et al*. 2006a; Sun *et al*. 2006b; Venier and Hites 2010a, Venier and Hites 2010b). Concentrations of endosulfans, DDT, chlordane, α-HCH and γ-HCH in all phases are decreasing steadily (Figure 3). The fastest rates of decline are in α-HCH and γ-HCH, which have halving times of 3 to 4 years in all phases (Venier and Hites 2010a, Venier and Hites 2010b). The slowest rate of decline is for endosulfans, which has a halving time of 11 to 14 years (Venier and Hites 2010a, Venier and Hites 2010b). This is not surprising as endosulfans are still used in agriculture with a complete phase-out scheduled in the U.S. in 2016. Until the phase out is complete, the slow rate of decline is expected to continue.

Concentrations of chlordane are about ten times higher at the urban stations than at the more remote master stations, most likely due to the use of chlordane as a termiticide in buildings (Figure 4, Venier and Hites 2010a, Sun et al. 2006b). Dieldrin and ΣDDTs show similar increases in urban locales.

On the other hand, numerical modeling studies have shown that long-range transport of pesticides (e.g. lindane and toxaphene) emitted in regions outside of the Great Lakes may contribute significantly to the occurrence and deposition of these contaminants in the Great Lakes Basin (Ma et al., 2003; Ma et al., 2005).

Polycyclic aromatic Hydrocarbons (PAHs)

Concentrations of PAHs, such as phenanthrene and chrysene, have been slowly decreasing in all phases at the master and urban stations and are decreasing more rapidly than PCB concentrations (Venier and Hites 2010b). Concentrations of PAHs can be roughly correlated with human population, with highest levels in Chicago and Cleveland, followed by the semi-urban site at Sturgeon Point, and lower concentrations at the other remote master stations (Venier and Hites 2010a). In general, PAH concentrations in Chicago and Cleveland are about ten to one hundred times higher than at the rural master stations.

Dioxins and Furans

Concentrations of dioxins and furans have decreased over time (Figure 5) with the largest declines in areas with the highest historical concentrations (unpublished data, T. Dann, Environment Canada 2006). Data collected as part of the IADN program between 2004 and 2007 show no significant changes in concentration of dioxins and furans which is not surprising given the short time scale (Venier *et al*. 2009). Data do suggest that urban and industrial areas act as source of these chemicals to the atmosphere.

Mercury

An analysis of data from the Mercury Deposition Network (MDN) through 2005 show that concentrations of mercury in precipitation were decreasing for nearly half of the network's sites, particularly across Pennsylvania and into the Northeast. However, the sites in the Great Lakes region do not generally show this decreasing trend, except for 1 site in Indiana (Prestbo and Gay 2009).

A recent analysis of annual and weekly mercury concentrations, precipitation depths, and mercury wet deposition in the Great Lakes region found that mercury wet deposition was mostly unchanged from 2002 to 2008, with any small decreases in concentration offset with increases in precipitation (Risch et al. 2011).

Flame Retardants (FRs)

There does not appear to be any strong trend for flame retardants in the atmosphere around the Great Lakes (Figure 6), with a few notable exceptions. With the voluntary phase-out of the penta- and octa-BDE formulations by the only U.S. manufacturer in 2004, concentrations of these congeners appear to be decreasing, with an overall halving time in the atmosphere of about 6 years (Salamova and Hites 2011). These rates of decline are much faster than those for other persistent organic pollutants such as PCBs (~17 years), PAHs (~10 years), and sum-DDTs (~9 years) indicating that the production restrictions are having immediate benefits. The overall concentrations don't appear to be changing in the graphic because concentrations of other flame retardants that are still in production are not yet decreasing. For example, deca-BDE, which is still in production, is not yet decreasing. Deca-BDE accounts for about 25% of the total flame retardant concentrations. However, deca-BDE contributes a relative large fraction of the total flame retardant concentrations at Cleveland and Sturgeon Point, indicating that there may be a local source in the vicinity of Cleveland (Venier and Hites 2008, Salamova and Hites 2011). Perhaps, when restrictions on production and use of Deca-BDE go into effect after 2013, its concentration will start to decline. It should be noted, though, that even when these commercial mixtures will be completely retired from the market, large amounts of flame retardants will still be present in the environment since they have been used in a variety of consumer products that have a long life (i.e. mattresses, sofas, electronics, and upholstery).

Similar observations were found at the two Canadian master stations as described above for the U.S. stations (see Figure 7). Figure 7 shows the trend plots in the atmosphere derived for PBDE congeners 47 and 99 for Point Petre and Burnt Island in the gas and particle phases. BDE-47 and 99 appear to be decreasing. Their halflives at Point Petre (3 and 3.1 years, respectively) are both shorter than at Burnt Island (13 and 5.2 years, respectively). Due to proximity of Point Petre to urban areas, the decline is reflective of both reduction in use and environmental removal processes from the atmosphere (e.g. degradation and partitioning into other media). Burnt Island is more remote, and therefore, the decline observed probably reflects mainly environmental removal.

Figure 7 also shows the trend plots derived for BDE-209 in the gas and particle phases. For BDE-209, BNT (halflife 7.3 years) shows a decreasing trend, but PPT shows an increasing trend (doubling every 12 years). This increasing trend may be attributed to the proximity of PPT to urban locations and the continued usage of DecaBDE technical mixture.

Recently, IADN and tree bark data was also used to identify the source(s) of dechlorane plus (another recently identified flame retardant in the environment) in Niagara Falls, New York (Qiu and Hites 2008, Salamova and Hites, 2010).

Loadings

An atmospheric loading is the amount of a pollutant entering a lake from the air, which equals wet deposition (rain) plus dry deposition (falling particles) plus gas absorption into the water minus volatilization out of the water. Absorption minus volatilization equals net gas exchange, which is the most significant part of the loadings for many semi-volatile PBT pollutants. For many banned or restricted substances that IADN monitors, net atmospheric inputs to the lake are headed toward equilibrium; that is, the amount going into the lake equals the amount volatilizing out. Current-use pesticides, such as γ-HCH (lindane) and endosulfan, as well as PAHs and trace metals, still have net deposition from the atmosphere to the Lakes.

A report on the atmospheric loadings of these compounds to the Great Lakes for data through 2005 is available online at: http://www.epa.gov/glnpo/monitoring/air2/iadn/reports/IADN_Toxics_Deposition_Thru_2005.pdf. To receive a hardcopy, please contact one of the agencies listed at the end of this report.

Summary

Atmospheric deposition of toxic compounds to the Great Lakes is likely to continue into the future. The levels of compounds no longer in use, including many organochlorine pesticides, may decrease to undetectable levels.

Residual sources of PCBs remain in the U.S. and throughout the world; therefore, atmospheric deposition will still be significant at least decades into the future. PAHs and metals continue to be emitted and therefore concentrations of these substances may not decrease or will decrease very slowly depending on further pollution reduction efforts or regulatory requirements. Even though emissions from many sources of mercury and dioxin have been reduced over the past decade, both pollutants are still seen at elevated levels in the environment. This problem will continue unless the emissions of mercury and dioxin are reduced further.

Atmospheric deposition of chemicals of emerging concern, such as brominated flame retardants and other compounds that may currently be under the radar, could also serve as a future stressor on the Great Lakes. Efforts are being made to screen for other chemicals of potential concern, with the intent of adding such chemicals to Great Lakes monitoring programs given available methods and sufficient resources.

Linkages

Atmospheric deposition is a significant route by which persistent bioaccumulative toxic chemicals, such as PCBs, currently enter the Great Lakes. Increases in the concentration and loadings of atmospheric PBTs may result in increased contamination in sediment, toxic chemicals in offshore waters and contaminants in whole fish and waterbirds. Bioaccumulation of these PBTs in fish may result in fish consumption advisories.

Management Challenges/Opportunities

Although concentrations of PCBs continue to decline slowly, somewhat of a “leveling-off” trend seems to be occurring in air, fish, and other biota as shown by various long-term monitoring programs. Remaining sources of PCBs, such as contaminated sediments, sewage sludge, and in-use electrical equipment, may need to be addressed more systematically through efforts like the Canada-U.S. Binational Toxics Strategy and national regulatory programs in order to see more significant declines. Many such sources are located in urban areas, which is reflected by the higher levels of PCBs measured in Chicago and Cleveland by IADN, and by other researchers in other areas (Wethington and Hornbuckle 2005; Totten et al. 2001). Research to investigate the significance of these remaining sources is underway. This is important because fish consumption advisories for PCBs exist for all five Great Lakes.

In terms of in-use agricultural chemicals, further restrictions on the use of these compounds may be warranted. Recently the agricultural chemical lindane was phased out in the U.S. and Canada and endosulfans are scheduled to be phased out in the U.S. and Canada by 2016 (Federal Register, 2010; Health Canada Pest Management Regulatory Agency, 2011). These restrictions will hopefully result in an increased rate of decline in their concentrations in the atmosphere.

PAH inputs to the Great Lakes may be reduced through controls on the emissions of combustion systems, such as those in factories and motor vehicles.

Progress has been made in reducing emissions of dioxins and furans, particularly through regulatory controls on incinerators. Residential garbage burning (burn barrels) is now the largest current source of dioxins and furans (Environment Canada and U.S. Environmental Protection Agency 2003). Basin and nationwide efforts are underway to eliminate emissions from burn barrels.

World-wide, the largest remaining source of mercury emissions to the atmosphere is coal-fired power plants. Regionally, many sources are reducing emissions; however, additional local and global actions may be needed to reduce the transport and deposition of mercury to the Great Lakes.

Pollution prevention activities, technology-based pollution controls, screening of in-use and new chemicals, and chemical substitution (for pesticides, household, and industrial chemicals) can aid in reducing the amounts of toxic chemicals deposited to the Great Lakes. Efforts to achieve reductions in use and emissions of toxic substances worldwide through international assistance and negotiations should also be supported, since PBTs used in other countries can reach the Great Lakes through long-range transport.

Continued long-term monitoring of the atmosphere is necessary in order to measure progress brought about by toxic reduction efforts. Environment Canada and U.S. EPA recently added routine monitoring of PBDEs and some non-PBDE flame retardants to the IADN program. Screening and method development for additional non-PBDE flame retardants is currently under way. Additional urban monitoring is needed to better characterize atmospheric deposition to the Great Lakes.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				

Acknowledgments

Author:

This report was prepared on behalf of the IADN Steering Committee by Todd Nettesheim, IADN Program Manager, U.S. Environmental Protection Agency, Great Lakes National Program Office, Michelle Craddock, Oak Ridge Institute for Science and Education Research Fellow, appointed to the U.S. Environmental Protection Agency, Great Lakes National Program Office, Sum Chi Lee, IADN Research Manager, Environment Canada, Science and Technology Branch, and Hayley Hung, IADN Principal Investigator, Environment Canada, Science and Technology Branch,, (2011).

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Link to IADN data: http://www.on.ec.gc.ca/natchem/Login/Login.aspx, or contact Helena Dryfhout-Clark, IADN Data Manager, Environment Canada, Science and Technology Branch, 6248 Eighth Line, Egbert (Ontario) L0L 1N0, Helena.Dryfhout-Clark@ec.gc.ca, 705 458-3316.

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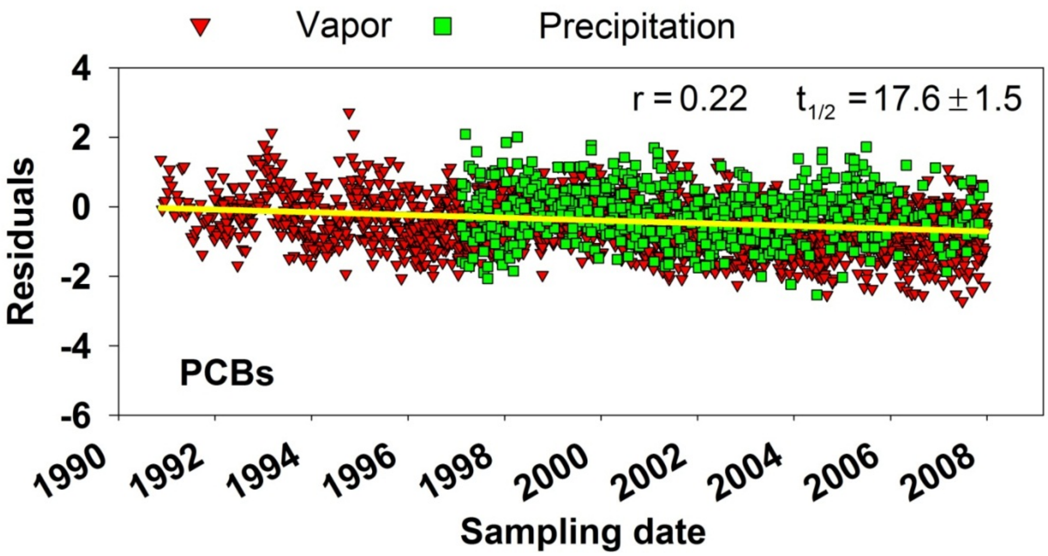

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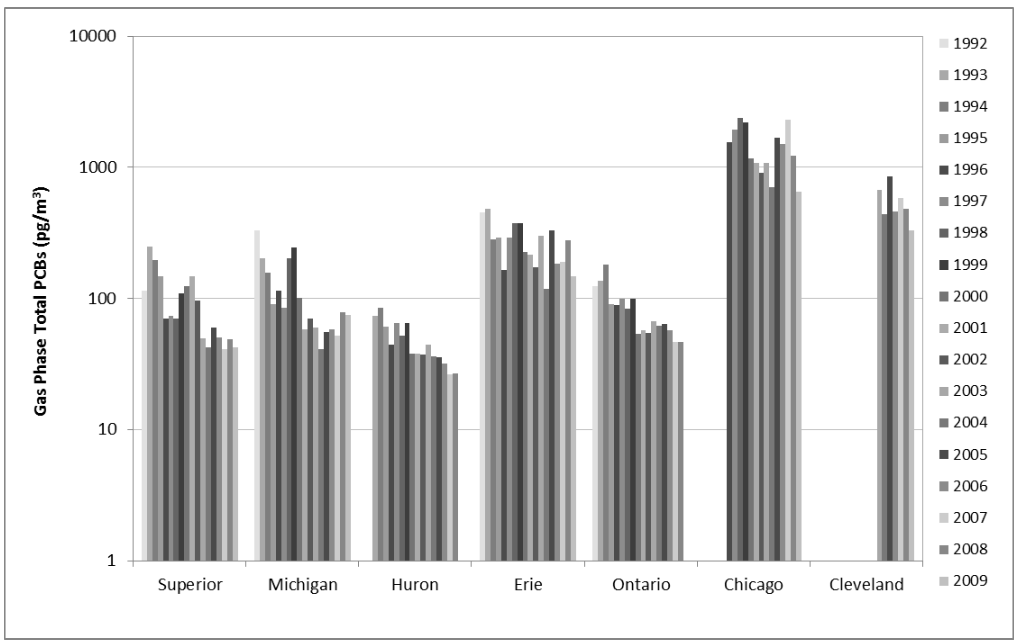

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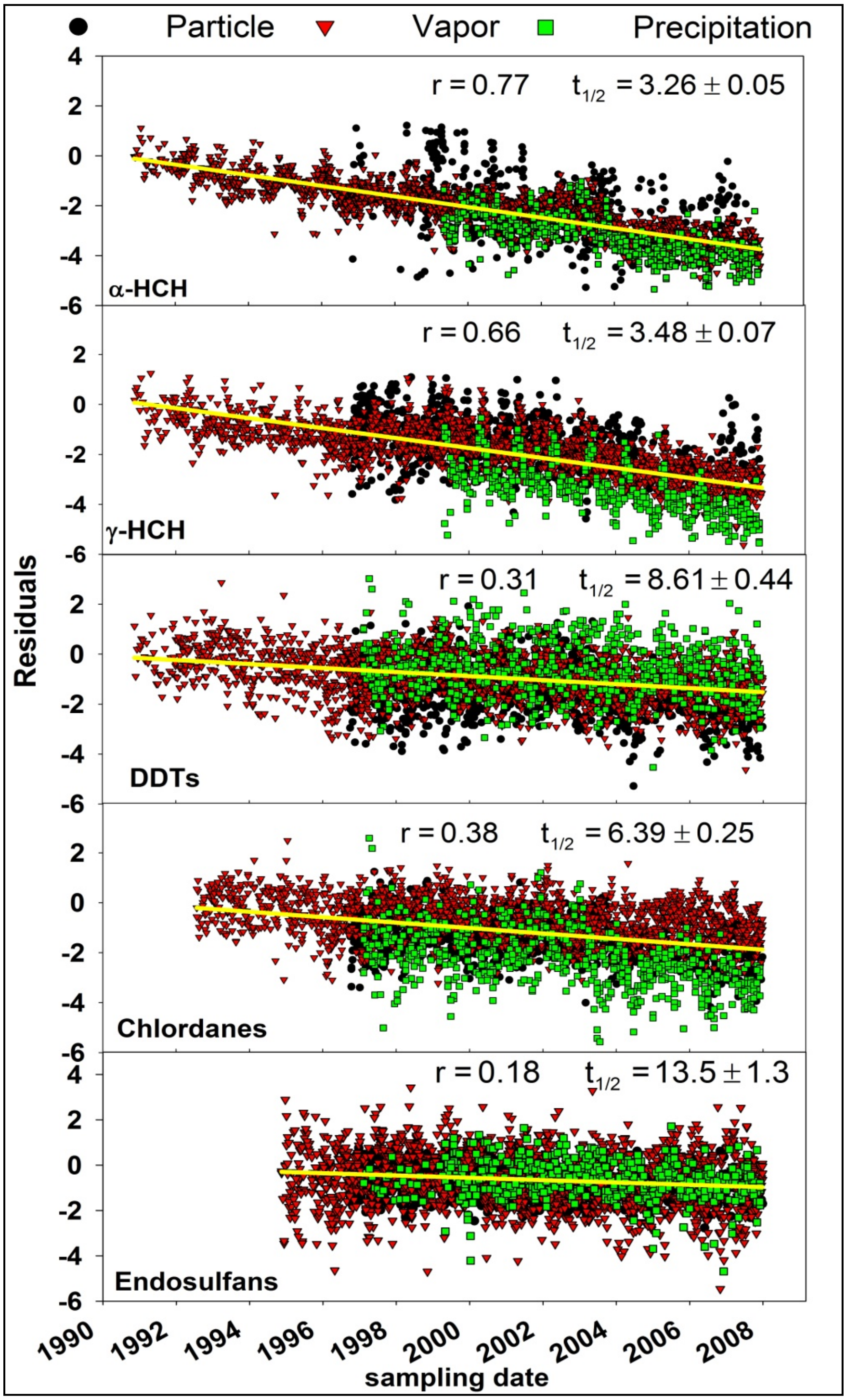

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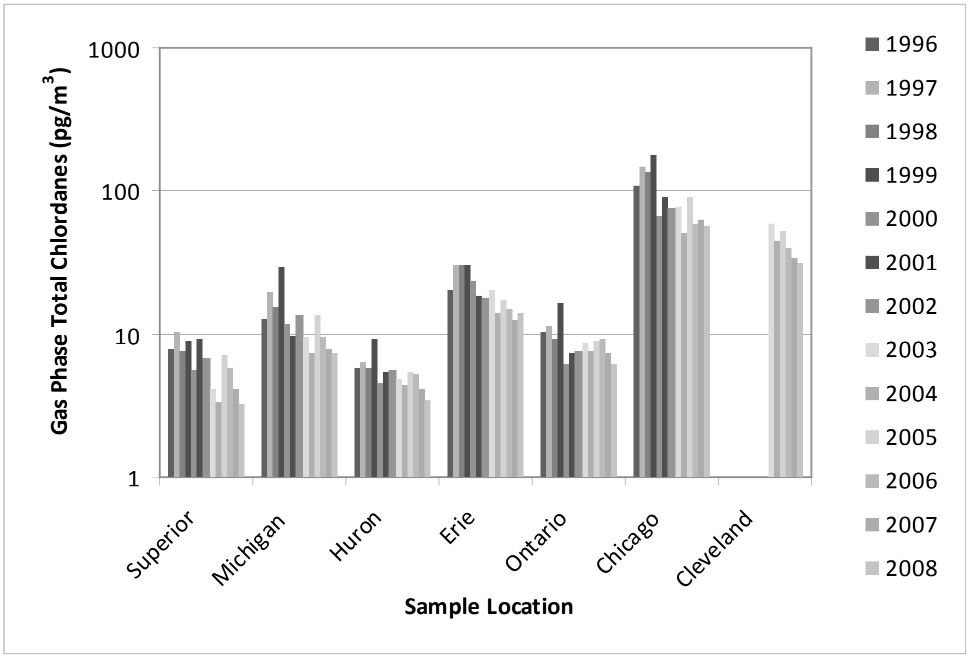

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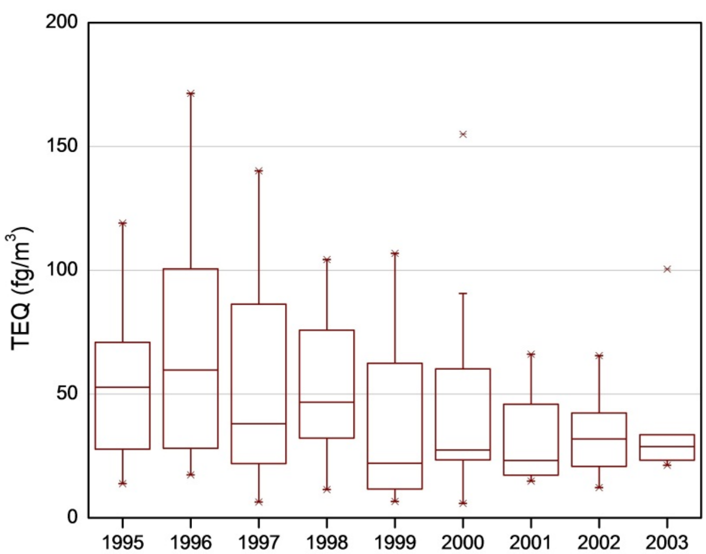
Source: IADN Steering Committee, unpublished, 2011.



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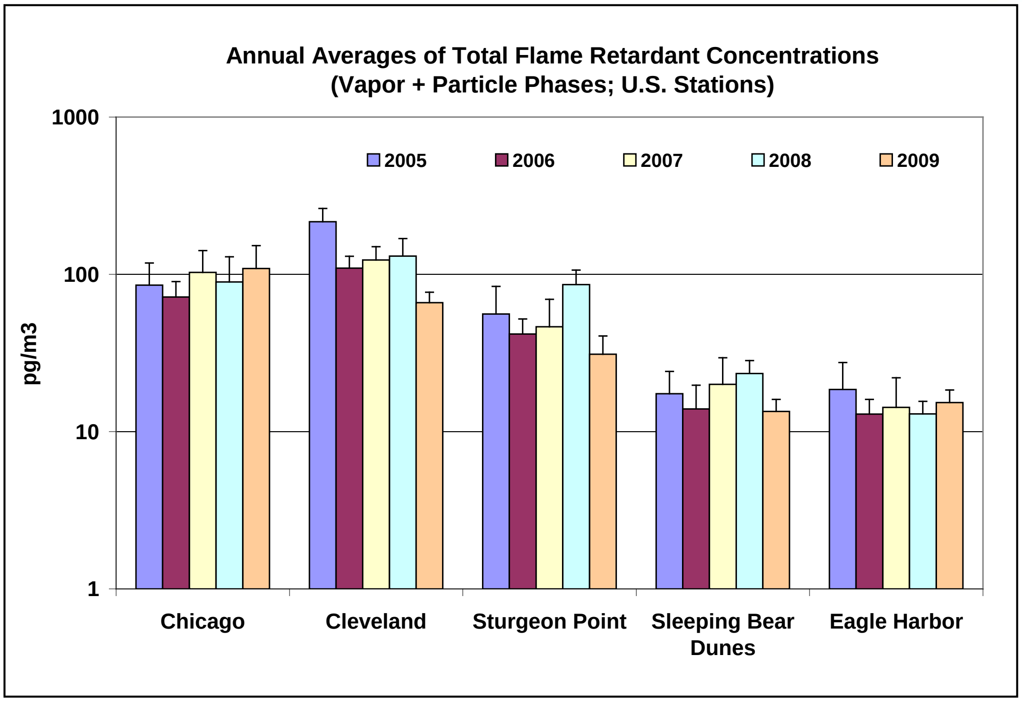
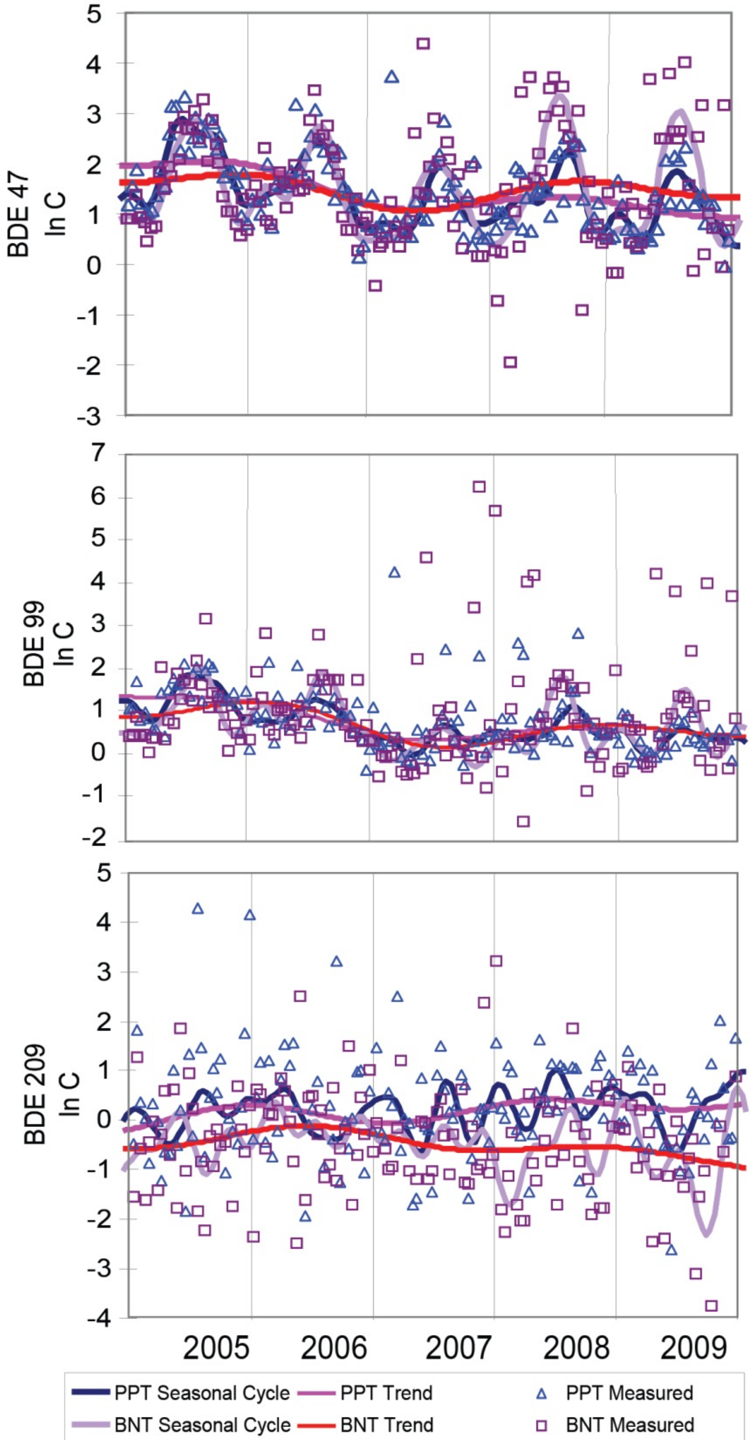


Figure 6. Annual Averages of Total Flame Retardant Concentrations (Vapor + Particle Phases; U.S. Stations). Source: IADN Steering Committee, unpublished, 2011.



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Source: IADN Steering Committee, unpublished 2011.

Base Flow Due to Groundwater Discharge

Overall Assessment
Status: **Fair**
Trend: **Undetermined**
Rationale: **Human activities are estimated to have detrimentally impacted groundwater discharge on at least a local scale in some areas of the Great Lakes basin; although discharge in other areas of the basin has not been significantly impaired. Trends in baseflow with time have not been analyzed for the basin.**

Lake-by-Lake Assessment
Individual lake basin assessments were not prepared for this report.

Purpose
- This indicator measures the contribution of base flow due to groundwater discharge to total stream flow by sub-watershed (lake-scale).
- To detect the impacts of anthropogenic factors on the quantity of the groundwater resource.
- The Base Flow Due to Groundwater indicator is used in the Great Lakes indicators suite as a State indicator in the Landscapes and Natural Processes top level reporting category.

Ecosystem Objective
The capacity of groundwater discharge to maintain in-stream conditions and aquatic habitat at, or near, potential is not compromised by anthropogenic factors.

Ecological Condition
Measure
Aquatic ecosystems in the streams in the Great Lakes Basin have developed in response to natural variations in flow including low-flow conditions. In the Great Lakes Basin, streams generally receive groundwater discharge as evidenced by increasing streamflow volumes downstream, and this groundwater discharge during times of low precipitation is often referred to as baseflow. Because baseflow maintains both streamflow volume and stream temperature during times of low precipitation it is considered important in maintenance of aquatic ecosystem. Long term average base flow relative to stream flow is referred to as base flow index. Base flow index is a dimensionless value between 0 and 1 where increasing values of the index indicate increasing groundwater discharge and base flow. For example, a base flow index value of 0.28 indicates that 28% of stream flow is estimated to be base flow. Significant extents of sand and gravel within a watershed often result in relatively large values of base flow index while significant extents of clay often result in relatively small values. Human impacts on base flow can potentially be detected using trend analysis of base flow over time and by identifying areas where base flow index is higher or lower than expected based on climate, geology, and other land cover characteristics.

Endpoint
Anthropogenic factors are not responsible for deviations in the base flow characteristics of sub-watersheds. No endpoint or reference value is available at this time.

Background
A significant portion of precipitation over the inland areas of the Great Lakes basin returns to the atmosphere by evapotranspiration. Water that does not return to the atmosphere either flows across the ground surface or infiltrates into the subsurface and recharges groundwater. Water that flows across the ground surface discharges into surface water features (rivers, lakes, and wetlands) and then flows toward and eventually into the Great Lakes. Water that

infiltrates into the subsurface and recharges groundwater also results in flow toward the Great Lakes. Most recharged groundwater flows at relatively shallow depths at local scales and discharges into adjacent surface water features. However, groundwater also flows at greater depths at regional scales and discharges either directly into the Great Lakes or into distant surface water features. The quantities of groundwater flowing at these greater depths can be significant locally but are generally believed to be modest relative to the quantities flowing at shallower depths.

The component of stream flow due to runoff from the ground surface is rapidly varying and transient, and results in the peak discharges of a stream. Groundwater discharge to surface water features in response to precipitation is greatly delayed relative to surface runoff. The stream flow resulting from groundwater discharge is, therefore, more uniform. In the Great Lakes region, groundwater discharge is often the dominant component of base flow. Base flow is the less variable and more persistent component of total stream flow.

Natural groundwater discharge is not the only component of base flow however, as various human and natural factors also contribute to the base flow of a stream. Flow regulation, the storage and delayed release of water using dams and reservoirs, creates a steady stream flow signature that is similar to that of groundwater discharge. Lakes and wetlands also moderate stream flow, transforming rapidly varying surface runoff into more slowly varying flow that approximates the dynamics of groundwater discharge. It is important to note that these varying sources of base flow affect surface water quality, particularly with regard to temperature.

Status of Base Flow

Base flow is frequently determined using a mathematical process known as hydrograph separation. This process uses stream flow monitoring information as input and partitions the observed flow into rapidly and slowly varying components, i.e., surface runoff and base flow, respectively. The stream flow data that are used in these analyses are collected across the Great Lakes basin using networks of stream flow gauges that are operated by the United States Geological Survey (USGS) and Environment Canada. Neff et al. (2005) summarize the calculation and interpretation of base flow for 3,936 gauges in Ontario and the Great Lakes states using six methods of hydrograph separation and length-of-record stream flow monitoring information for the periods ending on December 31, 2000 and September 30, 2001, respectively. The results reported by Neff et al. (2005) are the basis for this report.

Results corresponding to the United Kingdom Institute of Hydrology (UKIH) method of hydrograph separation (Piggott et al. 2005) are referenced throughout this report in order to maintain consistency with the previous report for this indicator. However, results calculated using the five other methods are considered to be equally probable outcomes.

Figure 1 illustrates the daily stream flow monitoring information and the results of hydrograph separation for the Nith River at New Hamburg, Ontario, for January 1 to December 31, 1993. The rapidly varying response of stream flow to precipitation and snow melt are in contrast to the more slowly varying base flow.

Application of hydrograph separation to daily stream flow monitoring information results in lengthy time series of output. Various measures are used to summarize this output. For example, base flow index is a simple, physical measure of the contribution of base flow to stream flow that is appropriate for use in regional scale studies. Base flow index is defined as the average rate of base flow relative to the average rate of total stream flow, is unitless, and varies from zero to one where increasing values indicate an increasing contribution of base flow to stream flow. The value of base flow index for the data shown in Figure 1 is 0.28, which implies that 28% of the observed flow is estimated to be base flow.

Neff et al. (2005) used a selection of 960 gauges in Ontario and the Great Lakes states to interpret base flow. Figure 2 indicates the distribution of the values of base flow index calculated for the selection of gauges relative to the gauged and ungauged portions of the Great Lakes basin.

The variability of base flow within the basin is apparent. However, further processing of the information is required to differentiate the component of base flow that is due to groundwater discharge and the component that is due to delayed flow through lakes and wetlands upstream of the gauges.

An approach to the differentiation of base flow calculated using hydrograph separation into these two components is summarized in the following paragraphs of this report.

Variations in the density of the stream flow gauges and discontinuities in the coverage of monitoring are also apparent in Figure 2 and may have significant implications relative to the interpretation of base flow.

The values of base flow index calculated for the selection of gauges using hydrograph separation are plotted relative to the extents of surface water upstream of each of the gauges in Figure 3. The extents of surface water are defined as the area of lakes and wetlands upstream of the gauges relative to the total area upstream of the gauges. While there is considerable scatter among the values, the expected tendency for larger values of base flow index to be associated with larger extents of surface water is confirmed.

Neff et al. (2005) modeled base flow index as a function of surficial geology and the spatial extent of surface water. Surficial geology is assumed to be responsible for differences in groundwater discharge and is classified into coarse and fine textured sediments, till, shallow bedrock, and organic deposits.

The modeling process estimates a value of base flow index for each of the geological classifications, calculates the weighted averages of these values for each of the gauges based on the extents of the classifications upstream of the gauges, and then modifies the weighted averages as a function of the extent of surface water upstream of the gauges.

A non-linear regression algorithm was used to determine the values of base flow index for the geological classifications and the parameter in the surface water modifier that correspond to the best match between the values of base flow index calculated using hydrograph separation and the values predicted using the model. The process was repeated for each of the six methods of hydrograph separation.

Extrapolation of base flow index from gauged to ungauged watersheds was performed using the results of the modeling process. The ungauged watersheds consist of 67 tertiary watersheds in Ontario and 102 eight-digit hydrologic unit code (HUC) watersheds in the Great Lakes states. The extents of surface water for the ungauged watersheds are shown in Figure 4 where the ranges of values used in the legend match those used to average the values of base flow index shown in Figure 3.

A component of base flow due to delayed flow through lakes and wetlands appears to be likely over extensive portions of the Great Lakes basin.

The distribution of the classifications of geology is shown in Figure 5. Organic and fine textured sediments are not differentiated in this rendering of the classifications because both classifications have estimated values of base flow index due to groundwater discharge in the range of 0.0 to 0.1. However, organic deposits are of very limited extent and represent, on average, less than 2% of the area of the ungauged watersheds.

The spatial variation of base flow index shown in Figure 5 resembles the variation shown in Figure 2. However, it is important to note that the information shown in Figure 2 includes the influence of delayed flow through lakes and wetlands upstream of the gauges while this influence has been removed, or at least reduced, in the information shown in Figure 5.

Figure 6 indicates the values of the geological component of base flow index for the ungauged watersheds obtained by calculating the weighted averages of the values for the geological classifications that occur in the watersheds. This map therefore represents an estimate of the length-of-record contribution of base flow due to groundwater discharge to total stream flow that is consistent and seamless across the Great Lakes basin.

The pie charts indicate the range of values of the geological component of base flow index for the six methods of hydrograph separation averaged over the sub-basins of the Great Lakes. Averaging the six values for each of the sub-basins yields contributions of base flow due to groundwater discharge of approximately 60% for Lakes Huron, Michigan, and Superior and 50% for Lakes Erie and Ontario. There is frequently greater variability of this contribution within the sub-basins than among the sub-basins as the result of variability of geology that is more uniformly averaged at the scale of the sub-basins.

Mapping the geological component of base flow index, which is assumed to be due to groundwater discharge, across the Great Lakes basin in a consistent and seamless manner is an important accomplishment in the development of this indicator.

Additional information is, however, required to determine the extent to which human activities have impaired groundwater discharge. There are various alternatives for the generation of this information. For example, the values of base flow index calculated for the selection of stream flow gauges using hydrograph separation can be compared to the corresponding modeled values. If a calculated value is less than a modeled value, and if the difference is not related to the limitations of the modeling process, then base flow is less than expected based on physiographic factors and it is possible that discharge has been impacted by human activities. Similarly, if a calculated value is greater than a modeled value, then it is possible that the increased base flow is the result of human activities such as flow regulation and wastewater discharge. Time series of base flow can also be used to assess these impacts. No attempt has yet been made to systematically assess change at the scale of the Great Lakes basin.

Change in base flow over time may be subtle and difficult to quantify (e.g., variations in the relation of base flow to climate) and may be continuous (e.g., a uniform increase in base flow due to aging water supply infrastructure and increasing conveyance losses) or discrete (e.g., an abrupt reduction in base flow due to a new consumptive water use). Change may also be the result of cumulative impacts due to a range of historical and ongoing human activities, and may be more pronounced and readily detected at local scales than at the scales that are typical of continuous stream flow monitoring.

A local-scale approach to illustrating the impact of flow regulation on base flow is shown in Figure 7, with data for the Grand River at Galt, Ontario. The cumulative depth of base flow calculated annually as the total volume of flow at the location of the gauge during each year divided by the area that is upstream of the gauge, is plotted relative to cumulative total flow. The base flow index is the slope of the accumulation of base flow relative to the accumulation of total flow shown in Figure 7. The change in slope and increase in base flow index from a value of 0.45 prior to the construction of the reservoirs that are located upstream of the gauge to 0.57 following the construction of the reservoirs clearly indicates the impact of active flow regulation to mitigate low and high flow conditions. Calculating and interpreting diagnostic plots such as Figure 7 for hundreds to thousands of stream flow gauges in the Great Lakes basin will be a large and time consuming, but perhaps ultimately necessary, task.

Pressures

The discharge of groundwater to surface water features is the end-point of the process of groundwater recharge, flow, and discharge. Human activities impact groundwater discharge by modifying the components of this process where the time, scale, and to some extent the severity, of these impacts is a function of hydrogeological factors and the proximity of surface water features. Increasing the extent of impervious surfaces during residential and commercial development and installation of drainage to increase agricultural productivity are examples of activities that may reduce groundwater recharge and ultimately groundwater discharge.

Withdrawals of groundwater as a water supply and during dewatering (pumping groundwater to lower the water table during construction, mining, etc.) remove groundwater from the flow regime and may also reduce groundwater discharge. Groundwater discharge may be impacted by activities such as the channelization of water courses that restrict the motion of groundwater across the groundwater and surface water interface. Human activities also have the capacity to intentionally, or unintentionally, increase groundwater discharge. Induced storm water infiltration, conveyance losses within municipal water and wastewater systems, and closure of local water supplies derived from groundwater are examples of factors that may increase groundwater discharge. Climate variability and change may compound the implications of human activities relative to groundwater recharge, flow, and discharge.

Linkages

Base flow due to the discharge of groundwater to the rivers, inland lakes and wetlands of the Great Lakes basin is a significant and often major component of stream flow, particularly during low flow periods. Base flow frequently satisfies flow, level, quality and temperature requirements for aquatic species and habitat. Water supplies and the capacity of surface water to assimilate wastewater discharge are also dependent on base flow. Base flow due to groundwater discharge is therefore critical to the maintenance of water quantity, quality, and integrity of aquatic species and habitat. Natural factors such as climate variability modify both average rates of base flow and the annual distribution of flow. Pressures such as urban development and water use, in combination with the potential for climate change impacts, may alter base flow. Reductions in base flow may compromise the assimilative capacity of surface water for wastewater discharge during periods of otherwise low flow and result in reduced water quality.

Management Challenges/Opportunities

Groundwater has important societal and ecological functions across the Great Lakes basin. Groundwater is typically a high quality water supply that is used by a significant portion of the population, particularly in rural areas where it is often the only available source of water. Groundwater discharge to rivers, lakes, and wetlands is also critical to aquatic species and habitat and to in-stream water quantity and quality. These functions are concurrent and occasionally conflicting.

Pressures such as urban development and water use, in combination with the potential for climate impacts and further contamination of the resource, may increase the frequency and severity of these conflicts. In the absence of systematic accounting of groundwater supplies, use, and dependencies, it is the ecological function of groundwater that is most likely to be compromised.

Managing the water quality of the Great Lakes requires an understanding of water quantity and quality within the inland portion of the basin, and this understanding requires recognition of the relative contributions of surface runoff and groundwater discharge to stream flow. The results described in this report indicate the significant contribution of groundwater discharge to flow within the tributaries of the Great Lakes. The extent of this contribution has tangible management implications. There is considerable variability in groundwater recharge, flow, and discharge that must be reflected in the land and water management practices that are applied across the basin.

The dynamics of groundwater flow and transport are different than those of surface water flow. Groundwater discharge responds more slowly to climate and maintains stream flow during periods of reduced water availability, but this capacity is known to be both variable and finite. Contaminants that are transported by groundwater may be in contact with geologic materials for years, decades, and perhaps even centuries or millennia. As a result, there may be considerable opportunity for attenuation of contamination prior to discharge. However, the lengthy residence times of groundwater flow also limit opportunities for the removal of contaminants, in general, and non-point source contaminants, in particular.

Comments from the author(s)

The indicated status and trend are estimates that the authors consider to be a broadly held opinion of water resource specialists within the Great Lakes basin. Further research and analysis is required to confirm these estimates and to determine conditions on a lake by lake basis.

Base flow information cited in the report is a product of the study, Groundwater and the Great Lakes: A Coordinated Binational Basin-wide Assessment in Support of Annex 2001 Decision Making, conducted by the U.S. Geological Survey in cooperation with Environment Canada's National Water Research Institute and the Great Lakes Protection Fund. Data are published in Neff et al. (2005), cited below.

Recent investigations on trends in streamflow characteristics (Hodgkins and others, 2007) could be expanded to the Canadian part of the basin. Similarly, analyses of trends in groundwater recharge (Rivard and others, 2009) could be completed in greater detail across both the Canadian and U.S. portions of the basin.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				

Acknowledgments
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Contributors:
Lori Fuller and Jim Nicholas of U.S. Geological Survey were contributors to the previous version of this report.

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Figure 1. Hydrograph of observed total stream flow (black) and calculated base flow (red) for the Nith River at New Hamburg during 1993.
Source: Environment Canada and the U.S. Geological Survey.

Figure 2. Distribution of the calculated values of base flow index relative to the gauged (light grey) and ungauged (dark grey) portions of the Great Lakes basin.
Source: Environment Canada and the U.S. Geological Survey.
Figure 3. Comparison of the calculated values of base flow index to the corresponding extents of surface water. The step plot (red) indicates the averages of the values of base flow index within the four intervals of the extent of surface water.
Source: Environment Canada and the U.S. Geological Survey.
Figure 4. Distribution of the extents of surface water for the ungauged watersheds.
Source: Environment Canada and the U.S. Geological Survey.
Figure 5. Distribution of the geological classifications. The classifications are shaded using the estimated values of the geological component of base flow index shown in parentheses.
Source: Environment Canada and the U.S. Geological Survey.
Figure 6. Distribution of the estimated values of the geological component of base flow index for the ungauged watersheds. The pie charts indicate the estimated values of the geological component of base flow index for the Great Lakes sub-basins corresponding to the six methods of hydrograph separation. The charts are shaded using the six values of base flow index and the numbers in parentheses are the range of the values.
Source: Environment Canada and the U.S. Geological Survey.
Figure 7. Cumulative base flow as a function of cumulative total flow for the Grand River at Galt prior to (red), during (green), and following (blue) the construction of the reservoirs that are located upstream of the stream flow gauge. The step plot indicates the cumulative storage capacity of the reservoirs where the construction of the largest four reservoirs is labeled. The dashed red and blue lines indicate uniform accumulation of flow based on data prior to and following, respectively, the construction of the reservoirs.
Source: Environment Canada and the U.S. Geological Survey.

Last Updated
State of the Great Lakes 2009 report.
A partial update was completed for the 2011 reporting

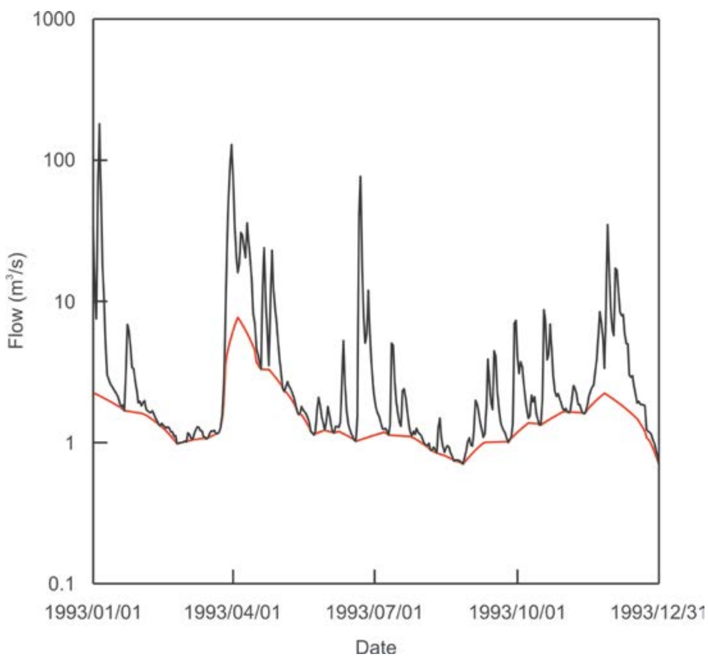
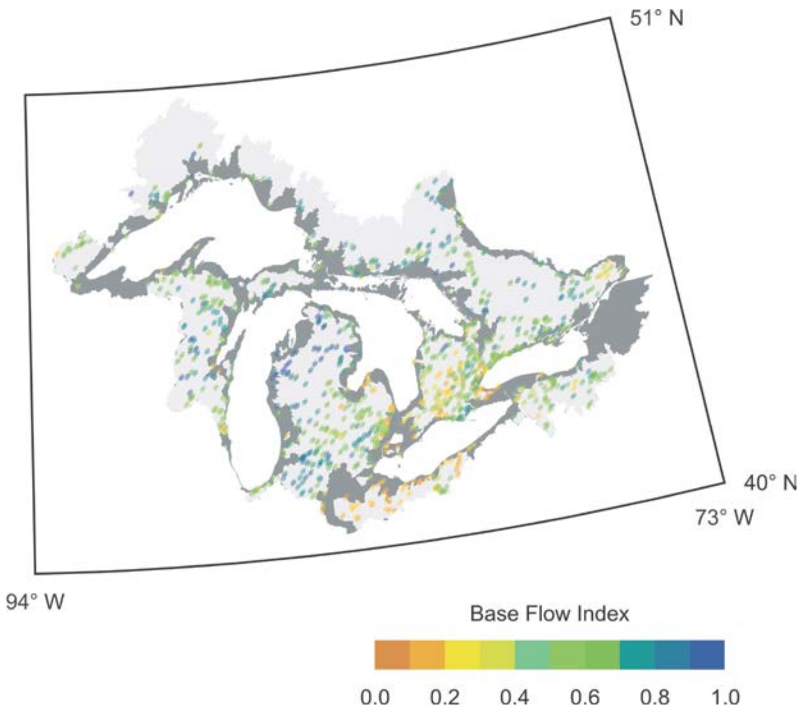


Figure 1. Hydrograph of observed total stream flow (black) and calculated base flow (red) for the Nith River at New Hamburg during 1993.
Source: Environment Canada and the U.S. Geological Survey.



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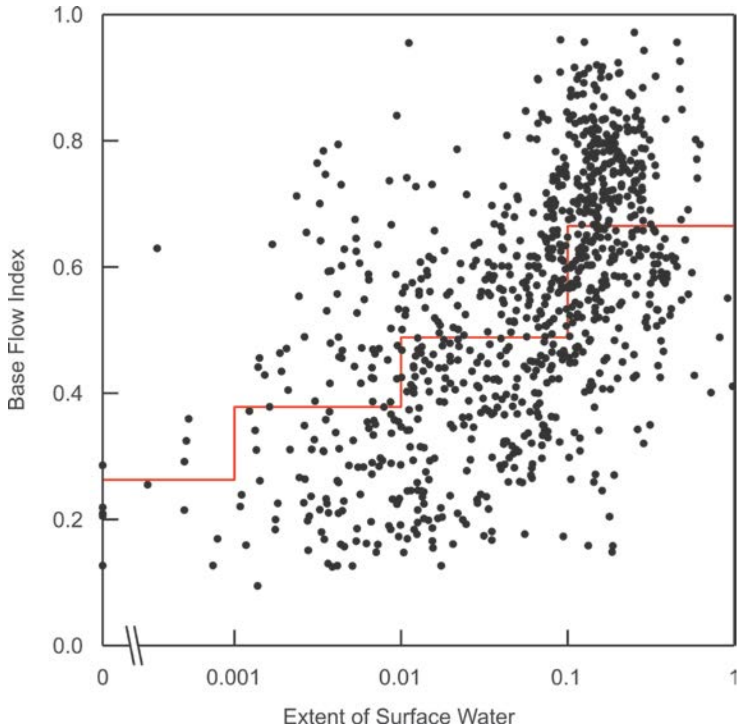

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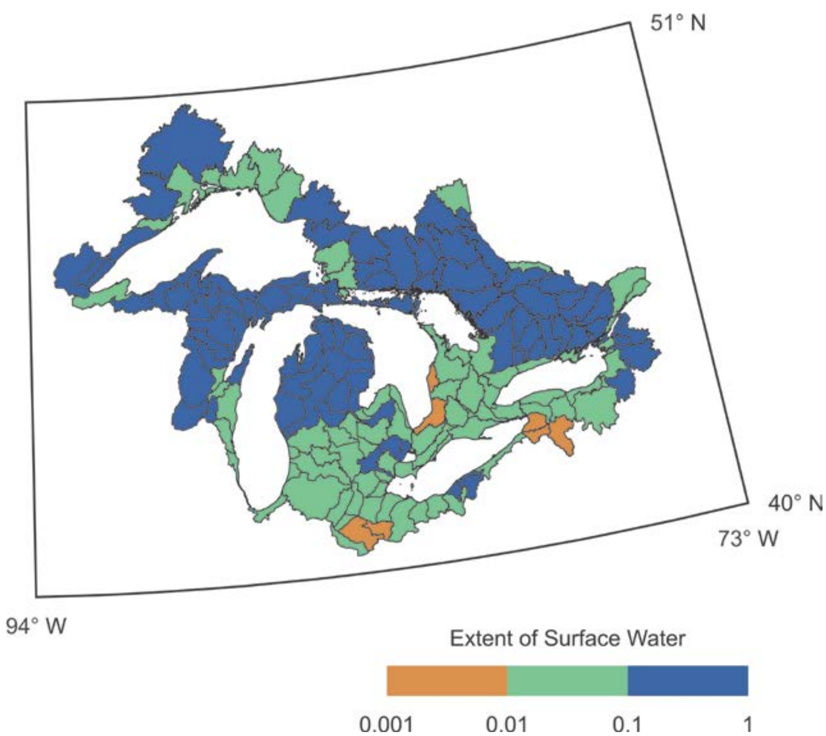

Figure 4. Distribution of the extents of surface water for the ungauged watersheds.
Source: Environment Canada and the U.S. Geological Survey

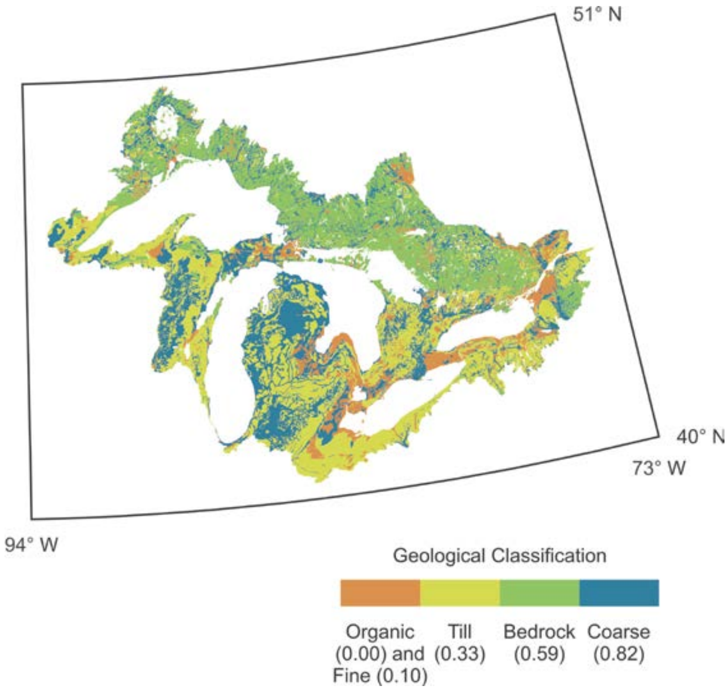

Figure 5. Distribution of the geological classifications.
The classifications are shaded using the estimated values of the geological component of base flow index shown in parentheses. Source: Environment Canada and the U.S. Geological Survey

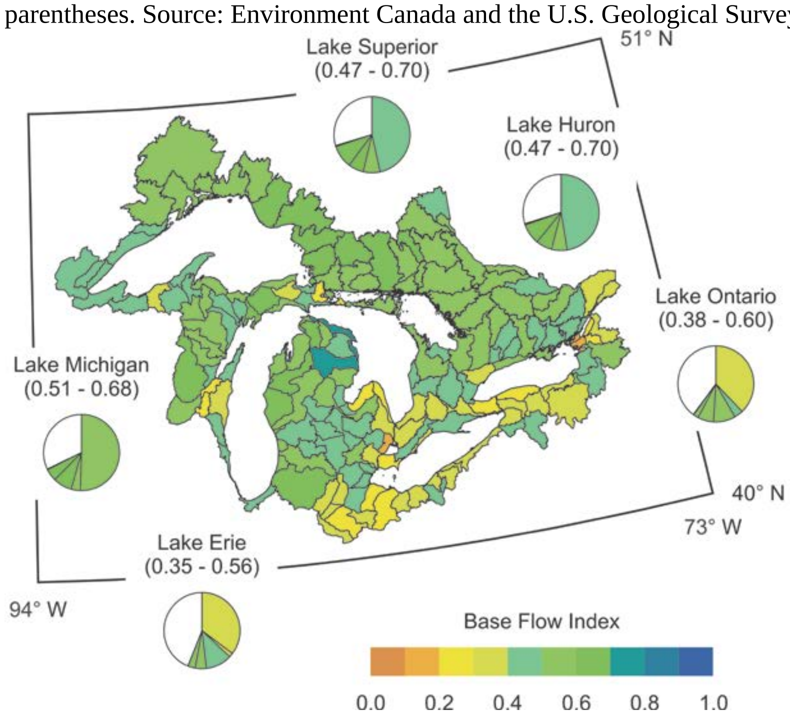

Figure 6. Distribution of the estimated values of the geological component of base flow index for the ungauged watersheds.
The pie charts indicate the estimated values of the geological component of base flow index for the Great Lakes sub-basins corresponding to the six methods of hydrograph separation. The charts are shaded using the six values of base flow index and the numbers in parentheses are the range of the values.
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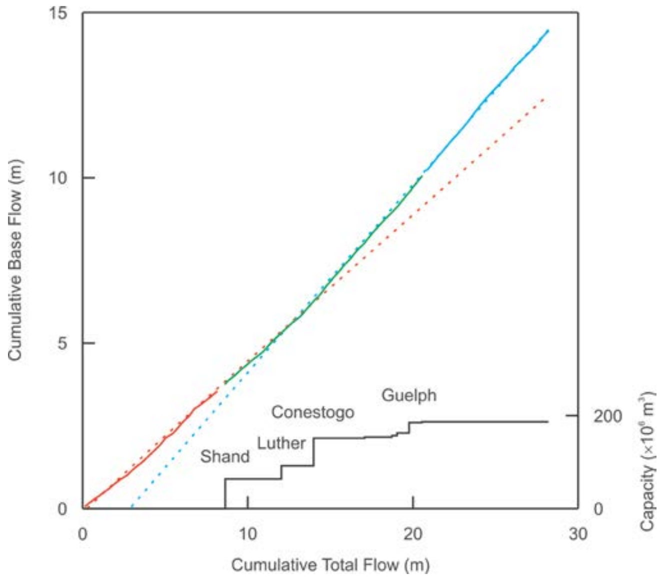

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Source: Environment Canada and the U.S. Geological Survey

Beach Advisories

Overall Assessment
Status: Fair
Trend: Unchanging
Rationale: The percentage of monitored U.S. Great Lakes beaches that were open and safe for swimming during 2008 - 2010 is an average of 93%. This standard differs from the last report in that the focus of lake summary information in the U.S. is now exclusively on monitored beaches. The percentage of monitored Canadian Great Lakes beaches that were open and safe for swimming during 2008-2010 is an average of 79%. Differences in the percentage of open and posted beaches between the U.S. and Canada may reflect differing posting criteria. Please note that for consistency, all 2006 and 2007 results for Great Lakes beaches have been recalculated and reassessed based on the new beach indicator reporting method. Beach advisories are now calculated based on the number of days a monitored beach is open and safe for swimming during the summer season rather than assessing the percentage of monitored and non-monitored beaches that are open 95% of the swimming season. Only those beaches that are monitored by beach safety programs are included in the analysis. It should also be noted that the statistics have changed from the 2009 *State of the Great Lakes* report due to the new reporting methods used in this report.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: U.S.: Unchanging; Canada: Deteriorating
Rationale: During 2008 through 2010, on average, 97% of monitored Lake Superior beaches were open and safe for swimming in the U.S. In addition, efforts to identify and remediate sources of contamination are being conducted at several Lake Superior beaches. In Canada, during 2008 through 2010, 88% of monitored Lake Superior beaches were open and safe for swimming during the swimming season. The trend shows deteriorating conditions, from 96% in 2006-2007; however, there was an increase in 30% more beaches being monitored from the last reporting cycle.

Lake Michigan
Status: Good
Trend: Unchanging
Rationale: During 2008 through 2010, on average, 93% of monitored Lake Michigan beaches were open and safe for swimming. In addition, efforts to identify and remediate sources of contamination are being conducted at several Lake Michigan beaches.

Lake Huron
Status: Good
Trend: U.S.: Unchanging; Canada: Deteriorating
Rationale: During 2008 through 2010, on average, 98% of U.S. monitored Lake Huron beaches were open and safe for swimming. In addition, efforts to identify and remediate sources of contamination are being conducted at several Lake Huron beaches. In Canada, during 2008 through 2010, 83% of monitored Lake Huron beaches were open and safe for swimming. The trend appears to be deteriorating from 94% in 2006-2007.

Lake Erie
Status: Fair
Trend: Deteriorating
Rationale: During 2008 through 2010, on average, 86% of U.S. monitored Lake Erie beaches were open and safe for swimming. While there has been an annual 2% decline in the percentage of Lake Erie beaches that are open and safe for swimming since 2008, efforts are being conducted to identify sources of contamination so measures can be taken to mitigate the contamination. In Canada, during 2008 through 2010, 78% of Lake Erie monitored beaches were open and safe for swimming. The trend appears to be deteriorating from 87% in 2006-2007.

Lake Ontario
Status: Good
Trend: U.S.: Improving; Canada: Unchanging
Rationale: During 2008 through 2010, on average, 93% of U.S. monitored Lake Ontario beaches were open and safe for swimming. Although the trend is improving, efforts continue to be conducted to identify sources of contamination so measures can be taken to mitigate the contamination. In Canada, during 2008 through 2010, 75% of Lake Ontario monitored beaches were open and safe for swimming during the swimming season. The trend appears to be slightly deteriorating from 79% in 2006 – 2007.

Purpose

- To assess the number of days that Great Lakes beaches are open and safe for swimming by assessing the health-related swimming posting (advisories or closings) days for recreational areas (beaches).
- To infer potential harm from pathogens to human health through body contact with nearshore recreational waters.
- The Beach Advisories indicator is used in the Great Lakes indicator suite as an indicator in the Human Impacts top level reporting category.

Ecosystem Objective

Waters should be safe for recreational use. Waters used for recreational activities involving body contact should be substantially free from pathogens, including bacteria, parasites, and viruses, that may harm human health. This indicator supports Annexes 1, 2, and 13 of the GLWQA (1987).

Ecological Condition

Measure

The percentage of days in the beach season that monitored Great Lakes beaches are open and safe for swimming. Previous reports used a measure of percentage of beaches with beach advisories during the swimming season. For example, a sentence stating “93% of beaches were open and safe for swimming” does not indicate that the beaches were open 93 days of the season; it indicates that the beaches were, on average, open and safe for swimming 104 days out of the 112 days in the swimming season (.i.e. 93%). The beach season is generally from the Memorial Day/Victoria Day weekend to Labor Day; however, some health units/counties vary so all beach days that are reported on by counties and health units will be used.

Endpoint

For each Canadian lake basin, the status will be considered good if 80% or more of the beach season for monitored Great Lakes beaches are open and safe for swimming. For each U.S. lake basin, the status will be considered good if 90-100% of the monitored Great Lakes beaches are open and safe for swimming. The previous beach reports used criteria of 90% of monitored, high priority beaches meeting bacteria standards for more than 95% of the swimming season.

Background

Beach monitoring is conducted primarily to detect bacteria that indicate the possible presence of disease-causing microbes (pathogens) from fecal pollution. People swimming in water contaminated with pathogens can contract diseases of the gastrointestinal tract, eyes, ears, skin, and upper respiratory tract. When monitoring results reveal elevated levels of indicator bacteria, the state or local government/health units issue a beach advisory or closure notice until further sampling shows that the water quality is meeting the applicable water quality standards.

A health-related advisory day is one that is based upon elevated levels of *E. coli*, or other indicator organisms, as reported by county health departments (U.S.), Public Health Units (Ontario), or municipal health departments in the Great Lakes basin. *E. coli*, Enterococci, and other bacterial organisms are measured in beach water samples because they act as indicators for the potential presence of pathogens which can potentially harm human health through body contact with nearshore recreational waters

The Ontario provincial standard is 100 *E. coli* colony forming units (cfu) per 100 mL, based on the geometric mean (GM) of a minimum of one sample per week from each of at least 5 sampling sites per beach (Ontario Ministry of Health and Long-Term Care, 2008). The Beach Management Protocol states that beaches of 1000 meters of length or greater require one sampling site per 200 meters, with a minimum of 5 samples taken at each site. In some cases local Health Units in Ontario have implemented a more frequent sampling procedure than is outlined by the provincial government. When *E. coli* levels exceed the standard, beach waters are posted as unsafe for the health of bathers until further sampling shows that the water quality is meeting the applicable water quality standards. The average swimming season in Ontario begins at the end of May and continues until the first weekend in September, but some health units may have a longer or shorter season than the norm. The difference in the swimming season length, the number of beaches sampled each season, as well as the frequency of sampling are all factors that may skew the final result of the percent of beaches open and safe for swimming throughout the season.

In the U.S., the water quality criteria for bacteria for fresh coastal recreation waters are a single sample maximum (SSM) value of 235 *E. coli* colony forming units (cfu) per 100 ml of water (State of Michigan uses 300 cfu per 100 ml), and an SSM of 61 Enterococci cfu per 100 ml (Federal Register 2004). When levels of these indicator organisms exceed water quality standards, swimming at beaches is prohibited or advisories are issued to inform beachgoers that swimming may be unsafe. The swimming season starts Memorial Day weekend and ends on Labor Day. The U.S. Environmental Protection Agency (U.S. EPA) annually publishes a summary report and data about beach closings and advisories for the previous year's swimming season statistics. The report is based on beach monitoring and notification data submitted each year by the states to U.S. EPA.

The Beaches Environmental Assessment and Coastal Health (BEACH) Act amended the Clean Water Act in 2000 and authorizes U.S. EPA to award grants to coastal and Great Lakes states, territories and eligible tribes to help local authorities monitor their coastal and Great Lakes beaches and notify the public of water quality conditions that may be unsafe for swimming. Great Lakes beach managers are now able to regularly monitor beach water quality and advise bathers of potential risks to human health when water quality standards for bacteria are exceeded. The BEACH Act also requires states that have coastal recreation waters, including the Great Lakes, to adopt bacteriological criteria as protective as EPA's recommended criteria (under Section 304(a) of the Clean Water Act) at their coastal waters. In December 2012, U.S. EPA released its revised nationally recommended recreational water quality criteria to protect human health in inland and coastal waters. The revised criteria, which meet the BEACH Act requirements, reflect the latest scientific knowledge and are designed to protect the public from exposure to harmful levels of pathogens while participating in water-contact activities.

Status of Great Lakes Beach Advisories

Since the last reporting period, the percentage of U.S. Great Lakes beaches open and safe for swimming has remained about the same (Figure 1). Overall, the percentage of monitored Great Lakes beaches that were open and safe for swimming during 2007 – 2010 was an average of 94% (percent of beach days not under an action).

The percentage of U.S. beaches open the entire swimming season (100% of the time) from 2007 to 2009 decreased for Lakes Erie, Huron, and Ontario (Figure 3). From 2009 to 2010, while there appears to be a significant decrease in the percentage of beaches open the entire swimming season, it is because only monitored beaches are now included in the assessment. The prior Beach Advisories, Postings and Closures reports (and the 2007-2009 data in Figure 3) also included non-monitored beaches. The non-monitored beaches were listed as open and safe for swimming for 100% of the beach season because the lack of monitoring resulted in no postings or advisories. It is important to include only the beaches for which we have data in order to get an accurate assessment of Great Lakes beach water quality and all Beach Advisory reports moving forward will only include information for Great Lakes monitored beaches. It is also important to note that previous Beach Advisory indicator reports included older data; however, data from 1999 to 2005 were not available in the format needed to allow for the recalculations based on the new reporting methods.

In Canada, overall the percentage of Great Lakes beaches open and safe to swim during 2008-2010 was 79%. The trend appears to be slightly deteriorating from 82% in 2006-2007 (Figure 2). This analysis is based on the number of days within a swimming season that beaches are open and safe to swim. Please note that this analysis differs from past SOLEC reports, which focused on the number of postings within each swimming season. The last reporting cycle was based on the U.S. standard that beaches should be open 95% or more of the entire swimming season. The proposed new Ontario Public Health standard (Ministry of Health *in draft*, 2008) indicates that beaches should be open 80% or more of the swimming season. This standard better reflects the difference in beach posting standards between the U.S. and Canada. The number of beach postings within each swimming season was calculated based on this new standard to provide a consistent analysis with the past SOLEC report. All 2006 and 2007 results have been recalculated and reassessed based on the Ontario Public Health standards used in this report to provide consistency. The original data set included only those beaches monitored throughout the beach season; therefore there has been no change in the type of reporting for Canadian beaches. All Canadian health units with beaches residing on the Great Lakes provided their 2008-2010 beach data for this report.

The percentage of Canadian beaches open the entire (100%) swimming season slightly improved from 26% during 2006 to 2007 to 30% during 2008 to 2010 (Figure 4). The percentage of Canadian Great Lakes beaches open 80% or more of the swimming season during 2008 – 2010 was 64%. This shows a deteriorating trend from 80% during the 2006 – 2007 reporting cycle. It is also evident that between 2008 to 2010, the percentage of Canadian Great Lakes beaches that were open 80% or more of the swimming season also deteriorated. In 2008, the percentage of beaches open more than 80% or more of the swimming season was 69%, in 2009, the percentage of beaches open more than 80% or more of the swimming season was 62%, and in 2010 the percentage of beaches open more than 80% or more of the swimming season was 60%. Within 3 years, the percentage of beaches open more than 80% or more of the swimming season decreased by 9%. However, from 2006 to 2007, the percentage of beaches open more than 80% or more of the swimming season increased from 74% in 2006 to 85% in 2007. Annual variability in weather may affect the variability in bacterial counts between each swimming season.

Comparisons of the frequency of beach closings between Canada and the U.S. will be limited due to use of different water quality criteria in the Great Lakes. The change in the Canadian standard, indicating that beaches should be open 80% or more of the swimming season, rather than the entire beach season, provides a slightly improved comparison of beach postings in the Great Lakes.

Management Challenges/Opportunities

Annual variability in the data may result from the variability in monitoring frequencies among beach management entities and variations in reporting, and may not be solely attributable to actual increases or decreases in levels of bacterial indicators. In addition, annual variability of weather may affect the variability in bacterial counts.

Additional point and non-point source pollution at coastal areas due to population growth and increased land use may result in additional beach postings, particularly during wet weather conditions. Unless contaminant sources are reduced or removed (or new sources introduced), Great Lakes beach sample results generally contain similar bacteria levels after events with similar meteorological conditions (primarily wind direction and the volume and duration of rainfall). If episodes of poor recreational water quality can be associated with specific events (such as meteorological events of a certain threshold), then forecasting for episodes of elevated bacterial counts may become more accurate.

There are a number of activities being conducted in the U.S. to make the Great Lakes cleaner and safer for swimming. In 2010, the Great Lakes Restoration Initiative (GLRI) provided funding to numerous Great Lakes entities to conduct sanitary surveys at more than 400 Great Lakes beaches to identify sources of contamination affecting beach water quality. Identification of pollution sources at beaches is a critical first step to enabling beach managers to reduce pollution and increase the time that beaches are safe for recreation. GLRI funds have also been issued in 2011 to implement projects to reduce or eliminate contamination sources that have been identified through the use of sanitary surveys.

Identification of pollution sources affecting beach water quality followed by the implementation of actions to reduce or eliminate the pollution will help reduce the presence of bacteria, viruses and pathogens to levels in which water quality standards can be met, one of the long term goals of the *Great Lakes Restoration Initiative Action Plan*. This goal is addressed by two *Action Plan* objectives, “By 2014, 50% of high priority Great Lakes beaches will have been assessed using a standardized sanitary survey tool to identify sources of contamination” and “By 2014, 20% of high priority Great Lakes beaches will have begun to implement measures to control, manage or remediate pollution sources identified through the use of sanitary surveys.” It is important for the source identification and remediation work to continue in order to improve water quality, better protect public health, and increase the opportunities for safe recreation at Great Lakes beaches.

There may be new indicators and new detection methods available through current research efforts occurring bi-nationally in both public and private sectors and academia. Although currently a concern in recreational waters, viruses and parasites are difficult to isolate and quantify, and feasible measurement techniques have yet to be implemented. Although considered reliable indicators of potential harm to human health, the presence of *E. coli* and/or Enterococcus may not necessarily be related to fecal contamination.

Many Ontario health units are participating in beach management programs to monitor public bathing beaches and to improve public awareness. Although each health unit differs slightly, most improve recreational water quality by participating in assisting in enhanced beach grooming; in-water and land debris clean-up; waterfowl and gull deterrent; and public campaigns to encourage people to dispose of food scraps rather than feeding the birds which further pollutes the recreational water (City of Toronto, 2006). The Blue Flag program is becoming a well known program and an effective way of promoting clean beaches in Canada. It is an eco-label that is internationally recognized and only awarded to beaches that achieve high standards in areas such as water quality, education, environmental management and safety (Environmental Defense, 2010). In 2010, Ontario already had nine awarded Blue Flag beaches on the Great Lakes.

In Ontario, the first Great Lakes beach data depository, the Seasonal Water Monitoring and Reporting System (SWMRS) was launched in the summer of 2011. This web-based application, partnered by Environment Canada and the Ontario Ministry of Health and Long-Term Care, provides local Health Units with a tool to manage beach sampling data. Health Unit beach data from the past decade is currently being entered into the system. The result will be a system that can potentially have predictive modeling capability, as well as improve the interface for public use. The system will help identify areas of chronic beach postings and, as a result, will aid in improved targeting of programs to address the sources of bacterial contamination.

In the U.S., one of the biggest challenges is the proposed elimination of BEACH Act funding in 2014. Without these funds many health departments will have to eliminate beach water testing and public notification programs, which would significantly reduce the amount of the beach data available which enables reporting on beach water quality conditions in the Great Lakes.

Linkages

Beach postings may be the result of pressures including bacterial loadings from tributaries and extreme precipitation events. Improved wastewater treatment in response to these pressures may limit the number of beach postings. Implementation of best management practices and green infrastructure to reduce the volume of storm water runoff may also limit the number of beach advisories.

Comments from the author(s)

This indicator was updated in 2011 to more closely reflect the impacts to human health and the national metric used in the U.S. Non-monitored beaches will no longer be included in the measure for this indicator as they had been in the U.S. in the past. Non-monitored beaches are entered into U.S. databases as open and safe for swimming for 100% of the beach season because the lack of monitoring resulted in no postings. This assumption that non-monitored beaches were always safe for swimming may have resulted in an overstatement of the safety of Great Lakes beaches.

The new Great Lakes beach metric is “Percent of days of the beach season that the Great Lakes beaches monitored by state beach safety programs are open and safe for swimming.” This metric is consistent with EPA’s Office of Water National Program Guidance beach measure (SP-9) and with the language proposed to be revised in the GLRI Action Plan. This change in reporting structure and status justification poses challenges to establish a basin-wide trend and to compare current status with that previously reported through SOLEC. The use of both monitored and non-monitored (U.S.) beaches in past State of the Great Lakes reports also complicates comparisons between previous and current status situations.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				

Acknowledgments

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Kristin Stevens, U.S. EPA; stevens.kristin@epa.gov

Information Sources

Great Lakes beach data provided by U.S. EPA
http://water.epa.gov/type/oceb/beaches/seasons_2010_index.cfm

Canadian Great Lakes Beach data provided by the following Ontario Health Units with beaches residing along the Great Lakes: Algoma; Chatham Kent; Durham Region; Elgin St. Thomas; Grey Bruce; Haldimand Norfolk: Haliburton Kawartha Pine Ridge District; Halton Region; Hamilton; Hastings and Prince Edward Counties; Huron County; Lambton County; Niagara Region; North Bay Parry Sound District; Peel Region; Simcoe Muskoka District; Sudbury & Distruct; Thunder Bay District; Toronto; Windsor-Essex County

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List of Figures

Figure 1. Percentage of beach days that U.S. Great Lakes beaches are open and safe for swimming (2010 data includes only monitored beaches while 2007-2009 data includes both monitored and non-monitored beaches). Source: Data collected from U.S. states and reported to U.S. EPA's Beach Advisory and Closing On-Line Notification (BEACON) system.

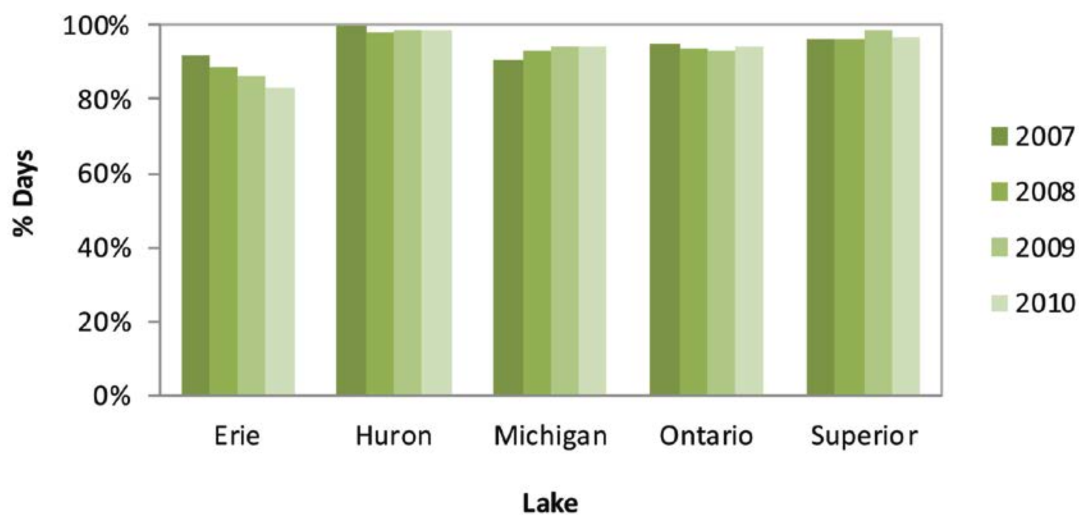
Figure 2. Percentage of beach days that Canadian monitored Great Lakes beaches are open and safe for swimming. Source: Data collected from Ontario Health Units located along the Great Lakes (see Health Units listed in information source section), 2010.

Figure 3. Overview of U.S. beach advisories 2007 – 2010 within each lake basin swimming season (2010 data includes only monitored beaches while 2007-2009 data includes both monitored and non-monitored beaches). Source: Data collected from U.S. states and reported to U.S. EPA's Beach Advisory and Closing On-Line Notification (BEACON) system.

Figure 4. Overview of Canadian beach advisories 2006 – 2010 within each lake basin swimming season. Green represents those beaches that were open 100% of the swimming season; blue represents those beaches that were open between 80-100% of the swimming season; yellow represents those beaches that were open 50-80% of the swimming season; and red represents those beaches that were open less than 50% of the swimming season. For

example, in 2010, in Lake Ontario, 19% of monitored beaches were open 100% of the swimming season, which is approximately 12 monitored beaches.
Source: Data collected from Ontario Health Units located along the Great Lakes (see Health Units listed in information source section), 2010.

Last Updated
State of the Great Lakes 2011



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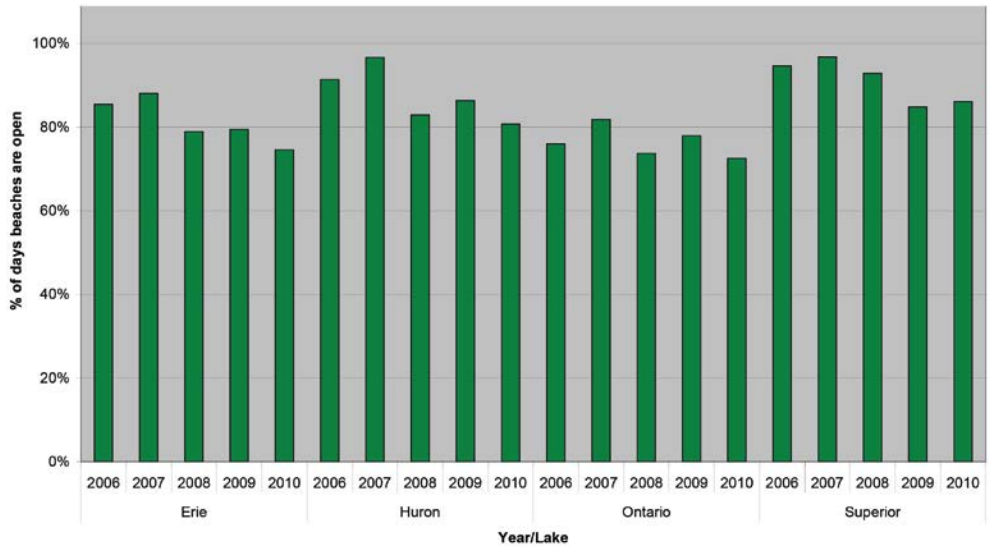

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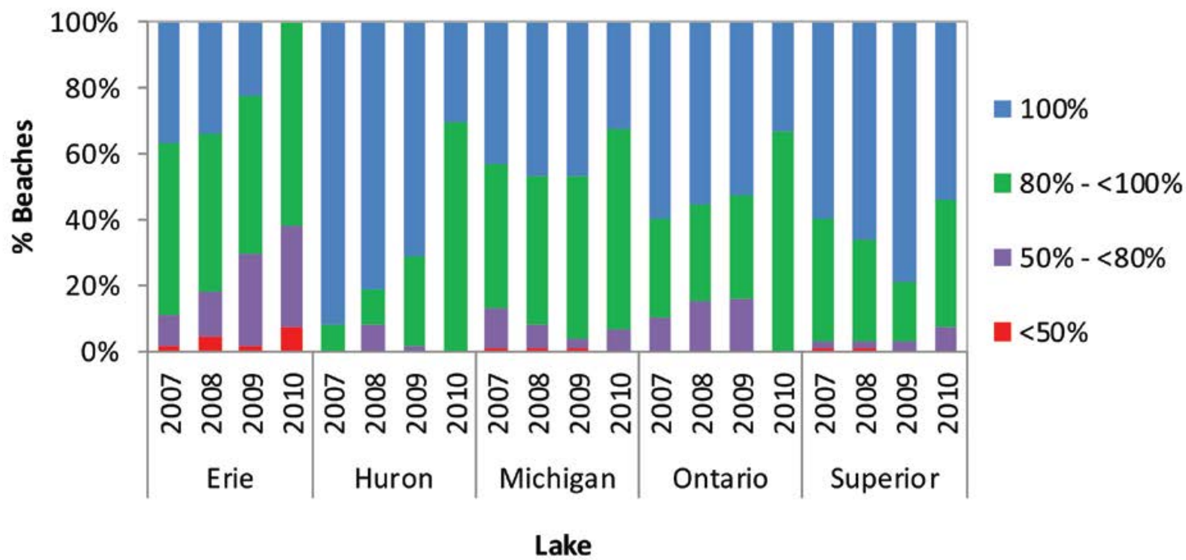

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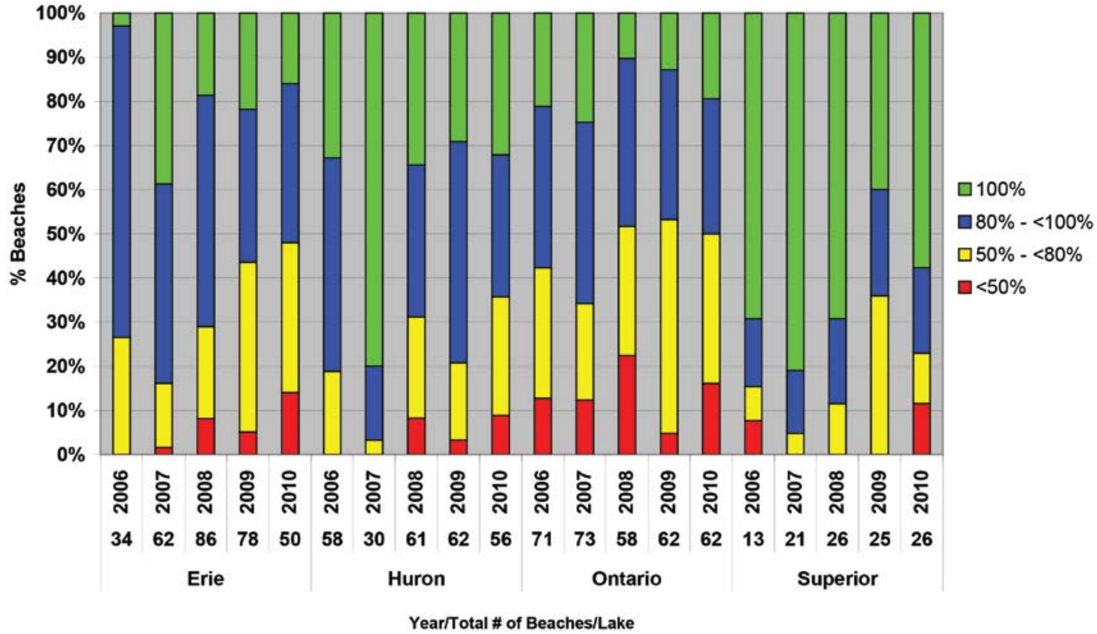

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Source: Data collected from Ontario Health Units located along the Great Lakes (see Health Units listed in information source section), 2010.

Benthos Diversity and Abundance

Overall Assessment
Status: Mixed
Trend: Unchanging to deteriorating
Rationale: Based on the benthic community, the trends in the trophic condition of the lakes are mixed in the period from 1998 through 2009. Some near shore sites are becoming more eutrophic while some off-shore, deep water sites more oligotrophic.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Unchanging
Rationale: All sites in Lake Superior were classified as oligotrophic based on the oligochaete community index since 1997.

Lake Michigan
Status: Good
Trend: Unchanging
Rationale: Most sites in Lake Michigan have a trophic index value below 0.6 indicating an oligotrophic condition. Since 2002 nearshore sites on the eastern side of the southern basin and in southern Green Bay have oscillated between meso- and eutrophic. Since 2006 only the nearshore site near the Kalamazoo River outlet and one Green Bay site were above 1.

Lake Huron
Status: Undetermined
Trend: Undetermined
Rationale: Most sites in Lake Huron have been below 0.6 over the past decade; since 2006 all but two sites would be considered oligotrophic. The site in Saginaw Bay oscillates between mesotrophic and eutrophic. The nearshore site located on the eastern shore near the outlet of Saugeen River in Ontario, Canada has been eutrophic since 2008 and has very high densities of oligochaetes, the highest densities of all of all sites sampled in Lake Huron.

Lake Erie
Status: Poor
Trend: Unchanging
Rationale: Most sites sampled over the past decade in Lake Erie were above 1.0 and would be classfied as eutrophic. Since 2000 sites in the eastern basin tended to be more eutrophic than the central or western basin sites; however, in 2008-2009 all sites in the western basin were classified as eutrophic. Sites in the central basin tended to be the lest eutrophic.

Lake Ontario
Status: Fair
Trend: Deteriorating
Rationale: All of the off-shore deep water sites in Lake Ontario would be classified as oligotrophic since 2003. Nearshore sites however have tended toward mesotrophic and eutrophic, and since 2003 western basin sites along the southern shore of Lake Ontario have become increasingly eutrophic.

Purpose

- The purpose of this analysis is to assess trends in the benthic community composition over time with respect to trophic status of the Great Lakes
- The Benthos and Diversity and Abundance indicator is used in the Great Lakes indicator suite as a State of indicator in the Aquatic-dependent Life top level reporting category.

Ecosystem Objective

With respect to the benthos of the Great Lakes, the ecosystem objective is that the composition of benthic community in the Great Lakes should remain relatively constant over time and space and be comparable to unimpaired waters with similar depth and substrate conditions. One estimate of benthic community status is based on Milbrink's Modified Envrionmental Index (1983) which uses oligochaete diversity, trophic classifications, and abundances to compute the trophic status of a body of water. Trophic classifications are based on individual species responses to organic enrichment. This indicator supports Annex 2 of the 1987 Great Lakes Water Quality Agreement.

<u>Calculation of Oligochaete Trophic Index (OTI)</u>

To evaluate trends in the benthic community of the Great Lakes, SOLEC uses an Oligochaete Trophic Index (OTI). The OTI was initially described by Mosley and Howmiller (1977) with subsequent modifications by Howmiller and Scott (1977), Milbrink (1983), and Lauritsen et al. (1985). The SOLEC indicator primarily follows Milbrink's formula; however since there are different interpretations of the formula we have defined our process below in an attempt to clarify the calculations going forward. Milbrink classifies Tubificids and Lumbriculids oligochaetes into four ecological classes relative to trophic status of the lake. The values range from 0 indicating intolerant of enrichment (oligotrophic conditions) to 3 indicating tolerant of enrichment (highly eutrophic conditions). The index is calculated as:

$$c * [(1/2\sum n_0 + \sum n_1 + 2\sum n_2 + 3\sum n_3) / (\sum n_0 + \sum n_1 + \sum n_2 + \sum n_3)]$$

where n_0, n_1, n_2, and n_3 indicate the abundances of organisms in each of the four trophic categories (Table 1) and c is a density coefficient that scales the index to absolute densities of Tubificids and Lumbriculids. The c coefficient is as follows (Milbrink 1983):

c=1 if n > 3,600
c=0.75 if 1,200 < n <3,600
c=0.5 if 400 < n < 1,200
c=0.25 if 130< n < 400
c=0 if n < 130

There are several parts of the OTI calculation that are open to interpretation so we have included a clarification of how we interpreted these points below:

- we only used lumbriculids and tubificids to calculate the index;
- all immature lumbriculids were classified as *Stylodrilus heringianus (*Styheri*);*
- the *c* coefficient was estimated from abundances (n) of mature and immature lumbriculids and tubificids;
- Milbrink (1983) assigned the tubificid *Tubifex tubifex* (Tubtubi) dual classifications depending on the dominance of Styheri or *Limnodrilus hoffmeisteri* (Limhoff). We formalized the dual classifications as follows: if the ratio of abundances of n_0 oligochaetes to n_3 oligochaetes (Limhoff) > 1 then Tubtubi is classified as a 3; if the ratio is < 1 then Tubtubi is classified as a 0; however, if the ratio is close to one (0.75 to 1.25) then Tubtubi is a 3 if $c \geq 0.5$ and a 0 if $c < 0.5$;

- if Limhoff density is zero and n_0 is relatively high and/or total density is low, then Tubtubi is 0, otherwise 3; and,
- if the total density of oligochaetes is zero, then the index is zero.

Trophic classifications were obtained from literature for the Great Lakes and are shown in Table 1.

Ecological Condition
Annex 2 of the 1987 Great Lakes Water Quality Agreement states that there should be no impairment of Great Lakes benthos. SOLEC uses the oligochaete based trophic condition index (Milbrink, 1983; a modification of Howmiller and Scott, 1977) to assess trophic status of each site. The trophic condition index is calculated based on known organic enrichment tolerances and abundances of oligochaete taxa (see attached summary of calculation procedure). The index ranges from 0 – 3: scores less than 0.6 (the lower line in Figure 1) indicate oligotrophic conditions; scores above 1 (the top line in Figure 1) indicate eutrophic conditions; and, scores between 0.6 and 1.0 suggest mesotrophic conditions. Scores approaching 3 indicate high densities of oligochaetes dominated by the pollution tolerant *Limnodrilus hoffmeisteri* and *Tubifex tubifex*.

During the study period of 1998 through 2009 we observed a consistent difference in trophic conditions between Lakes and a few trends within Lake basins. Averaged across the study period, Lake Erie was consistently and significantly more eutrophic than all the other Lakes followed in order of increasing oligotrophication by Lakes Ontario, Michigan, Huron and Superior. Lakes Huron and Superior had significantly lower average trophic index scores than the other three Lakes. Summarized by Lake, we observed no significant trends in trophic condition over the study period. Summarized by Lake basin, there were a few trends noted: increasing eutrophication in the eastern and central basins of Lake Erie, in the southern basin of Lake Michigan, and in the western basin of Lake Ontario. In Lakes Ontario and Michigan these trends are driven by increasing OTI scores for nearshore sites.

In Lake Erie, the most eutrophic conditions were found in the eastern basin, which tended to increase up until about 2003 and remain between 2.0 and 2.5 through 2009. There was a similar trend in the data for central basin although the OTI scores were less eutrophic. The western basin varied substantially but no trends were obvious.

Lake Huron sites were mostly classified as oligotrophic since 2007. In the period from 1998 through 2001, the southernmost site was classified as mesotrophic or eutrophic but has been consistently oligotrophic since 2002 (one minor exception in 2006). The Saginaw Bay site was extremely eutrophic from 1997 through 2001, improved to mesotrophic, but has trended towards eutrophic again starting in 2007. One site in the central basin, HU96B (44m) off Southampton, Ontario, near the outlet of the Saugeen River, was very eutrophic in 2004, 2008 and 2009 (Figure 1). At this site counts of dreissenids were about 50 /m^2 in 2004 and increased to 2,800/m^2 in 2008; counts of oligochaetes (mature and immature) increased from 450/m^2 in 2000, 1,700/m^2 in 2004, and 11,560/m^2 in 2009.

Most sites in Lake Michigan were classified as oligotrophic. The exceptions were the nearshore sites along the southern and central Michigan basins' eastern coast (near the Grand and Kalamazoo River outlets) and along the western coast near Green Bay. The sites in Green Bay have been consistently mesotrophic to mildly eutrophic.

Deepwater sites in Lake Ontario have been classified as oligotrophic throughout the study period. Average scores in the western basins showed a trend toward increasing eutrophication since 2001, primarily due to increasingly eutrophic nearshore sites along the southern shore.

Pressures
The oligochaete indicator used for SOLEC assesses trophic status of the Lakes and may suggest pressures due to organic enrichment. Some nearshore sites and sites near large river mouths do show increasing eutrophication

across all five Lakes. This suggests that pollution abatement mitigation in the upland watersheds could help to improve water quality and sediment conditions at these sites. Other pressures not accounted for in the oligochaete trophic index include invasive species, regional climate change, water level changes, toxic or other contaminats, and other unforeseen changes to the ecosystem. Recent changes due to invasive species, especially the invasive dreissenid mussles, pose severe threats to the ecosystem function. Incorporating indicators to track community composition changes due to new invasive species are needed to better track benthos changes as invasive species pressures change throughout the basin.

Management Challenges/Opportunities

The Milbrink Environmental Index is a good tool to assess changes in organic enrichment in sediments and detect changes in the trophic status of the benthic community. Some nearshore sites across the Lakes are becoming increasingly eutrophic. Some of these changes may be related to terrestrial inputs from large rivers. However, many of the recent changes in the benthic community have been due to invasive species, especially dreissenid mussels. Likely consequences have been the loss of the native amphipod *Diporeia* sp. from many sites in the lower Lakes and changes in the relative abundances of other species. For example, our analysis has shown a trend toward decreasing densities of sphaeriid clams in Lakes Michigan, Huron and Ontario which could be related to direct competition with dreissenid mussles. In addition, some researchers have found that oligochaeta densities may increase with presence of dreissenid mussels becaue the oligochaetes can feed off the dreissenid feces and pseudofeces (although others have found no changes or decreasing densities of oligochaetes; see Soster et al. 2011). Although our analyses did not detect signficant upward trends in the abundances of oligocheates over time, these changes may occur on a site-by-site basis. If dreissenid mussels resulted in an increase in the numbers of oligochaetes, this could result in an elevated MIlbrink's index indicating organic enrichment causes of commnunity change instead of impacts due to invasive species. Additional indices need to be developed that can track changes in the benthic community independent of changes due to trophic status and more accrurately assess trends in the benthic community.

Comments from the author(s)

Dreissenid populations are expected to have altered the ecology of all four lower Lakes and may be part of the cause of the suspected oligotrophication of Lake Huron and other changes such as algae blooms and *Cladophora* fouling of beaches. However, the Milbrink's trophic index did not detect Lake Huron oligotrophication using the benthic coummunity as indicator taxa. This suggests a need for develoment of additional indices that can better track changes in the benthic community composition with respect to other changes that are occuring in the Lakes. Additional environmental variables are needed to enable the development of additonal benthic community indicators that together with the Milbrink's index, will better assess the lake condition based on trends in the benthic community.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		x				
2. Data are traceable to original sources		x				
3. The source of the data is a known, reliable and respected generator of data		x				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				x		
5. Data obtained from sources within the U.S. are comparable to those from Canada						x

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				

Clarifying Notes: Number 4: missing near shore sites; Dreissenid data is missing from prior to 2007. Number 6: uncertain about 1997 data.

Acknowledgments

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List of Tables

Table 1. Trophic classifications for select mature lumbriculids and tubificids taken from Howmiller and Scott (1977), Milbrink (1983) with additions from Kreiger (1984), Lauritsen et al. (1985). If Milbrink classifications differed from Howmiller and Scott, Howmiller and Scott was used.

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Figure1. Scatterplot of the index values for Milbrink's (1983) Modified Environmental Index, applied to data from GLNPO's 1998 through 2009 summer surveys. Values ranging from 0 to less than 0.6 indicate oligotrophic conditions; values from 0.6 to 1.0 indicate mesotrophic coniditons; and values greater than 1.0 indicate eutrophic conidtions. Index values for taxa were taken from literature (Barbour et al. 1994, Howmiller and Scott 1997, Krieger 1984, Milbrink 1983). Data points represent the average of triplicate samples taken at each sampling site; immature specimens were included in the analysis for calculation of overall density used to establish the coefficent *c* but only mature specimens were used to calculate the number belonging to each ecological group of oligochaetes (see attached description of index calculation).
Figure 2. Map of the Great Lakes showing the trophic status at each sampling site calculated for 2009. Trophic status was based on the modified trophic index for oligochaete worms from Milbrink (1983). One site in the western basin of Lake Superior had no oligochaetes and two sites had only Enchytraeidae in the samples. Given that there were no oligochaetes and previous years had indices <0.2, these sites were shown as oligotrophic.
Figure 3. Maps of the Great Lakes showing differences in trophic status between 2000 and 2009 (3A) and between 2005 and 2009 (3B). Values represent the difference between mean index values calculated at each site in 2000, 2005, and 2009. The differences were then standardized by the mean and standard deviation for each lake. Increased oligotrophication or eutrophication indicates a rate of change greater than one standard deviation above or below the mean.

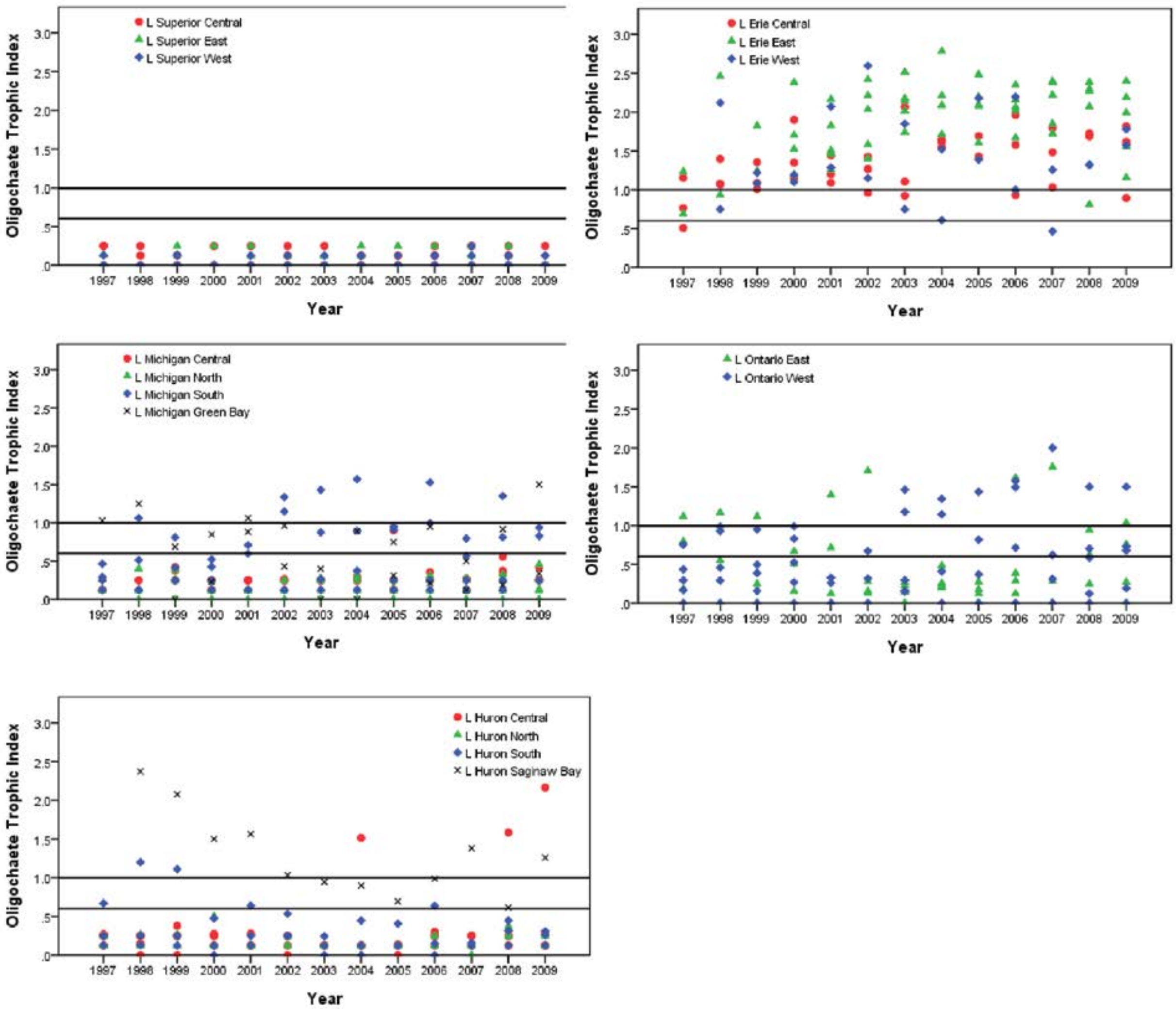
Last Updated

State of the Great Lakes 2011

Trophic classifications for select mature lumbriculids and tubificids

SPECCODE	GENUS	SPECIES	Trophic Class	Source	Comment
RHYCOCC	Rhyacodrillus	coccineus	0	Howmiller and Scott 1977	Same classification as Krieger 1984 & Lauritsen et al. 1985
TASAMER	Tasserkidrilus	americanus	0	Howmiller and Scott 1977	formerly *T. kessleri* in both Lauritsen et al. 1985 and Kreiger
LIMPROF	Limnodrilus	profundicola	0	Howmiller and Scott 1977	Same classification as Krieger 1984 & Lauritsen et al. 1985
RHYMONT	Rhyacodrilus	montana	0	Kreiger 1984	Same classification as Lauritsen et al. 1985
RHYSP	Rhyacodrilus	spp.	0	Kreiger 1984	Same classification as Lauritsen et al. 1985
SPINIKO	Spirosperma	nikolskyi	0	Kreiger 1984	Same classification as Lauritsen et al. 1985
STYHERI	Stylodrilus	heringianus	0	Howmiller and Scott 1977	General agreement from all sources for this taxon
TASSUPE	Tasserkidrilus	superiorensis	0	Kreiger 1984	Same classification as Lauritsan et al. 1985
AULAMER	Aulodrilus	americanus	1	Howmiller and Scott 1977	Classification based on Aulodrilus sp.
AULLIMN	Aulodrilus	limnobius	1	Milbrink 1983	
AULPIGU	Aulodrilus	pigueti	1	Milbrink 1983	
ILYTEMP	Ilyodrilus	templetoni	1	Kreiger 1984	Same classification as Milbrink 1983 & Lauritsen et al. 1985
ISOFREY	Isochaetides	freyi	1	Kreiger 1984	Same classification as Lauritsen et al. 1985
SPIFERO	Spirosperma	ferox	1	Howmiller and Scott 1977	Same classification as Krieger 1984 & Lauritsen et al. 1985
AULPLUR	Aulodrilus	pluriseta	2	Milbrink 1983	
LIMANGU	Limnodrilus	angustipenis	2	Howmiller and Scott 1977	
LIMCERV	Limnodrilus	cervix	2	Howmiller and Scott 1977	same as Milbrink 1983
LIMCECL	Limnodrilus	cervix/ claparedeianus	2	Howmiller and Scott 1977	same as Milbrink 1983
LIMCLAP	Limnodrilus	claparedeianus	2	Howmiller and Scott 1977	same as Milbrink 1983
LIMMAUM	Limnodrilus	maumeensis	2	Howmiller and Scott 1977	
LIMUDEK	Limnodrilus	udekemianus	2	Howmiller and Scott 1977	same as Milbrink 1983
POTBEDO	Potamothrix	bedoti	2	Milbrink 1983	
POTMOLD	Potamothrix	moldaviensis	2	Milbrink 1983	Same classification as Lauritsen et al. 1985
POTVEJD	Potamothrix	vejdovskyi	2	Milbrink 1983	Same classification as Lauritsen et al. 1985
QUIMULT	Quistadrilus	multisetosus	2	Howmiller and Scott 1977	
LIMHOFF	Limnodrilus	hoffmeisteri	3	Milbrink 1983	Differs from classification in Lauritsen et al. 1985
TUBTUBI	Tubifex	tubifex	0 or 3	Milbrink 1983	Depends on densities of LIMHOFF and STYHERI and total oligochaete density

Table 1. Trophic classifications for select mature lumbriculids and tubificids taken from Howmiller and Scott (1977), Milbrink (1983) with additions from Kreiger (1984), Lauritsen et al. (1985). If Milbrink classifications differed from Howmiller and Scott, Howmiller and Scott was used.



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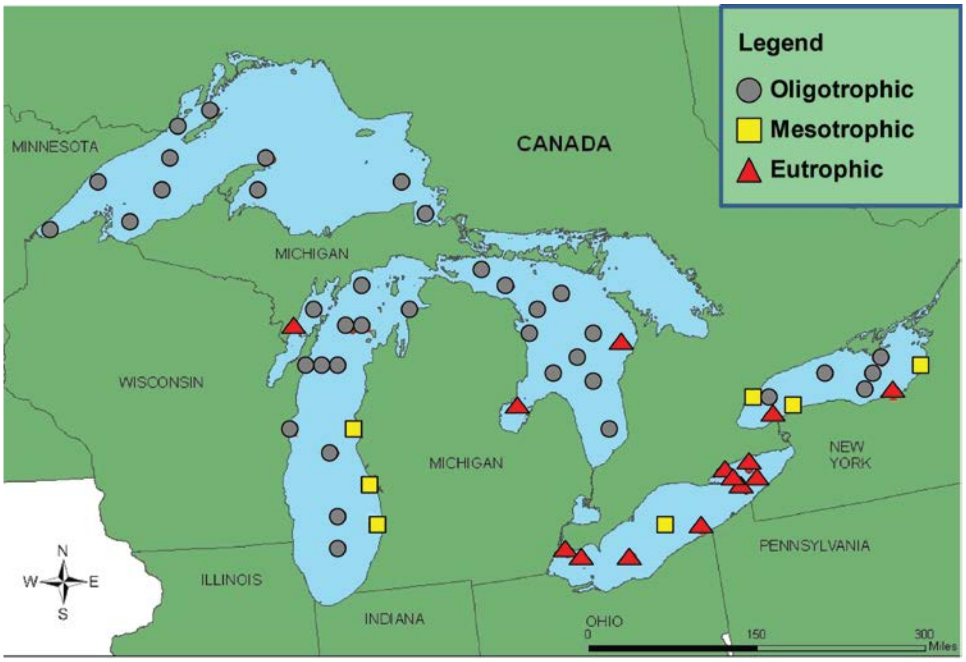

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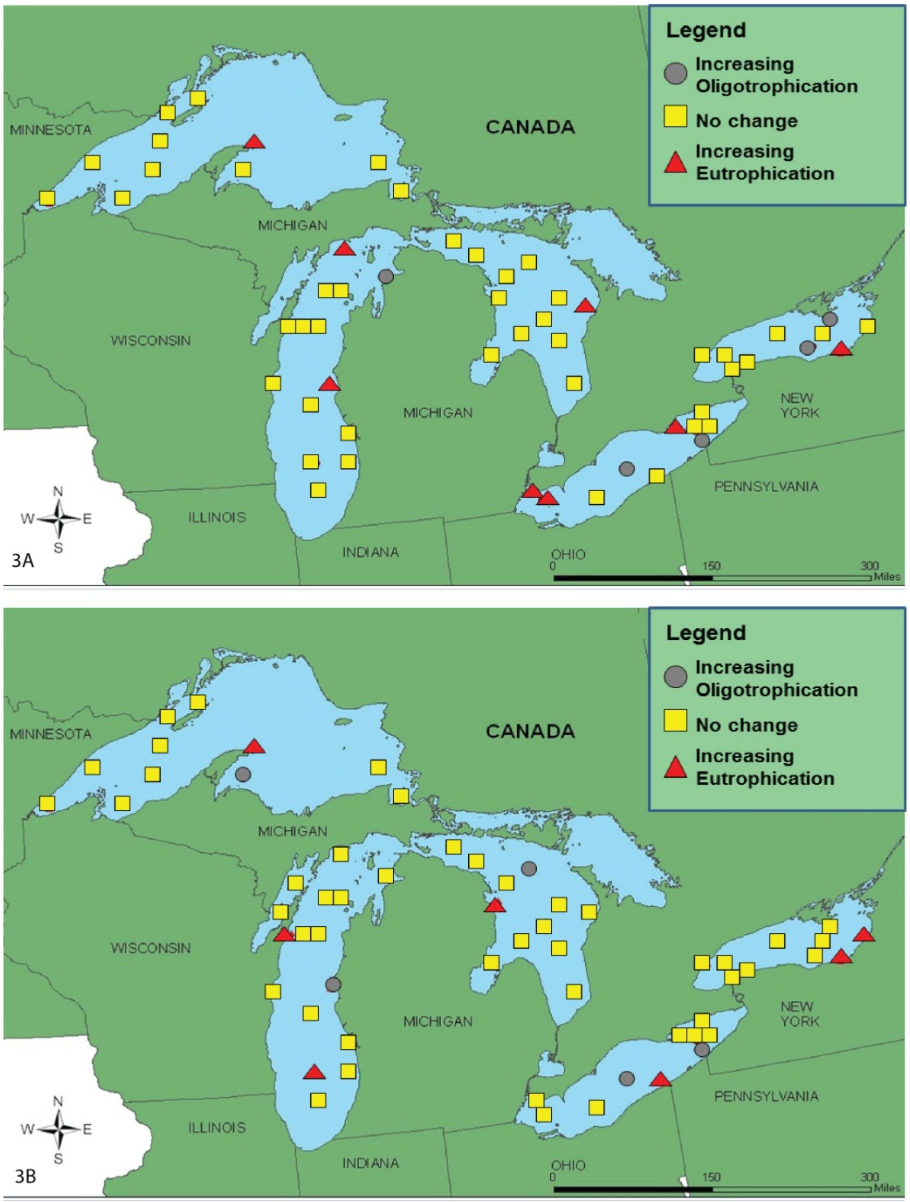

Figure 3. Maps of the Great Lakes showing differences in trophic status between 2000 and 2009 (3A) and between 2005 and 2009 (3B). Values represent the difference between mean index values calculated at each site in 2000, 2005, and 2009. The differences were then standardized by the mean and standard deviation for each lake. Increased oligotrophication or eutrophication indicates a rate of change greater than one standard deviation above or below the mean.

Botulism Outbreaks

Overall Assessment
Trend: Undetermined
Rationale: Avian mortality estimates vary greatly due to fluctuations in anthropogenic and environmental factors as well as inconsistencies in data collection and monitoring.

Lake-by-Lake Assessment
Lake Superior
Trend: No Change
Rationale: Avian mortality estimates due to *Clostridium botulinum* type E are infrequent and small in scale.

Lake Michigan
Trend: Undetermined
Rationale: Avian mortality estimates fluctuate substantially between years during which records were provided.

Lake Huron
Trend: Undetermined
Rationale: Avian mortality estimates were recorded for the United States in the 1960s and either no outbreaks or monitoring has occurred since that time. Canadian estimates exist as of 1998 but are skewed due to insufficient monitoring.

Lake Erie
Trend: Undetermined
Rationale: Avian mortality estimates are consistently in the thousands for the United States during 2000 to 2008, however, no recorded data exist before or after this time frame. Canadian estimates are considerably lower during these same years.

Lake Ontario
Trend: Undetermined
Rationale: Avian mortality estimates for recorded years show numbers in the hundreds and thousands for both the United States and Canada. Existing data are less than 10 years for both countries and monitoring discontinued in 2010 due to budgetary constraints.

Purpose
- To estimate the number of bird mortalities (by species) in the Great Lakes related to *Clostridium botulinum* type E (avian botulism)
- To infer the effects of invasive species and seasonality on incidence of botulism outbreaks
  The Botulism Outbreaks indicator is used in the Great Lakes indicators suite as an Impact indicator in the Fish & Wildlife top level reporting category.

Ecosystem Objective
The goal is to ultimately reduce or, if possible, eliminate the number of bird, fish and other species mortalities due to the toxin produced by active bacterium spores of *Clostridium botulinum* type E. The favorable conditions through which the toxin is released and has the potential to move through the food chain, may be the result of various environmental and anthropogenic factors. The Great Lakes Regional Collaboration recommends in the GLRC Strategy to Restore and Protect the Great Lakes that further “research [is needed] to clarify sources and transport of biotoxins (i.e., botulism) through the foodweb.”

This indicator supports the Great Lakes Water Quality Agreement objectives under Annex 1 addressing microbial agents that can affect human health, Annex 2 listing impairment of beneficial uses and Annex 17 delineating "research need to support the achievement of the goals of this Agreement" (GLWQA 1987). Lakewide Management Plan managers also consider outbreaks of Type E botulism to be a significant ongoing and emerging issue and recommend further research.

Ecological Condition

Background

The type E strain of *Clostridium botulinum* is one of seven different types of botulism bacteria. This strain in particular is responsible for vast mortalities of water birds in the Great Lakes region and in other parts of the United States, generally during the late summer through fall seasons.

Botulism is a neuromuscular disease that can affect a variety of species from invertebrates, amphibians and reptiles to fish and birds. Some species are more susceptible to contracting the toxin than others primarily due to their eating habits. For instance, a diving duck may ingest the botulism toxin through consumption of mussels that have strained the active toxin-producing bacteria from their environment (Fig 1). It is through the food chain that many water birds may then contract botulism, in turn acting as a highly visible indicator of the toxin's presence in the environment.

Birds that have ingested the toxin will often display outward signs of paralysis before dying, including an inability to fly, to utilize their neck muscles and hold the head erect (known as limberneck) and unresponsive inner eyelids. Generally the birds will drown before reaching shore, however, those that do reach land tend to die soon afterward of respiratory failure (Locke and Friend 1989). The severity of poisoning depends upon the amount of toxin ingested and the species of bird, however the incubation period is generally 12 hours and mortality can occur anytime within a three-day period (personal communication with Steven Riley 2011; Gross 1971).

Dormant spores of the botulism bacterium are naturally abundant in sediments, soils and even the intestinal tracts of live, healthy animals and are endemic to the Great Lakes region. Under certain conditions, namely an anoxic environment with suitable nutrients and favorable temperatures and pH, these dormant spores reach the vegetative or active growth stage and begin producing the botulism toxin (Brand et al. 1988). The spores are resistant to extreme temperatures and desiccations, and so are capable of remaining in the ecosystem for long periods of time (Domske 2003).

Status of type E botulism

Avian mortalities are currently our primary indicator for the presence of active toxin-producing type E botulism in the environment. Monitoring programs are generally run through state/federal agencies and universities or concerned citizens send in reports. Due to budgetary constraints both past and present as well as differences in data collection procedures and analysis, the number of avian mortalities estimated for each of the Great Lakes is not always representative of the far-ranging effects of the toxin in both Canada and the United States.

Total estimated avian mortalities for U.S. Great Lakes states were aggregated using data from the USGS National Wildlife Health Center's wildlife mortality database and from the State of Michigan's Department of Natural Resources. Represented are only the years during which data were collected and estimates provided. The data are limited in that they do not encompass all the mortality events that have occurred for both reported and non-reported years. However, despite the limitations in established reporting mechanisms the data illustrate that at least 116,265 avian mortalities have occurred on the United States side since the 1960s (Fig 2). It is important to note that not all of these birds were tested for botulism, however, a subset of birds from these locations tested positive for the toxin in those years.

Canadian data are also limited due to a lack of consistent reporting mechanisms. Estimates for avian mortalities attributed to type E botulism have only been monitored since 1998 and because of differences in data collection and analysis these numbers are likely not representative of actual mortality events in the lakes. The notable increase in estimated mortalities in 2004 is the result of further monitoring efforts by the Canadian Wildlife Service in Lake Ontario. Funding for this monitoring was again reduced in 2010 and we once again see a decline in the number of mortalities (Fig 3).

Lake Superior

While Lake Superior is not traditionally associated with type E botulism outbreaks and is not included in the lake-by-lake graphical assessment (Fig 4), there have been recorded instances according to records kept by Michigan Department of Natural Resources. In 1967, 39 gull and three common loon mortalities were reported. Similarly the subsequent year, 19 gulls, nine loons and one unknown species of duck succumbed to botulism intoxication. Then, no cases were reported until 1981 when 13 common loons found on the coast of southeast Lake Superior at Whitefish Point in Chippewa County tested positive for type E botulism (Cooley 2011). No other known cases of type E botulism events have been monitored or reported and all reports have been on the U.S. side of the Great Lakes. However, knowing that incidents have occurred in the past demonstrates a need for further understanding of the presence of the toxin in the Lakes.

Lake Michigan

Reports for type E botulism outbreaks date back as far as 1963 and 1964, with massive mortalities estimated at 7,725 and 12,650 water birds respectively. A variety of bird species were impacted, but most commonly found among the mortalities were loons, gulls, grebes and ducks. The number of water bird deaths was likely due to the major alewife population crash resulting in large numbers of alewives washing up on shore and decaying. Scientists confirmed their suspicions after examining deceased gulls and loons to determine that alewives were the dominant food item showing up in their gizzards (Fay 1966). Prior to these incidences, no known wild bird die-offs had occurred due to type E botulism in North America. In 1965 and 1966 water bird die-offs continued to occur, but no estimates were determined and are therefore not included in the graphical assessment (Fig 4). Botulism outbreak estimates were collected sporadically for the next three decades either when a large enough event occurred or reports were available. It was not until recently that botulism outbreaks have once again become particularly severe in Lake Michigan. In 2006, the number of deceased water birds increased with over 3,000 mortalities in the Sleeping Bear Dunes National Lakeshore area. The next year brought an even greater die-off with over 4,000 mortalities ranging from Ludington State Park north and including most of the Michigan beaches in the Upper Peninsula (Zuccarino-Crowe 2009). The most recent large-scale outbreak occurred in 2010 with an estimated 2,677 bird mortalities spanning the Upper Peninsula, Sleeping Bear Dunes National Lakeshore and other locations north along the Michigan shoreline (personal communication with Thomas Cooley 2011). Lake Michigan has the most extensive data record and to date accounts for an estimated 34,269 water bird mortalities.

Lake Huron

Documented cases of type E botulism outbreaks for Lake Huron began in 1965 with an estimated 400 deceased gulls in the Saginaw Bay area. Then again in 1967 with 579 gull kills at the mouth of Saginaw River, Saginaw Bay and north to Tawas Point and Oscoda (personal communication with Thomas Cooley 2011). According to data from the USGS National Wildlife Health Center, another estimated 1,300 water birds were killed in 1969 on the U.S. side of Lake Huron. No mortalities were reported again until 1998 presumably a combination of fewer occurrences, less notable outbreak events, and insufficient monitoring and reporting. At this time, the Canadian Cooperative Wildlife Health Center is the only known entity keeping track of avian mortalities from type E botulism in Lake Huron. As evident in the lake-by-lake graphical assessment, mortality numbers appear to be very low (Fig 5). The low mortality numbers are in part due to the available reporting mechanism. Only water birds that have tested positive for type E botulism and those that are of the same species found in the same location qualify as mortalities. It is likely that a greater number of mortalities are occurring, however, without additional monitoring we will not know for certain.

Lake Erie

As opposed to the previous three lakes, Lake Erie presents the opportunity to compare data from the United States and Canada. In 1999, both countries began tracking mortalities from botulism outbreaks presumably due to greater or more noticeable mortalities in the lake. The increase in mortalities could be attributed to environmental conditions such as water level changes, storm events and temperature fluctuations as well as anthropogenic factors like increases in nutrient loading to the lake. Since Lake Erie is more shallow than the other Great Lakes, fluctuations tend to have a greater impact and as a result it is possible that the conditions needed to foster germination of the botulism bacteria can more easily occur. At any rate since 2000, Lake Erie has continuously experienced annual mortalities in the thousands. One year in particular, 2002 had a record estimate of 21,000 mortalities in the eastern basin according to the USGS National Wildlife Health Center. Testing on a subset of carcasses was performed and botulism was confirmed. The deaths were thus presumed to be the result of type E botulism and comprised of thousands of gulls, common loons, grebes, cormorants and shorebirds. Fish kills were also in the thousands, mostly sheepshead and a few sturgeon (Robinson 2008). The opportunity for comparison is reflected in the lake-by-lake graphical assessments for the United States and Canada (Fig 4 and Fig 5). According to data from the USGS National Wildlife Health Center there have been over 62,000 estimated water bird mortalities from 1999 to 2008. Data provided by the Canadian Cooperative Wildlife Health Center for the same time frame shows an estimated 111 water bird mortalities. Reasons for the disparity could be due in part to data collection and reporting methods, available monitoring and reporting mechanisms or perhaps even environmental causes. Regardless the difference is significant and requires further study.

Lake Ontario

Annual reporting for Lake Ontario began in 2002 with the advent of a significant botulism outbreak killing an estimated 1,046 water birds. Since that time annual die-offs have been in the thousands. In 2006 and 2007, the number of die-offs escalated to an estimated 5,553 and 3,649 mortalities respectively (USGS-NWHC 2011). It is possible that environmental conditions were at play, for instance higher temperatures, due to the fact that increases in avian mortalities were seen during the same years for Lake Erie and Lake Michigan. The U.S. data for Lake Ontario was compiled by the USGS National Wildlife Health Center, however, the New York State Department of Environmental Conservation is the agency responsible for collecting, counting and conducting pathology on the birds. The U.S. data for Lake Erie was compiled by the New York Department of Environmental Conservation. In the past two years, budgetary constraints have impacted NY DEC's ability to continue monitoring botulism outbreaks, which is apparent in the data (personal communication with Helen Domske 2011).

Canadian data for Lake Ontario were provided by the Canadian Cooperative Wildlife Health Centre and the Canadian Wildlife Service. As previously mentioned, the number of recorded avian mortality estimates began in 2003, but the data show a drastic increase in 2004. This increase is due to additional data provided by Chip Weseloh looking at colonial water bird mortalities offshore on five islands in the eastern basin and one island in the central basin (Weseloh et al. 2011). Funding for this project continued through to 2009, at which point the data once again reflect a decrease likely due to a reduction in monitoring efforts (Fig 5). The addition of the data from this one monitoring project also influences the overall Canadian avian mortalities that we see attributed to type E botulism (Fig 3). Lake Ontario serves as a prime example of how additional monitoring efforts would provide researchers and decision makers with a better idea of which species and areas are most heavily impacted, as well as some insight into how anthropogenic factors may play into this process.

Linkages

As aforementioned many anthropogenic and environmental factors may contribute to the conditions suitable for *Clostridium botulinum* type E germination. Excess nutrient run-off, climate shifts and the impact of invasive species in the food chain and in fostering these conditions, have all been listed as probable factors leading to proliferation of botulism and the notable wide-spread mortalities in the Great Lakes.

The amount of dissolved oxygen in the water is key not only to the survival of oxygen-dependent species, but also because its absence satisfies one of the conditions needed to foster proliferation of the botulism pathogen. Temperature is inversely correlated with the amount of dissolved oxygen in the water, the higher the temperature the less dissolved oxygen. Similarly, the depth of the water can also affect concentrations of dissolved oxygen, although it may vary depending upon the processes of respiration, decomposition and photosynthesis (University of Maine 2006). The National Oceanic and Atmospheric Administration predicts climate change may potentially lead to decreases in lake-wide water levels and warmer water temperatures, meaning a greater likelihood of anoxic conditions leading to future botulism outbreaks in the Great Lakes (Quinn 1998).

The role of invasive species in this process only builds upon the impacts of climate change. *Cladophora glomerata*, for instance, is thought to be structurally rich in simple organics and may work with climate factors to produce an anoxic environment when decomposition occurs. Scientists have found that at Sleeping Bear Dunes National Lakeshore, incidences of avian die-offs due to type E botulism coincide with massive blooms of green algae, consisting mostly of *Cladophora*. Further research is needed to determine whether or not *Cladophora* may be providing the perfect substrate for germination and growth of *Clostridium botulinum*, and in turn providing a pathway into the food chain.

Zebra and quagga mussels are also thought to be a pathway for *Clostridium botulinum* type E into the food chain. Numerous species may rely on the mussels as a food source from fish and birds to reptiles and amphibians (Fig 1). Since the mussels are filter feeders and not known to be susceptible to the toxin produced by *Clostridium botulinum*, they may accumulate the toxin within their bodies and transfer it to other species. It is also believed that similar to *Cladophora*, the mussels themselves are organically rich and at times produce an anoxic substrate in which *Clostridium botulinum* may proliferate (personal communication with Thomas Cooley 2011; Getchell and Bowser 2006).

Management Challenges/Opportunities

Through the objectives of the Great Lakes Water Quality Agreement as well as the Great Lakes Regional Collaboration and the Lakewide Management Plans, the goal is to further understand the epidemiology of *Clostridium botulinum* type E to identify methods of reducing its impact on fish and wildlife populations and potential effects on human health.

Clearly identifying the factors that may produce an anoxic and nutrient rich environment that fosters proliferation of the pathogen is a necessary step in moving forward. It has been identified thus far that various anthropogenic and environmental factors may contribute to not only germination of the pathogen but its movement throughout the food web. Although it may likely be impossible to ever know the actual number of birds and other species dying, knowing more about species sensitivity, effects of seasonality and location of actual ingestion of the toxin may help us identify problem areas and target monitoring, research and on-the-ground efforts.

At this time we have no affordable real-time technology that would allow us to sample for the toxin on site and rely heavily on water birds either demonstrating symptoms of botulism poisoning or testing carcasses. Removal of carcasses early on is one of the few preventative measures that currently exist.

Of the monitoring efforts currently in place, data collection and analysis varies greatly for each country depending upon the organization involved. Consistency in these procedures may provide researchers and management with a clearer picture in regards to focusing future monitoring and research.

Comments from the author(s)

The number of avian mortalities will always be an estimate due to the nature of this indicator and the inability of researchers to record with accuracy all the species that succumb to the *Clostridium botulinum* toxin. It may instead be useful to develop consistent data collection methods that include susceptible species, geospatial data and correlate this information with the probable contributing factors listed in the linkages section.

Also, it may be possible to identify specific water bird species as strong indicators of the presence of the toxin. One challenge with figuring out target areas is that most water birds can fly for a short time after ingesting the toxin or may drown and wash up on shore elsewhere. Identifying species that remain in a particular location during the late summer and fall season may assist researchers further in pinpointing target areas. The Red-Necked Grebe may be a potential indicator species due to its loss of primary feathers at that time of year and thus inability to travel far from its food source. However, further research is necessary to determine the benefit of using this species or any other as an indicator (personal communication with Thomas Cooley 2011).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						X
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada				X		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report						X

Clarifying Notes: Budgetary constraints for monitoring have made it difficult to obtain sufficient scope of data, and many years have no reported estimates despite knowing that outbreak events did occur. Due to inconsistencies in data collection and analysis between organizations, the data is highly variable and not every case is documented. Although data is included for each of the Great Lakes, detailed geographic coverage is not always available and limited to areas that are actually monitored. Furthermore, not all birds reported as dead were tested for avian botulism, as such, many may have died from other causes.

Acknowledgments

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National Park Service
U.S Forest Service
Illinois Department of Natural Resources
Common Coast Research and Conservation, Michigan
New York State Department of Environmental Conservation
Presque Isle State Park, Pennsylvania
Pennsylvania Sea Grant
Wisconsin Department of Natural Resources

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List of Figures

Figure 1. Consumption of *Clostridium botulinum*. This figure is a simplified food web demonstrating the pathways through which *Clostridium botulinum* type E may transfer by way of ingestion.
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Figure 2. Overall United States avian mortalities attributed to type E botulism. This figure shows the aggregated avian mortality totals for all five Great Lakes on the U.S. side during years with recorded estimates.

Source: Mortality figures compiled through the coordination of USGS National Wildlife Health Center and the Michigan Department of Natural Resources. Estimated totals supplied via personal communication with Jennifer Chipault, August 2011 and Thomas Cooley, September 2011.

Figure 3. Overall Canadian avian mortalities associated with type E botulism. This figure shows the aggregated avian mortality totals for all four Great Lakes on the Canadian side during years with recorded estimates.

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Figure 4. United States water bird mortalities associated with confirmed cases of type E botulism. The four graphs on the left-hand side represent recorded data from 1963-1983. A gap in the data set exists between 1983 and 1999, during which time no data was recorded for any Lake. The four graphs to the right display data recorded between the years 1999-2010. If no data is available for a Lake it will read 'No Reported Data.' Any years with no recorded data are designated with black stars.

Note: This data was provided by several sources and may vary. A comprehensive historical dataset of suspected botulism mortalities is not maintained by one entity at this time.

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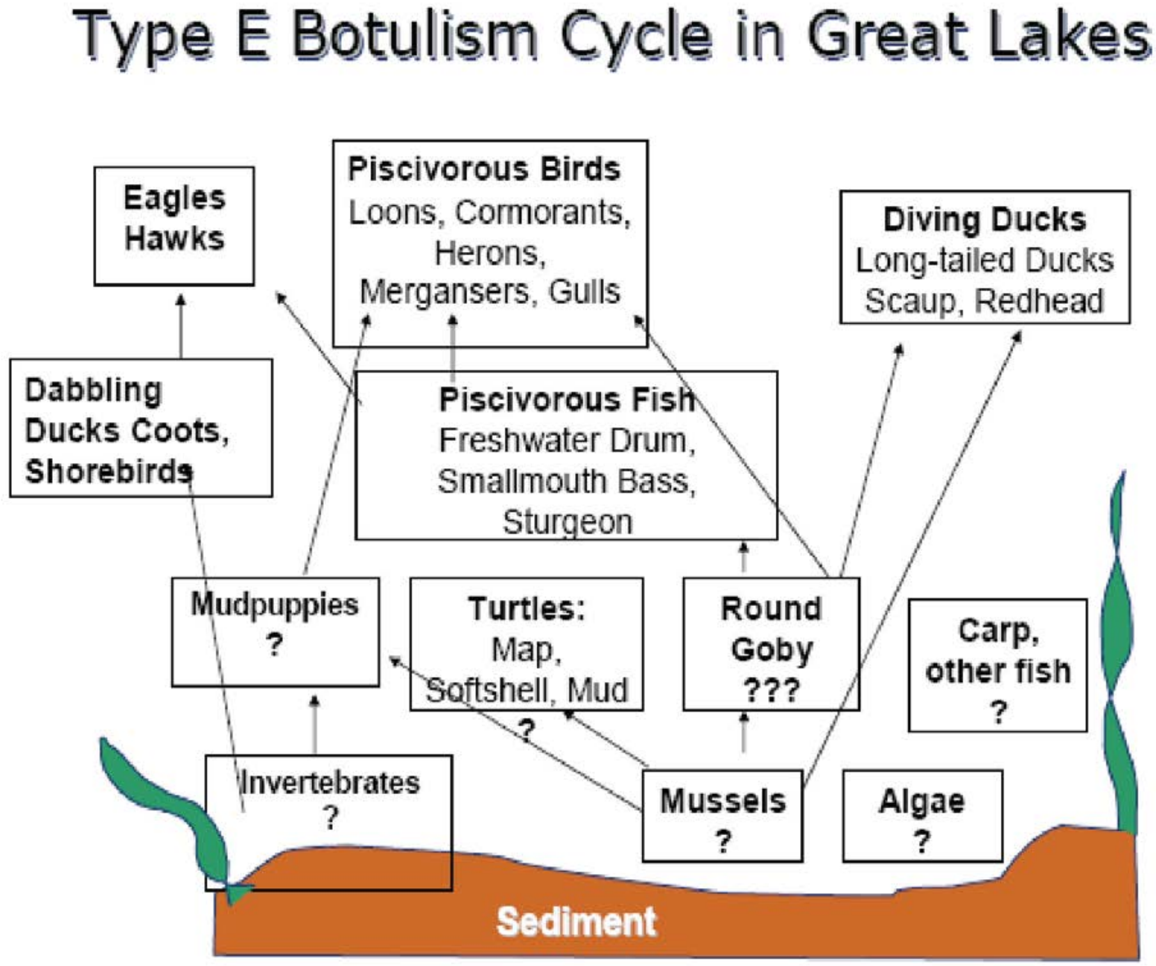
Last Updated

State of the Great Lakes 2011



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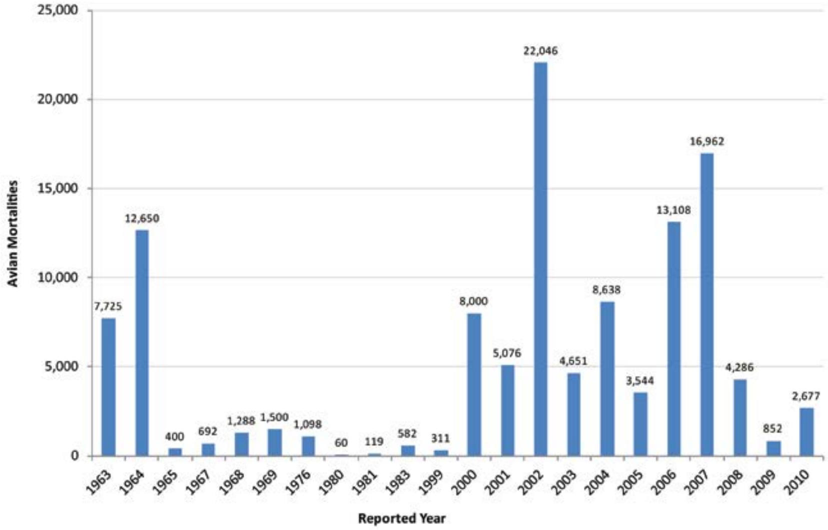

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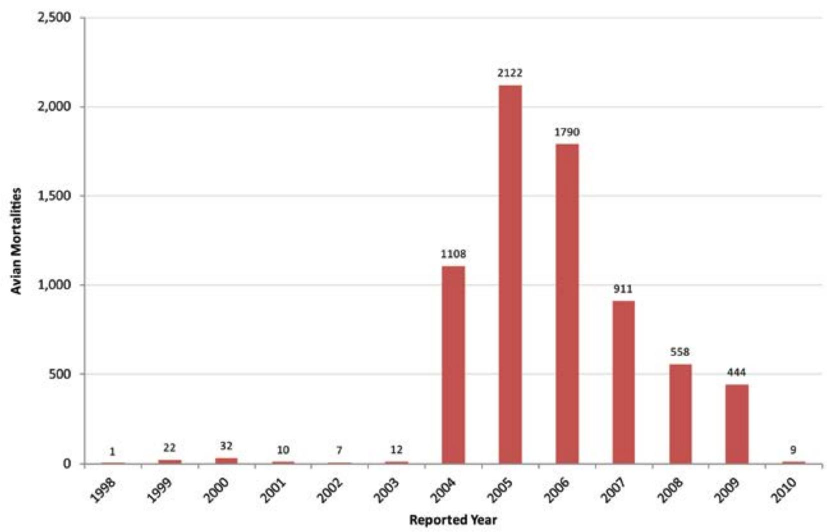

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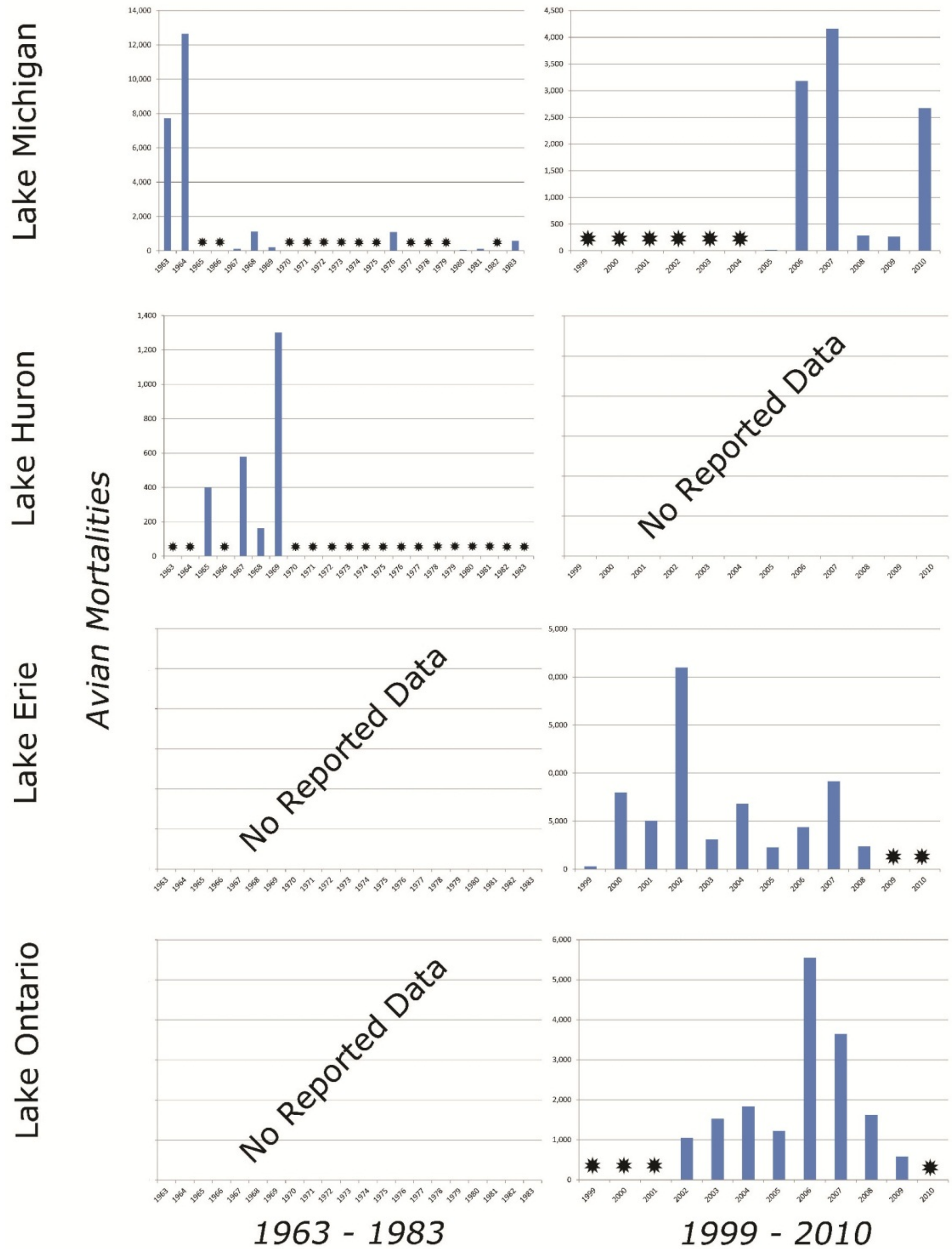

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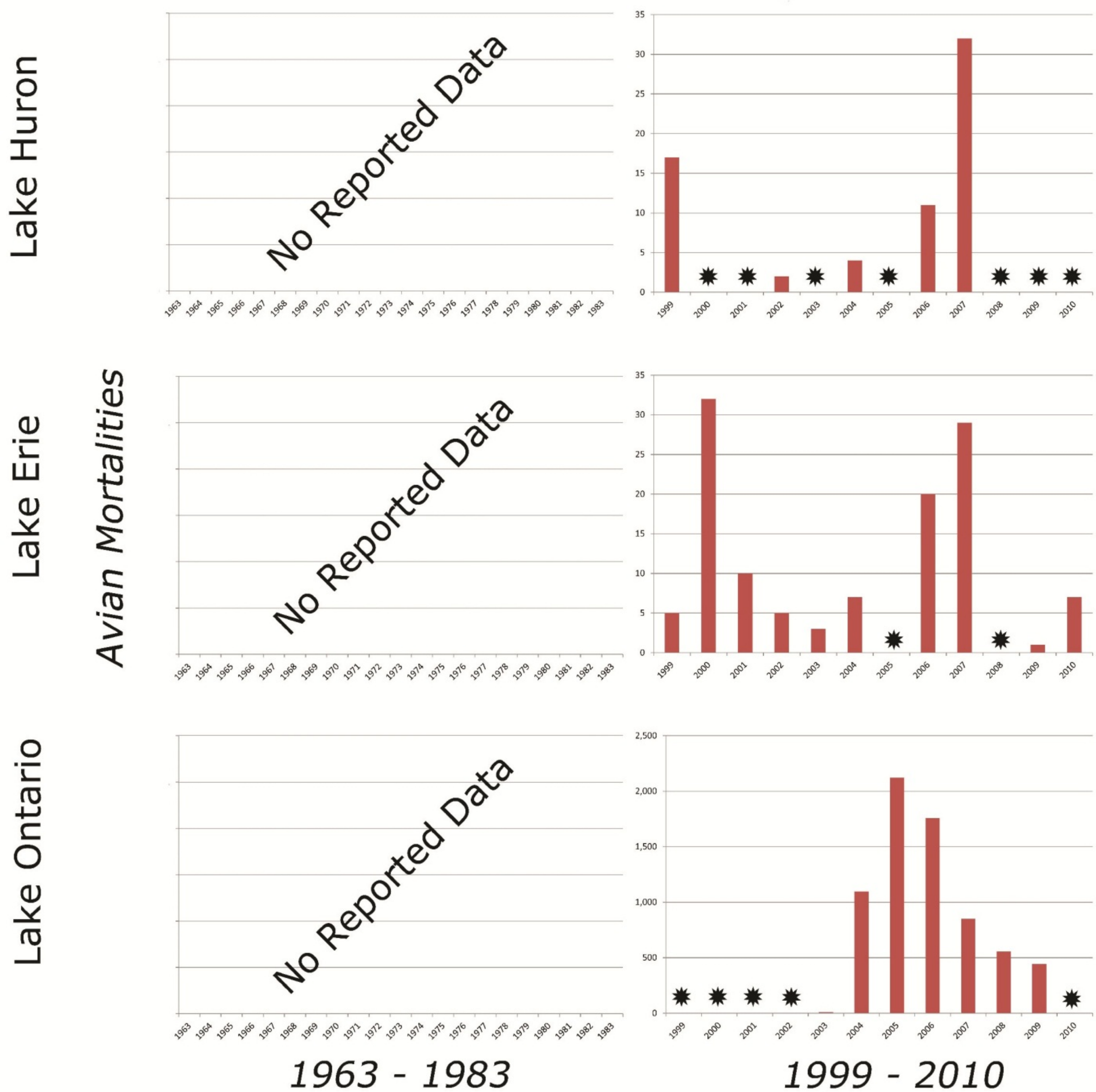

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Cladophora

Overall Assessment
Status: Fair
Trend: Undetermined
Rationale: *Cladophora* is widely distributed over hard surfaces (e.g. bedrock, boulders, piers, etc.) in the nearshore of all the Laurentian Great Lakes and reaches nuisance levels in lakes Ontario, Erie Michigan, and isolated locations in Lake Huron. Fouling of shoreline by beached algae, composed mostly of *Cladophora*, is now an annual feature across many beaches and harbors in these lakes. Quantitative monitoring information is limited in geographic coverage and sporadic in duration. There is inadequate information to track temporal trends in the distribution or abundance of *Cladophora* at this time with the exception of Lake Michigan.

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Unchanging
Rationale: Shore fouling by *Cladophora* has not historically been an issue in Lake Superior. There is no observational evidence that the occurrence of *Cladophora* has changed in recent years.

Lake Michigan
Status: Poor
Trend: Unchanging
Rationale: *Cladophora* is widely abundant in the nearshore over parts of the western shores of the lake covering a high proportion of the lakebed composed of hard surfaces. Reported biomass levels exceed the thresholds for shore fouling consistent with observations of shore fouling in multiple geographic areas. There have been surveys of the regional distribution of *Cladophora* and detailed area-specific studies of *Cladophora* productivity and ecology in recent years. Circumstantial evidence and simulation models suggest that growth rates and bloom formations increased following dreissenid mussel invasion. Monitoring of biomass levels annually since 2006 indicates that while peak biomass varies among years there is no trend.

Lake Huron
Status: Fair
Trend: Undetermined
Rationale: *Cladophora* grows near suspected points of nutrient input over the Canadian and U.S. shorelines of the main basin where adjacent shoreline may also be fouled. In the absence of point sources of nutrients, *Cladophora* growth and biomass accrual is minimal in the main basin. Recently *Cladophora* has been detected at low densities at depths where wave scouring is reduced. However, there is insufficient monitoring information to determine if this represents a recent change. Shore fouling by algae thought to be composed partially of *Cladophora* has been reported in areas of Saginaw Bay (see below).

Lake Erie
Status: Poor
Trend: Undetermined
Rationale: *Cladophora* is widely distributed in the shallow nearshore Lake Erie, notably the northern shoreline of the eastern basin where hard substrate is widely distributed. *Cladophora* biomass reached nuisance levels following dreissenid invasion, and shoreline fouling is widespread along the Canadian portion of

the eastern basin. Circumstantial evidence and simulation models indicate that biomass and shoreline fouling increased following dreissenid invasion.

Lake Ontario
Status: Poor
Trend: Undetermined
Rationale: *Cladophora* is widely distributed in the nearshore covering a high proportion of the lakebed composed of hard substrate. Reported biomass levels at multiple locations, particularly at sites influenced from point sources of nutrients, exceed threshold nuisance conditions. There have been surveys of the regional distribution of *Cladophora* and detailed area-specific studies of *Cladophora* ecology in recent years. There is insufficient information to determine if the distribution and abundance of *Cladophora* has changed in recent years.

Other Spatial Scales
Saginaw Bay
Status: Undetermined
Trend: Undetermined
Rationale: Periodic fouling of shoreline and beaches in Saginaw Bay by decaying plant material of mixed composition termed "muck" appears to be a long-standing feature of parts of Saginaw Bay which predates the arrival of dreissenid mussels (Craig Stow personal communications). *Cladophora* contributes to the varying mix of plants that includes macrophytes, *Chara*, other filamentous algae and diatoms (periphyton) that accumulates on the shoreline. The contribution of *Cladophora* to shore fouling is not well defined at this time.

Purpose
- To evaluate temporal and spatial trends in biomass and areal coverage of *Cladophora* in the Great Lakes.
- Data can be used to infer the availability of *Cladophora* to be transported to the lake shore where it may foul beaches and clog water intakes.
- The *Cladophora* indicator is used in the Great Lakes indicators suite as an indicator in the Human Impacts top level reporting category.

Ecosystem Objective
Cladophora should not be found at nuisance levels (criteria discussed below). Waters and beaches should be safe for recreational use and be free from nuisance algae which may negatively impact water intake infrastructure and beach use. This indicator supports Annexes 3 and 11 of the GLWQA.

Ecological Condition
Background
Prior to the mid-1980s, fouling of shorelines by rotting mats of the filamentous green algae *Cladophora* was common place in parts of the lower Great Lakes. Excessive *Cladophora* growth and bloom formation during this period were associated with phosphorus pollution. An apparent hiatus of *Cladophora* blooms and shore fouling from the mid 1980s until the mid 1990s has been interpreted, based on limited field monitoring and hind casting using field-calibrated growth models and historical water quality data, as a positive outcome of the reduction in phosphorus loading to the Great Lakes set in place by the Great Lakes Water Quality Agreement. Beginning in the mid-1990 there have been growing numbers of reports of shore fouling including areas that did not experience shore fouling in the past. Today *Cladophora* contributes to degradation of the aesthetic value of Great Lakes beaches and waterfronts and sporadically fouls water intakes of power plants. Researchers in Canada and the US have examined the present day occurrence of *Cladophora* in parts of lakes Ontario, Erie, Michigan and Huron and confirm the

overabundance of *Cladophora* and associated shore fouling dispersed over wide areas around the Great Lakes. Detailed accounts of *Cladophora* as a nuisance algae in the Great Lakes and the recent changes in environmental condition facilitating the proliferation of *Cladophora* today are given by Auer and Bootsma (2008), Auer et al. (2010), Bootsma et al. (2004) and Higgins et al. (2008).

The colonization of the Great Lakes by zebra and quagga mussels (dreissenid mussels) has had a strong effect on lake ecosystems including features which are influential to the growth of benthic algae such as increased bioavailability of nutrients, increased water clarity and increased distribution of hard surfaces (dreissenid shells) that *Cladophora* filaments can attach. Increased water clarity associated with particle-filtering activity of dreissenid mussels acts to reduce light limitation of algae growth with depth and increase the area of lakebed available to support growth of benthic algae. In short, the more light reaching the lakebed means more habitat available for growth. The positive effects of changed water clarity on *Cladophora* production have been documented for lakes Ontario, Erie and Michigan (Higgins et al. 1995; Malkin et al. 2008; Tomlinson et al. 2010).

Recent surveys across lakes Erie, Ontario, Michigan, and Huron indicate that *Cladophora* growth in these lakes are limited by phosphorus availability. A challenging and still evolving question concerns the role that dreissenid mussels play in facilitating the supply of phosphorus to support the growth of algae on the lakebed including *Cladophora.* Dreissenid mussels scavenge nutrients in particulate form from the water column through active filtration and subsequently release phosphorus in dissolved form and in particulate form as feces, or pseudofeces. It remains to be determined whether increased quantity and bioavailability of phosphorus associated with dreissenid waste products are a significant part of the nutrient budget of *Cladophora*, and under what conditions. From a management perspective, understanding the role of dreissenid mussels in the nutrition of *Cladophora* is critical because this knowledge is needed to predict how growth rates and bloom formations will react to changes in phosphorus loading at various geographic scales (e.g. local point sources, basin scale, regional scale). The potential management of *Cladophora* (lakewide and at locally enriched sites) is dependent on an accurate understanding of the relationship between external inputs of phosphorus and *Cladophora* productivity. While it is currently possible to predict *Cladophora* growth rates (and the potential for blooms) based on ambient phosphorus concentrations, it remains difficult to make such predictions based on external loads due to the uncertain role of the dreissenids in modifying exposure to phosphorus. What is clear is that the proliferation of *Cladophora* in Lake Ontario and Lake Michigan is not attributable to increased basin-scale nutrient concentrations. Open lake concentrations of phosphorus have been trending downward in both lakes over the period of the apparent resurgence in *Cladophora*. Paradoxically, the wide dispersal of high *Cladophora* biomass over the nearshore areas of lakes Erie, Ontario and Michigan indicates that at some base level the overabundance is supported by basin-scale nutrient levels. Such changes suggest that the bioavailability of Phosphorus has increased since dreissenid invasion. The absence of wide-spread *Cladophora* in the more phosphorus-poor lakes Huron and Superior is consistent with this hypothesis. Nutrient regimes in the nearshore can be highly variable with scope for local and/or regional nutrient inputs to affect productivity of *Cladophora* as has historically been the case in Lake Huron. Recent studies in Lake Ontario indicate that *Cladophora* biomass is higher in urbanized areas than over less developed shoreline (Higgins et al. pending).

Biomass and Areal Cover of *Cladophora* as Metrics of Occurrence

Field based assessment of the distribution and abundance of *Cladophora* is challenging due to the high spatial and temporal variability that characterize *Cladophora* growth, biomass accrual, and sloughing (e.g. detachment from lake bottom and physical transport to beaches or depositional zones). *Cladophora* biomass can be highly variable across relatively short timeframes (days to weeks), complicating the comparison of biomass (e.g. evaluating trends) over space (e.g. between lakes) or over longer time frames (between years). The effects of variable growth rate on standing biomass is further complicated by the ongoing and erratic sloughing of the attached algae by water movement which periodically transports algae to the shoreline with increasing frequency as water temperature rise over the summer. Such complications are well documented features of the ecology of *Cladophora* in the Great Lakes (see Journal of Great Lakes Research 1982 *Cladophora* special issue; Higgins et al. 2008).

Nonetheless, given appropriate consideration for seasonality, biomass, areal coverage, and nutrient content of filaments can be useful indicators of the status of *Cladophora* and water quality. First, sub-optimal timing of sampling will tend to underestimate biomass and areal coverage. None-the-less, where field measurements of biomass or cover indicate that nuisance conditions exist, they most likely do. Second, while estimates of biomass suffer from problems of accuracy and precision, it is generally possible to determine whether nuisance conditions are a lake-wide phenomenon or a response to localized conditions (e.g. point source nutrient loading). Such a distinction is critical for management, since the management response should occur at the appropriate spatial scale to effectively address the problem (i.e. lake wide or localized nutrient abatement strategies). The capacity of *Cladophora* to respond to localized areas of nutrient input at the shoreline, especially obvious in areas where *Cladophora* does not occur on a regional scale, complicates the reporting of occurrence data. Random placement of measurement sites over the nearshore can provide an area-wide appraisal of conditions; however, it may not detect problematic shoreline fouling that is focused at localized areas of *Cladophora* growth along the shoreline. Reliance on broader scale assessment of areal cover using remote or visual semi-qualitative methods may offer means to augment surveys. The depth distribution of *Cladophora* is variable among areas. Abundance with depth is influenced by onshore-offshore gradients in water clarity, nutrients, physical disturbance, substrate, temperature and possibly abundance of dreissenid mussels. Since the depth of maximal biomass is variable there is no one optimal depth of where sampling should occur. Typically, biomass is highest below the wave zone (> 0.5m depth) where scouring can reduce standing crop, and above the depth where light becomes growth limiting (variable among sites). In general it is optimal to survey several depths at each site. Available data for *Cladophora* biomass and coverage is reported in Figures 1 and 2. Where data was available for multiple depths, the finding for the depth of maximum development of *Cladophora* is reported.

Previous efforts have indicated that areal density (areal coverage x height of the *Cladophora* bed from the lake bottom) can be effectively used to provide reasonable estimates of biomass (Howell 1998, Higgins et al. 2005). Such an approach, combined with deployable camera systems, or hydroacoustics (Depew et al. 2009), may be a useful means to increase the spatial coverage of sampling activities. A three level status evaluation is suggested until a more robust approach is developed and tested: 1) Poor is the condition where there is high surface cover (>50%) of *Cladophora* over optimal habitat on a regional-scale and where multiple locations surveyed by random sampling designs reach biomass levels that exceed the nuisance threshold of 50 g/m^2 dry weight (see Canale and Auer 1982), 2) Fair is when neither of the criteria for poor are met but where there are multiple areas of localized growth of *Cladophora* on the lakebed which result in public complaints of fouling over limited portions of shoreline, and, 3) Good is when *Cladophora* is largely absent in quantities that result in shore fouling prompting public complaint. See figures 1 to 3 for a summary of *Cladophora* occurrence data.

The nutrient content of *Cladophora* filaments is a useful metric of the potential for nutrient abatement programs to be effective in controlling growth. While quantities of potentially limiting nutrients may be highly variable (spatially and temporally) in the overlying water column, or below analytical detection limits, values of these nutrients within *Cladophora* tissues represent their availability for growth. While concentrations of carbon, nitrogen and phosphorus in Cladophora biomass are sometimes measured, it is phosphorus that most often limits growth rates in the Great Lakes region and is the most informative (Higgins et al. 2008). Levels of phosphorus are typically expressed as a proportion of dry mass (Q_P). There has been a significant amount of research devoted to linking tissue concentrations of phosphorus to potential growth rates (e.g. Auer and Canale 1982, Painter and Jackson 1989). Generally, values of Q_P exceeding 1.6 mg P/g are considered saturated in P, values between 0.16 and 0.06 mg P/g are considered P limited, and values below 0.06 mg P/g are insufficient to sustain growth rates and are thus critically limiting. As with biomass, Q_P exhibits intra-site variability and care is required to account for the effects of seasonality and of non-nutrient related factors affecting Q_P (e.g. light level) when comparing Q_P among areas or years.

Availability of *Cladophora* Monitoring data

The 2008 Great Lakes/SOLEC report " *Cladophora* in the Great Lakes: Guidance for Water Quality Managers" critiques monitoring of *Cladophora* in the Great Lakes. Briefly, monitoring of the status of *Cladophora* in the Great Lakes after about 1985 was largely lacking until recently when the apparent resurgence was reported in Lake Ontario, Erie and Michigan. Monitoring is sporadic and proceeds largely independently in pockets often supported by area-specific research activities. The lack of any systematic, Great lakes-wide monitoring of *Cladophora* has been repeatedly cited as a shortcoming in understanding present day *Cladophora* shore fouling problems. Despite being a widespread problem in the lower Great Lakes, information on the occurrence of *Cladophora* is primarily associated with the work of a small number of research groups examining the environmental basis for the apparent resurgence following dreissenid invasion, and is generally geographically-focused in areas where algae fouling problems occur. There have been agency based monitoring surveys of *Cladophora* distribution over parts of Lakes Ontario, Erie, Michigan and Huron. Surveys of the distribution of *Cladophora* in Lake Ontario were included in the study design for the bi-national cooperative monitoring of the coastal zone in 2008 (Higgins et al. pending).

At present there is little information with which to assess year to year variability in the occurrence of *Cladophora* in areas of high abundance. It is not known whether the abundance of *Cladophora* is changing in any consistent manner with the exception of Lake Michigan where biomass has been monitored on a regular basis since 2006 by researchers at the University of Wisconsin-Milwaukee (Figure 4). Notable in this work is the attention to through time data collection to identify peak seasonal abundance allowing robust comparisons of *Cladophora* biomass among years. The wide variability in biomass among years in the absence of a temporal trend (Figure 4) suggests that monitoring of *Cladophora* to detect change will be demanding.

Development of a Great Lakes *Cladophora* Monitoring Strategy

Recent publications have made recommendations on how monitoring of *Cladophora* in the Great Lakes might be improved. Auer et al. (2010) recommended that biomass and nutrient status of *Cladophora* tissues are the most practical choice of metrics for characterizing nuisance *Cladophora* conditions over space and time. The assessment of *Cladophora* biomass and nutrient status at a limited number of sentinel sites around the Great Lakes would be a useful means to determine temporal trends (within and between years) and provide data for calibrating/validating *Cladophora* growth models. Sites within each lake should be geographically dispersed, include areas where growth is driven primarily by lake-wide nutrient concentrations and also sites where growth is driven by point sources (i.e. tributaries, sewage or industrial discharges, etc.). Methodologies for such monitoring programs are relatively simple and low-cost, but are labor intensive and sensitive to the timing of surveys (Higgins et al. 2005, 2008; Auer et al. 2010). While useful as sentinels, the ability of a monitoring program focused on a limited number of sites to capture the status of *Cladophora* at larger spatial scales (i.e. basin, lake, region) is limited.

New and emerging tools are potentially available to augment, and increase the efficacy of, survey techniques to assess the distribution and abundance of *Cladophora*. Recently, hydro-acoustic technologies have been used to map *Cladophora* distribution patterns across larger spatial scales (kilometers) than could be accomplished with snorkeling or diver based (meters) surveys (Depew et al. 2009). The use of remote sensing to determine large-scale distribution patterns of *Cladophora* is being evaluated by researchers at Michigan Technological University (Sayers et al. 2011) and elsewhere. Images in the visible light range collected by satellite are evaluated using algorithms which interpret the presence of algae on the shallow lakebed in terms of surface coverage and biomass concentration. Examples of remotely estimated distributions of *Cladophora* on the shores of Lake Michigan and Ontario are presented in Figure 5. Such an approach holds promise to assess distribution of *Cladophora* in the Great Lakes at lake-wide and regional scales.

Originally developed during the late 1970's (Auer et al. 1982), *Cladophora* growth models have recently been revised to address conditions post-dreissenid invasion (Higgins et al. 2005, 2006; Tomlinson et al. 2010). Such models are useful to assess management options at local, and to some degree, lake-wide scales. However, such models require intensive sampling efforts to provide model inputs (e.g. solar insolation, water clarity, temperature, soluble phosphorus) at sufficient spatial and temporal resolution for model simulations to be meaningful. Efforts are currently underway to link *Cladophora* growth models with three-dimensional lake-wide hydrodynamic-biological models that provide the necessary environmental input data required to estimate *Cladophora* growth at moderate spatial scales (e.g. 50m x 50m). If successfully calibrated and validated, such models will be highly useful tools to advise potential management approaches to controlling *Cladophora* blooms at local, lake-wide and regional scales.

Ideally, opportunities for the testing and evaluation of candidate techniques can be integrated with ongoing monitoring and research studies with the aim of working towards more in depth monitoring of *Cladophora* distribution in the future.

Linkages

The growth of *Cladophora* in an area is potentially affected by a range of factors both operating within the lake ecosystem and acting externally upon the lake. The linkages to other SOLEC indicators vary in directness. For example indicators for Nutrients in Lakes and Water Clarity under the Water Quality suite of indictors describe measures which relate to growth limiting factors for *Cladophora*. Whereas the indicators Dreissenid Mussels and Benthos Diversity and Abundances may be correlated with the occurrence levels of *Cladophora* and connected by indirect mechanisms that may or may not be understood. Similarly, indicators under the Landscape and Natural Processes as well as the Pollution and Nutrients Suite capture changes in the broader environment which may contribute to a changing nutrient regime in the lake (Inland Water Quality Index and Tributary Flashiness) or in-lake growing conditions (Water Levels and Surface Water Temperatures) that may be correlated with *Cladophora*.

Management Challenges/Opportunities

The fouling of shoreline by *Cladophora* and other forms of algae elicits public complaint and is perceived as a sign of deteriorating water quality. Limited information on the extent and temporal features of shore fouling, and the underlying causative factors (i.e. abundance of algae on the lakebed) have made it difficult to understand the scope of the problem in any robust sense. This indicator can work towards a better understanding of the extent of the problem assuming that more effort goes into monitoring of *Cladophora*. The reported interactions between dreissenid mussels and environmental conditions which may promote the growth of *Cladophora* means that greater incidence of shore fouling today then in the resent past does not necessarily mean that external nutrient pollution is changing. Education to help the public better understand shore fouling by *Cladophora* will need to be an ongoing. The indicator may have a role as part of a broader communication effort.

Comments from the author(s)

The ability to fit *Cladophora* biomass or cover data to end points predicting adverse levels of shore fouling is a desirable attribute of an environmental indicator for *Cladophora*. The often cited value of 50 gDW m^2 as a threshold for transition to nuisance conditions was developed prior to colonization by dreissenid mussels and should be re-examined under present day conditions considering that the depth distribution of *Cladophora* is generally deeper today and that the shoreline may accumulate algae from deeper depths then in the past. A metric describing incidence of shoreline fouling based on field observation or public complaints to responsible authorities, or beach postings should be considered as a complimentary element of a *Cladophora* indicator. Notwithstanding the significance of the occurrence of *Cladophora* on the lakebed as an indicator of ecosystem condition, the overabundance of *Cladophora* is considered a water quality problem primarily due to the fouling of shoreline and beaches by detached algae.

While *Cladophora* represents the bulk of the shore fouling algae at many locations, there are additional species of benthic green algae which can occur in areas affected by *Cladophora* shore fouling. Filamentous green algae of the family zgnemataceae (e.g. *Spirogyra*, *Zygnema* and *Mougeotia*) are often observed co-occurring with *Cladophora*. In parts of lakes Huron and Michigan, the filamentous green algae *Chara* also contributes to fouling of shoreline. A further contributor to the organic material dominated by *Cladophora* which washes up on the shoreline is a diverse assemblage of micro algae which grow amongst and upon *Cladophora* and are more generally termed periphyton. In some cases there may be a "muck-like" appearance to beached material which is likely due to the contribution of periphyton.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X	X			
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X	X			

Acknowledgments
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Mike Sayers, Michigan Tech Research Institute, Ann Arbor, Michigan, USA

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Figure 1. Maximum biomass levels reported for Great Lakes sites since 2005.
Source: *Lake Ontario* - Depew 2009; Higgins et al. 2012, Malkin et al. 2008; *Lake Erie* - Depew 2009, T. Howell unpublished data, ; *Lake Huron* - Depew 2009, T. Howell unpublished data; *Lake Michigan* - H. Bootsma unpublished data, Garrison et al. 2008, Tomlinson et al. 2010.

Figure 2. Maximum percent cover levels reported for Great Lakes sites since 2005.
Source: *Lake Ontario* - T. Howell unpublished data, C. Pennuto unpublished; *Lake Erie* - T. Howell unpublished data; *Lake Huron* - T. Howell unpublished data.

Figure 3. Locations where there have been reports of nuisance *Cladophora* since 1995. Nuisance defined broadly as including: causing fouling of shoreline and beaches, fouling of water intakes and areas reported with conspicuous presence of *Cladophora*.
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Figure 4. Seasonal biomass of *Cladophora* from 2006 to 2011 in the nearshore of Lake Michigan at a site near Milwaukee.
Source: Graph provided courtesy of Harvey Bootsma, Great Lakes Water Institute, University of Wisconsin-Milwaukee.

Figure 5. Examples of Areal distribution of *Cladophora* determined by remote sensing.
Source: Images courtesy of by M. Sayers, Michigan Tech Research Institute.

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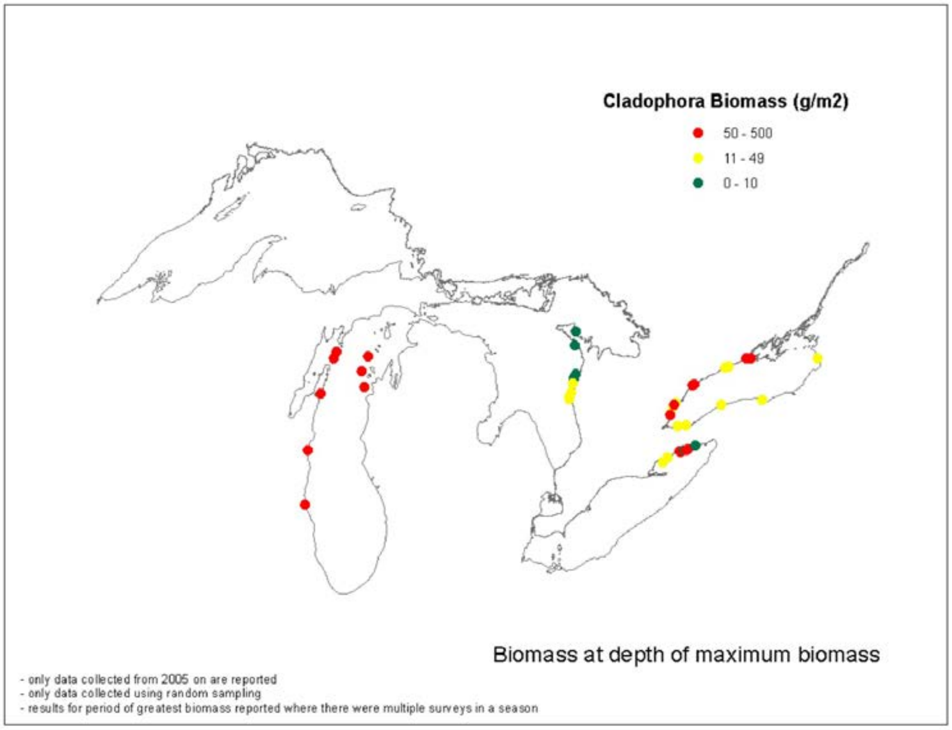

Figure 1. Maximum biomass levels of Macro Algae (*Cladophora*) on the lakebed reported for Great Lakes sites since 2005.
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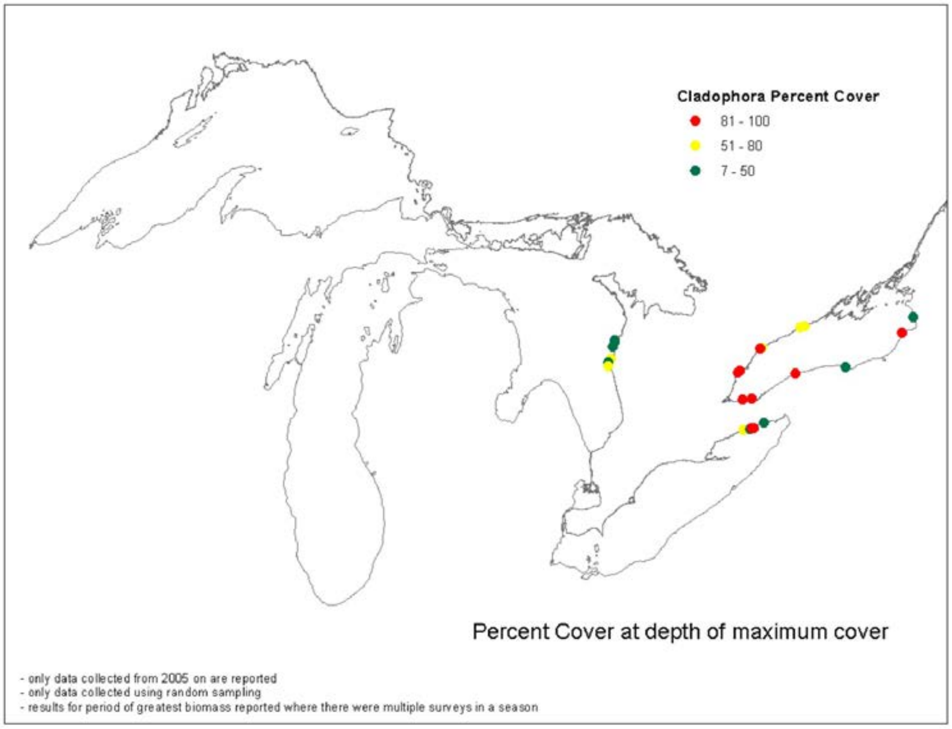
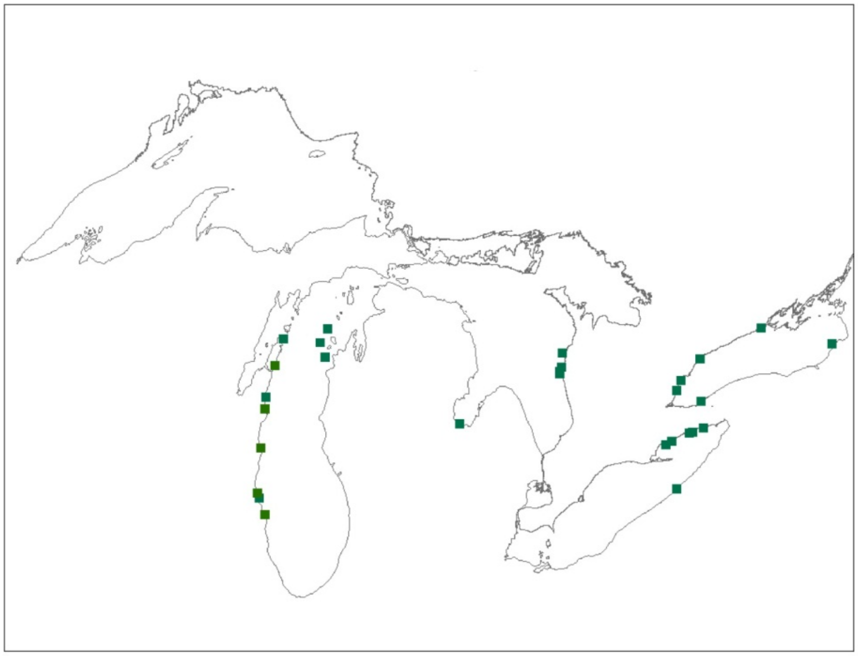


Figure 2. Maximum percent surface cover levels by Macro Algae (*Cladophora)* reported for Great Lakes sites since 2005.

Source: *Lake Ontario* - T. Howell unpublished data, C. Pennuto unpublished; *Lake Erie* - T. Howell unpublished data; *Lake Huron* - T. Howell unpublished data.



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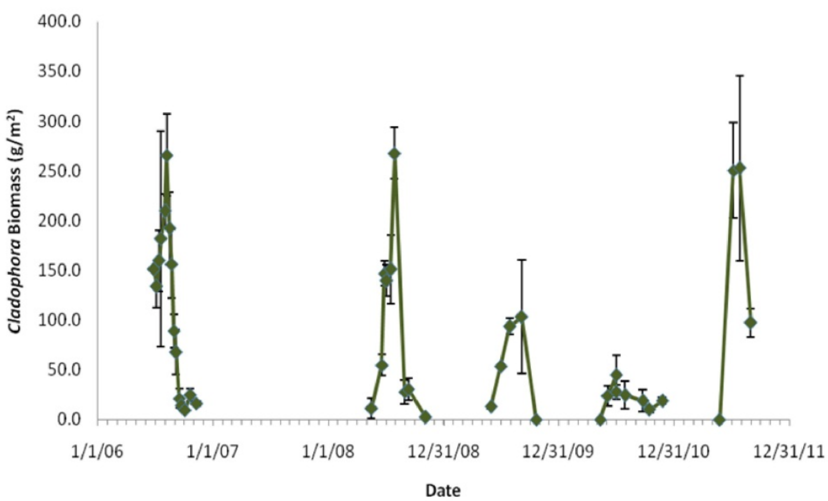

Figure 4. Seasonal biomass of *Cladophora* from 2006 to 2011 in the nearshore of Lake Michigan (~5 km north of Milwaukee, depth = 9 m).
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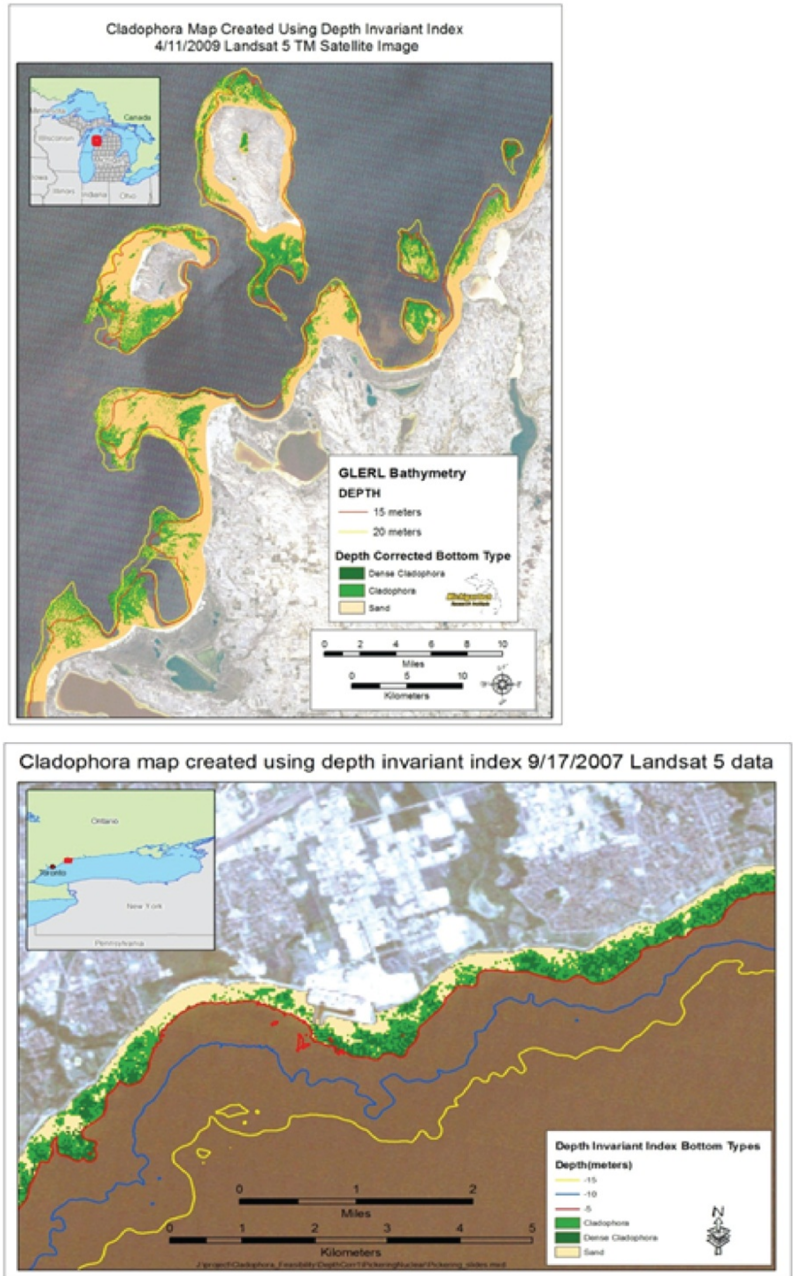

Figure 5. Distribution of *Cladophora* in NE Lake Michigan and NW Lake Ontario determined by remote sensing. Source: Images courtesy of by M. Sayers, Michigan Tech Research Institute.

Coastal Wetland Amphibians

Overall Assessment
Status: Poor
Trend: Unchanging
Rationale: The occurrence of over half the species was stable between 1995 and 2010 (5 of 8 [63%]), whereas the occurrence of two species significantly increased (25%) and one significantly decreased (12%). The occurrence of each species is below its endpoint.

Lake-by-Lake Assessment
Lake Superior
Status: Undetermined
Trend: Undetermined

Lake Michigan
Status: Poor
Trend: Unchanging
Rationale: The occurrence of about half of the species significantly decreased between 1995 and 2010 (3 of 7 [43%]), whereas the occurrence of one species significantly increased (14%) and three were stable (43%). The occurrence of each species is below its endpoint.

Lake Huron
Status: Poor
Trend: Unchanging
Rationale: The occurrence of about half of the species significantly decreased between 1995 and 2010 (3 of 7 [43%]), whereas the occurrence of one species significantly increased (14%) and three were stable (43%). The occurrence of each species is below its endpoint.

Lake Erie
Status: Poor
Trend: Unchanging
Rationale: The occurrence of over half of the species was stable between 1995 and 2010 (4 of 7 [57%]), whereas the occurrence of one species significantly increased (14%) and two significantly decreased (29%). The occurrence of each species is below its endpoint.

Lake Ontario
Status: Poor
Trend: Unchanging
Rationale: The occurrence of about half of the species significantly increased between 1995 and 2010 (3 of 7 [43%]), whereas the occurrence of one species significantly decreased (14%) and three were stable (43%). The occurrence of each species is below its endpoint.

Purpose
- To assess changes in the relative occurrence of wetland-breeding anuran species (i.e., belonging to an order of amphibians comprised of frogs, toads, and tree frogs that lay their eggs in wetlands)
- To infer condition of wetland habitat as it relates to factors that influence this ecologically and culturally important resource
- The Coastal Wetland Amphibian indicator is used in the Great Lakes indicators suite as a State indicator in the Aquatic Dependent Life top level reporting category.

Ecosystem Objective

To restore and maintain self-sustaining populations of Great Lakes wetland-breeding anuran species across their historic ranges. Numerous wetlands in the Great Lakes basin are threatened by urban and agricultural development and other incompatible land uses and these wetlands should be identified, preserved, and where necessary rehabilitated (GLWQA Annex 13). Monitoring and assessment activities provide information on the location, severity, aerial or volume extent, and frequency of Great Lakes wetlands (Annex 11 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

Ecological Condition

Measure

Changes in relative occurrence of wetland-breeding amphibians are based on data from nighttime surveys using Bird Studies Canada's Great Lakes Marsh Monitoring Program (MMP) anuran point count protocol or a modification of it (Marsh Monitoring Program 2009). MMP data from coastal and inland wetlands throughout the Great Lakes basin or throughout each individual lake basin (e.g., Lake Erie; Fig. 1) are used to calculate annual indices of relative occurrence for a suite of wetland anuran species. Wetlands dominated by non-woody emergent plants such as cattails (*Typha* spp.) and sedges (e.g., *Carex* spp.) are targeted by the program. Species-specific population trends over time are calculated using repeated measures logistic regression in a Bayesian mode of inference with uninformative priors (Kéry 2010).

Endpoint

Populations of most wetland-breeding anuran species have declined or remained stable since data collection began for this indicator in 1995. Therefore, one endpoint is population indices for nearly all wetland-breeding anuran species that are as high as or higher than population indices reported by the MMP in the late 1990s, when the program began. A potentially better endpoint, however, might be based on MMP occurrence indices from pristine or near-pristine wetlands throughout the Great Lakes basin (i.e., least disturbed based on indices of anthropogenic disturbance within and surrounding the wetland) —guided by a literature search of other current and historical data and expert opinion. Population indices from this approach are likely to be higher than those reported by the MMP in the late 1990s, given that many wetlands throughout the Great Lakes basin were degraded by that time (e.g., Hecnar and M'Closkey 1996, 1998). Presumably the two approaches estimate the extremes of a range of occurrence that is likely to contain the carrying capacity that the landscape is currently capable of supporting and, therefore, somewhere near the middle of the range is the most suitable endpoint. This is the endpoint used in this report.

Background

Wetland-breeding amphibians are influenced by the physical, chemical, and biological components of the wetlands and surrounding landscapes in which they breed. The abundance and/or reproductive success of multiple species in the Great Lakes basin, for example, declines as (1) wetland size decreases; (2) wetland habitat and natural cover in the surrounding landscape decreases; and (3) pesticide, herbicide, and runoff from other sources of pollution into wetlands from the surrounding landscape increases (Hecnar 1995; Hecnar and M'Closkey 1996; Bishop et al. 1999; Crosbie and Chow Fraser 1999; Kolozsvary and Swihart 1999; Houlahan and Findlay 2003; Price et al. 2004; Brazner et al. 2007a,b; Gagné and Fahrig 2007; Eigenbrod et al. 2008b). Thus, the abundance of wetland-breeding amphibians is a valuable indicator of the health of wetlands and the surrounding landscape.

Status of Wetland Amphibians

A grand total of 13 anuran species were recorded across all surveys and years throughout the Great Lakes basin between 1995 and 2010. Of these, the data for eight species were suitable for analysis at the scale of the Great Lakes basin, whereas the data for seven species were suitable in each individual Great Lakes basin (Table 1). Data were suitable if the species occurred at >15 routes per year on average.

Great Lakes Basin

The occurrence of over half of the species was stable between 1995 and 2010 (5 of 8 [63%]), whereas the occurrence of Green Frog (*Rana clamitans* ; see Table 1 for a list of scientific names for all subsequent common names) and Spring Peeper significantly increased and Chorus Frog significantly decreased (Fig. 2). Species that significantly increased made up 25% of the species analyzed and species that significantly decreased made up 12%. Pollution from agricultural and urban areas is often identified as one of the leading causes of anuran declines in the Great Lakes basin (e.g., Bishop et al. 1999). The relative resistance of Green Frogs to nitrates from fertilizer runoff may partly explain the increase in this species; nitrate resistance in Spring Peepers is unknown (Hecnar 1995, Rouse et al. 1999). By contrast, Chorus Frogs are more sensitive to nitrates, which may partly explain the decrease in this species (Hecnar 1995). The resistance of different anuran species to pollution, however, is complicated by variability in resistance among populations within species and by interactions with other factors such as habitat loss, which makes relationships difficult to identify. Spring Peeper is reportedly the most sensitive anuran to human disturbance in the Great Lakes basin, so its significant increase between 1995 and 2010 may be a positive sign, although it currently remains below its endpoint (Brazner et al. 2007a, Price et al. 2007). The status of the indicator is similar in previous reports, whereas the deteriorating trend in the previous report is now unchanging. The apparent improvement in the trend may be short-lived because there is high year-to-year variation in populations of most anuran species in the Great Lakes basin. Given that the occurrence of each species is below its endpoint and the occurrence of most species was stable between 1995 and 2010, the overall status is poor and the trend is unchanging.

Lake Michigan

The occurrence of about half of the species significantly decreased between 1995 and 2010 (3 of 7 [43%]), whereas the occurrence of one species significantly increased (14%) and three where stable (43%). The occurrence of each species is below its endpoint. The status of the indicator is similar in previous reports, whereas the deteriorating trend in the previous report is now unchanging. The apparent improvement in the trend may be short-lived because there is high year-to-year variation in populations of most anuran species in the Lake Michigan basin. Given that the occurrence of each species is below its endpoint and the occurrence of about half of the species was stable between 1995 and 2010, the overall status is poor and the trend is unchanging (Table 1).

Lake Huron

The occurrence of about half of the species significantly decreased between 1995 and 2010 (3 of 7 [43%]), whereas the occurrence of one species significantly increased (14%) and three where stable (43%). The occurrence of each species is below its endpoint. The status of the indicator is similar in previous reports, whereas the deteriorating trend in the previous report is now unchanging. The apparent improvement in the trend may be short-lived because there is high year-to-year variation in populations of most anuran species in the Lake Huron basin. Given that the occurrence of each species is below its endpoint and the occurrence of about half of the species was stable between 1995 and 2010, the overall status is poor and the trend is unchanging (Table 1).

Lake Erie

The occurrence of over half of the species was stable between 1995 and 2010 (4 of 7 [57%]), whereas the occurrence of one species significantly increased (14%) and two significantly decreased (29%). The occurrence of each species is below its endpoint. The status of the indicator is similar in previous reports, whereas the deteriorating trend in the previous report is now unchanging. The apparent improvement in the trend may be short-lived because there is high year-to-year variation in populations of most anuran species in the Lake Huron basin. Given that the occurrence of each species is below its endpoint and the occurrence of over half of the species was stable between 1995 and 2010, the overall status is poor and the trend is unchanging (Table 1).

Lake Ontario

The occurrence of about half the species significantly increased between 1995 and 2010 (3 of 7 [43%]), whereas the occurrence of one species significantly decreased (14%) and three where stable (43%). The occurrence of each species is below its endpoint. The status and trend of the indicator is similar in previous reports. Given that the occurrence of each species is below its endpoint and the occurrence of about half of the species decreased between 1995 and 2010, the overall status is poor and the trend is unchanging (Table 1).

Linkages

Wetland-breeding amphibians are influenced by numerous characteristics of the wetlands and surrounding landscapes in which they breed, many of which are monitored as SOLEC indicators. The wetland anuran indicator can be expected to co-vary with indicators that track wetland breeding anuran habitat (e.g., #4863: Coastal Wetland Plant Community; #4863: Land Cover Adjacent to Coastal Wetlands) and prey (#4501 Coastal Wetland Invertebrate Community Health) and factors that indirectly influence them, such as pollution runoff from surrounding uplands (#7100 Natural Groundwater Quality and Human-induced Changes), which reduces anuran prey abundance (Camargo et al. 2005) and which also directly lowers survivorship of anuran eggs and/or adults. Wetland amphibians also can be expected to co-vary with road density (#7200 Land Cover/Land Conversion) and vehicle use (#7064 Vehicle Use), given dispersing individuals are extremely vulnerable to vehicle collisions (Eigenbrod et al. 2008a), and amount of wetland buffering via natural vegetation (#7028 Sustainable Agriculture Practices), given pollution in runoff is trapped by such buffers (Rouse et al. 1999).

Management Challenges/Opportunities

Maintain or improve the quality of wetlands and adjacent uplands for breeding wetland amphibians by mitigating or eliminating influences that are detrimental to wetland health such as water level fluctuations, invasive species, and inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made, considerably more conservation and restoration work is needed to ensure maintenance of healthy and functional wetlands throughout the Great Lakes basin.

Comments from the author(s)

The utility of the Wetland Amphibians indicator is dependent on the continuation of the MMP across the Great Lakes basin. Therefore, recruitment and retention of volunteer surveyors has been, and will continue to be, high priority. Despite this, there are areas where coverage is too sparse for analysis and could be improved (e.g., Lake Superior). As a result, a power analysis was conducted to quantify the MMP's ability to detect changes in occurrence of wetland-breeding anuran species at the scales explored in this report. The analysis suggests that the MMP has 80% power to detect percent annual changes in occurrence as small as 1.0% in the Great Lakes basin; 2.0% in the Lake Erie and Ontario basins; and 2.5% in the Lake Michigan and Huron basins for most species (Fig. 3). These numbers should be considered preliminary and exploratory, however, until the effects of spatial and temporal dependence amongst surveys and detection probability can be fully assessed, which is an ongoing and evolving area of study (Seavy and Reynolds 2007, Patuxent Wildlife Research Center 2003).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	x					
2. Data are traceable to original sources	x					
3. The source of the data is a known, reliable and respected generator of data	x					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	x					
5. Data obtained from sources within the U.S. are comparable to those from Canada	x					

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	x					

Acknowledgments

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Contributors:

Hundreds of volunteers who generously donate their time, equipment, and skills to ensure long-term, broad-scale monitoring of the health of Great Lakes wetlands.

Robert W. Rankin, Data Analyst, Bird Studies Canada, P.O. Box 160, 115 Front Street, Port Rowan, ON N0E 1M0. Rob provided much-appreciated analytical assistance.

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List of Tables

Table 1. Population trends of wetland-breeding anuran species used to assess the health of wetlands and their surrounding landscapes in the Lake Michigan, Huron, Erie, and Ontario basin, based on occurrence indices derived from Marsh Monitoring Program point count surveys between 1995 and 2010. Statistically significant trends are indicated by * (i.e., Bayesian credible intervals do not overlap zero). Note that sample sizes were insufficient to analyze Wood Frog within individual lake basins.
Source: Great Lakes Marsh Monitoring Program.

List of Figures

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Source: Great Lakes Marsh Monitoring Program.
Figure 2. Percent annual change of occurrence indices for some wetland-breeding anuran species from 1995 to 2010 in the Great Lakes basin. Indices estimated with repeated-measures logistic regression. Statistically significant positive trends are green, significant negative trends are red, and stable (non-significant) trends are white. Bayesian credible intervals did not overlap zero for significant trends.
Source: Great Lakes Marsh Monitoring Program.
Figure 3. Box-and-whisker plots showing minimum detectable annual change (%) of occurrence indices of some wetland-breeding anuran species in the Great Lakes basin (All) and in individual Great Lakes basins (e.g., Michigan), derived from Great Lakes Marsh Monitoring Program data. The figure summarizes the 7 (Michigan, Huron, Erie, Ontario) or 8 (All) species used to assess wetland health in this report.
Source: Great Lakes Marsh Monitoring Program.

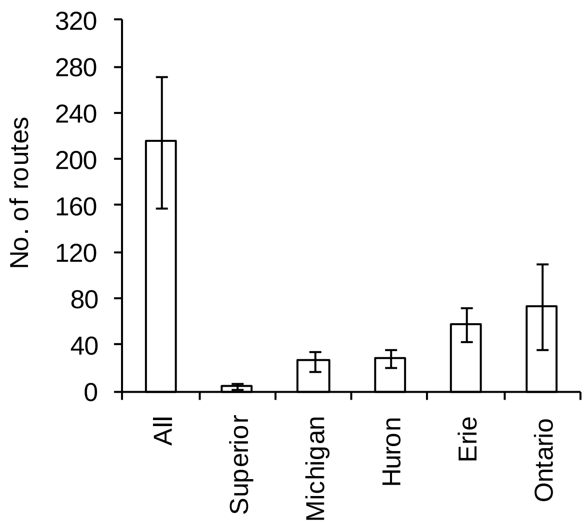
Last Updated

State of the Great Lakes 2011 report

Population trends of wetland-breeding anuran species

Common Name	Scientific Name	Michigan	Huron	Erie	Ontario
American Toad	*Bufo americanus*	+0.7	*-5.5	+0.2	-2.1
Bullfrog	*Rana catesbeiana*	+4.0	*+4.0	-1.2	-1.8
Chorus Frog	*Pseudacris triseriata*	+1.0	*-8.6	*-9.9	*-5.1
Green Frog	*Rana clamitans*	*+4.9	*-4.0	*+3.4	*+5.8
Gray Treefrog	*Hyla versicolor*	*-5.6	+0.4	+0.5	-0.9
Northern Leopard Frog	*Rana pipiens*	*-5.5	-1.2	*-1.4	*+2.5
Spring Peeper	*Pseudacris crucifer*	*-8.3	+2.8	+1.4	*+9.4
Wood Frog	*Rana sylvatica*	–	–	–	–
TOTAL	8	7	7	7	7

Table 1. Population trends of wetland-breeding anuran species used to assess the health of wetlands and their surrounding landscapes in the Lake Michigan, Huron, Erie, and Ontario basin, based on occurrence indices derived from Marsh Monitoring Program point count surveys between 1995 and 2010. Statistically significant trends are indicated by * (i.e., Bayesian credible intervals do not overlap zero). Note that sample sizes were insufficient to analyze Wood Frog within individual lake basins.
Source: Great Lakes Marsh Monitoring Program



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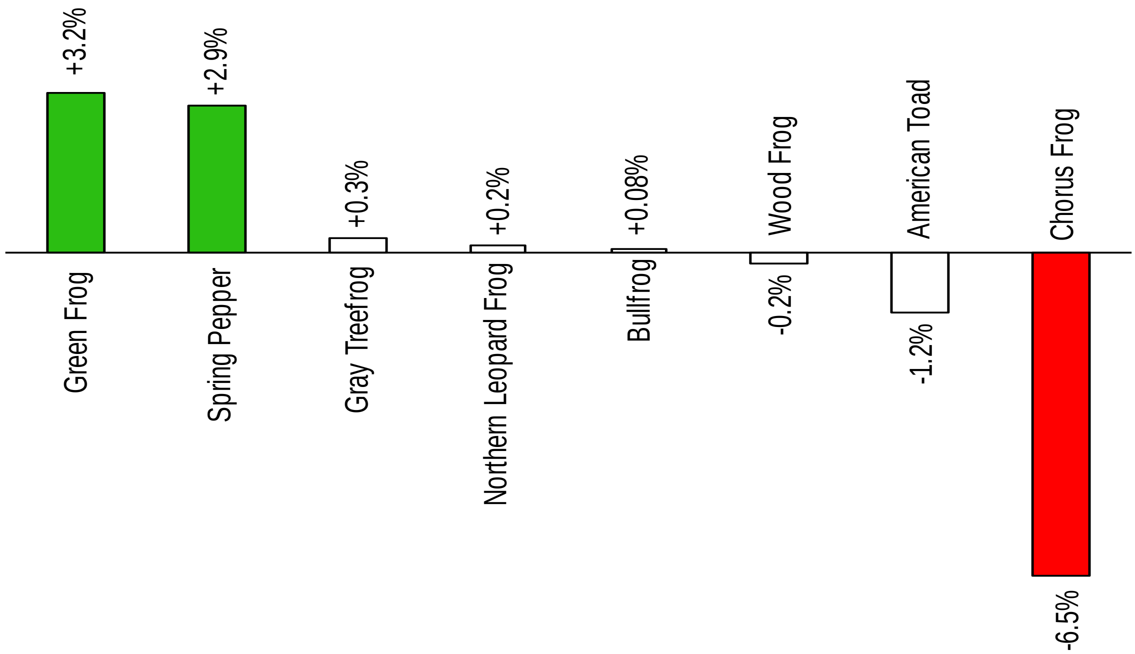

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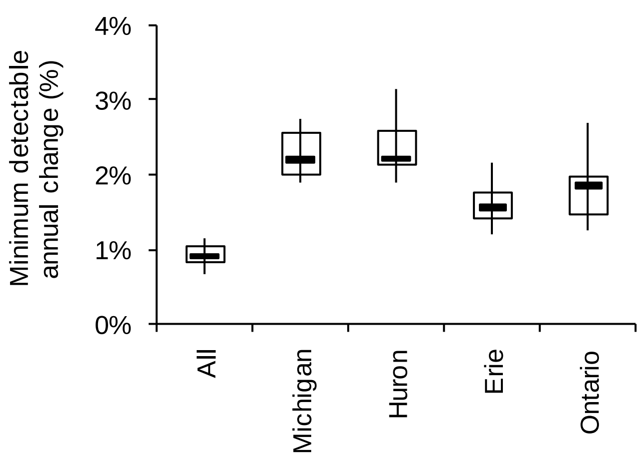
Source: Great Lakes Marsh Monitoring Program



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Source: Great Lakes Marsh Monitoring Program

Coastal Wetland Birds

Overall Assessment
Status: Poor
Trend: Deteriorating
Rationale: The abundance of half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (10 of 19 [52%]). By contrast, the abundance of only three such species significantly increased (16%]). Similar patterns occur in previous reports.

Lake-by-Lake Assessment
Lake Superior
Status: Undetermined
Trend: Undetermined

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: The abundance of nearly half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (7 of 15 [47%]). By contrast, the abundance of no such species significantly increased. Similar patterns occur in previous reports.

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: The abundance of nearly half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (7 of 16 [44%]). By contrast, the abundance of only two such species significantly increased (12%). Similar patterns occur in previous reports.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: The abundance of over half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (12 of 18 [67%]). By contrast, the abundance of only three such species significantly increased (17%). Similar patterns occur in previous reports.

Lake Ontario
Status: Poor
Trend: Deteriorating
Rationale: The abundance of almost half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (7 of 17 [41%]). By contrast, the abundance of only three such species significantly increased (18%). Similar patterns occur in previous reports.

Purpose
- To assess changes in the relative abundance of wetland-dependent breeding bird species
- To infer condition of wetland habitat as it relates to factors that influence this ecologically and culturally important resource
- The Coastal Wetland Birds indicator is used in the Great Lakes indicators suite as a State indicator in the Aquatic Dependent Life top level reporting category.

Ecosystem Objective

To restore and maintain self-sustaining populations of Great Lakes wetland-dependent breeding bird species across their historic ranges. Numerous wetlands in the Great Lakes basin are threatened by urban and agricultural development and other incompatible land uses and these wetlands should be identified, preserved, and where necessary rehabilitated (GLWQA Annex 13). Monitoring and assessment activities provide information on the location, severity, aerial or volume extent, and frequency of Great Lakes wetlands (Annex 11 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

Ecological Condition

Measure

Changes in relative abundance of wetland-dependent breeding birds are based on data from morning or evening surveys using Bird Studies Canada's Great Lakes Marsh Monitoring Program (MMP) bird point count protocol or a modification of it (Marsh Monitoring Program 2009). MMP data from coastal and inland wetlands throughout the Great Lakes basin or throughout each individual lake basin (e.g., Lake Erie; Fig. 1) are used to calculate annual indices of relative abundance for a suite of wetland bird species. Wetlands dominated by non-woody emergent plants such as cattails (*Typha* spp.) and sedges (e.g., *Carex* spp.) are targeted by the program. Species-specific population trends over time are calculated using repeated measures Poisson regression in a Bayesian mode of inference with uninformative priors (Kéry 2010).

Endpoint

Populations of most wetland-dependent breeding bird species have declined since data collection began for this indicator in 1995. Therefore, one endpoint is population indices for nearly all wetland-dependent breeding bird species that are as high as or higher than population indices reported by the MMP in the late 1990s, when the program began. A potentially better endpoint, however, might be based on MMP abundance indices from pristine or near-pristine wetlands throughout the Great Lakes basin (i.e., least disturbed based on indices of anthropogenic disturbance within and surrounding the wetland) —guided by a literature search of other current and historical data and expert opinion. Population indices from this approach are likely to be higher than those reported by the MMP in the late 1990s, given that many wetlands throughout the Great Lakes basin were degraded by that time. Presumably the two approaches estimate the extremes of a range of abundance that is likely to contain the carrying capacity that the landscape is currently capable of supporting and, therefore, somewhere near the middle of the range is the most suitable endpoint. This is the endpoint used in this report.

Background

Wetland-dependent breeding birds are influenced by the physical, chemical, and biological components of the wetlands and surrounding landscapes in which they breed. The abundance and/or reproductive success of multiple species in the Great Lakes basin, for example, declines as (1) wetland size decreases; (2) wetland habitat and natural cover in the surrounding landscape decreases; (3) pesticide, herbicide, and runoff from other sources of pollution into wetlands from the surrounding landscape increases; and (4) generalist predators (e.g., raccoons [*Procyon lotor*]) associated with anthropogenic habitats in the surrounding landscape increase (Brazner et al. 2007a,b; Crosbie and Chow-Fraser 1999; Howe et al. 2007; Grandmaison and Niemi 2007; Naugle et al. 2000; Smith and Chow-Fraser 2010 a,b; Tozer et al. 2010). Thus, the abundance of wetland-dependent breeding birds is a valuable indicator of the health of wetlands and the surrounding landscape.

Status of Coastal Wetland BirdsA grand total of 56 bird species that use marshes (e.g., for feeding, loafing, nesting) were recorded across all surveys and years throughout the Great Lakes basin between 1995 and 2010. Of these, 19 species regularly or always nest in emergent wetlands. Members of this latter group of species were used to assess the health of wetlands and their surrounding landscapes in this report because they rely completely or nearly completely on resources within or relatively close to their nesting wetlands (i.e., within a few kilometres). Only a subset of these 19 species, however, was observed in each individual Great Lakes basin (Table 1).

Great Lakes Basin

The abundance of half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (10 of 19 [52%]; Fig. 2). By contrast, the abundance of only three species that regularly or always nest in wetlands significantly increased between 1995 and 2010 (16%; Fig. 2). The Trumpeter Swan (*Cygnus buccinator*; see Table 1 for a list of scientific names for all subsequent common names) increased primarily due to relatively recent reintroductions after the species was nearly extirpated about a century ago (Mitchell and Eichholz 2010) and the Sandhill Crane continues to increase following continental population lows in the early 1900s (Tacha et al. 1992), both of which may have little to do with the health of wetlands in the Great Lakes basin between 1995 and 2010; these two species are also responsible for most of the significant population increases identified within individual Great Lakes basins in the following sections. The abundance of the remaining six species that regularly or always nest in wetlands was stable between 1995 and 2010 (32%). Similar patterns occur across the Great Lakes basin for this indicator in previous reports. Given that populations of half the species that regularly or always nest in wetlands continue to decline below each of the suggested endpoints, the overall status is poor and the trend is deteriorating.

Lake Michigan

The abundance of nearly half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (7 of 15 [47%]). By contrast, the abundance of no such species significantly increased. The abundance of the remaining eight species that regularly or always nest in wetlands was stable between 1995 and 2010 (53%). Similar patterns occur in the Lake Michigan basin for this indicator in previous reports. Given that populations of nearly half of the species that regularly or always nest in wetlands continue to decline below each of the suggested endpoints, the overall status is poor and the trend is deteriorating (Table 1).

Lake Huron

The abundance of nearly half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (7 of 16 [44%]). By contrast, the abundance of only two such species significantly increased (12%). The abundance of the remaining seven species that regularly or always nest in wetlands was stable between 1995 and 2010 (44%). Similar patterns occur in the Lake Huron basin for this indicator in previous reports. Given that populations of nearly half the species that regularly or always nest in wetlands continue to decline below each of the suggested endpoints, the overall status is poor and the trend is deteriorating (Table 1).

Lake Erie

The abundance of over half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (12 of 18 [67%]). By contrast, the abundance of only three such species significantly increased (17%). The abundance of the remaining three species that regularly or always nest in wetlands was stable between 1995 and 2010 (17%). Similar patterns occur in the Lake Erie basin for this indicator in previous reports. Given that populations of over half the species that regularly or always nest in wetlands continue to decline below each of the suggested endpoints, the overall status is poor and the trend is deteriorating (Table 1).

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The abundance of almost half of the species that regularly or always nest in wetlands declined significantly between 1995 and 2010 (7 of 17 [41%]). By contrast, the abundance of only three such species significantly increased (18%). The abundance of the remaining seven species that regularly or always nest in wetlands was stable between 1995 and 2010 (17%). Similar patterns occur in the Lake Ontario basin for this indicator in previous reports. Given that populations of almost half of the species that regularly or always nest in wetlands continue to decline below each of the suggested endpoints, the overall status is poor and the trend is deteriorating (Table 1).

Linkages
Wetland-dependent breeding birds are influenced by numerous characteristics of the wetlands and surrounding landscapes in which they breed, many of which are monitored as Great Lakes (SOLEC) indicators. For instance, populations of some of the 19 wetland-dependent breeding bird species used to assess Great Lakes wetland health in this report are known to co-vary with changing water levels at local and individual Great Lakes basin scales (Timmermans et al. 2008, Jobin et al. 2009). Thus, the Coastal Wetland Bird indicator will co-vary with the Water Levels indicator report. The Coast al Wetland Bird indicator can also be expected to co-vary with indicators that track wetland breeding bird habitat (e.g., Coastal Wetland Plant Community Health; Coastal Wetland Landscape Extent and Composition) and prey (Coastal Wetland Invertebrate Community Health; Coastal Wetland Fish Community Health) and factors that indirectly influence them, such as invasive plant species that encroach upon preferred native vegetation and pollution runoff from surrounding uplands that reduce prey abundance and/or availability.

Management Challenges/Opportunities
Maintain or improve the quality of wetlands and adjacent uplands for breeding coastal wetland birds by mitigating or eliminating influences that are detrimental to wetland health such as water level fluctuations, invasive species, and inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made, considerably more conservation and restoration work is needed to ensure maintenance of healthy and functional wetlands throughout the Great Lakes basin.

Comments from the author(s)
The utility of the Coastal Wetland Birds indicator is dependent on the continuation of the MMP across the Great Lakes basin. Therefore, recruitment and retention of volunteer surveyors has been, and will continue to be, high priority. Despite this, there are areas where coverage is too sparse for analysis and could be improved (e.g., Lake Superior). As a result, a power analysis was conducted to quantify the MMP's ability to detect changes in population sizes of wetland-dependent breeding bird species at the scales explored in this report. The analysis suggests that the MMP has 80% power to detect percent annual changes in occurrence indices as small as 1.5% in the Great Lakes basin; 3% in the Lake Huron, Erie, and Ontario basins; and 4% in the Lake Michigan basin for most species (Fig. 3). These numbers should be considered preliminary and exploratory, however, until the effects of spatial and temporal dependence amongst surveys and detection probability can be fully assessed, which is an ongoing and evolving area of study (Seavy and Reynolds 2007, Patuxent Wildlife Research Center 2003).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Contributors:

Hundreds of volunteers who generously donate their time, equipment, and skills to ensure long-term, broad-scale monitoring of the health of Great Lakes wetlands.

Robert W. Rankin, Data Analyst, Bird Studies Canada, P.O. Box 160, 115 Front Street, Port Rowan, ON N0E 1M0. Rob provided statistical assistance.

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List of Tables

Table 1. Population trends of wetland-nesting bird species used to assess the health of wetlands and their surrounding landscapes in the Lake Michigan, Huron, Erie, and Ontario basin, based on abundance indices derived from Marsh Monitoring Program point count surveys between 1995 and 2010. Statistically significant trends are indicated by * (i.e., Bayesian credible intervals do not overlap zero).
Source: Great Lakes Marsh Monitoring Program.

List of Figures

Figure 1. Mean (±SD) number of Marsh Monitoring Program routes surveyed for birds per year in the Great Lakes basin (All) and in each individual Great Lakes basin (e.g., Superior) between 1995 and 2010. A route consists of multiple, spatially-clustered point count survey locations, typically located in the same wetland, all of which can be surveyed by the same person in a single morning or evening.
Source: Great Lakes Marsh Monitoring Program.

Figure 2. Percent annual change of population indices for some wetland-nesting bird species from 1995 to 2010 in the Great Lakes basin. Indices estimated with a Bayesian mixed-model framework, assuming a Poisson distribution. Statistically significant positive trends are green, significant negative trends are red, and stable (non-significant) trends are white.
Source: Great Lakes Marsh Monitoring Program.

Figure 3. Box-and-whisker plots showing minimum detectable annual change (%) of population indices of some wetland-nesting bird species in the Great Lakes basin (All) and in individual Great Lakes basins (e.g., Superior), derived from Great Lakes Marsh Monitoring Program data. The figure summarizes the 19 species used to assess wetland health in this report, with the exception of Trumpeter Swan, which was considered an outlier and removed for ease of interpretation; for this species, minimum detectable annual change was 7% in the Great Lakes basin and 10 and 25% in the Lake Ontario and Erie basins, respectively.
Source: Great Lakes Marsh Monitoring Program.

Last Updated

State of the Great Lakes 2011 report

Population trends of wetland-nesting bird species

Common Name	Scientific Name	Michigan	Huron	Erie	Ontario
American Bittern	*Botaurus lentiginosus*	–	*-0.5	*-2.8	-1.1
American Coot	*Fulica americana*	*-14.1	*-11.2	*-15.5	*-5.4
Black Tern	*Chlidonias niger*	*-18.3	*-12.2	*-4.6	*-13.3
Canada Goose	*Branta canadensis*	-2.0	+1.94	*-5.7	+0.61
Common Grackle	*Quiscalus quiscula*	+0.07	*-3.4	*-2.7	-0.3
Common Moorhen	*Gallinula chloropus*	*-16.9	*-11.8	*-13.7	*-6.8
Common Yellowthroat	*Geothlypis trichas*	+0.63	*+2.21	*+1.66	*+1.34
Forster's Tern	*Sterna forsteri*	–	–	*-13.7	–
Least Bittern	*Ixobrychus exilis*	*-6.1	*-4.2	*-7.0	*-2.9
Marsh Wren	*Cistothorus palustris*	-1.5	+1.43	*-2.5	-0.9
Mute Swan	*Cygnus olor*	-5.2	–	-3.3	+2.74
Pied-billed Grebe	*Podilymbus podiceps*	*-7.7	*-5.6	-2.7	*-8.1
Red-winged Blackbird	*Agelaius phoeniceus*	+0.04	-0.7	*-1.1	*-0.7
Sandhill Crane	*Grus canadensis*	+6.16	*+14.51	*+13.89	–
Sora	*Porzana carolina*	*-4.0	+0.04	*-4.1	-2.1
Swamp Sparrow	*Melospiza georgiana*	-0.6	-1.2	*-0.9	*+1.2
Trumpeter Swan	*Cygnus buccinator*	–	–	*+77.68	*+32.38
Virginia Rail	*Rallus limicola*	*-8.6	*-2.5	*-4.9	*-3.4
Wilson's Snipe	*Gallinago delicata*	–	-1.3	–	+9.85
TOTAL	19	15	16	18	17

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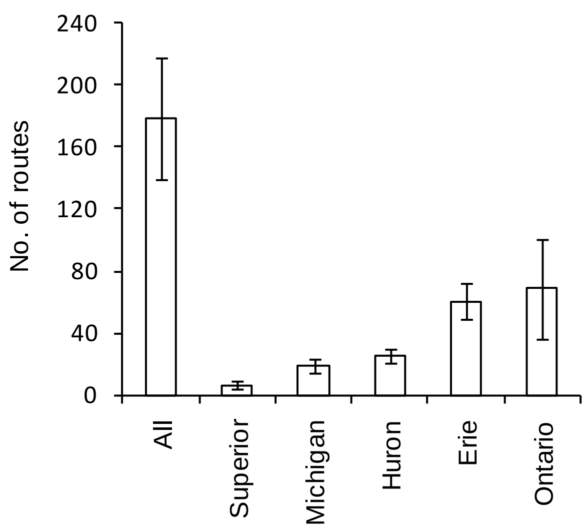
Source: Great Lakes Marsh Monitoring Program.



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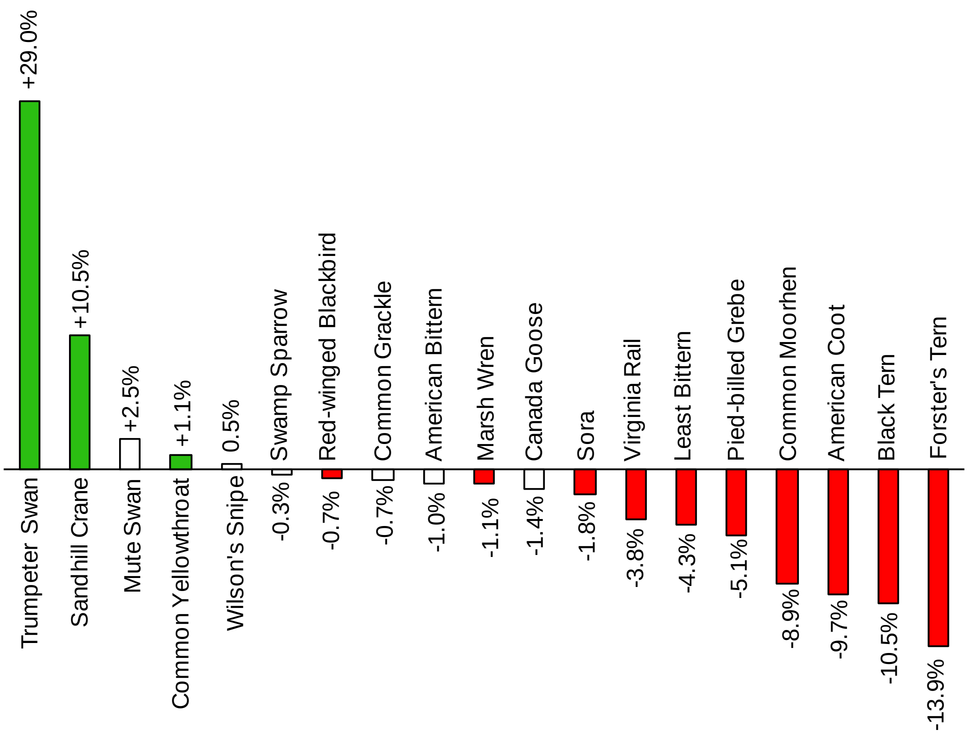

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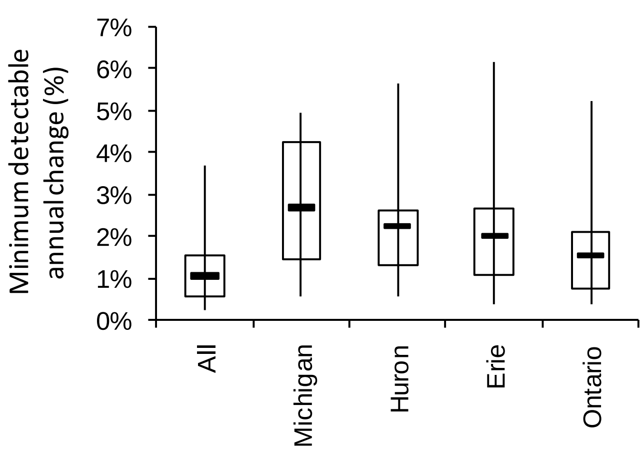

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Source: Great Lakes Marsh Monitoring Program.

Coastal Wetland Fish Community Health

Overall Assessment
Status: Not Assessed
Trend: Not Assessed
Rationale: This indicator will be evaluated as part of an overall analysis of biological communities of Great Lakes coastal wetlands and nearshore aquatic systems.

Note: This is a progress report towards implementation of this indicator. The indicator is currently being used throughout the entire Great Lakes basin, but data will not be available until 2012. The following evaluation was constructed using input from investigators collecting fish community composition data from Great Lakes coastal wetlands over the last several years. Regarding the following, neither experimental design nor statistical rigor has been used to specifically address the status and trends of fish communities of coastal wetlands of the five Great Lakes. However, in the spring of 2011, an effort was put forth by a consortium of universities that established a statistically sound basin-wide coastal wetland monitoring program. This indicator will be used, along with others, at the majority of coastal wetlands with a surface water connection to the Great Lakes that are greater than 4 hectares in size. The effort is bi-national and basin wide and will produce scientifically-defensible information on the status and trends of Great Lakes coastal wetlands.

Lake-by-Lake Assessment
Each lake was categorized with a not assessed status and an undetermined trend, indicating that data were not available yet.

Purpose
- To assess the fish community composition, and to infer suitability of habitat and water quality for Great Lakes coastal wetland fish communities.

Ecosystem Objective
Restore and maintain the diversity of the fish community of Great Lakes coastal wetlands, while indicating overall ecosystem health. Significant wetland areas in the Great Lakes System that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

Ecological Condition
Development of this indicator is complete and the indicator is currently be implemented. However, data are not available at this time. Several different fish metrics developed by the Great Lakes Coastal Wetlands Consortium are being utilized.

Mean abundance and richness per (fyke) net-night of resident fish species within dominant inundated vegetation zones; primarily bulrush (*Schoenoplectus*) and cattail (*Typha*); across survey stations specific to a vegetation zone; percent non-native richness; mean Shannon Diversity index; mean evenness; and, mean abundance and richness of Omnivores, insectivores, piscivores, and carnivores (insectivores+ piscivore+zooplanktivore).

In order to properly manage the Great Lakes coastal wetland fish community health there must be consistent sampling methods. Sampling is being conducted no earlier than mid June and no later than August due to migration patterns of the fish communities. Dominant vegetation zones are being identified because different zones support different types of fish. Two main vegetation zones are *Schoenoplectus*-Bulrush and *Typha*-cattail, but all are being included. When sampling fish using fyke netting it is recommended to use a minimum of three replicate fyke nets with 4.8mm mesh for each dominate vegetation zone. There are two sizes of fyke nets that can be used 0.5-m x 1-m opening and 1-m x 1-m opening. The smaller nets are placed in water that is 0.25-0.5 m deep and the larger fyke nets are placed in water that is greater than 0.50 m deep. The leads are 7.3 m long with 1.8 m long wings . Nets are randomly placed a minimum of 20 m apart in each vegetation zone. The fyke nets are placed perpendicular to the vegetation zone, therefore, fish swimming along the edge of the vegetation zone are captured.

Any fish collected that is greater than 25mm should be identified down to species. The number of the fish caught per fyke net should be recorded. Also 10 to 20 specimens of each species, life stage and size at age should be chosen randomly to record.

Using the methods stated above, scientists have determined the composition of fish communities is related to plant community type within wetlands (Uzarski *et al*. 2005, Wei *et al*. 2004). Uzarski *et al*. (2005) found no relationship between wetland fish composition and a specific Great Lake, suggesting that fish communities of any single Great Lake were no more impacted than those from any other Great Lake. However, of the 61 wetlands sampled in 2002 from all five lakes, Lake Erie and Lake Ontario tended to have more wetlands containing cattail communities (a plant community type that correlates with nutrient enrichment), and the fish communities found in cattails tended to have lower richness and diversity than fish communities found in other vegetation types. Wetlands found in northern Lake Michigan and Lake Huron tended to have relatively high quality coastal wetland fish communities. The seven wetlands sampled in Lake Superior contained relatively unique vegetation types, so fish communities of these wetlands were not directly compared with those of wetlands of other lakes.

When the fish communities of reference wetlands are compared across the entire Great Lakes, the most similar sites come from the same ecological province rather than from any single Great Lake or specific wetland types. Data from several GLEI project studies indicate that the characteristic groups of fish species in reference wetlands from each ecological province tend to have similar water temperature and aquatic productivity preferences.

John Brazner and co-workers from the U.S. EPA Laboratory in Duluth, MN, sampled fishes of Green Bay (Lake Michigan) wetlands in 1990, 1991, 1995, 2002, and 2003. They sampled three lower bay and one middle bay wetland in 2002 and 2003. Their data suggested that these sites were improving in water clarity and plant cover, and that they supported a greater diversity of both macrophyte and fish species, especially more centrarchid species, than they had in previous years. They also noted that the 2002, and especially 2003, year classes of yellow perch were very large. Brazner's observations suggest that the lower Green Bay wetlands are improving slowly and the middle bay site seems to be remaining relatively stable in moderately good condition (J. Brazner, personal observation). The most turbid wetlands in the lower bay were characterized by mostly warm-water, turbidity-tolerant species such as gizzard shad (*Dorosoma cepedianum),* white bass (*Morone chrysops*), freshwater drum (*Aplodinotus grunniens),* common shiners (*Luxilus cornutus),* and common carp (*Cyprinus carpio).* Meanwhile the least turbid wetlands in the upper bay were characterized by several centrarchid species, golden shiner (*Notemigonus chrysoleucas*), logperch (*Percina caprodes),* smallmouth bass (*Micropterus dolomieu)* and northern pike (*Esox lucius)*. Green sunfish (*Lepomis cyanellus)* was the only important centrarchid in the lower bay in 1991, while in 1995, bluegill and pumpkinseed sunfishes (*L. macrochirus* and *L. gibbosus)* had become much more prevalent, and a few largemouth bass (*M. salmoides)* were also present. There were more banded killifish (*Fundulus diaphanous)* in 1995 and 2003 compared with 1991, and white perch (*Morone americana)* were very abundant in 1995 as this non-native species became dominant in the bay. The upper bay wetlands were in relatively good condition based on the fish and macrophyte communities that were observed. Although mean fish species richness was significantly lower in developed wetlands across the whole bay, differences between less developed and more developed wetlands were most pronounced in the upper bay where the highest quality wetlands in Green Bay are found (Brazner 1997).

Round gobies (*Neogobius melanostomus)* were introduced to the St. Clair River in 1990 (Jude and Pappas 1992), and they have since spread to all of the Great Lakes. Jude studied them in many tributaries of the Lake Huron-St. Clair River-Lake Erie corridor and found that both round and tubenose gobies (*Proterorhinus marmoratus*) were very abundant at river mouths and had colonized far upstream. They were also found at the mouth of Old Woman Creek in Lake Erie, but not within the wetland proper. Jude and Janssen's work in Green Bay wetlands showed that round gobies had not invaded three of the five sites sampled, but a few were found in lower Green Bay along the sandy and rocky shoreline west of Little Tail Point.

Uzarski and Burton (unpublished) consistently collected a few round gobies from a fringing wetland near Escanaba, MI, where cobbles were present. In the Muskegon River-Muskegon Lake wetland complex on the eastern shoreline, round gobies are abundant in the heavily rip-rapped harbor entrance to Lake Michigan, and they have just begun to enter the river/wetland complex on the east side of Muskegon Lake (Cooper *et* al. 2007; D. Jude, personal observations). Based on intensive fish sampling prior to 2003 at more than 60 sites spanning all of the Great Lakes, round gobies have not been sampled in large numbers at any wetland or been a dominant member of any wetland fish community (Jude *et al*. 2005). Round gobies were collected at 11 of 80 wetlands sampled by the GLEI project (Johnson *et al*. unpublished data). Lapointe (2005) assessed fish-habitat associations in the shallow (less than 3 m) Canadian waters of the Detroit River in 2004 and 2005 using boat-mounted electrofishing and boat seining techniques. The round goby avoided complex macrophytes in all seasons at upper, mid-, and downstream segments of the Detroit River. However, in 2006, beach seining surveys at shoreline sites in Canadian waters of Lake St. Clair, the Detroit River, and western Lake Erie, both tubenose and round gobies were collected in areas with aquatic vegetation (Corkum, Univ. of Windsor, unpublished data). It seems likely that wetlands may be a refuge for native fishes, at least with respect to the influence of round gobies (Jude *et al*. 2005), however, small gobies seem to be increasing in abundance in many Great Lakes coastal wetlands.

There is little information on the habitat preferences of the tubenose goby within the Great Lakes with the exception of studies on the Detroit River (Lapointe 2005), Lake St. Clair and the St. Clair River (Jude and DeBoe 1996, Pronin *et al*. 1997, Leslie *et al*. 2002). Within the Great Lakes, tubenose goby that were studied at a limited number of sites along the St. Clair River and on the south shore of Lake St. Clair occurred in turbid water associated with rooted submersed vegetation (*Vallisneria americana, Myriophyllum spicatum, Potamogeton richardsonii* and *Chara* sp.;Leslie *et al*. 2002). Few specimens were found on sandy substrates devoid of vegetation, supporting similar findings by Jude and DeBoe (1996). Leslie *et al*. (2002) collected tubenose goby in water with no or slow flow on clay or alluvium substrates, where turbidity varies and where rooted vegetation was sparse, patchy or abundant. Lapointe (2005) found that the association between tubenose goby and aquatic macrophytes differed seasonally in the Detroit River. For example, tubenose goby was strongly negatively associated with complex macrophytes in the spring and summer, but positively associated with complex macrophytes in the fall (Lapointe 2005). Because tubenose goby shared habitats with fishes representing most ecoethological guilds, Leslie *et al*. (2002) suggested that the tubenose goby would expand its geographic range within the Great Lakes.

Ruffe (*Gymnocephalus cernuus*) have never been found in high densities in coastal wetlands anywhere in the Great Lakes. In their investigation of the distribution and potential impact of ruffe on the fish community of a Lake Superior coastal wetland, Brazner *et al*. (1998) concluded that coastal wetlands in western Lake Superior provide a refuge for native fishes from competition with ruffe. The mudflat-preferring ruffe actually avoids wetland habitats due to foraging inefficiency in dense vegetation that characterizes healthy coastal wetland habitats. This suggests that further degradation of coastal wetlands or heavily vegetated littoral habitats could lead to increased dominance of ruffe in shallow water habitats elsewhere in the Great Lakes.

There are a number of carp introductions that have the potential for substantial impact on Great Lakes fish communities, including coastal wetlands. Goldfish (*Carassius auratus*) are common in some shallow habitats, and they occurred along with common carp young-of-the-year in many of the wetlands sampled along Green Bay. In addition, there are several other carp species, e.g., grass carp (*Ctenopharyngodon idella),* bighead carp (*Hypophthalmichthys nobilis)* and silver carp (*Hypophthalmichthys molitrix)* that escaped aquaculture operations and are now in the Illinois River and migrating toward the Great Lakes through the Chicago Sanitary and Ship Canal. Most of these species attain large sizes. Some are planktivorous, but also eat phytoplankton, snails, and mussels, while the grass carp eats vegetation. These species represent yet another substantial threat to food webs in wetlands and nearshore habitats with macrophytes (U.S. Fish and Wildlife Service (USFWS) 2002).

In 2003, Jude and Janssen (unpublished data) determined that bluntnose minnows (*Pimephales notatus)* and johnny darters (*Etheostoma nigrum)* were almost absent from lower Green Bay wetland sites, but they comprised 22% and 6%, respectively, of upper bay catches. In addition, other species, usually associated with plants and/or clearer water, such as rock bass, sand shiners (*Notropis stramineus*) and golden shiners (*Notemigonus crysoleucus),* were also present in upper bay samples, but not in lower bay samples. In 2003, Jude and Janssen found that there were no alewife (*Alosa pseudoharengus)* or gizzard shad in upper Green Bay site catches, but in lower bay wetland sites, they composed 2.7% and 34%, respectively, of the catches by number.

Jude and Pappas (1992) found that fish assemblage structure in Cootes Paradise, a highly degraded wetland area in Lake Ontario, was very different from other less degraded wetlands analyzed. They used ordination analyses to detect fish-community changes associated with degradation.

According to a study completed by Seilheimer and Chow-Fraser northern coastal wetlands had higher water quality indices than southern lakes coastal wetlands. Lake Superior had a good status while Lake Huron and Georgian Bay were classified with a very good status. Southern coastal wetlands in Lake Ontario, Erie and Michigan were classified as moderately degraded (Seilheimer and Chow-Fraser, 2007).

During this study pumpkinseed (*Lepomis gibbosus*) occurred in 94 out of 100 wetlands studied, and over 6,000 pumpkinseed individuals were captured. Brown bullhead (*Ameiurus nebulosus*) was the second most abundant fish captured and it was found in 80 wetlands. Another abundant species was the Spottail shiner (*Notropis hudsonius*) which was found in 39 coastal wetlands with a little less than 3,800 individual captured. Other abundant species found in the Great Lakes coastal wetlands are the Largemouth bass (*Micropterus salmoides*), Bluntnose minnow (*Pimephales notatus*), and the Bluegill (*Lepomis macrochirus*).

Pressures

Agriculture

Agriculture degrades wetlands in several ways, including nutrient enrichment from fertilizers, increased sediments from erosion, increased rapid runoff from drainage ditches, introduction of agricultural non-native species (reed canary grass), destruction of inland wet meadow zone by plowing and diking, and addition of herbicides. In the southern lakes, Saginaw Bay, and Green Bay, agricultural sediments have resulted in highly turbid waters which support few or no submergent plants.

Urban development

Urban development degrades wetlands by hardening shoreline, filling wetland, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increased nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline. Thoma (1999) and Johnson *et al*. (2006) were unable to find coastal wetlands on the U.S. side of Lake Erie that experienced minimal anthropogenic disturbances. According to Seilheimer and Chow-Fraser there has been accelerated loss of wetland fish habitat in Lake Ontario, Lake Erie and Lake Michigan near urban areas and agriculture.

Residential shoreline development

Along many coastal wetlands, residential development has altered wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the introduction of non-native species. Shoreline hardening can completely eliminate wetland vegetation, which results in degradation of fish habitat. It appears that when a wetland becomes affected by human development, the fish community changes to that typical of a warmer, richer, more southerly wetland. This finding may help researchers anticipate the likely effects of regional climate change on the fish communities of Great Lakes coastal wetlands.

Mechanical alteration of shoreline
Mechanical alteration takes a diversity of forms, including diking, ditching, dredging, filling, and shoreline hardening. With all of these alterations, non-native species are introduced by construction equipment or in introduced sediments. Changes in shoreline gradients and sediment conditions are often adequate to allow non-native species to become established.

Introduction of non-native species
Non-native species are introduced in many ways. Some were purposefully introduced as agricultural crops or ornamentals, later colonizing in native landscapes. Others came in as weeds in agricultural seed. Increased sediment and nutrient enrichment allow many of the worst aquatic weeds to out-compete native species. Most of the worst non-native species are either prolific seed producers or reproduce from fragments of root or rhizome. Non-native animals have also been responsible for increased degradation of coastal wetlands. One of the worst invasive species has been Asian carp, who's mating and feeding result in loss of submergent vegetation in shallow marsh waters.

Pressures were described by Dennis Albert in the Coastal Wetland Plant Communities Indicator.

Management Challenges/Opportunities
Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on basin wide scale has not yet occurred. Implementations of a long term coastal wetland monitoring program is pending, however support for this program is need4ed by resource managers throughout the basin.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments
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Last Updated

State of the Great Lakes 2009 report.

An editor's note was added for the 2011 reporting cycle

Coastal Wetland Invertebrate Communities

Overall Assessment
Status: Not Assessed
Trend: Not Assessed
Rationale: Part of an overall analysis of biological communities of Great Lakes coastal wetlands.

Note: This is a progress report towards implementation of this indicator. The indicator is currently being used throughout the entire Great Lakes basin, but data will not be available until 2012. The following evaluation was constructed using input from investigators collecting invertebrate community composition data from Great Lakes coastal wetlands over the last several years. Regarding the following, neither experimental design nor statistical rigor has been used to specifically address the status and trends of invertebrate communities of coastal wetlands of the five Great Lakes. However, in the spring of 2011, an effort was put forth by a consortium of universities that established a statistically sound basin-wide coastal wetland monitoring program. This indicator will be used, along with others, at the majority of coastal wetlands with a surface water connection to the Great Lakes that are greater than 4 hectares in size. The effort is bi-national and basin wide and will produce scientifically-defensible information on the status and trends of Great Lakes coastal wetlands.

Lake-by-Lake Assessment
Each lake was categorized with a not assessed status and an undetermined trend, indicating that data were not available yet.

Purpose
- To directly measure specific components of invertebrate community composition
- To infer the chemical, physical and biological integrity and range of degradation of Great Lakes coastal wetlands

Ecosystem Objective
Significant wetland areas in the Great Lakes System that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). Conducting monitoring and surveillance activities will gather definitive information on the location, severity, aerial or volume extent, and frequency of the Great Lakes coastal wetlands (Annex 11 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

Ecological Condition
Teams of Canadian and American researchers from several research groups (e.g. the Great Lakes Coastal Wetlands Consortium, the Great Lakes Environmental Indicators project investigators, the U.S. Environmental Protection Agency (U.S. EPA) Regional Environmental Monitoring and Assessment Program (REMAP) group of researchers, and others) sampled large numbers of Great Lakes wetlands. In 2002 the Great Lakes Coastal Wetlands Consortium conducted extensive surveys of wetland invertebrates of the four lower Great Lakes. The Consortium-adopted Index of Biotic Integrity (IBI, Uzarski *et al.* 2004) was applied in wetlands of northern Lake Ontario. The results can be obtained from Environment Canada (Environment Canada and Central Lake Ontario Conservation Authority 2004). These methods are now being used basin-wide by a consortium of universities but these data will not be available until 2012.

Uzarski *et al.* (2004) collected invertebrate data from 22 wetlands in Lake Michigan and Lake Huron during 1997 through 2001. They determined that wetland invertebrate communities of northern Lakes Michigan and Huron generally produced the highest IBI scores. IBI scores were primarily based on richness and abundance of Odonata, Crustacea plus Mollusca taxa richness, total genera richness, relative abundance Gastropoda, relative abundance Sphaeriidae, Ephemeroptera plus Trichoptera taxa richness, relative abundance Crustacea plus Mollusca, relative abundance Isopoda, Evenness, Shannon Diversity Index, and Simpson Index. Wetlands near Escanaba and Cedarville, Michigan, scored lower than most in the area. A single wetland near the mouth of the Pine River in Mackinac County, MI, consistently scored low. In general, all wetlands of Saginaw Bay scored lower than those of northern Lakes Michigan and Huron. However, impacts are more diluted near the outer bay and IBI scores reflect this. Wetlands near Quanicassee and Almeda Beach, MI, consistently scored lower than other Saginaw Bay sites.

Burton and Uzarski also studied drowned river mouth wetlands of eastern Lake Michigan quite extensively since 1998. Invertebrate communities of these systems show linear relationship with latitude. However, this relationship also reflects anthropogenic disturbance. Based on the metrics used (Odonata richness and abundance, Crustacea plus Mollusca richness, total genera richness, relative abundance Isopoda, Shannon Index, Simpson Index, Evenness, and relative abundance Ephemeroptera), the sites studied were placed in increasing community health in the order Kalamazoo, Pigeon, Muskegon, White, Pentwater, Pere Marquette, Manistee, Lincoln, and Betsie. The most impacted systems of eastern Lake Michigan are located along southern edge and impacts decrease to the north.

Wilcox *et al.* (2002) attempted to develop wetland IBIs for the upper Great Lakes using microinvertebrates. While they found attributes that showed promise during a single year, they concluded that natural water level changes were likely to alter communities and invalidate metrics. They found that Siskiwit Bay, Bark Bay, and Port Wing had the greatest overall taxa richness with large catches of cladocerans. They ranked microinvertebrate communities of Fish Creek and Hog Island lower than the other four western Lake Superior sites. Their work in eastern Lake Michigan testing potential metrics placed the sites studied in decreasing community health in the order Lincoln River, Betsie River, Arcadia Lake/Little Manistee River, Pentwater River, and Pere Marquette River. This order was primarily based on the median number of taxa, the median Cladocera genera richness, and also a macroinvertebrate metric (number of adult Trichoptera species).

Pressures

Physical alteration and eutrophication of wetland ecosystems continue to be a threat to invertebrates of Great Lakes coastal wetlands. Both can promote establishment of non-native vegetation, and physical alteration can destroy plant communities altogether while changing the natural hydrology to the system. Invertebrate community composition is directly related to vegetation type and densities; changing either of these components will negatively impact the invertebrate communities.

<u>Agriculture</u>

Agriculture degrades wetlands in several ways, including nutrient enrichment from fertilizers, increased sediments from erosion, increased rapid runoff from drainage ditches, introduction of agricultural non-native species (reed canary grass), destruction of inland wet meadow zone by plowing and diking, and addition of herbicides.

<u>Urban development</u>

Urban development degrades wetlands by hardening shoreline, filling wetland, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increased nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

<u>Residential shoreline development</u>

Along many coastal wetlands, residential development has altered wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the introduction of non-native species.

<u>Mechanical alteration of shoreline</u>

Mechanical alteration takes a diversity of forms, including diking, ditching, dredging, filling, and shoreline hardening. With all of these alterations, non-native species are introduced by construction equipment or in introduced sediments.

Introduction of non-native species
Non-native species are introduced in many ways. Some were purposefully introduced as agricultural crops or ornamentals, later colonizing in native landscapes. Others came in as weeds in agricultural seed. Increased sediment and nutrient enrichment allow many of the worst aquatic weeds to out-compete native species. Most of the worst non-native species are either prolific seed producers or reproduce from fragments of root or rhizome. Non-native animals have also been responsible for increased degradation of coastal wetlands.

Pressures were described by Dennis Albert in the Coastal Wetland Plant Communities Indicator.

Management Challenges/Opportunities
Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on basin wide scale has not yet occurred. Implementations of a long term coastal wetland monitoring program is pending, however support for this program is need4ed by resource managers throughout the basin.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Wetlands 22(3):588-615

Last Updated
State of the Great Lakes 2009 report.

An editor's note was added for the 2011 reporting cycle

Coastal Wetland Landscape Extent and Composition

Overall Assessment

Status: **Fair**

Trend: **Deteriorating**

Rationale: **To monitor losses of coastal wetland area due to human actions and gains to coastal wetlands due to restoration activities.**

Note: In the spring of 2011, an effort was put forth by a consortium of universities that established a statistically sound basin-wide coastal wetland monitoring program. This indicator will be used, along with others, at the majority of coastal wetlands with a surface water connection to the Great Lakes that are greater than 4 hectares in size. The effort is bi-national and basin wide and will produce scientifically-defensible information on the status and trends of Great Lakes coastal wetlands.

Lake-by-Lake Assessment

Each lake was categorized with a not assessed status and an undermined trend, indicating that assessments were not made on an individual lake basis.

Purpose

- To assess the periodic changes in area (particularly losses) of coastal wetland types, taking into account natural lake level variations

Ecosystem Objective

- Maintain total aerial extent of Great Lakes coastal wetlands, ensuring adequate representation of coastal wetland types across their historical range (Great Lakes Water Quality Agreement, Annexes 2 and 13, United States and Canada 1987).

State of the Ecosystem

The status of this indicator has not been updated since the *State of the Great Lakes 2005* report. Future updates to the status of this indicator will require the repeated collection and analysis of remotely-sensed information. Currently, technologies and methods are being assessed for an ability to estimate wetland extent. Next steps, including determination of funding and resource needs, as well as pilot investigations, must occur before an indicator status update can be made. The timeline for this is not yet determined. However, once a methodology is established, it will be applicable for long-term monitoring for this indicator, which is imperative for an improved understanding of wetland functional responses and adaptive management. The 2005 assessment of this indicator follows.

Despite the fact that several wetland restoration and protection efforts have improved specific areas, wetlands continue to be lost and degraded. The ability to track and determine the extent and rate of this loss in a standardized way is not yet feasible.

In an effort to estimate the extent of coastal wetlands in the basin, the Great Lakes Coastal Wetland Consortium (GLCWC) coordinated completion of a binational coastal wetland database. The project involved building from existing Canadian and U.S. coastal wetland databases (Environment Canada and Ontario Ministry of Natural Resources 2003; Herdendorf *et al*. 1981a-f) and incorporating additional auxiliary federal, provincial and state data to create a more complete, digital Geographic Information System (GIS) vector database. All coastal wetlands in the database were classified using a Great Lakes hydrogeomorphic coastal wetland classification system (Albert *et al*. 2005). The project was completed in 2004. The GIS database provides the first spatially explicit seamless binational summary of coastal wetland distribution in the Great Lakes system. Coastal wetlands totaling 216,743 ha (535,582 acres) have been identified within the Great Lakes and connecting rivers up to Cornwall, ON (Fig. 1). However, due to existing data limitations, estimates of coastal wetland extent, particularly for the upper Great Lakes are acknowledged to be incomplete.

Despite significant loss of coastal wetland habitat in some regions of the Great Lakes, the lakes and connecting rivers still support a diversity of wetland types. Barrier protected coastal wetlands are a prominent feature in the upper Great Lakes, accounting for over 60,000 ha (150,000 acres) of the identified coastal wetland area in Lake Superior, Lake Huron and Lake Michigan (Fig. 2). Lake Erie supports 22,000 ha (54,500 acres) of coastal wetland, with protected embayment wetlands accounting for over one third of the total area (Fig. 2). In Lake Ontario, barrier protected and drowned rivermouth coastal wetlands account for 19,000 ha (47,000 acres), approximately three quarters of the total coastal wetland area.

Connecting rivers within the Great Lakes system also support a diverse and significant quantity of wetlands (Fig. 3). The St. Clair River delta occurs where the St. Clair River outlets into Lake St. Clair, and it is the most prominent single wetland feature accounting for over 13,000 ha (32,000 acres). The Upper St. Lawrence River also supports a large area of wetland habitats that are typically numerous small embayment and drowned rivermouth wetlands associated with the Thousand Island region and St. Lawrence River shoreline.

Pressures

There are many stressors which have contributed and continue to contribute to the loss and degradation of coastal wetland area. These include: filling, dredging and draining for conversion to other uses such as urban, agricultural, marina, and cottage development; shoreline modification; water level regulation; sediment and nutrient loading from watersheds; adjacent land use; invasive species, particularly non-native species; and climate variability and change. The natural dynamics of wetlands must be considered in addressing coastal wetland stressors. Global climate variability and change have the potential to amplify the dynamics by reducing water levels in the system in addition to changing seasonal storm intensity and frequency, water level fluctuations and temperature.

<u>Agriculture</u>

Agriculture degrades wetlands in several ways, including nutrient enrichment from fertilizers, increased sediments from erosion, increased rapid runoff from drainage ditches, introduction of agricultural non-native species (reed canary grass, *Phalaris arundinacea*), destruction of inland wet meadow zones by plowing and diking, and addition of herbicides. In the southern lakes, Saginaw Bay, and Green Bay, agricultural sediments have resulted in highly turbid waters which support few or no submergent plants.

<u>Urban development</u>

Urban development degrades wetlands by hardening shoreline, filling wetlands, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increasing nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

<u>Residential shoreline development</u>

Residential development has altered many coastal wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the introduction of non-native species. Shoreline hardening can completely eliminate wetland vegetation.

<u>Mechanical alteration of shoreline</u>

Mechanical alteration takes a diversity of forms, including diking, ditching, dredging, filling, and shoreline hardening. With all of these alterations, non-native species are introduced via construction equipment or in introduced sediments. Changes in shoreline gradients and sediment conditions are often adequate to allow non-native species to become established.

Introduction of non-native species
Non-native species are introduced in many ways. Some were purposefully introduced as agricultural crops or ornamentals, later colonizing in native landscapes. Others came in as weeds in agricultural seed. Increased sediment and nutrient enrichment allow many of the most damaging aquatic weeds to out-compete native species. Most of the most damaging non-native species are either prolific seed producers or reproduce from fragments of root or rhizome. Non-native animals have also been responsible for increased degradation of coastal wetlands. One of the most damaging non-native species has been Asian carp; these species' mating and feeding result in loss of submergent vegetation in shallow marsh waters.

Pressures were described by Dennis Albert in the Coastal Wetland Plant Communities Indicator.

Management Implications
Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on a basin-wide scale has net yet occurred. Implementations of a long-term coastal wetland monitoring program is pending, however support for this program is needed by resource managers throughout the basin.

Many of the pressures result from direct human actions, and thus, with proper consideration of the impacts, can be reduced. Several organizations have designed and implemented programs to help reduce the trend toward wetland loss and degradation.

Because of growing concerns around water quality and supply, which are key Great Lakes conservation issues, and the role of wetlands in flood attenuation, nutrient cycling and sediment trapping, wetland changes will continue to be monitored closely. Providing accurate useable information to decision-makers from government to private landowners is critical to successful stewardship of the wetland resource.

Comments from the author(s)
Development of improved, accessible, and affordable remote sensing technologies and information, along with concurrent monitoring of other Great Lakes indicators, will aid in implementation and continued monitoring and reporting of this indicator.

The GLCWC database represents an important step in establishing a baseline for monitoring and reporting on Great Lakes coastal wetlands including extent and other indicators. Affordable and accurate remote sensing methodologies are required to complete the baseline and begin monitoring change in wetland area by type in the future. Other GLCWC-guided research efforts are underway to assess the use of various remote sensing technologies in addressing this current limitation. Preliminary results from these efforts indicate the potential of using radar imagery and methods of hybrid change detection for monitoring changes in wetland type and conversion.

The difficult decisions on how to address human-induced stressors causing wetlands loss have been considered for some time. Several organizations and programs continue to work to reverse the trend, though much work remains. A better understanding of wetland functions, through additional research and implementation of biological monitoring within coastal wetlands, will help ensure that wetland quality is maintained in addition to areal extent. An educated public is critical to ensuring that wise decisions about the stewardship of the Great Lakes basin ecosystem are made.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada					X	
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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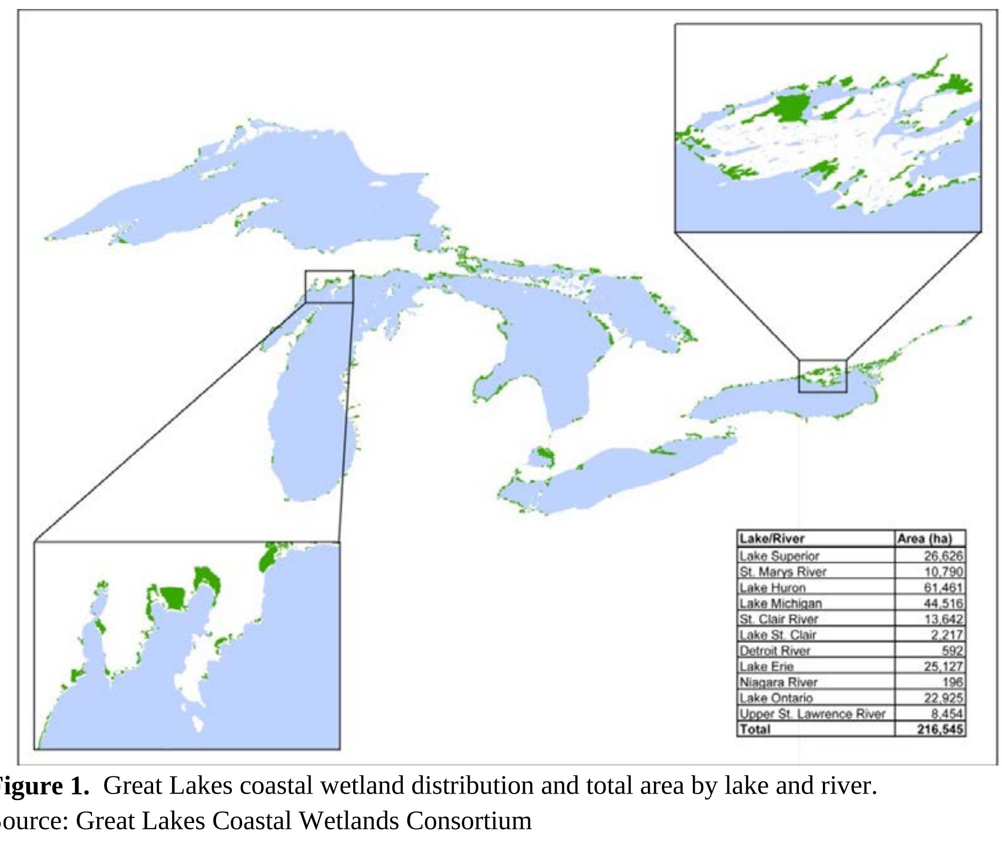
Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium

Figure 2. Coastal wetland area by geomorphic type within lakes of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

Figure 3. Coastal wetland area by geomorphic type within connecting rivers of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

Last Updated

State of the Great Lakes 2009 report.
An editor's note was added for the 2011 reporting cycle.
The "Mixed" status term used in the 2009 report were replaced with the "Fair" status term to be consistent with definitions used for the 2011 reporting cycle.



Lake/River	Area (ha)
Lake Superior	26,626
St. Marys River	10,790
Lake Huron	61,461
Lake Michigan	44,516
St. Clair River	13,642
Lake St. Clair	2,217
Detroit River	592
Lake Erie	25,127
Niagara River	196
Lake Ontario	22,925
Upper St. Lawrence River	8,454
Total	**216,545**

Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium

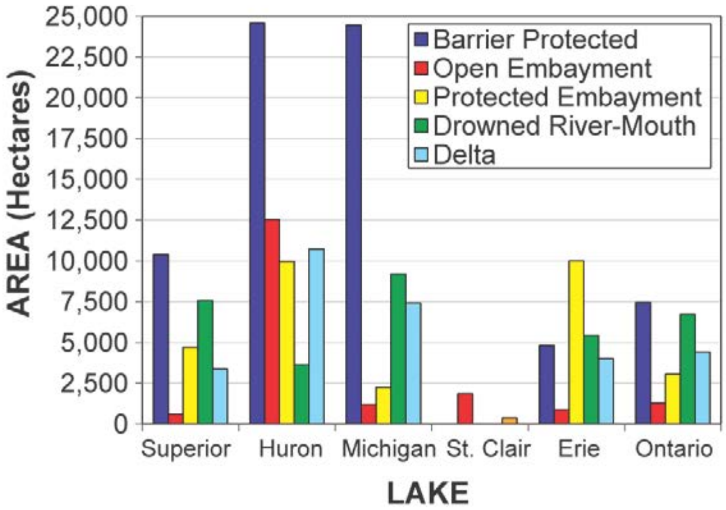


Figure 2. Coastal wetland area by geomorphic type within lakes of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

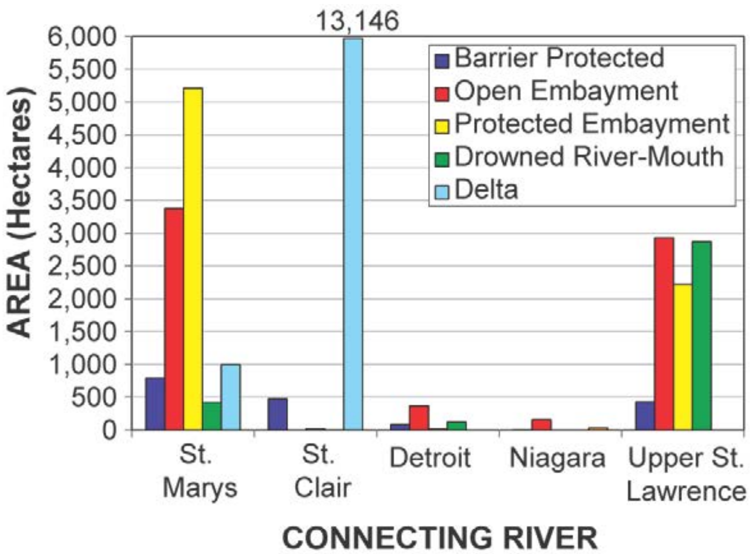


Figure 3. Coastal wetland area by geomorphic type within connecting rivers of the Great Lakes system.
Source: Great Lakes Coastal Wetlands Consortium

Coastal Wetland Plants

Overall Assessment

Status: **Fair**

Trend: **Undetermined**

Rationale: **The status of the coastal wetland plant community in the Great Lakes is mixed because Lake Superior and Lake Ontario have individual wetlands plant communities that have a good status. Lake Michigan, Lake Huron, and Lake Erie are all listed with a fair status of their coastal wetland plant community health.**

Note: In the spring of 2011, an effort was put forth by a consortium of universities that established a statistically sound basin-wide coastal wetland monitoring program. This indicator will be used, along with others, at the majority of coastal wetlands with a surface water connection to the Great Lakes that are greater than 4 hectares in size. The effort is binational and basin wide and will produce scientifically-defensible information on the status and trends of Great Lakes coastal wetlands.

Lake-by-Lake Assessment

Lake Superior

Status: Fair

Trend: Undetermined

Rationale: Degradation around major urban areas. Coastal wetlands plants in Lake Superior generally have a good status.

Lake Michigan

Status: Fair

Trend: Undetermined

Rationale: High quality wetlands in the northern part of the lake. Lakes Michigan's northern open embayments and protected embayment are higher quality compared to the coastal wetlands in the drowned river mouth.

Lake Huron

Status: Fair

Trend: Undetermined

Rationale: Plowing, raking and mowing on Saginaw Bay wetland during low water causing degradation. Northern wetlands are higher quality. Lake Huron's northern protected embayments and open embayments generally have fair to good status with individual wetlands having good status. However, in Saginaw Bay the open embayment have poor to fair status. Loss of emergent vegetation has occurred in wetlands bordering the St. Marys River, connecting river between Lakes Superior and Huron during 1999 to 2011 low-water conditions, probably the result of both winter ice and ship wakes on exposed sediments and vegetation beds.

Lake Erie

Status: Fair

Trend: Deteriorating

Rationale: Generally poor on U.S. shore with some restoration at Metzger Marsh Ohio. Presque Isle, Pennsylvania and Long Point, Ontario have high quality wetlands. Lake Erie's open and sand-spit embayments have a fair status. The lake is also classified as deteriorating based on historically data from 1975 in Lake Erie.

Lake Ontario
Status: Poor
Trend: Unchanging
Rationale: Degraded by nutrient loading and water level control. Some scattered Canadian wetlands of higher quality. Lake Ontario's barrier beach lagoons have higher quality than the drowned river mouths and the protected embayments. However, individual coastal wetlands in the protected embayments have good status.

Purpose

- To assess the level of native vegetative diversity and cover for use as a surrogate measure of quality of coastal wetlands which are impacted by coastal manipulation or input of sediments.
- The Coastal Wetland Plant Communities indicator is used in the Great Lakes indicator suite as a State indicator in the Aquatic-dependent Life top level reporting category.

Ecosystem Objective

Coastal wetlands throughout the Great Lakes basin should be dominated by native vegetation, with low numbers of invasive and non-native plants species that have low levels of coverage. Significant wetland areas in the Great Lakes System that are threatened by urban and agricultural development and waste disposal activities should be identified, preserved and, where necessary, rehabilitated (Annex 13 GLWQA). This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin and beneficial uses dependent on healthy wetlands (Annex 2 GLWQA).

Ecological Condition

The conditions of the plant community in coastal wetlands naturally differ across the Great Lakes basin, due to differences in geomorphic and climatic conditions. The characteristic size and plant diversity of coastal wetlands vary by wetland type, lake, and latitude; in this document these differences will be described broadly as "regional wetland types."

Regional Wetland Types

Coastal wetlands are divided into three main categories based on the hydrology of the area. Lacustrine wetlands are connected to the Great Lakes, and they are largely impacted by fluctuations in lake levels. Riverine wetlands occur near rivers that are found in the Great Lakes basin. Typically, the quality of riverine wetlands are dominated by the river drainage system, however coastal process can cause lakes to flood back into these wetlands. The last type of coastal wetlands is barrier protected. Barrier protected wetlands are derived from coastal processes that separate the wetland from the Great Lakes by barrier beaches. All coastal wetlands contain different zones (swamp, meadow, emergent, submergent), some of which may be absent in certain types of wetlands. Great Lakes wetlands were classified and mapped in 2004 (see http://glc.org/wetlands/inventory.html). United States coastal wetlands inventory map (see http://glc.org/wetlands/us_mapping.html) and Canada coastal wetland inventory map (see http://glc.org/wetlands/can_mapping.html).

Lake Variations

Physical properties such as the type of shoreline and chemical and physical water quality parameters vary between great lakes. The variation of nutrient levels creates a north to south gradient, and nutrient levels also increase in lake basins further to the east. This includes Lake Erie, Lake Ontario, and in the upper St. Lawrence River. Lake Superior is the most distinct great lake due to its low alkalinity and prevalence of bedrock shoreline.

Differences in Latitude

Latitudinal variations result in different climatic conditions based on the location of the coastal wetlands. Temperature differences between the north and south lead to differences in the species of plants found in coastal wetlands. The southern portion of the Great Lakes also has increased agricultural activity along the shorelines, resulting in increased nutrient loads, sedimentation and non-native species introductions.

There are characteristics of coastal wetlands that make usage of plants as indicators difficult in certain conditions. Among these are:

Water level fluctuation
Great Lakes water levels fluctuate greatly from year to year. Either an increase or decrease in water level can result in changes in numbers of species or overall species composition in the entire wetland or in specific zones. Such a change makes it difficult to monitor change over time. Changes are great in two zones: the wet meadow, where grasses and sedges may disappear in high water or new annuals may appear in low water, and in shallow emergent or submergent zones, where submergent and floating plants may disappear when water levels drop rapidly. Recent studies indicate that prolonged periods of low water favor rapid expansion of invasive species like Phragmites australis (Albert and Brown 2008, Lishawa etal. 2010)

Lake-wide alterations
For the southern lakes, most wetlands have been dramatically altered by both intensive agriculture and urban development of the shoreline. Alterations of coastal wetland especially in the wet meadow and upper emergent zone will lead to drier conditions which may allow invasive species to establish.

There are several hundred species of plants that occur within coastal wetlands. To evaluate the status of wetlands using plants as indicators, several different plant metrics have been suggested. These are discussed briefly here.

Invasive Plant Cover
The invasive plant cover for an entire site and all coastal wetlands zones including wet meadows, dry emergent, flooded emergent and submergent zones that are considered high quality should not have any invasive plants present. For low quality coastal wetlands all zones are expected to have 25 to 50% cover of invasive plants. Invasive plant cover that is more than 50% is considered to be very low quality (Albert, 2008). Invasive plant cover includes both native and non-native invasive plants.

Invasive Frequency
The invasive frequency is measured similar to invasive plant cover. Invasive plants are expected to be absent in all coastal wetland zones to be considered a high quality coastal wetlands. When invasive frequency is consider low to very low quality invasive plants are present in 25 to more than 50% of the coastal wetland (Albert, 2008). Invasive frequency includes both native and non-native invasive plants.

Mean Conservatism (Native Species)
Conservatism indices were developed using the Floristic Quality Assessment (FQA) program. The mean conservatism is an index that measures the specificity of a particular species of plant to a specific habitat (Albert, 2008). The mean conservatism index also evaluates the intactness of coastal wetlands, which is based on all of the plant species in the wetlands. A species is considered conservative if it only grows in a specific, high quality environment. Plant species that are ubiquitous receive a low conservatism score (0) however plant species that are rare and only found in specific habitats are assigned a high conservatism score (10) (Swink, and Wilhelm, 1994). The mean conservatism index includes all of the species found in a habitat.

Mean conservatism ratios may also be calculated. The ratio is derived by taking the mean conservatism index for all species present divided by the mean conservatism index for native species. Mean conservatism ratios that are less than 0.79 are expected to represent large numbers of exotic species present with degraded conditions. Mean conservatism ratios that are 0.8 and above represent medium to high quality conservatism with many native species present (Albert, 2008). See Table 1.

Lake Assessment Scale for Mean Conservatism Scores
Good – 6.0 and above
Fair – 3.0 - 5.9
Poor – 0.0 - 2.9
Mixed – Combination of two categories

The total marsh in Lake Superior appears to have the highest quality wetlands when compared to the other lakes with a 6.4 conservatism index. Lake Michigan and Lake Huron have very similar total marsh conservatism indices ranging from 4.5 to 5.6. Lake Erie has a fair conservatism index ranging from 3.1 to 4.5. However, compared to historic ratings the coastal wetlands are deteriorating. Lastly, Lake Ontario has a fair conservatism index with a range consisting of 3.9 to 5.7. Overall, a majority of the lake fall into the fair quality of coastal wetland based on the conservatism index.

The state of the wetland plant community is quite variable, ranging from good to poor across the Great Lakes basin. The wetlands in individual lake basins are often similar in their characteristics because of water level controls and lake-wide near-shore management practices. There is evidence that the plant component in some wetlands is deteriorating in response to extremely low water levels in some of the Great Lakes, but this deterioration is not seen in all wetlands within these lakes. In general, there is slow deterioration in many wetlands as shoreline alterations introduce non-native species. However, the turbidity of the southern Great Lakes has reduced with expansion of zebra mussels, resulting in improved submergent plant diversity in many wetlands.

Trends in wetland health based on plants have not been well established. In the southern Great Lakes (Lake Erie, Lake Ontario, and the Upper St. Lawrence River), almost all wetlands are degraded by either water level control, nutrient enrichment, sedimentation, or a combination of these factors. Probably the strongest demonstration of this is the prevalence of broad zones of cat-tails, reduced submergent diversity and coverage, and prevalence of non-native plants, including reed (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), purple loosestrife (*Lythrum salicaria*), curly pondweed (*Potamogeton crispus*), Eurasian milfoil (*Myriophyllum spicatum*), and frog bit (*Hydrocharis morsus-ranae*). In the remaining Great Lakes (Lake St. Clair, Lake Huron, Lake Michigan, Georgian Bay, Lake Superior, and their connecting rivers), intact, diverse wetlands can be found for most geomorphic wetland types. However, low water conditions have resulted in the almost explosive expansion of reed in many wetlands, especially in Lake St. Clair and southern Lake Huron, including Saginaw Bay (Albert and Brown 2008). As water levels rise, the response of reed should be monitored.

One of the disturbing trends is the expansion of frog bit, a floating plant that forms dense mats capable of eliminating submergent plants, from the St. Lawrence River and Lake Ontario westward into Lake Erie. This expansion will probably continue into all or many of the remaining Great Lakes, and has been seen since 2008, when additional populations have been documented in Lake St. Clair and the St. Clair River delta, as well as along the St. Marys River connecting Lakes Huron and Superior.

Studies in the northern Great Lakes have demonstrated that non-native species like reed, reed canary grass, and purple loosestrife have become established throughout the Great Lakes, but that the abundance of these species is low, often restricted to only local disturbances such as docks and boat channels. It appears that undisturbed marshes are not easily colonized by these species. However, as these species become locally established, seeds or fragments of plants may be able to establish themselves when water level changes create appropriate sediment conditions. Hybrid cat-tail (*Typha* x *glauca*) expansion has also been recently documented in northern Lakes Michigan andHuron and the St. Marys River (Lishawa etal. 2010).

Pressures

Agriculture

Agriculture degrades wetlands in several ways, including nutrient enrichment from fertilizers, increased sediments from erosion, increased rapid runoff from drainage ditches, introduction of agricultural non-native species (reed canary grass), destruction of inland wet meadow zone by plowing and diking, and addition of herbicides. In the southern lakes, Saginaw Bay, and Green Bay, agricultural sediments have resulted in highly turbid waters which support few or no submergent plants.

Urban development

Urban development degrades wetlands by hardening shoreline, filling wetland, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increased nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

Residential shoreline development

Along many coastal wetlands, residential development has altered wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the introduction of non-native species. Shoreline hardening can completely eliminate wetland vegetation.

Mechanical alteration of shoreline

Mechanical alteration takes a diversity of forms, including diking, ditching, dredging, filling, shoreline hardening, and disking and plowing of coastal vegetation by private landowners. With all of these alterations, non-native species are introduced by construction equipment or in introduced sediments. Changes in shoreline gradients and sediment conditions are often adequate to allow non-native species to become established. Disking and plowing of coastal wetlands continues through 2011 in exposed coastal marshes along Saginaw Bay, Grand Traverse Bay, and on islands within the St. Clair River delta.

Introduction of non-native species

Non-native species are introduced in many ways. Some were purposefully introduced as agricultural crops or ornamentals, later colonizing in native landscapes. Others came in as weeds in agricultural seed. Increased sediment and nutrient enrichment allow many of the worst aquatic weeds to out-compete native species. Most of the worst non-native species are either prolific seed producers or reproduce from fragments of root or rhizome. Non-native animals have also been responsible for increased degradation of coastal wetlands. One of the worst invasive species has been Asian carp, who's mating and feeding result in loss of submergent vegetation in shallow marsh waters.

Pressures were described by Dennis Albert in the Coastal Wetland Plant Communities Indicator.

Management Challenges/Opportunities

Although monitoring protocols have been developed for this indicator by the Great Lakes Coastal Wetlands Consortium, monitoring on basin wide scale has net yet occurred. Implementations of a long term coastal wetland monitoring program is pending, however support for this program is need4ed by resource managers throughout the basin.

While plants are currently being evaluated as indicators of specific types of degradation, there are limited examples of the effects of changing management on plant composition. Restoration efforts at Cootes Paradise, Oshawa Second, and Metzger Marsh have recently evaluated a number of restoration approaches to restore submergent and emergent marsh vegetation, including carp elimination, hydrologic restoration, sediment control, and plant introduction. The effect of agriculture and urban sediments may be reduced by incorporating buffer strips along streams and drains. Nutrient enrichment could be reduced by more effective fertilizer application, thereby reducing algal blooms. However, even slight levels of nutrient enrichment cause dramatic increases in submergent plant coverage. For most urban areas it may prove impossible to reduce nutrient loads adequately to restore native aquatic vegetation. Mechanical disturbance of coastal sediments appears to be one of the primary vectors for introduction of non-native species. Thorough cleaning of equipment to eliminate seed source and monitoring following disturbances might reduce new introductions of non-native plants.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			

Clarifying Notes: Data was collected by the Great Lakes Coastal Wetlands Consortium using the Great Lakes Coastal Wetland Monitoring Plan. There has been a lot of sampling, with most of the larger marshes in all of the Great Lakes being sampled. The only exception is Georgian Bay, where the sampling has been spottier and the overall development of indicators less detailed.

Acknowledgments

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Dennis Albert, Michigan Natural Features Inventory, Michigan State University Extension. (2006-2008). Curently Senior Research Faculty, Horticulture Department, Oregon State University.

Danielle J. Sass, Oak Ridge Institute of Science and Education (ORISE) Research Fellow, Appointed to the U.S. Environmental Protection Agency (U.S. EPA), Great Lakes National Program Office (GLNPO) (2008)

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List of Tables

Table 1. Mean Conservatism Scores for the Great Lakes Coastal Wetlands Plant Communities in Meadow, and Emergent zones, and the Total Marsh

Source: Central Michigan University and Oregon State University. Data were collected and interpreted from Table 3-4 written by Albert, D.A., March 2008. Great Lakes Coastal Wetlands Monitoring Plan, Chapter Three Vegetation Community Indicators. Developed by the Great Lakes Coastal Wetlands Consortium, A project of the Great Lakes Commission

Last Updated

State of the Great Lakes 2009 report.

An editor's note was added for the 2011 reporting cycle.

The "Mixed" status term used in the 2009 report were replaced with the "Fair" status term to be consistent with definitions used for the 2011 reporting cycle.

Mean Conservatism Scores for the Great Lakes Coastal Wetlands Plant Communities

LAKE or REGIONAL MARSH TYPE	MEADOW ZONE	EMERGENT ZONE	TOTAL MARSH
Lake Erie Open Embayments**	3.1 (4.6)	3.8 (5.3)	3.7 (5.3)
Lake Erie Sand-spit Embayments	4.3 (4.5)	4.4 (6.1)	4.5 (4.8)
Georgian Bay Protected Embayments*	5.1 (6.5)	6.4 (7.2)	5.8 (6.8)
Lake Huron (northern) protected Embayments	5.1	5.6	5.6
Lake Huron (northern) Open Embayments (Rich Fens)	5.5	4.5	5.1
Lake Huron's Saginaw Bay Open Embayment	3.2	4.5	3.9
Lake Huron Swale Complex (Barrier Enclosed)	-	-	4.9 (6.4)
Lake Michigan Drowned River Mouths	4.0	4.9	4.5
Lakes Michigan (northern) Open Embayments (Rich Fens)	5.5	4.5	5.1
Lake Michigan (northern) Protected Embayments	5.1	5.6	5.6
Lake Michigan Swale Complex (Barrier Enclosed)	-	-	5.3 (6.3)
Lake Ontario Barrier Beach Lagoons	5.0	5.7	5.3
Lake Ontario Drowned River Mouths	4.2	4.3	4.2
Lake Ontario Protected Embayments*	4.7 (6.4)	3.9 (5.8)	4.5 (6.3)
Lake St. Clair Open Embayments**	3.1	3.8	3.7
Lake Superior Barrier Beach Lagoons & Riverine Wetlands	6.3	6.7	6.4
Lake Superior Swale Complex (Barrier Enclosed)	-	-	5.9 (6.9)
St. Clair River Delta	4.2	5.5	4.7
St. Lawrence River Drowned River Mouths	4.4	5.5	5.0
St. Marys River Connecting Channel	5.1	5.6	5.6

Table 1. Mean Conservatism Scores for the Great Lakes Coastal Wetlands Plant Communities in Meadow, and Emergent zones, and the Total Marsh

* For Lake Ontario and Georgian Bay protected wetlands the mean scores for each zone are based on the score of several wetlands rather on a mean coverage value for all of the marshes studies. The maximum score of a single wetland for each zone is shown in parenthesis when the data is available ( ).

**For Lake Erie, mean C scores from historic data collected in high quality wetland at Perry's Victory Monument (Stuckey 1975) is show in brackets [ ].

Source: Central Michigan University and Oregon State University. Data were collected and interpreted from Table 3-4 written by Albert, D.A., March 2008. Great Lakes Coastal Wetlands Monitoring Plan, Chapter Three Vegetation Community Indicators. Developed by the Great Lakes Coastal Wetlands Consortium, A project of the Great Lakes Commission

Conserving and Protecting Forest Lands

Overall Assessment

Trend: **Undetermined**

Rationale: **Previously, SOLEC reported province-wide and state-wide on forest certifications only and tracked an increasing trend in forest certifications. On further consideration it was concluded that the forest certification measure did not fully capture the intent of the indicator. The increasing trend in certifications did not necessarily reflect any increase in well managed forests since the certification programs were new and the trend reflected start-up. Furthermore the lack of specificity to the basin geography was problematic. This report establishes baseline Great Lakes basin specific data for future trend reporting; as such the current trend could not be stated. However, anecdotally the relatively mature sustainable forest management infrastructure in Canada and the United States suggests that publicly owned forests would be managed sustainably as a matter of course, and that the opportunity for variation in management quality lies primarily with privately held forests.**

Lake-by-Lake Assessment

Note: Lake-by-Lake assessment is not possible at this time. Some data is spatial at this time and some is available at county resolution, but considerable information must still be estimated proportionally from state-based summaries. Further extrapolation to lake basins was not attempted.

Other Spatial Scales: State-by-State

Illinois: Lake Michigan

Trend: Undetermined

Rationale: The very limited extent of the Lake Michigan basin (25,782 ha) in Illinois is dominated by urban development, being Chicago and surrounds, with considerable hardened surfaces. The state's basin has six per cent (1,522 ha) forest cover in what would be considered forest stands. These residual forests appear to be entirely under local government jurisdiction as park and natural areas protected spaces. It is notable that most residential urban neighborhoods are mature and exhibit considerable forest cover that on visual inspection often exceeds 25%.

Indiana: Lake Michigan and Lake Erie

Trend: Undetermined

Rationale: A number of significant urbanized areas are located in the Indiana basins of both Lake Michigan (East Chicago, Gary, Michigan City) and Lake Erie (Fort Wayne); however, urbanization does not dominate the landscape patterns overall. Tree cover is significant in the Lake Michigan basin portion. In the Lake Erie basin the agricultural land base dominates but has dispersed forest cover both as a component of the farms but also as protected spaces in and outside urban areas. No certified forests are identified in the Indiana Great Lakes basin but due to various agencies attached to protected spaces there is some uncertainty here as these lands were not quantified but would qualify as managed forests for indicator purposes. Identified managed forests include ATFS certified holdings (4,923 ha) being six per cent of the identified forest area in the landscape and an estimate extrapolated to the Great Lakes basin from 2008 county specific data for the tax incentive managed forests (13,750 ha) (Indiana Classified Forest and Wildlands program which provides an option to join the Indiana Classified Forest Certified Group which provides certification through the American Tree Farm System).

Michigan: Lake Superior, Lake Michigan, Lake Huron, and Lake Erie

Trend: Undetermined

Rationale: Significant certified forest lands were identified being 45 per cent (2.5 million ha) of the identified forested area in the Michigan Great Lakes basin (5.5 million ha). The managed forests may be larger but the actual enrollment of lands in the tax incentive forests category was not determined and may increase the area under management were it determined and included in the sum. Thirty seven per cent (5.5 million ha) of the basin is forest area.

Minnesota: Lake Superior

Trend: Undetermined

Rationale: The Lake Superior basin in Minnesota has 53 per cent (840,253 ha) forest cover. A total of 45 per cent (376,404 ha) of the forest area was identified as well managed for the purposes of the indicator.

New York: Lake Erie, Lake Ontario

Trend: Undetermined

Rationale: New York State has 48 per cent (2,500,783 ha) of the Great Lakes basin in forest cover. Three per cent of the basin was identified as well managed forests.

Ohio: Lake Erie

Trend: Undetermined

Rationale: The Ohio Great Lakes basin is 14 per cent (433,626 ha) forest cover and 9 per cent (41,086 ha) of this was identified as well managed forest.

Ontario: Lake Superior, Lake Huron, Lake Erie, Lake Ontario

Trend: Undetermined

Rationale: In the Great Lakes basin 66 per cent (almost 15 million ha) is forest cover. The identified managed forest is 78% (11.5 million ha) of the forest area. The westerly half of the Lake Ontario basin in Ontario is heavily agricultural and/or urban with very little forest cover.

Pennsylvania: Lake Erie

Trend: Undetermined

Rationale: Only one per cent (931 ha) of the 46 per cent (71,034 ha) of the Great Lakes basin which is forest cover was identified as well managed. This is likely an underestimate as the forest tax law program (Clean and Green Program) land area was not ascertained.

Wisconsin: Lake Superior, Lake Michigan

Trend: Undetermined

Rationale: While 95 per cent (1.5 million ha) of the forest cover in the Wisconsin Great Lakes basin was identified as well managed, the forest cover is highly concentrated in the north of Wisconsin. The southern three quarters of the Wisconsin Lake Erie basin is heavily agricultural with very limited forest cover.

Purpose

- Forest management objectives relating to water resources are to minimize downstream water yield fluctuations, water quality degradation, and the harmful alteration, disruption, or destruction of fish habitat.
- To assess proportion of forests and forest management activities that meet best management practices, as reflected by a sustainable forest management third-party certification or other relevant legislation determining forest management standards, to protect water-related resources (using Criterion 4.3.a of the Montreal Process).
- Third-party certifications as those endorsed by the Programme for the Certification of Forest Certification schemes (PEFC) such as the Sustainable Forestry Initiative (SFI), the Canadian Standards Association (CSA), the Forest Stewardship Council (FSC), and the American Tree Farm System (ATFS).

- Relevant legislation specifies signing and approval of forest management plans by competent forest managers, normally registered professionals, and under such programs as provincial and state tax incentive enrollment programs (e.g. Wisconsin Managed Forest Law) and uncertified but official forest management plans (e.g. Ontario Forest Management Plans).
- The Conserving and Protecting Forest Lands indicator is used in the Great Lakes indicator suite as a Response indicator in the Restoration and Protection top level reporting category.

Ecosystem Objective

To minimize effects of forest management practices on water quality (GLWQA Annex 2).

Forest management objectives relating to water resources are to minimize downstream water yield fluctuations, water quality degradation, and the harmful alteration, disruption, or destruction of fish habitat. Sustainable forest management practices include standards (roads, water crossings, soil protection, vegetative cover) implemented during harvesting operations by the forest industry that maintain the quantity and quality of water within, and flowing from, forested ecosystems. The primary focus for water conservation centers on producing potable water for human and wildlife use, and suitable aquatic environments for fish, plants and other animals.

The indicator considers change in forest lands certified by programs endorsed by the Programme for the Certification of Forest Certification schemes (PEFC). The relevant programs in North America include the Sustainable Forestry Initiative (SFI), the Canadian Standards Association (CSA), the Forest Stewardship Council (FSC), and the American Tree Farm System (ATFS). The indicator also considers forest lands managed under a plan accepted by credible government authorities as being sustainable forest management. These plans include forest management plans signed by registered professionals in such programs as provincial and state tax incentive enrollment programs (e.g. Wisconsin Managed Forest Law) and sustainable forest management plans (e.g. Ontario Forest Management Plans). These third-party certifications and professionally endorsed plans ensure forests are grown and harvested in ways that protect local ecosystems.

Linkages

Forests reduce concentrations of greenhouse gases in the atmosphere, minimize sedimentation in lakes and rivers, and protect against flooding, mudslides and erosion.

Management Challenges/Opportunities

Costs for certifications and their maintenance, plus land title encumbrances associated with government programs promoting private land forestry deter many land owners from participating in formal agreements but they may practice good management voluntarily.

Many private and public land parcels with forest cover of some type in the Great Lakes watersheds might never be considered well managed forest lands either due to limited size of the parcel or due to the main use being residential or protected (e.g. park land or a conservation designation, although some have been certified for instance as in Wisconsin).

Comments from the author

The hypothesis that well managed forest lands is a suitable proxy measure of the degree of protection afforded water quality from the terrestrial watershed is tenable but still constitutes an assumption. Goodly portions of the basin are dominated by agricultural lands. Water quality in these agricultural lands is being managed with mitigation which would not qualify as well managed forest. While some mitigation techniques would employ tree cover in buffer strips these would not be captured in managed or certified forest area. Non-tree cover measures also mitigate the effects of agriculture and so one must be careful not to jump to conclusions but rather use the indications here to decide what further tests may be warranted before conclusions are drawn.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			

Clarifying Notes:

Data for documenting water yield trends and timing, water quality, and the health of aquatic flora and fauna is not currently collected in association with individual forest management operations. Detailed, long-term local monitoring is also required to separate the effects of forest management from natural variation. A proxy indicator has therefore been used to monitor forest water resources.

Information is incomplete due to survey response rate variability.

Acknowledgments

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List of Tables

Table 1. Estimates of Great Lakes basin well managed forest area.

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Table 1 Estimates[1] of Great Lakes basin well managed forest[2] area.

State or Province	Total area in GL basin	Forested area in the GL basin[3]	% of GL basin area forested	American Tree Farm System (ha)	Third Party Certifica-tions[4] (ha) (CSA, SFI, FSC)	Tax Incentive Program Managed Forests (ha)	Other managed forest (ha)	Estimate[5] of well managed forest (ha)	Forest identified as well managed
Illinois	25,782	1,522	6%	0	0	0	1,522	1,522	100%
Indiana	906,881	86,980	10%	4,923	0	13,750	Not quantified	13,750	16%
Michigan	14,845,392	5,565,634	37%	334,355	2,149,987	485,623	Not quantified	2,484,342	45%
Minnesota	1,590,090	840,253	53%	0	338,185	38,219	Not quantified	376,404	45%
New York	5,170,230	2,500,783	48%	23,709	36,459	41,881	Not quantified	78,341	3%
Ohio	3,015,390	433,626	14%	9,066	2,091	19,804	19,191	41,086	9%
Ontario	22,567,592	14,785,506	66%	0	8,297,605	392,469	2,831,818	11,521,892	78%
Pennsylvania	155,341	71,034	46%	931	0	Not quantified	Not quantified	931	1%
Wisconsin	4,453,613	1,561,647	35%	288,537	858,997	403,212	342,352	1,489,886	95%

[1] Great Lakes basin specific data, GIS datasets, are rare at this time (Wisconsin), so data is largely extrapolated from county sums.

[2] Well managed forest = forest area managed sustainably under a forest management plan, or equivalent mechanism, supervised by a competent authority.

[3] Satellite thematic data forest and forested wetlands, Dale Gormanson, USDA Forest Service, Northern Research Station, St. Paul, MN

[4] Double counting avoided. Private certifications were included where geographic locale of the forest holding was identifiable to the Great Lakes basin. CSA - Canadian Standards Association; SFI - Sustainable Forestry Initiative, FSC - Forest Stewardship Council

[5] Sums derived to avoid double counting to the extent possible, row totals are therefore not necessarily the sum across the columns; for example, American Tree Farm System certifications are often also enrolled in a tax incentive programs, and so on

Conserving Soil, Improving Water Quality and Enhancing Wildlife Habitat on Agricultural Lands

Overall Assessment

Trend: Increasing

Rationale: The number of best management practices implemented on private agricultural lands aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased from 2005 to present.

Lake-by-Lake Assessment

Lake Superior

Canadian Trend: Undetermined

Canadian Rationale: Small proportion of agricultural land in the Ontario portion of this lakeshed.

U.S. Trend: Increasing

U.S. Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Lake Michigan

Canadian Trend: Not Applicable

Canadian Rationale: Lake Michigan entirely within U.S. boundary.

U.S. Trend: Increasing

U.S. Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Lake Huron

Canadian Trend: Increasing (for part of lakeshed assessed)

Canadian Rationale: The number of best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

U.S. Trend: Increasing

U.S. Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Lake Erie

Canadian Trend: Increasing

Canadian Rationale: The number of best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased

U.S. Trend: Increasing

U.S. Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Lake Ontario
Canadian Trend: Increasing
Canadian Rationale: The number of best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased
U.S. Trend: Increasing
U.S. Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Other Spatial Scales
Lower Fox River Watershed (U.S.)
Trend: Increasing
Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Saginaw River Watershed (U.S.)
Trend: Increasing
Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Maumee River Watershed (U.S.)
Trend: Increasing
Rationale: The area of land removed from previous agricultural production has increased. The area of agricultural land affected by best management practices aimed at conserving soil, improving water quality and enhancing wildlife habitat has increased.

Purpose
- To quantify the number of field-scale best management practices (BMPs), both structural and practice/technology, implemented and assumed maintained on private agricultural land in Great Lakes basin portions of Canada and the United States
- To determine progress towards the general goals of reducing on- and off-site impacts of agricultural production on water quality and quantity, soil quality and wildlife habitat/populations.
- The Conserving Soil, Improving Water Quality and Enhancing Wildlife Habitat on Agricultural Lands indicator is used in the Great Lakes indicator suite as a response indicator in the Restoration and Protection top level reporting category.

Ecosystem Objective
This indicator supports Annexes 2, 3, 12 and 13 of the GLWQA.

Ecological Condition
Measure
The most readily accessible and reliable source of data for this type of indicator at this scale is the databases used to track the number of best management practices (BMPs) financially supported by U.S. and Canadian federal agri-environmental cost-share and incentive programs.

Adoption of practices in the U.S. is quantified by participation in Farm Bill programs including:

- the Conservation Reserve Program (CRP),
- Conservation Reserve Enhancement Program (CREP),
- Wildlife Habitat Incentives Program (WHIP),
- Conservation Stewardship Program (CSP), and,
- Environmental Quality Incentives Program (EQIP).

This participation is documented by the Farm Service Agency (FSA) database and the Natural Resources Conservation Service (NRCS) Protracts database.

Adoption of practices in Ontario, Canada is documented by participation in:

- Federal/Provincial Canada Ontario Farm Stewardship Program (COFSP: 2005-2011),
- Greencover Canada (GC: 2005-2009 only, Ontario only) and,
- Canada-Ontario Water Supply Expansion Program (COWSEP: 2005-2009 only).

Databases for these agri-environmental programs do not include practices that may have been solely supported by state/provincial or local programs or implemented by agricultural producers without federal government financial support. Thus, they are a conservative estimate of the agricultural sector's response to conserving soil, improving water quality/quantity and enhancing wildlife habitat.

The practices tabulated include both structural and practice/technology activities. Examples of structural activities include:

- establishment of permanent vegetative filter strips at field edges to reduce non-point source pollutant movement to surface water;
- construction of manure storages so that nutrients can be applied at the most appropriate times of the year and to prevent runoff from manure piles;
- construction of retention ponds to trap runoff from confined animal feeding operations;
- diversion of clean water around agricultural facilities;
- fencing livestock out of riparian areas;
- erosion control structures;
- nutrient recovery and water treatment technologies; and
- complete retirement of fields and marginal land from agricultural production by tree planting and natural vegetative succession.

Examples of practice/technology activities include:

- practicing integrated pest management(IPM) so that pesticides are used judiciously;
- practicing nutrient management (NM) to match nutrient application with crop needs using optimal timing, rates and methods of nutrient application to increase plant utilization and avoid field losses from runoff or leaching;
- using precision farming tools to maintain specified distances from streams and wells, and minimize overlap of applications of pesticides and nutrients;
- irrigation scheduling;
- field wind strips; and
- cover crops.

For the indicator, the number of selected practices funded are tabulated for fiscal years since April 1, 2005 in Ontario and October 1, 2004 in the United States. The number of practices is normalized by the number of hectares of agricultural land for each spatial unit as determined by the Canada 2006 Census of Agriculture or United States

2006 National Land Cover Data (NLCD).

Overall Assessment - Canada

In Ontario, the number of BMPs funded and implemented per hectare of agricultural land has been cumulatively increasing since 2005. The Environmental Farm Plan Program directs farmers to priority actions on their farms through a process of education and risk assessment. Associated cost-share funding helps to accelerate their adoption of these practices or actions. Over the past 6 years, funding has accelerated the implementation of almost 19,000 best management practices by producers in Ontario (Figure1). The rate of increase has slowed as agri-environmental program funding available for cost share has decreased since 2008. The distribution by county (Figure 2) shows the areas of the province which have had the most BMPs per 1000 ha of agricultural land cumulatively adopted. Southwestern Ontario, with the greatest proportion of cropland and livestock production in the province, has generally had the greatest intensity of funding and adoption of BMPs.

A spatial analysis of the adoption of nutrient management related BMPs over the period 2005-2010 was also conducted. From the overall number of BMPs supported, a subset of 33 practices for both livestock and crop production nutrient management were selected. The crop spatial analysis compared the number of crop nutrient management BMPs adopted to the area receiving commercial fertilizer inputs on a county basis (Figure 3). This relationship is highly significant with 87% of the variation in adoption being explained. The livestock spatial analysis compared the number of livestock nutrient management BMPs adopted with the amount of nutrients produced in manure on a county basis. Figure 4 illustrates the BMP adoption relationship with phosphorus produced from manure; 92% of the variation in adoption is explained by total manure P generated in each county. The breakpoints used for mapping high, medium and low categories are included in the captions for each figure. Both analyses show there is a higher adoption of nutrient management BMPs in Ontario where there is an increased risk of excess nutrients.

Overall Assessment - United States

The number of active contracts between the USDA Farm Service Agency and private landowners that remove land from agricultural production increased from 34,662 in 2005 to 44, 965 in 2010. This increase in contracts translates into an increase in area from 189,153 hectares (468,202 acres) to 239, 128 hectares (591,903 acres). This increase represents 2.1% of agricultural land use based on 2006 National Land Cover Data (NLCD) representing both cultivated cropland and hayland/pasture land.

The cumulative number of applied best management practices on privately owned agricultural land and cost shared by the USDA Natural Resources Conservation Service (NRCS) implemented under the Environmental Quality Incentive Program, Conservation Stewardship Program, or Wildlife Habitat Incentives Program increased from 4,131 to 14,173. It is important to note that these numbers assume a BMP applied using NRCS cost-share monies from 2005-2010 are assumed to be present and maintained for the expected lifespan of the respective BMP as well as in 2010 following termination of any NRCS contracts made during the period of interest (2005-2010). While some contracts may be active as of 2010, earlier contracts made between NRCS and a landowner (e.g., 2005-2007) may have expired.

This increase in best management practices translated into an increase in cumulative area of agricultural land treated from 7,496,810 hectares (18,556,459 acres) to 10,943,513 hectares (27,087,902 acres). It is important to note that differences in NRCS program goals, implementation, and tracking may affect these calculated areas of land affected. While programs like EQIP and WHIP are focused on particular BMPs implemented in specific areas of an agricultural operation, CSP provides annual payments for operation-level environmental benefits. Therefore, acreage accounted for by EQIP/WHIP may be characterized as practice-level where CSP acreage may be characterized as operation-level. When viewed relative to area of agricultural land (2006 NLCD) and USGS 8-digit HUCs, cumulative implementation of NRCS practices from 2005 to 2010 ranges from 0 to 58 practices/1000 hectares (Figure 5). The largest implementation relative to agricultural land (58) occurs along the north shore of Lake Superior. However, closer inspection of this area indicates the smallest total area of agricultural land (243 ha) and only 14 implemented practices.

A closer inspection of watersheds dominated by agricultural land use (cultivated crops and hayland/pastureland) indicated central and southern portions of the U.S. side of the basin have the greatest potential for implementation of agricultural best management practices (Figure 6). Some of these watersheds include the Lower Fox River (Wisconsin), Saginaw Bay watersheds (Michigan), and Western Lake Erie watersheds (Michigan, Ohio, and Indiana).

<u>Lakeshed Analysis - Ontario, Canada</u>

In the Canada Ontario Farm Stewardship Program (COFSP) database, practices are located in a county and a Conservation Authority (CA). Figure 7 illustrates the watersheds selected that were comparable to CA designations in the COFSP database and used to calculate the indicator on a lakeshed basis in Canada. To estimate practices adopted on a watershed basis, the area of agricultural land in a fundamental drainage area (as defined by Atlas of Canada) is interpolated from the 2006 Census of Agriculture information using an area-weighted approach. Thus error is introduced into the indicator when calculated on a watershed basis. This representation is also limited because not all lake basins have full CA coverage in Ontario so only Lakes Ontario, Erie and part of Huron are analyzed. Practices that are outside these boundaries are excluded from the lakeshed analysis (2434 practices or 13% of total for 6 years).

The number of BMPs implemented are cumulatively increasing in all lakesheds (Table 2). In Ontario, the Lake Erie basin has the greatest number of BMPs cost-shared per ha of agricultural land. The portion of the Lake Huron basin included for this indicator is next, followed by Lake Ontario. The acceleration of BMP adoption per ha of agricultural land is slowing similarly in all lakesheds as program funding has been reduced.

A categorization of practices by major effect was performed to aid in interpretation of trends by lakeshed. Categorization attempts to identify a major agri-environmental effect of a practice, however multiple benefits from application of a practice could occur. There has been no double counting of practices between categories, so some categories may be under-represented. Figure 8 illustrates that the type of the BMPs adopted can vary in each lakeshed. BMPs having a nutrient management effect are the highest proportion adopted in all lakesheds. Practices in the “Other” category cannot be simply classified in the water, nutrient management, habitat or soil categories. Examples of Other practices that were commonly adopted include berms for secondary containment around permanent on-farm storages for agricultural products, and equipment modifications, such as rate controllers, foam marker systems and air induction tips, to improve pesticide management.

<u>Lakeshed Analysis - United States</u>

On the U.S. side of the basin, area of agricultural land removed from production due to the Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP) currently ranges from 1,063 to 353,052 acres for lake basins (Figure 9a). Trends in agricultural land retired from production indicates the percent of land retired has increased to greater than 3% in Lake Erie basin, whereas all other lake basins are relatively steady or have decreased from their 2005 levels (Figure 9b). An exception is Lake Huron where percent of agricultural land retired from production peaked in 2007, followed by a decrease to about 2.5% (Figure 9b).

One hundred and six (106) different NRCS practices were reported to be applied in the Great Lakes Basin from 2005 to 2010 and represent a range of environmental concerns addressed on individual farms. A categorization of selected NRCS practices, performed to aid interpretation of trends, indicated varying application of practices on cropland, hayland/pastureland, and both land uses combined referred to as ag land (Figure 10). While this categorization attempts to identify a major environmental concern associated with agricultural operations, multiple benefits from application of these practices are expected. However, no double counting of practices between categories occurred. Approximately 6% to 13% of croplands in lake basins now adopt practices that reduce tillage/soil erosion (Figure 10a). Lake Erie and Ontario employ practices to reduce the impact of land managed for hay production and grazing on greater than 7% of that land use type (Figure 10b). Nutrient management practices (Figure 10c) that increase efficiencies of applied agrochemicals/nutrients while decreasing off-site losses are the most applied practices in many lake basins. Less than one percent of agricultural land in all lake basins is accounted for by practices implemented to intercept/redirect surface runoff and improve water quality of neighboring water bodies (Figure 10d) or improve habitat for wildlife (Figure 10e).

Other Spatial Scales

Closer examination of U.S. watersheds with a higher proportion of agricultural land use indicate variable distribution of cropland, pasture/hayland, and resulting implementation of NRCS practices. In Western Lake Erie watersheds, cropland is concentrated in the central portion of this watershed (Figure 11a), whereas pasture/hayland is concentrated in the northern portion (Figure 11b). Number of NRCS practices relative to agricultural land is distributed relatively evenly throughout these watersheds, both in central and northern areas (Figure 11c). Identification of NRCS practices which are likely to have the largest effect on reducing phosphorus losses from agricultural operations show largest implementation densities in northern portions of this watershed. Similar patterns in cropland and pasture/hayland distribution were present in the Saginaw Bay and Lower Fox River watersheds, showing concentrations of the land uses and associated operations differing in location (Figure 12a, 12b, 13a, and 13b). NRCS practices were also distributed throughout these watersheds and no apparent spatial pattern was evident based on land use data alone (Figure 12c, 12d, 13c, and 13d).

Linkages

This indicator is linked to the following Great Lakes indicators: nutrients in tributaries, pesticides in tributaries, watershed stressor index, land cover, nutrients in lakes, Cladophora, inland water quality index, bacterial loadings from tributaries, groundwater quality, beach postings, baseflow due to groundwater, sediment coastal nourishment, forest cover.

Management Challenges/Opportunities

The indicator quantifies adoption of BMPs by agricultural producers who participate in federally funded/tracked cost-shared incentive programs. The indicator is affected by government budget constraints, market forces, industry and consumer expectations and other socio-economic factors which affect the adoption of BMPs. The indicator is not expected to necessarily respond or reflect directly the state of environment due to: the temporal lag between BMP implementation and environmental effect; the influence of the spatial distribution of BMP uptake on environmental conditions; and, unmanageable factors such as aquatic invasive species and climate change. In addition, cumulative thresholds of BMP uptake might be needed before a causal effect between BMP uptake and change in environmental conditions can be measured. There is currently no standard way of measuring the condition or maintenance of these BMPs over their expected lifespan.

Comments from the author(s)

Programs differ between Ontario, Canada and the U.S. and thus do not necessarily have common definitions of agricultural best management practices or levels of funding. As the programs and jurisdictional context change (legislation, budget, and policies) over time, different agricultural practices have been emphasized, added or removed to these programs which may influence the number of BMPs funded and implemented in any one year. Based on eligibility criteria and funding available the number and rate of BMPs adopted can vary greatly between the two countries and in time.

Some practices may contribute to more than one outcome, or may even be somewhat antagonistic to each other. No attempt has been made in this analysis to rank or calculate net benefits or tabulate outcomes (i.e. soil quality vs. water quality vs. habitat) separately of different practices. Funding of management plans for such things as grazing, pesticide, irrigation, erosion and nutrient use are included as practices as they are assumed to be implemented.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada				X		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			

Clarifying Notes: The data source for each country is similar but the number/variety of BMPs funded and the information collected when a BMP is implemented (e.g. hectares treated) is not similar for the separate programs in each country. Because all selected practices funded are included in the tabulation there is no statistical sampling from which to calculate uncertainty or variability.

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Information Sources

Agriculture and Agri-Food Canada and Statistics Canada,
Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991

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North American Atlas – Waterbody

Atlas of Canada 1:1,000,000 National Frameworks Data, Hydrology – Fundamental Drainage Area

Atlas of Canada – Provincial Boundaries – 1:2,000,000

Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association

USGS 2006 National Land Cover Dataset

USDS NRCS Protract Database (Data as of 7-11-11)

USDA FSA CRP/CREP Database (Data as of 7-13-11)

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Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association

Figure 2. Distribution of BMPs per 1000 hectares of agricultural land cumulatively adopted by county in Ontario (2005-2011)

Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association; Agriculture and Agri-Food Canada and Statistics Canada, Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991; Atlas of Canada – Provincial Boundaries – 1:2,000,000

Figure 3. Comparison of number of crop nutrient management related BMPs adopted during COFSP (April 2005-March 2010) and the area receiving commercial fertilizer inputs in 2005 by municipality

Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association; Agriculture and Agri-Food Canada and Statistics Canada, Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991; Atlas of Canada – Provincial Boundaries – 1:2,000,000

Figure 4. Comparison of number of livestock nutrient management related BMPs adopted during COFSP (April 2005-March 2010) and phosphorus produced from manure in 2006 per hectare of farmland by municipality

Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association; Agriculture and Agri-Food Canada and Statistics Canada, Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991; Atlas of Canada – Provincial Boundaries – 1:2,000,000

Figure 5. Number of USDA NRCS practices implemented in USGS 8-digit HUC watersheds per 1000 hectares of agricultural land.

Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

Figure 6. Percent area of USGS 8-digit HUC watersheds in agricultural land use including cultivated cropland and pasture/hayland.

Source: USGS 2006 National Land Cover Dataset

Figure 7. Agricultural Lakesheds of Ontario

Source: Atlas of Canada – Provincial Boundaries – 1:2,000,000; Atlas of Canada 1:1,000,000 National Frameworks Data, Hydrology – Fundamental Drainage Area; North American Atlas – Waterbody.

Figure 8. Proportion of cumulative adoption of BMPs by major effect by lakeshed in Ontario.

Source: Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association.

Figure 9. Trends in USDA Conservation CRP and CREP contracts and percent of agricultural land in retirement.

Source: USGS 2006 National Land Cover Dataset & USDA FSA CRP/CREP Database

Figure 10. Trends in grouped NRCS EQIP, CSP, and WHIP practices implemented per unit of area. Practices grouped by tillage/erosion reduction (a), pasture/grazing management (b), nutrient management (c), water quality improvement through interception of surface runoff (d), and habitat improvements for wildlife (e)

Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

Figure 11. Western Lake Erie 12-digit HUC watersheds represent percent cropland (a), percent pasture/hayland (b), number of NRCS practices per area of agricultural land (c) and number of NRCS practices identified has high impact on phosphorus.

Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

Figure 12. Saginaw Bay 12-digit HUC watersheds represent percent cropland (a), percent pasture/hayland (b), number of NRCS practices per area of agricultural land (c) and number of NRCS practices identified has high impact on phosphorus.

Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

Figure 13. Lower Fox River 12-digit HUC watersheds represent percent cropland (a), percent pasture/hayland (b), number of NRCS practices per area of agricultural land (c) and number of NRCS practices identified has high impact on phosphorus.

Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

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Total BMPs adopted by Lakeshed per 1000 hectare of farmland by Funding Period

Lakeshed	2005-2008*	2008-2009	2009-2010	2010-2011	All Funding Years 2005-2011
Lake Erie	3.15	0.69	0.36	0.33	4.52
Lake Huron	2.64	0.67	0.40	0.33	4.04
Lake Ontario	2.24	0.55	0.34	0.30	3.42

*The first column for 2005-2008 represents 3 years cumulative adoption of practices as the COFSP database has combined these program years.

Table 1. Total BMPs adopted by Lakeshed per 1000 hectares of farmland by Funding Period in Ontario

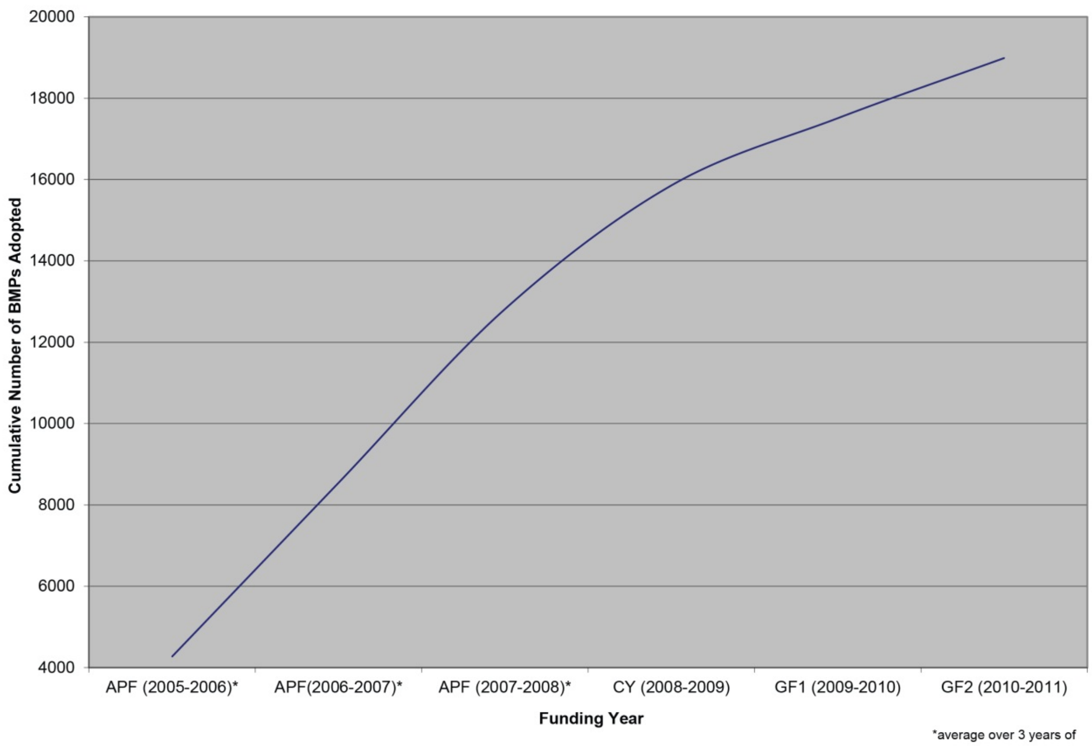


Figure 1. Cumulative adoption of BMPs in Ontario (from 2005 to 2011)
Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association

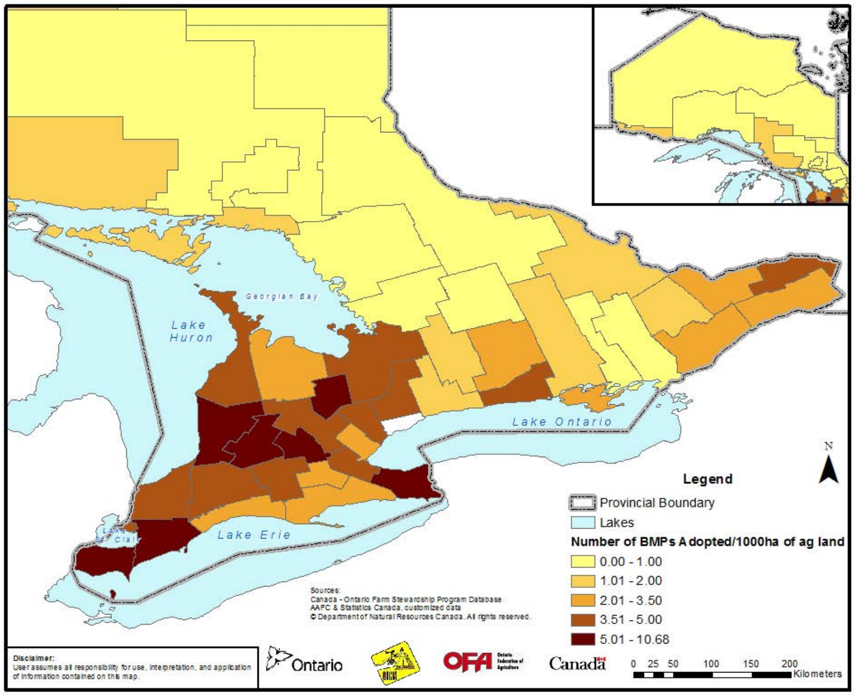
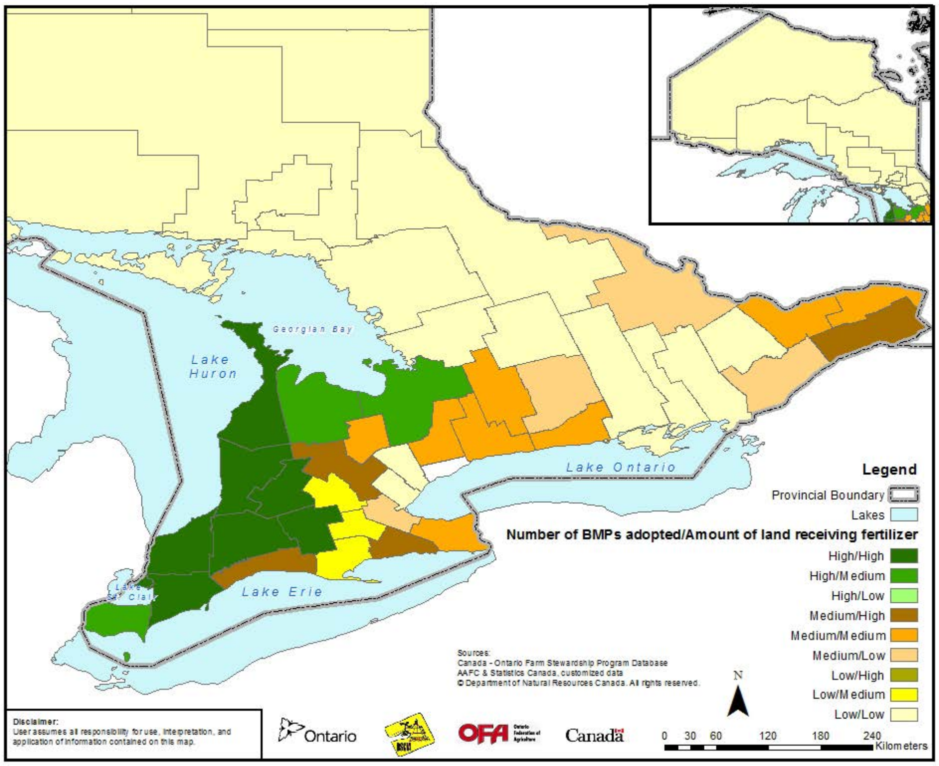
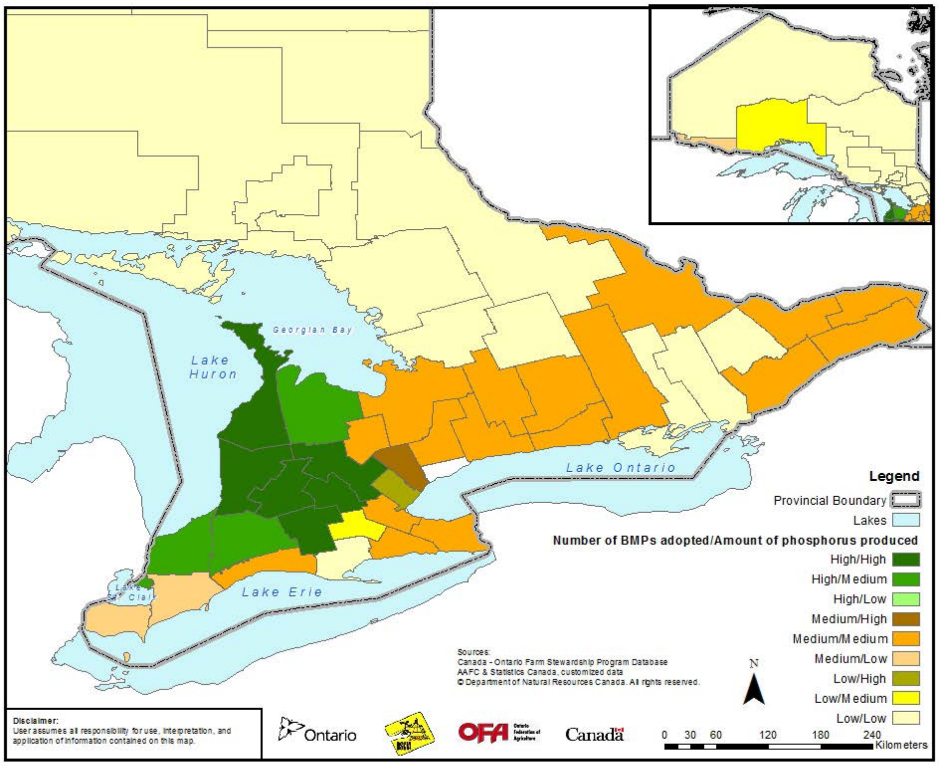


Figure 2. Distribution of BMPs per 1000 hectares of agricultural land cumulatively adopted by county (2005-2011) Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association; Agriculture and Agri-Food Canada and Statistics Canada, Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991; Atlas of Canada – Provincial Boundaries – 1:2,000,000; North American Atlas – Waterbody



Number of Crop Nutrient Management Related BMPs	Amount of Land receiving fertilizer (ha)
High >95	High >65,000
Medium 31-95	Medium 30,000-65,000
Low 0-30	Low 0-30,000

Figure 3. Comparison of number of crop nutrient management related BMPs adopted during COFSP (April 2005-March 2010) and the area receiving commercial fertilizer inputs in 2005 by municipality
Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association; Agriculture and Agri-Food Canada and Statistics Canada, Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991; Atlas of Canada – Provincial Boundaries – 1:2,000,000



Number of Livestock Nutrient Management Related BMPs	Amount of Phosphorus Produced from Manure (kg P/ha)
High >200	High >11
Medium 46-200	Medium 6-11
Low 0-45	Low 0-5

Figure 4. Comparison of number of livestock nutrient management related BMPs adopted during COFSP (April 2005-March 2010) and phosphorus produced from manure in 2006 per hectare of farmland by municipality
Source: Canada-Ontario Farm Stewardship Program Database provided by the Ontario Soil and Crop Improvement Association; Agriculture and Agri-Food Canada and Statistics Canada, Customized tabulations, Census of Agriculture CGC Base 1996, 2001, 2006, Census of Agriculture Regular Base 1971, 1976, 1981, 1986, 1991; Atlas of Canada – Provincial Boundaries – 1:2,000,000; North American Atlas – Waterbody

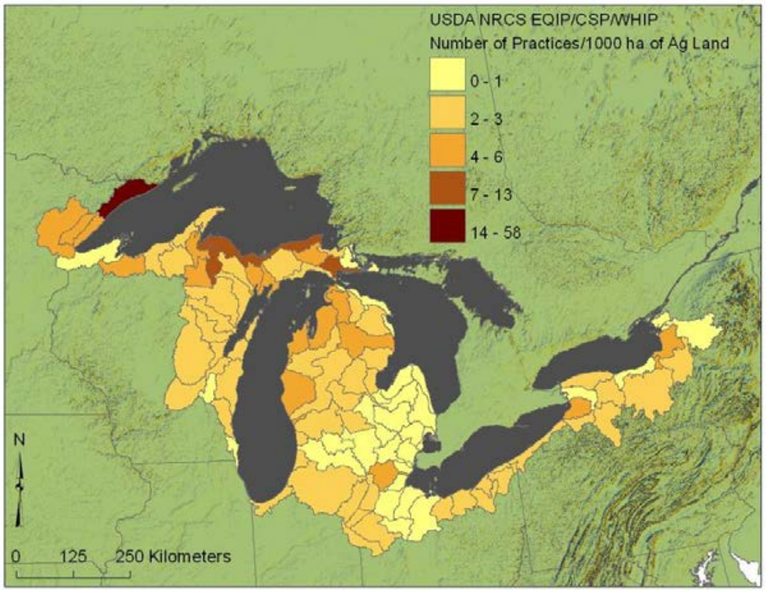
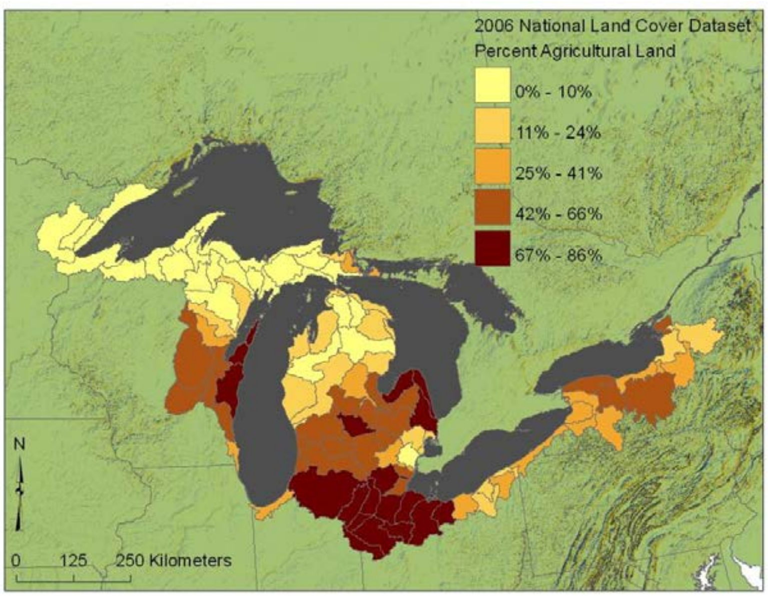


Figure 5. Number of USDA NRCS practices implemented in USGS 8-digit HUC watersheds per 1000 hectares of agricultural land.
Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database



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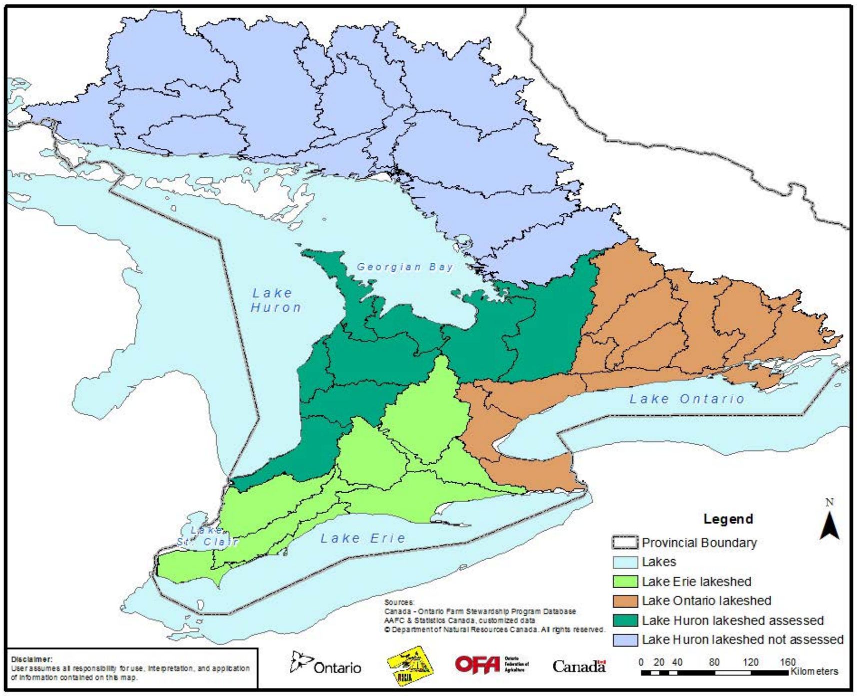
Source: USGS 2006 National Land Cover Dataset



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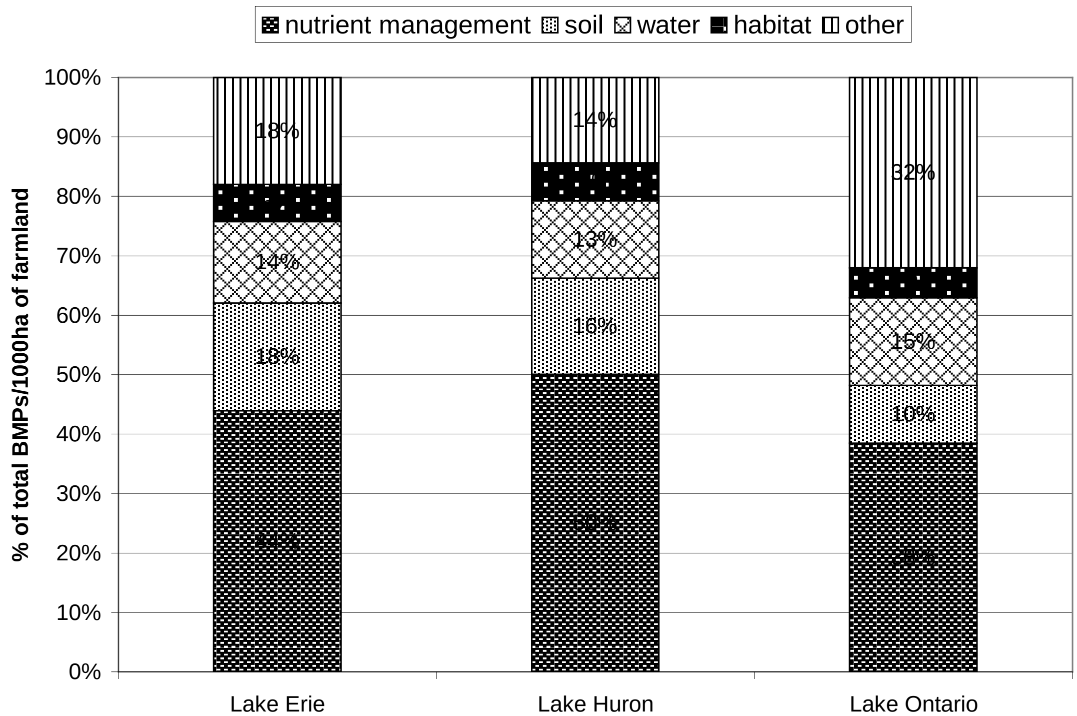

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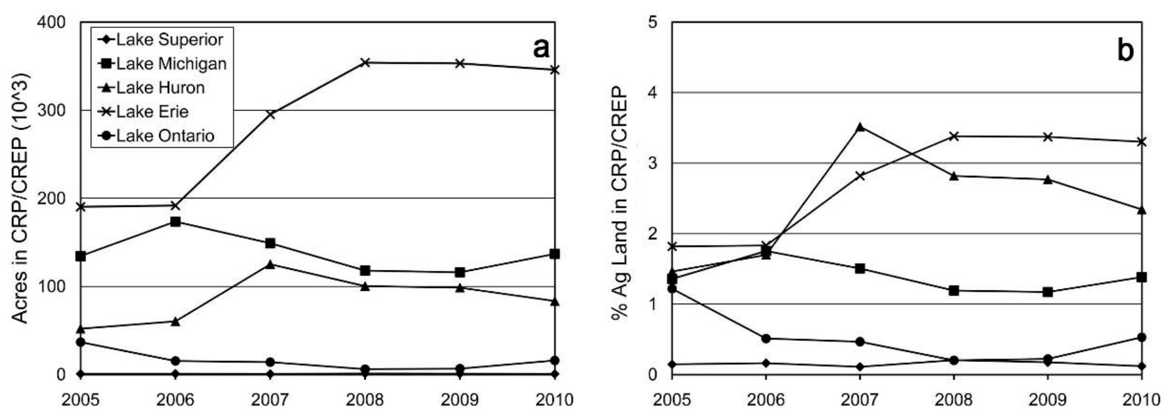

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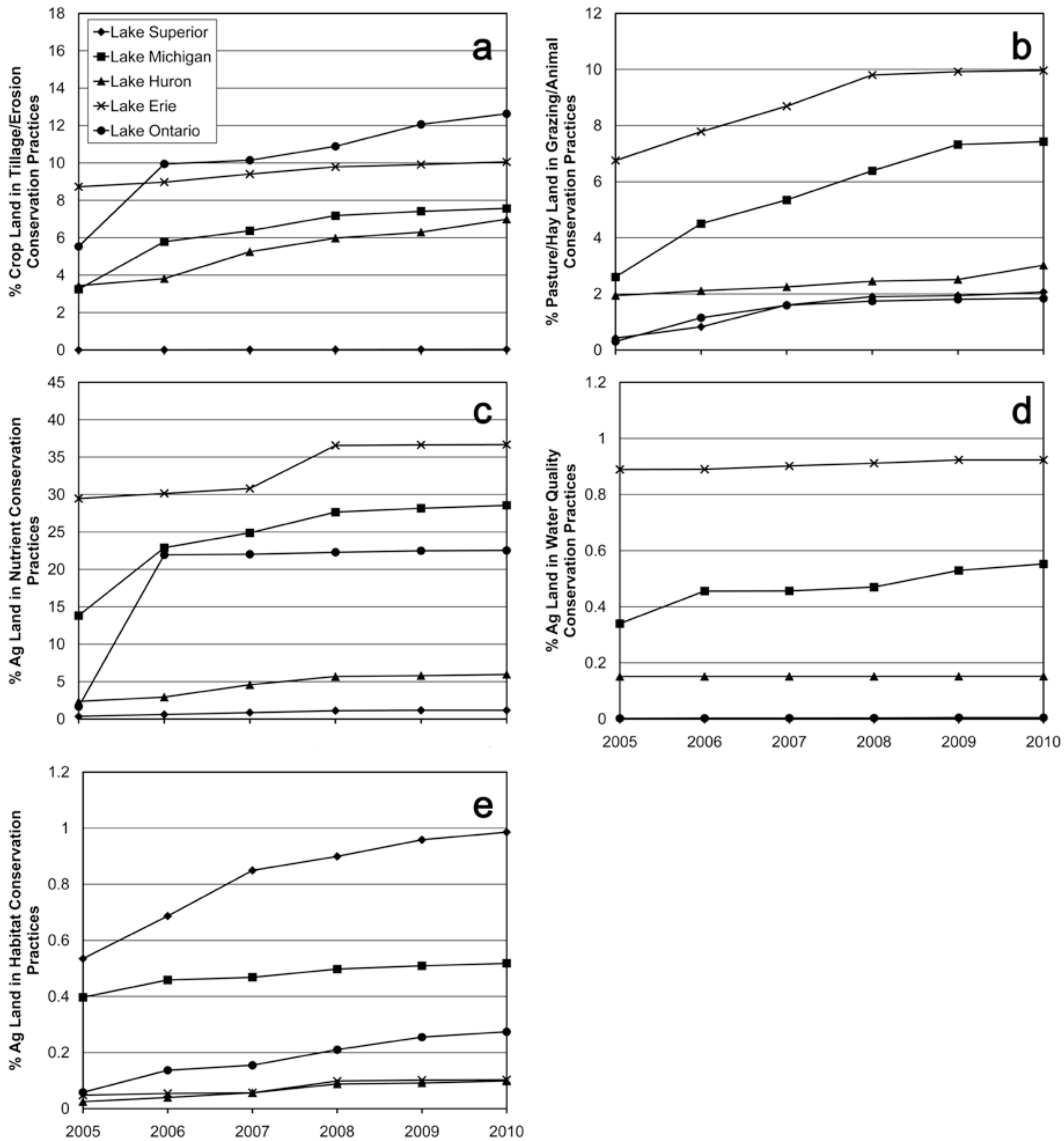
Source: USGS 2006 National Land Cover Dataset & USDA FSA CRP/CREP Database



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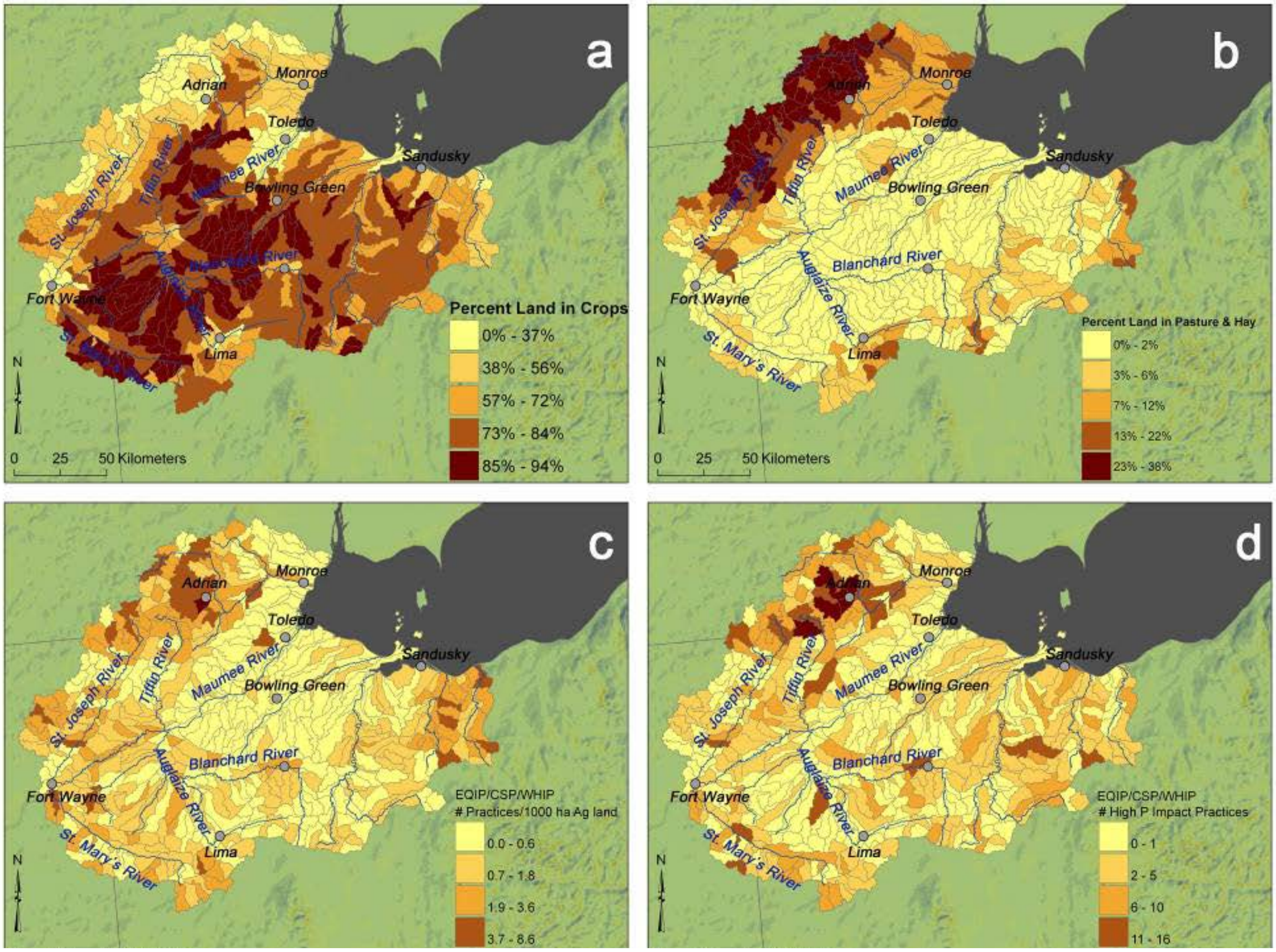
Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database



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Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

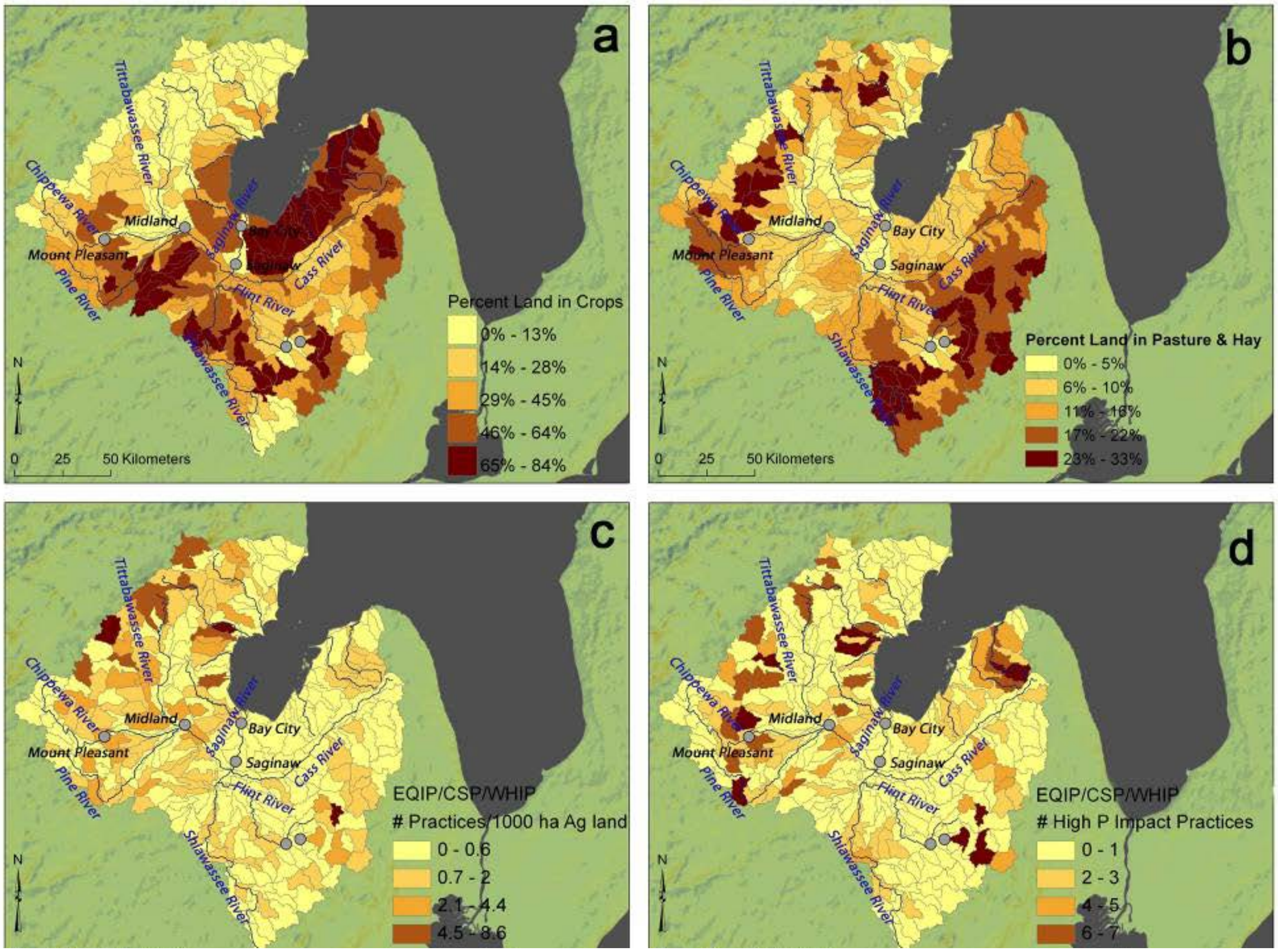

Figure 12. Saginaw Bay 12-digit HUC watersheds represent percent cropland (a), percent pasture/hayland (b), number of NRCS practices per area of agricultural land (c) and number of NRCS practices identified has high impact on phosphorus.
Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

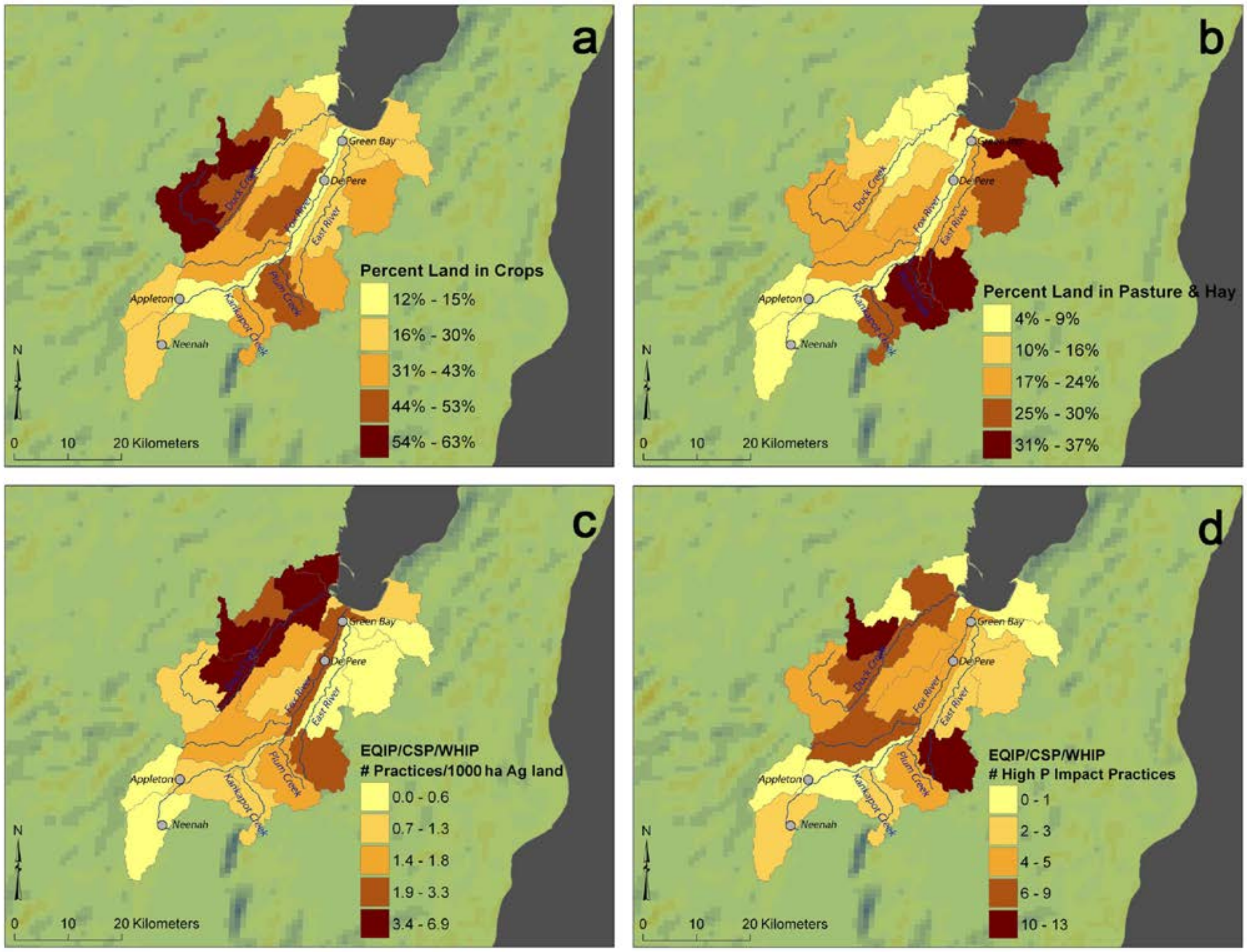

Figure 13. Lower Fox River 12-digit HUC watersheds represent percent cropland (a), percent pasture/hayland (b), number of NRCS practices per area of agricultural land (c) and number of NRCS practices identified has high impact on phosphorus.
Source: USGS 2006 National Land Cover Dataset & USDA Protracts Database

Contaminants in Waterbirds

Overall Assessment
Status: Good
Trend: Improving
Rationale: The long term trends (1974 to present) of virtually all legacy contaminants are declining. The short term trends, those over the last decade, are a mixture of some showing significant declines but others showing no significant change.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Improving.
Rationale: The traditional legacy contaminants, DDE, SUM PCBs and TCDD, have declined significantly in long term (1974-2009) and short term (2000-2009). Hg has declined significantly in the long term but neither it, nor SUM BDE, has declined significantly in the short term. Refer to Figure 2 for more detail on the long- and short-term trends by compound and water body.

Lake Michigan
Status: Good
Trend: Improving.
Rationale: The traditional legacy contaminants, DDE, SUM PCBs and TCDD, have declined significantly both since the 1970s (1974-2009) and in the last decade (2000-2009). Hg has declined significantly in the long term but neither it, nor SUM BDE, has declined significantly in the short term.

Lake Huron
Status: Good
Trend: Improving.
Rationale: The traditional legacy contaminants, DDE, SUM PCBs and TCDD and Hg, have declined significantly both since the 1970s (1974-2009) and in the last decade (2000-2009). No significant change for SUM BDE in the short term.

Lake Erie
Status: Fair
Trend: Unchanging.
Rationale: The legacy contaminants, DDE, SUM PCBs, TCDD and Hg, have all declined significantly since the 1970s (1974-2009). However, none of them, as well as SUM BDEs has declined significantly in the last decade (2000-2009).

Lake Ontario
Status: Fair
Trend: Unchanging.
Rationale: The legacy contaminants, DDE, SUM PCBs, TCDD and Hg, have all declined significantly since the 1970s (1974-2009). However, none of them, as well as SUM BDEs has declined significantly in the last decade (2000-2009).

Purpose
- To assess the current chemical concentrations and trends in representative colonial waterbirds (gulls, terns,

cormorants and/or herons) on the Great Lakes.
- To infer and measure the impact of contaminants on the health, i.e. the physiology and breeding characteristics of the waterbird population.
- To assess ecological and physiological endpoints in representative colonial waterbirds on the Great Lakes.
- The Contaminants in Waterbirds indicator is used in the Great Lakes indicators suite as a State indicator in the Water Quality top level reporting category.

Ecosystem Objective
Tracking progress of fish-eating colonial waterbirds on the Great Lakes toward an environmental condition in which there is no difference in contaminant levels and related biological endpoints between birds on and off the Great Lakes. As part of this indicator, contaminant levels are also measured in herring gull eggs to ensure that levels continue to decline.

Ecological Condition
Measure

- Annual concentrations of the DDT complex, PCBs/PCDFs/PCDDs and other organic contaminants, and Hg and other metals in Herring Gull eggs from 15 sites from throughout the Great Lakes (U.S. and Canada).
- Periodic measurement of biological features of gulls and other colonial waterbirds known to be directly or indirectly impacted by contaminants and other stressors. These include (but are not limited to): clutch size, eggshell thickness, hatching and fledging success, size and trends in breeding population, various physiological biomarkers including vitamin A, immune and thyroid function, stress (corticosterone) and growth hormone levels, liver enzyme induction, PAH levels in bile and porphyrins and genetic and chromsomal abnormalities. Additional monitoring considerations include: tracking porphyria, vitamin A deficiencies, and the evaluation of avian immune systems.

Endpoint

- Chemical levels and biological measures in colonial nesting waterbirds are not different from those from reference sites in Atlantic Canada or from the Prairies.
- Decreasing contaminant trends.

Additional Information

Since 1974, 10-13 eggs have been collected annually from up to 13 nesting colonies in the Great Lakes and in connecting channels (Figure 1). Egg contents were selected because, collection is rather easy and inexpensive and because lipid contents in eggs is less variable than in other tissues (Weseloh et al 2006). Further details are described in Pekarik and Wesoleh (1998).

Although there are Great Lakes wildlife species that are more sensitive to contaminants than Herring Gulls, and colonial nesting waterbird species in general, there is no other species which has the historical dataset that the Herring Gull does. As contaminant levels continue to decline (if they do), the usefulness of the Herring Gull as a biological indicator species may lessen (due to its reduced sensitivity to low levels of contamination) but its value as a chemical indicator will remain and probably increase - as levels become harder and harder to measure in other media. It is an excellent accumulation tracker since many of the above biological measures are correlated with contaminant levels in their eggs. In other colonial waterbirds, there are similar correlations between contaminant levels in eggs and various biological measures. Contaminant levels in eggs of other colonial waterbirds are usually correlated with those in Herring Gulls. Adult Herring Gulls nest on all the Great Lakes and the connecting channels and remain on the Great Lakes year-round. Because their diet is usually made up primarily of fish, they are an excellent terrestrially-nesting indicator of the aquatic community. The Herring Gull egg contaminants dataset is also the longest running continuous (annual) contaminants dataset for wildlife in the world.

The Contaminants in Waterbirds indicators is included in the Water Quality assessment for the Great Lakes because long term trends of contaminants in biota provide valuable insight into the relative abundance of contaminants in the vicinity of fish and waterbird populations. It is important to note, however, that contaminant levels in biota represent not just quantities of contaminants in the water, but are the result of the integration of many biological, chemical and physical interactions (e.g. bioaccumulation and biomagnification processes, variations in diet and growth rates).

Historical data on levels of chemical contamination in gull eggs are available, on an annual basis, for most sites in both the Canadian and U.S. Great Lakes dating back to the early 1970s. An immense database of chemical levels and biological measures from the Great Lakes, as well as many off-Lakes sites, is available from the Ecotoxicology and Wildlife Health Division at Environment Canada. Data on temporal trends, portrayed as annual contaminant levels over time, for 1974-present in most instances, are available for each site and each compound. For example, DDE, from 1974-2008, is available for Toronto Harbour and could be displayed graphically. Geographical patterns in contaminant levels, showing all sites relative to one another, are also available for most years from 1974-present and for most compounds. For example, PCBs, 2008, at 15 Great Lakes sites from Lake Superior to the St. Lawrence River (including U.S. sites) and could be displayed on both maps and graphs.

The size and distribution of the waterbird populations which breed on the Great Lakes is also an indicator of ecosystem health. Declining waterbird populations (number of breeding pairs or nests) and vital rates (hatching success, fledging success, mortality rates, etc.) can be indicators of local environmental stress. The Great Lakes-wide population of colonial waterbirds has been censused jointly, by the Canadian Wildlife Service and the U.S. Fish and Wildlife Service since the 1970s, approximately every 10 years; four "decadal" censuses have been conducted to date: in the 1970s, 1980s, 1990s and 2000s. Briefly, and in the long-term (from the 1970s to the 2000s), these censuses have shown that the breeding numbers of six species have increased: Double-crested Cormorants, Black-crowned Night-Herons, Great Egrets, Ring-billed Gulls, Great Black-backed Gulls, and Caspian Terns. Unfortunately, the numbers of three species, Great Blue Heron, Herring Gull and Common Tern, have gone declined. In the short-term (from the 1990s to 2000s), numbers of night-herons, the three gull species and Common Terns have declined. For Common Terns, which have declined continuously since the first census, the trend is alarming; numbers have declined from approximately 8,600 pairs to just 5,000 pairs (42%; Figure 3). The reasons for this decline are unclear but it is partially due to competition for nest sites with Ring-billed Gulls and habitat loss. Although the Herring Gull population is much more numerous (approximately 32,000 pairs), their decline should be monitored, especially in Lake Huron, where numbers have declined from approximately 33,500 pairs in the 1970s to 22,000 pairs in the 2000s (34%). Currently, drivers such as habitat change and loss, changes in trophic structure and abundance of fish prey, reduced access to alternate sources of food (for gulls, due to changes in agricultural and waste disposal practices), inter-specific competition for nesting space (e.g. increased pressure from overabundant species such as cormorants and Ring-billed Gulls) and stressors in overwintering areas likely play a larger role in regulating waterbird populations than contaminant-related impairments.

Linkages

There are many linkages between the contaminant levels in fish-eating waterbirds indicator and many other indicators within the Great Lakes (SOLEC) reporting suite. There is a link between Contaminants in fish-eating waterbirds and Contaminants in Whole Fish as well as with Top Predator Fish and Preyfish. Trends seen in fish-eating colonial waterbirds are also likely linked to those seen in Bald Eagles. A link has also been shown by Dr. Craig Hebert between contaminant levels in Herring Gull eggs and Ice Duration. There is a direct link between Herring Gull contaminants and Endocrine Disruption and, in terms of the health of Great Lakes fish-eating birds, between Herring Gulls and both Botulism Outbreaks and the Occurrence of Fish Diseases.

Data Limitations

Herring Gulls are highly tolerant of persistent contamination and may underestimate biological effects occurring in other less monitored, more sensitive species. Also, some adult Herring Gulls from the upper lakes, especially Lake Superior, move to the lower lakes, especially Lake Michigan, during harsh winters. This has the potential to confound the contaminant profile of a bird from the upper Lakes. Most of the gull's time is still spent on its home lake and this has not been noted as a serious limitation up to this point. Using contaminant accumulation by young, flightless gulls would eliminate this problem but their contaminant levels and effects would be less due to the much reduced contaminant exposure/intake.

It is difficult to show consistent differences in biological effects among colony sites within the Great Lakes. This is probably due to the great overall reduction in contaminant levels as well as the lessening in differences among Great Lakes sites. The comparisons which show the greatest differences for biological effects of contaminants are between sites on and off the Great Lakes.

Also, contaminant concentrations in most colonially-nesting, fish-eating birds are at levels where gross ecological effects, such as eggshell thinning, reduced hatching and fledging success, and population declines, are no longer apparent. Greater reliance for detecting biological effects of contaminants is being put upon physiological and genetic biomarkers. These are not as well characterized, nor are they understood as easily by the public. Other complementary species include: Double-crested Cormorant (*Phalacrocorax auritus*), Common Tern (*Sterna hirundo*), Caspian Tern (*Hydroprogne caspia*) and Black-crowned Night-Heron (*Nycticorax nycticorax*).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	x					
2. Data are traceable to original sources	x					
3. The source of the data is a known, reliable and respected generator of data	x					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	x					
5. Data obtained from sources within the U.S. are comparable to those from Canada	x					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	x					

Acknowledgments

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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. Environ. Monit. Assess. 53: 77-115.

Weseloh, D.V.C., D.J. Moore, C.E. Hebert, S.R. de Solla, B.M. Braune and D. McGoldrick. In press. Current concentrations and spatial and temporal trends in mercury in Great Lakes Herring Gull eggs, 1974-2009. Ecotoxicology.

Environment Canada, unpublished data.

List of Figures

Figure 1. Locations of annual Herring Gull egg collection sites on the Great Lakes and connecting channels.
Source: Canadian Wildlife Service, Environment Canada – Burlington/Downsview.

Figure 2. Change in concentration of DDE, sum PCBs, mercury (Hg) (ug/g, wet weight), 2,3,7,8-TCDD and sum BDEs (pg/g, wet weight) in Great Lakes Herring Gull eggs from year of first measurement (green bars) compared to values for 2000 (orange bars) and the most recent measurement (2009, yellow bars). Values in first year of measurement have been set to 100%. Years of first and most recent measurement are indicated below compound names on the x-axis. No eggs were available from Fighting in 2009, so the 2008 value has been used; similarly, 1973 DDE and Hg values were used for Lake Michigan. Values associated with each bar are the actual concentrations. Symbols above green bars indicate p-values from regressions on ln-transformed concentrations for the entire dataset (1st to last measured, red text) and the period from 1999-2009 (black text): **, $p \leq 0.0001$; *, $p \leq 0.001$; ^, $p \leq 0.01$; #, $p \leq 0.05$, ns, not significant.
Source: Ecotoxicology and Wildlife Health Division, Environment Canada – Burlington.

Figure 3. Changes in the number of Common Tern nests (red) and breeding colonies (blue) in Canadian waters of the Great Lakes and connecting channels during four “decadal” survey periods (1976-80, 1989-90, 1997-2000 and 2007-2009). Not shown: Lake Superior had 25 nests at a single colony during the second census period.
Source: Canadian Wildlife Service, Environment Canada – Burlington/Downsview.

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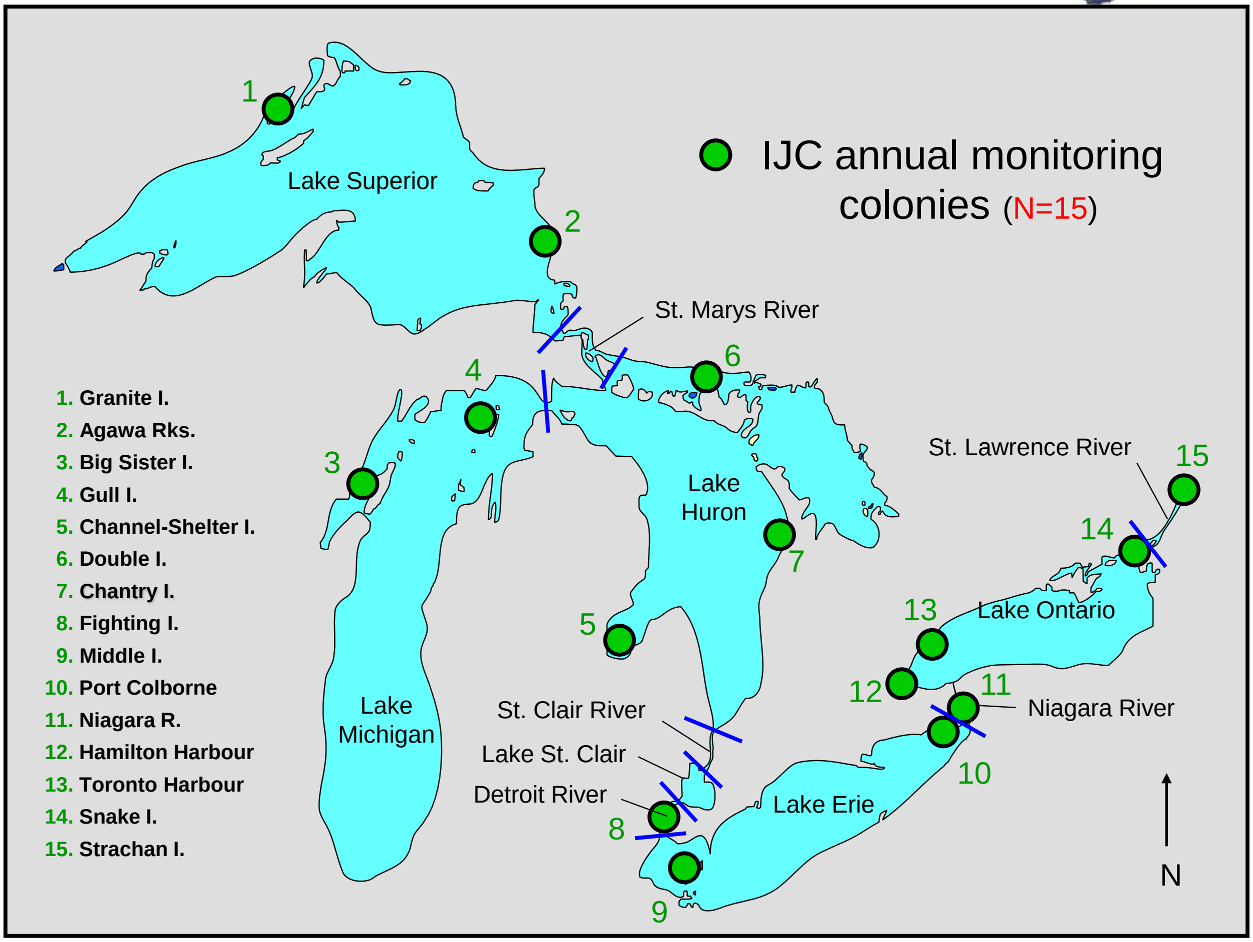

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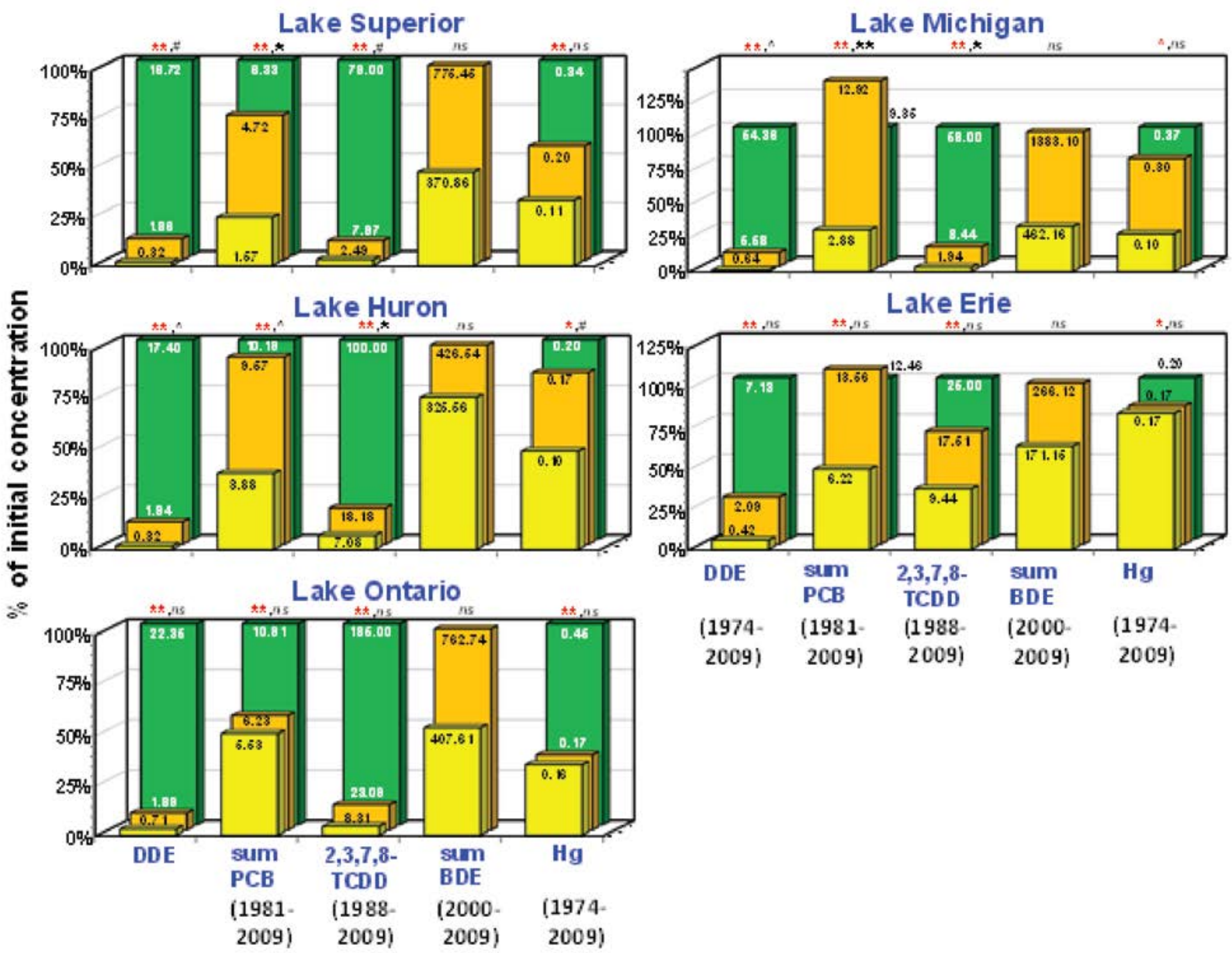

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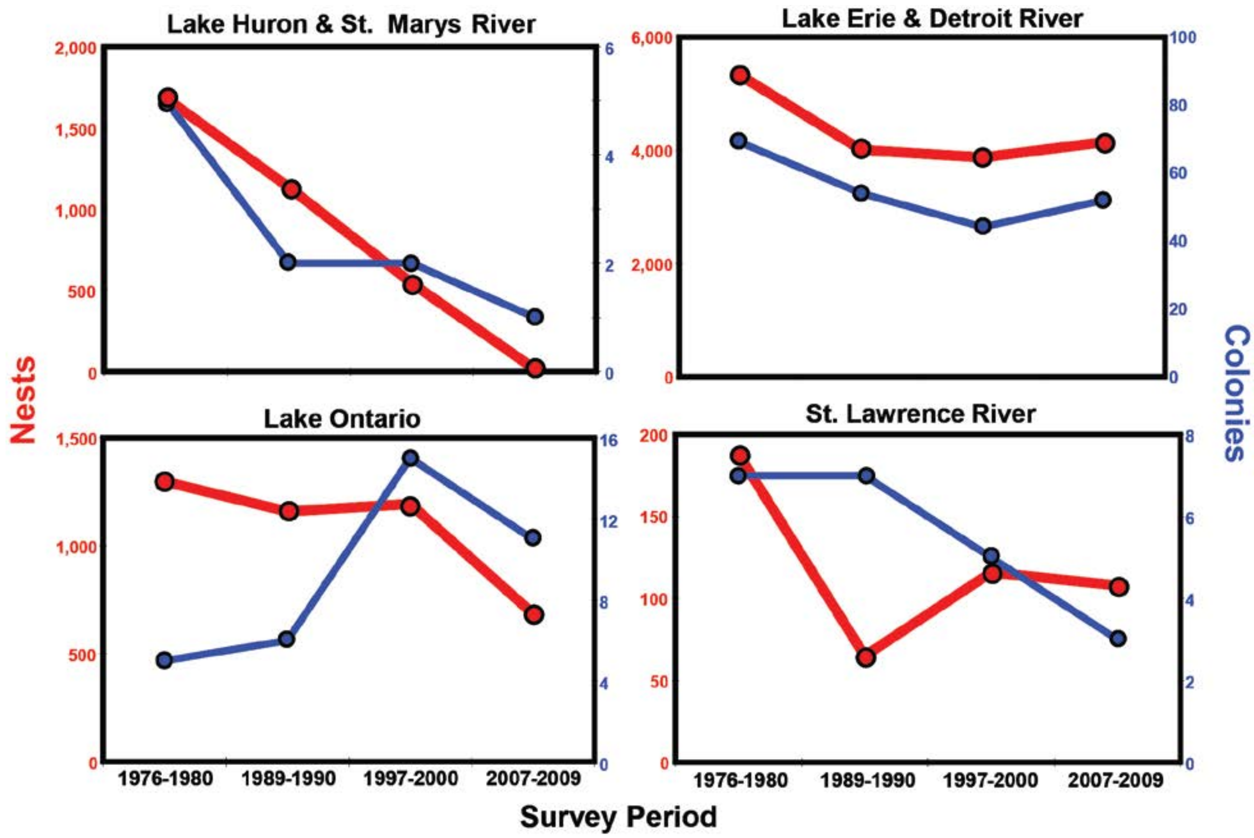
Source: Ecotoxicology and Wildlife Health Division, Environment Canada – Burlington.



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Source: Canadian Wildlife Service, Environment Canada – Burlington/Downsview

Contaminants in Whole Fish

Overall Assessment

Status: Fair

Trend: Deteriorating

Rationale: The assessment incorporates multiple contaminants and considers potential effects of exposure to fish eating wildlife. Total mercury concentrations remain below the target of 0.5ug/g ww in all lakes. However, concentrations appear to be increasing at locations within the basin signaling a deterioration of this indicator. Concentrations of PCBs and pentaPBDEs are currently above guidelines in Lake Trout and Walleye in all the Great Lakes; however concentrations of these contaminants are declining in most monitored fish.

Lake-by-Lake Assessment

Lake Superior

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout in Lake Superior and declining. Total Hg concentrations, although still below the target of 0.5 µg/g ww, have returned to levels observed in the 1980s and appear to be increasing.

Lake Michigan

Status: Fair

Trend: Unchanging

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout from the lake and declining. Total Hg concentrations are similar to observations in the other lakes but there is not enough data from recent years to confirm a significant trend.

Lake Huron

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout in Lake Huron and declining. Total Hg concentrations, although still below the target of 0.5 µg/g ww, have returned to levels observed in the 1980s and are increasing.

Lake Erie

Status: Fair

Trend: Deteriorating

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Walleye from Lake Erie and declining. Total Hg concentrations, although still below the target of 0.5 µg/g ww, have returned to levels observed in the 1980s and are increasing.

Lake Ontario

Status: Fair

Trend: Unchanging

Rationale: Concentrations of PCBs and pentaBDEs are above guidelines in Lake Trout from Lake Ontario and declining. Total Hg concentrations are no longer declining and may be increasing as observed in fish from Lakes Superior, Huron and Erie.

Purpose

- To describe temporal and spatial trends of bioavailable contaminants in representative open water fish species from throughout the Great Lakes
- To infer the effectiveness of remedial actions related to the management of critical pollutants
- To identify the nature and severity of new and emerging pollutants of concern
- The Contaminants in Whole Fish indicator is used in the Great Lakes indicators suite as a State indicator in the Water Quality top level reporting category.

Ecosystem Objective

Great Lakes waters should be free of toxic substances that are harmful to fish and wildlife populations and the consumers of this biota. Data on status and trends of contaminant conditions, using fish as biological indicators, support decisions about beneficial uses about degradation of fish populations and the requirements of the Great Lakes Water Quality Agreement (GLWQA, United States and Canada 1987) Annexes 1 (Specific Objectives), 2 (Remedial Action Plans and Lakewide Management Plans), 11 (Surveillance and Monitoring), and 12 (Persistent Toxic Substances).

Ecological Condition

Background and Methods

Long-term (greater than 25 years), basin-wide monitoring programs that measure whole body concentrations of contaminants in top predator fish (Lake Trout and/or Walleye) are conducted by both the U.S. Environmental Protection Agency (U.S. EPA) Great Lakes National Program Office through the Great Lakes Fish Monitoring and Surveillance Program, and Environment Canada's (EC) Water Quality Monitoring Surveillance Division, through the Fish Contaminants Monitoring and Surveillance Program, to identify the risk of contaminants to wildlife consumers of fish and to monitor trends in time. "The *Contaminants in Whole Fish* indicator is included in the Water Quality assessment for the Great Lakes because long term trends of contaminants in biota provide valuable insight into the relative abundance of bioaccumulative contaminants in the environment. Fish integrate exposure to contaminants over time and across their range and thus provide a broader assessment of environmental exposure than would a water sample taken at a single location at a point in time. Bioaccumulative contaminants are also found at higher concentrations in biota than they are in water, allowing for more accurate and cost effective determination of levels in the environment. It is important to note, however, that contaminant levels in biota represent not just quantities of contaminants in the water, but are the result of the integration of many biological, chemical and physical interactions (e.g. bioaccumulation and biomagnification processes, variations in diet and growth rates).

Environment Canada reports annually on contaminant burdens in similarly aged Lake Trout (4+ through 6+ year range) and Walleye (Lake Erie) as well as in Rainbow Smelt (*Osmerus mordax*), a common forage species. The U.S. EPA monitors contaminant burdens in similarly sized lake trout (600-700 mm total length) and walleye (Lake Erie, 400-500 mm total length) annually from alternating locations by year in each lake. Monitoring stations for both EC and U.S. EPA are shown in Figure 1. One additional difference between the EC and U.S. EPA programs, which limits the combination of data for statistical analyses, is that EC measures contaminants in individual fish and U.S. EPA measures contaminants in composite samples. As a result of these differences, all analyses and summary statistics are reported separately for each dataset. Unless stated otherwise, trends through time were assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines. Trends were deemed significant if the slope of model was greater or less than zero at $\alpha = 0.05$. When applicable, contaminant concentrations and trends are compared to criteria established in the GLWQA or other relevant guidelines developed to protect ecosystem quality. The GLWQA, first signed in 1972, renewed in 1978, and amended in 1987, expresses the commitment of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem. At present, negotiations between the governments of Canada and the United States to develop a new agreement are underway. When a new agreement is reached, the fish contaminant monitoring programs will be evaluated and modified to meet new requirements and objectives.

More information on the monitoring programs can be found at the following websites:

http://www.epa.gov/glnpo/monitoring/fish/index.html and
http://www.ec.gc.ca/scitech/default.asp?lang=en&n=828EB4D2-1

Chemical Concentrations in Whole Great Lakes Fishes
Since the late 1970s, concentrations of legacy organochlorine contaminants such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT) have declined in most monitored fish species. Conversely, the declines in concentrations of total mercury in fish through the 1980s have reversed in most lakes and are now increasing to levels observed at the onset of monitoring in the basin. In recent years, contaminants, such as polybrominated diphenyl ethers (PBDEs) and perfluorooctane sulphonate (PFOS), have garnered the attention of monitoring and regulatory agencies in the Great Lakes Basin. In general, the levels of regulated compounds are slowly declining or have stabilized in the tissues of Great Lakes top predatory fish. Basin wide, the changes are often lake-specific as they are dependant, in part, on the physio-chemical characteristics of the contaminants, hydrological characteristics of the lake, and the biological composition of the fish community and associated food webs.

Total polychlorinated biphenyls (PCBs)
Basin Wide Status: Fair; Improving
Total PCB concentrations in Great Lakes top predator fish have continuously declined since their phase-out in the 1970s (Figure 2). Median PCB concentrations in Lake Trout in Lakes Superior, Huron, and Ontario and Walleye in Lake Erie continue to decline; however, they are still above the target of 0.1 µg/g ww in the GLWQA (Table 1). Log-linear regression of Environment Canada data show the continued long-term annual declines of 5% in Lake Trout from Lake Superior and 7% in Lakes Huron and Ontario while PCBs in Lake Erie Walleye are declining by 3% per year. Similar analyses of U.S. EPA data show no significant annual declines of total PCB in Lake Trout from Lake Superior and 4%, 6%, 7%, and 4% annual declines in total PCB in Lake Trout from Lakes Huron, Michigan, Ontario, and Lake Erie Walleye, respectively. Data collected since the last SOLEC indicator report (2006-2009), show that total PCB concentrations in composited Rainbow Smelt measured by Environment Canada were all less than 0.1 µg/g ww in Lakes Superior and Huron. In Lake Erie, total PCB measured in 83% of Rainbow Smelt were below 0.1 µg/g ww, compared to only 34% of measurements in smelt from Lake Ontario. In Lake Ontario, total PCB concentrations in Rainbow Smelt are declining by ~8% per year since monitoring began in 1977.
Recent studies have suggested that rates of decline of PCB residues in fish are slowing or have stopped in some lakes in recent years (Bhavsar et al. 2007; Carlson et al. 2010). Despite potential changes in annual rates of decline, first-order log-linear regression models are still a good fit to observed concentrations in the lakes through time (Figure 2). Results generated in the next few years of monitoring should clarify whether or not the rates of decline are slowing and statistical methods to assess trends will be altered as required.

Dichlorodiphenyltrichloroethane (DDT) and metabolites
Basin Wide Status: Good; Improving
The concentration of opDDT and its metabolites, opDDD and opDDE, (sumDDT) in Great Lakes top predator fish have continuously declined since the use of the chemical was banned in 1972. Concentrations measured since the last indicator report (2006-2009) remain well below the GLWQA target of 1.0 µg/g ww across the basin (Table 2). Based on data collected at EC monitoring locations, annual rates of decline are 6.8% in L. Superior, 7.1% in L. Huron, 7.5% in L. Erie, and 7.3% in L. Ontario. Since the last indicator report, the rates of decline appear to be consistent with historical trends. Annual rates of decline determined using U.S. EPA data are slightly lower at 4.5% in L. Superior, 5.9% in L. Michigan, 5.9% in L. Huron, 6.0% in L. Erie, and 6.7% in L. Ontario. Rates of decline at

the U.S. monitoring stations in the years since the last indicator report appear to be increasing (i.e. declining faster) in lakes Michigan, Huron, and Ontario compared to historical trends while rates remain consistent with historical trends in Lakes Superior and Erie.

Total mercury

Basin Wide Status: Good; Deteriorating

There have been several studies on spatial and temporal trends of mercury in fish in the Great Lakes region since the last SOLEC indicator report (Bhavsar et al 2010; Monson et al. in press; Zananski et al. 2011). Both studies found that generally, the declines in mercury concentrations observed up until approximately 1990 have ceased and that mercury concentrations in fish have started to increase. EC and U.S. EPA data were used in the analyses of both studies and correspond with their findings (Figure 3). Concentrations of mercury are similar across all fish in all Great Lakes consistent with the assumption that concentrations of mercury in top predator fish are atmospherically driven and the recent increases may be a reflection, in part, of increased global mercury emissions (Pacyna et al. 2006). It is important to note that since the last indicator report (2006-2009) median concentrations of mercury in all top predator fish collected in Lakes Ontario, Erie, Huron and Michigan are below the GLWQA guideline of 0.5 µg/g and exceedances of the guideline only occurred in ~4% of the Lake Trout captured in Lake Superior (Table 3). Mercury concentrations in top predator fish are currently equal to or approaching the concentrations measured at the inception of the monitoring program in the late 1970s. Two segment linear piecewise regression of the EC dataset show that declines in mercury ceased in the late 1980s in lakes Superior and Huron and the early 1990s in lakes Erie and Ontario. Following the change points in each lake, mercury levels have been stable in lakes Huron and Ontario and appear to be increasing in lakes Superior and Erie. Mercury levels at U.S. EPA monitoring locations since 1999 mirror the EC results with one exception, in Lake Huron there has been a significant annual increase of mercury in Lake Trout of ~7%. Similar temporal patterns in mercury concentrations are also observed in Rainbow Smelt, a common forage fish for many fish and birds in the Great Lakes basin (Figure 4). The observed trend reversal in mercury concentrations in fish is consistent with recent findings (Monson 2009; Raymond & Rossmann 2009; Bhavsar et al. 2010; Monson et al. 2011) of mercury. Unfortunately, the data gap from the mid to late 1990s does not leave a sufficient number of data points to determine the current rates increase due to low statistical power. Continued monitoring of Hg levels in fish is required to definitively determine the rate of increase in mercury in all the lakes and adequately assess the future risk to wildlife consumers of fish in the Great Lakes basin.

Σα- & γ-Chlordane

Basin Wide Status: Good; Unchanging

Concentrations of α- + γ-chlordane in whole Lake Trout and Walleye have consistently declined since the chemical was banned by the U.S. EPA in 1988. In recent years, the concentrations in fish appear to have reached a steady state with no significant increases or decreases. The highest observed median concentrations since the last indicator report (2006-2009) are in Lake Trout from Lake Michigan (0.018 µg/g ww), followed by Lake Ontario (0.012 µg/g ww). Median concentration in Lakes Superior, Huron, and Erie are all below 0.01 µg/g ww. There is no target for chlordane in whole fish in the GLWQA. A report on the levels of chlordane in fish will not appear in future SOLEC indicator reports as focus is shifted to contaminants with established environmental quality guidelines or targets.

Mirex

Basin Wide Status: Good; Improving

Mirex is regularly detected only in fish from Lake Ontario due to historical releases in the Niagara River and other locations within the lake's watershed. Since the last indicator report (2006-09), median concentrations in Lake Trout were 0.061 µg/g ww (EC) and 0.041 µg/g ww (U.S. EPA). Declines in the concentration of mirex in Lake Trout from Lake Ontario are still declining at historical rates of between 4 and 12 % annually. According to the guidelines listed in the GLWQA, Mirex should be "substantially absent" from Great Lakes fish.

Dieldrin

Basin Wide Status: Good; Improving

The highest concentrations of dieldrin (and related compounds endrin and andrin) in top predator fish are observed in Lake Michigan (median = 0.034 µg/g ww) and Lake Ontario (median = 0.021 ug/g ww). Concentrations have declined substantially since monitoring began in the lakes and are still declining basin wide at rates ranging from 2 to 18% annually. There is no guideline for dieldrin in whole fish in the GLWQA. This will be the last report on the levels of dieldrin and related compounds SOLEC as focus is shifted to contaminants with established environmental quality guidelines or targets.

Toxaphene

Basin Wide Status: Fair; Improving

Decreases in toxaphene concentrations have been observed throughout the Great Lakes in all media following its ban in the mid-1980s. A recent study on toxaphene trends in Great Lakes fish show that concentrations remain the highest in Lake Superior (up to ~480 ng/g) and lowest in Lake Erie (up to ~50 ng/g) (Xia et al. 2012). Concentrations of toxaphene in Lake Trout and Walleye continue to exhibit exponential temporal declines in all of the Great Lakes; however, concentrations appear to level off starting in 2007 (Xia et al. 2012). Continued monitoring of toxaphene in top predator fish in the coming years should confirm whether toxaphene concentrations have reached a steady state in Great Lakes fish.

Polybrominated Diphenyl Ethers (PBDEs)

Basin Wide Status: Fair; Improving

The production and use of three popular commercial formulations of PBDE have or are being voluntarily phased out by industry in North America. The phase out of the more toxic penta- and octa-BDE compounds started in 2004 and by 2012, the use of deca-BDE will likely be reduced as a result of the voluntary withdrawal by industry (http:/www.bsef.com). In a national survey of PBDE concentrations in top predator fish from lakes across Canada, the highest concentrations were observed in fish from the Great Lakes and >95% of the PBDE compounds in the fish were tetra-, penta-, or hexa-BDEs (Gewurtz et al. 2011). Federal Environmental Quality Guidelines (FEQG) have been developed by Environment Canada for these three homologue groups which are meant to provide targets for acceptable environmental quality, assess the significance of observed concentrations, and to measure the success of risk management activities. The FEQGs to protect wildlife consumers of fish for tetra-, penta- and hexa-BDEs are 88, 1.0, and 420 ng/g ww respectively (Environment Canada 2010). Routine monitoring of PBDEs in whole top predator fish from the Great Lakes combined with retrospective analyses of archived samples by the U.S. EPA (Zhu & Hites, 2004) and Environment Canada have provided a complete picture of PBDE contamination in Great Lakes fish from 1977 to the present day. Concentrations of PBDEs in Lake Trout and Walleye rose continuously through to the early 2000s then began to decline as shown for penta-BDE in Figure 5**.** Log-linear regression of PBDE concentrations in Lake Trout and Walleye (U.S. EPA; Lake Erie), show significant declining trends of 5.8%/year for tetra-BDEs, 6.4% for penta-BDEs, and 3.4% for hexa-BDEs in Lake Ontario and annual declines of 19% for tetra-BDEs and 17% for penta-BDEs from Lake Michigan. PBDE concentrations in Lakes Superior, Huron, and Erie also appear to be declining as the slopes of the regressions are all negative; however, the slopes are not significantly different from zero at $\alpha = 0.05$ with a power of 80%. The majority of tetra-BDE and all hexa-BDE concentrations reported for Lake Trout and Walleye in 2009 from all the Great Lakes are below Environment Canada's FEQGs; however, all measured penta-BDE concentrations are well above the FEQG of 1.0 ng/g ww (Figure 6).

Other Contaminants of Emerging Interest

Perfluorinated acids

Perfluorooctane sulfonate (PFOS) is a synthetic substance belonging to a larger class of organic fluorochemicals that are either partially or completely saturated with fluorine. PFOS, perfluorocarboxylates and their precursors are used primarily in water, oil, soil, and grease repellents for paper and packaging, carpets, and fabrics, as well as in aqueous film forming foam (AFFF) for fighting fuel fires. PFOS was voluntarily phased-out of production by their primary supplier in 2002. However, PFOS use in Canada and the US continues due to specific use exemptions. Routine monitoring of PFOS in whole Lake Trout from the Great Lakes combined with retrospective analyses of archived samples from EC's National Aquatic Biological Specimen Bank have provided information on PFOS contamination in Lake Ontario Great Lakes fish from 1979 to 2008 (Figure 7). Concentrations of PFOS in Lake Trout rose continuously at a rate of 5.9%/year through to the late 1980s/early 1990s, after which no consistent change in time was observed. This contradicts trends observed in ringed seals in the Canadian Arctic, where significant PFOS declines were observed within the year following voluntary phase-outs (Butt et al. 2007). This contradiction may be due to continued inputs into Lake Ontario from the continued use of these substances. Perfluorooctanoic acid (PFOA) is another common fluorochemical and major manufacturers have voluntarily agreed to a 99% phase-out by 2015. However, PFOA is not highly bioaccumulative and time trends were not reliably measured in fish. Conversely, the concentration of two other fluorochemicals, perfluorodecane sulfonate (PFDS) and Perfluorooctane sulfonamide (PFOSA), have declined consistently in Lake Trout from Lake Ontario since 1992 at rates of 4.4% and 6.2% per year, respectively.

Synthetic Musks

The GLFMSP has begun screening for synthetic musks in fish tissue. These compounds are typically used in perfumes, colognes, shampoos, detergents, disinfectants and enter water through wastewater discharge and atmospheric deposition. The classes of synthetic musks that are of interest include: nitro-musks, polycylic musks, macrocyclic musks, alicyclic musks. To date, analytical results have indicated that two synthetic musks in particular, galoxolide and tonalide, are the most abundant musks found in GLFMSP samples. Concentrations of musks are highest in Lake Ontario followed by Lake Superior, Lake Huron, Lake Michigan, and Lake Erie. There is currently insufficient data to fully explain the spatial pattern in the Lakes; however, this could be evidence of significant atmospheric transport of musks. Detection of these chemicals in the laboratory is extremely difficult due to the high potential for sample contamination since these chemicals are present in numerous products, including laundry detergent, soaps, shampoos, deodorants, body sprays, cleaning supplies, etc. Experimental techniques, such as fragarance-free rooms for analysis may be employed for future analyses. Additional results for musks, and other emerging chemicals, will be reported in subsequent SOLEC indicator reports.

Linkages

Contaminant levels in Lake Trout and Walleye are dependent on complex biological and physiochemical interactions both within and outside of the Great Lakes basin as these apex predators integrate contaminant inputs from water, air, sediment, and their food sources. A changing climate and associated changes to precipitation and wind currents will alter the influx of contaminants from sources outside of the basin and may alter food webs and the contaminant transfer through them. Aquatic invasive species also alter food webs and change energy and contaminant dynamics in the lakes. They also may introduce new pathways by which sediment contaminant pools could be mobilized and transferred to fish. Many new contaminants of concern are components of consumer products, personal care products, or pharmaceuticals, as a result, wastewater treatment effluents are an important source of contamination which is growing along with the human population of the basin.

Management Challenges/Opportunities

Much of the current, basin wide, persistent toxic substance data that is reported focuses on legacy chemicals whose use has been previously restricted through various forms of legislation but that continue to be the source of the highest levels of contaminants detected in fish, eg. PCBs. However, both the U.S. and Canadian programs are making efforts to incorporate the monitoring and surveillance of emerging chemicals into their routine work. Chemicals of interest are identified through scientific studies (eg. Howard & Muir 2010), general screening of annual samples and also though risk assessments by regulatory bodies. As chemicals are identified through this process, they will be reported out through SOLEC, particularly those chemicals with established criteria.

Environmental Specimen Banks containing tissue samples are a key component of both the U.S. and Canadian monitoring programs, allowing for retrospective analyses of newly identified chemicals of concern to develop long-term trends in the short-term.

Fostering collaboration between U.S. and Canadian monitoring programs for various media will be beneficial, especially in times of fiscal restraint. In 2009, an ad-hoc binational group was formed to bring together government representatives and researchers working on identifying new chemicals in the Great Lakes ecosystem with the objective to facilitate best management practices and sharing of information and resources. The group provides a forum for agencies and researchers to seek and provide information on emerging contaminant surveillance, monitoring, chemical methods development, and provides a place to collaborate on similar chemicals, or classes of chemicals, in different media. Collaboration among research in differing media also provides an excellent opportunity for cost sharing, an accelerated rate of discovery, and a validation of results among the Great Lakes research and monitoring community.

Comments from author(s)

The authors have made efforts to improve the statistical rigor of this indicator report through the inclusion of error bounds on estimated concentrations and trends through time. The authors have also focused on contaminants with defined environmental targets, guidelines and/or thresholds to put observed concentrations in context with risk to the environment. Other improvements to statistical rigor, such as, better methods to characterize dataset with censored values (i.e. non-detects) should be investigated and incorporated in future reports on this indicator.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Daryl McGoldrick, Environment Canada

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Elizabeth Murphy, United States Environmental Protection Agency

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Table 1. Summary of total PCB concentrations for individual (Env. Canada; Arochlor 1254) and composited (U.S. EPA; total congeners) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report (2006-2009).
Source: Environment Canada and U.S. Environmental Protection Agency

Table 2. Summary of the concentrations of opDDT and its metabolites (opDDD and opDDE) in individual (Env. Canada) and composited (U.S. EPA) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report (2006-2009).
Source: Environment Canada and U.S. Environmental Protection Agency

Table 3. Summary of total mercury concentrations in individual (Env. Canada; 2006-2009) and composited (U.S. EPA; 2006-2007) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last Great Lakes/SOLEC indicator report.
Source: Environment Canada and U.S. Environmental Protection Agency

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Source: Environment Canada and U.S. Environmental Protection Agency

Figure 2. Total PCB concentrations (median & IQR) for individual (Environment Canada) and composited (U.S. Environmental Protection Agency) whole body Lake Trout or Walleye (Lake Erie) collected from each of the Great Lakes. Dashed lines show log-linear regression model if annual change is significantly different from zero (α = 0.05).
Source: Environment Canada and U.S. Environmental Protection Agency

Figure 3. Total mercury concentrations (median & IQR) for individual (Environment Canada) and composited (U.S. Environmental Protection Agency) whole body Lake Trout or Walleye (Lake Erie) collected from each of the Great Lakes. Results of 2-segment linear piecewise regression (solid red line) or log-linear regression (solid blue line) models. Mercury concentrations reported by Schmitt and Brumbaugh (1990) in Lake Michigan Lake Trout also provided.
Source: Environment Canada, U.S. Environmental Protection Agency and Schmitt and Brumbaugh

Figure 4. Median total mercury concentrations in composited Rainbow Smelt collected from the Canadian waters of the Great Lakes by Environment Canada. Lines denote 3 year moving average.
Source: Environment Canada and U.S. Environmental Protection Agency

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Source: Environment Canada and U.S. Environmental Protection Agency

Figure 6. Concentrations of the dominant PBDE congeners (ng/g ww) in whole body Lake Trout and Walleye (U.S. EPA; Lake Erie) in each of the Great Lakes measured in 2009 relative to the Federal Environmental Quality Guidelines developed by Environment Canada (red dashed line).
Source: Environment Canada and U.S. Environmental Protection Agency

Figure 7. Temporal trends of PFOS concentrations (geometric mean ± 95% confidence interval) in Lake Ontario Lake Trout measured by Environment Canada (De Silva, unpublished data) and Ontario Ministry of the Environment (Furdui et al. 2008).
Source: Environment Canada and U.S. Environmental Protection Agency

Figure 8. Average synthetic musk concentrations (ng/g ww) in whole body Lake Trout and Walleye (U.S. EPA; Lake Erie) in each of the Great Lakes measured in 2009.
Source: Environment Canada and U.S. Environmental Protection Agency

Last Updated:
State of the Great Lakes 2011

Summary of total PCB concentrations

	N	Median (IQR) µg/g ww	% measurements above target***
Lake Superior* Env. Canada	324	0.21 (0.08 – 0.41)	72
Lake Superior* U.S. EPA	35	0.37 (0.18 – 0.55)	100
Lake Michigan* Env. Canada	-	-	-
Lake Michigan* U.S. EPA	40	0.92 (0.78 – 0.99)	100
Lake Huron* Env. Canada	101	0.20 (0.16 – 0.26)	89
Lake Huron* U.S. EPA	40	0.73 (0.50 – 0.85)	100
Lake Erie** Env. Canada	142	0.77 (0.53 – 1.3)	100
Lake Erie** U.S. EPA	40	0.49 (0.38 – 0.79)	100
Lake Ontario* Env. Canada	324	0.85 (0.66 – 1.1)	100
Lake Ontario* U.S. EPA	38	0.87 (0.74 – 1.0)	100

* whole body Lake Trout
** whole body Walleye
*** 0.1 µg/g ww (GLWQA Annex 1)

Table 1. Summary of total PCB concentrations for individual (Env. Canada; Arochlor 1254) and composited (U.S. EPA; total congeners) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report (2006-2009).
Source: Environment Canada and U.S. Environmental Protection Agency

Summary of the concentrations of opDDT and its metabolites

	N	Median (IQR) µg/g ww	% measurements above target***
Lake Superior* Env. Canada	255	0.04 (0.03 – 0.07)	0
Lake Superior* U.S. EPA	37	0.09 (0.05 – 0.16)	0
Lake Michigan* Env. Canada	-	-	-
Lake Michigan* U.S. EPA	41	0.27 (0.21 – 0.32)	0
Lake Huron* Env. Canada	55	0.11 (0.07 – 0.14)	0
Lake Huron* U.S. EPA	43	0.21 (0.15 – 0.25)	0
Lake Erie** Env. Canada	142	0.06 (0.05 – 0.08)	0
Lake Erie** U.S. EPA	42	0.05 (0.04 – 0.05)	0
Lake Ontario* Env. Canada	200	0.21 (0.12 – 0.30)	0
Lake Ontario* U.S. EPA	40	0.24 (0.19-0.29)	0

* whole body Lake Trout
** whole body Walleye
*** 1.0 µg/g ww (GLWQA Annex 1)

Table 2. Summary of the concentrations of opDDT and its metabolites (opDDD and opDDE) in individual (Env. Canada) and composited (U.S. EPA) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report (2006-2009).
Source: Environment Canada and U.S. Environmental Protection Agency

Summary of total mercury concentrations

	N	Median (IQR) µg/g ww	% measurements above target***
Lake Superior* Env. Canada	266	0.18 (0.12 – 0.29)	4
Lake Superior* U.S. EPA	17	0.21 (0.14 – 0.33)	0
Lake Michigan* Env. Canada	-	-	-
Lake Michigan* U.S. EPA	19	0.15 (0.13 – 0.18)	0
Lake Huron* Env. Canada	101	0.10 (0.08 – 0.14)	0
Lake Huron* U.S. EPA	20	0.24 (0.20 – 0.28)	0
Lake Erie** Env. Canada	91	0.15 (0.13 – 0.17)	0
Lake Erie** U.S. EPA	20	0.11 (0.10 – 0.13)	0
Lake Ontario** Env. Canada	252	0.13 (0.11 – 0.15)	0
Lake Ontario** U.S. EPA	20	0.10 (0.10 – 0.13)	0

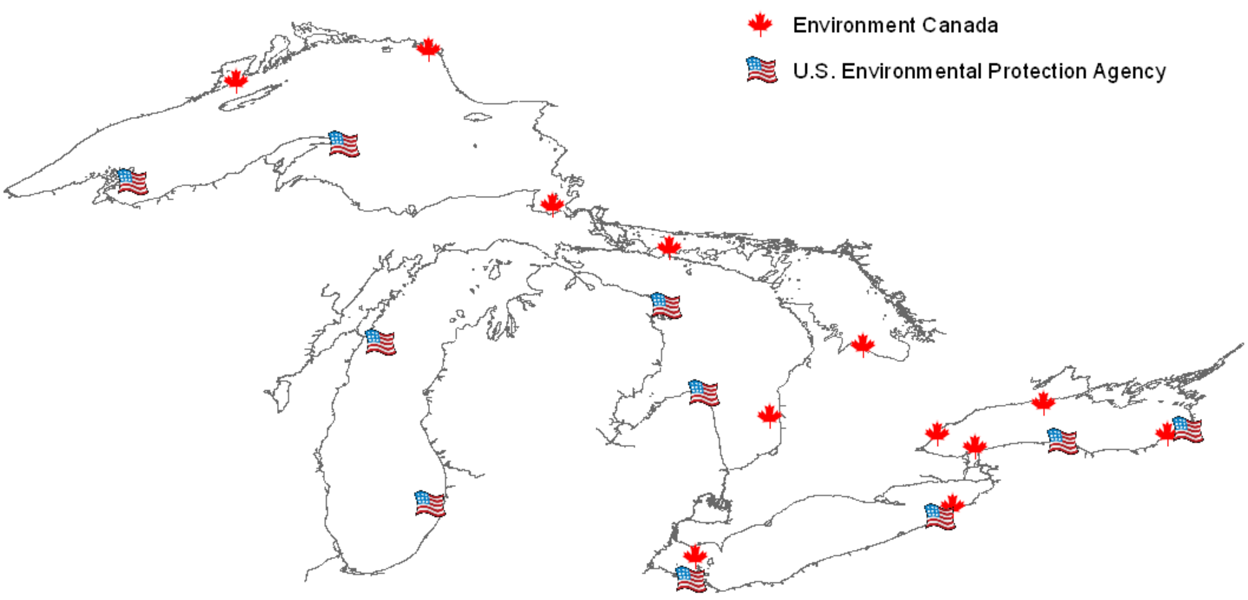
* whole body Lake Trout

** whole body Walleye

*** 0.5 µg/g ww (GLWQA Annex 1)

Table 3. Summary of total mercury concentrations in individual (Env. Canada; 2006-2009) and composited (U.S. EPA; 2006-2007) whole body Lake Trout or Walleye collected from the each of the Great Lakes measured since the last SOLEC indicator report.

Source: Environment Canada and U.S. Environmental Protection Agency



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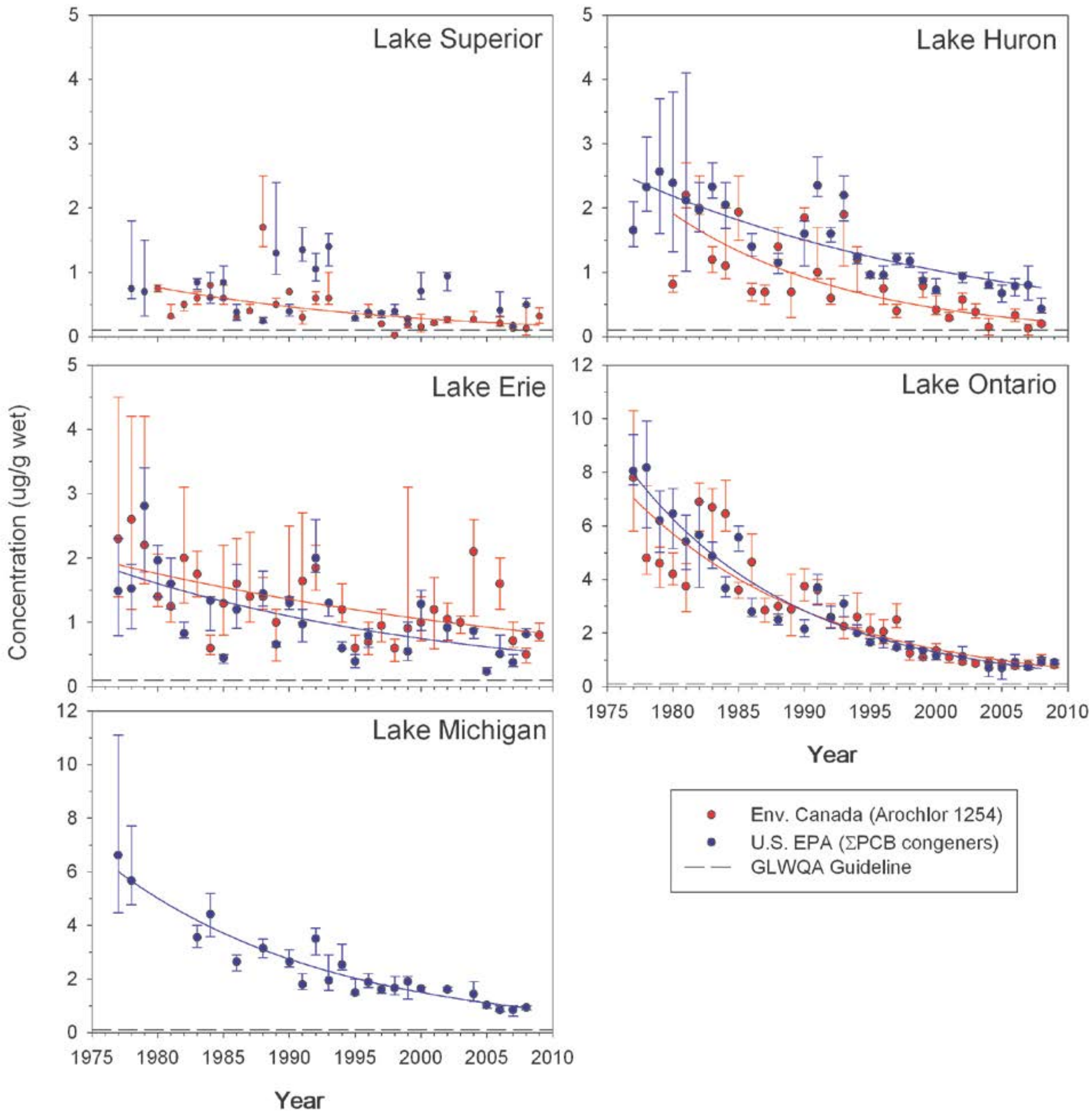
Source: Environment Canada and U.S. Environmental Protection Agency



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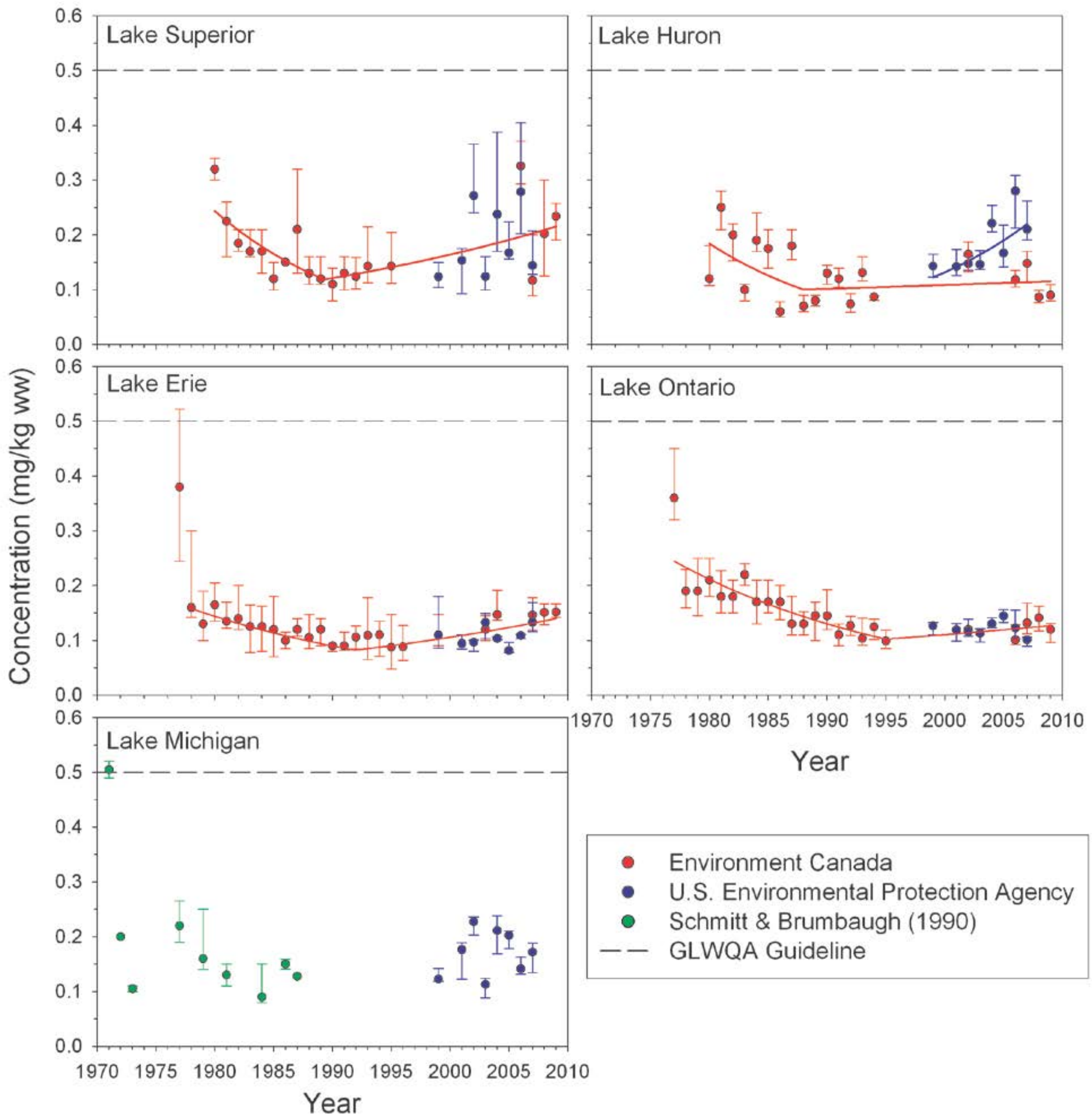
Source: Environment Canada and U.S. Environmental Protection Agency



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Source: Environment Canada, U.S. Environmental Protection Agency and Schmitt and Brumbaugh

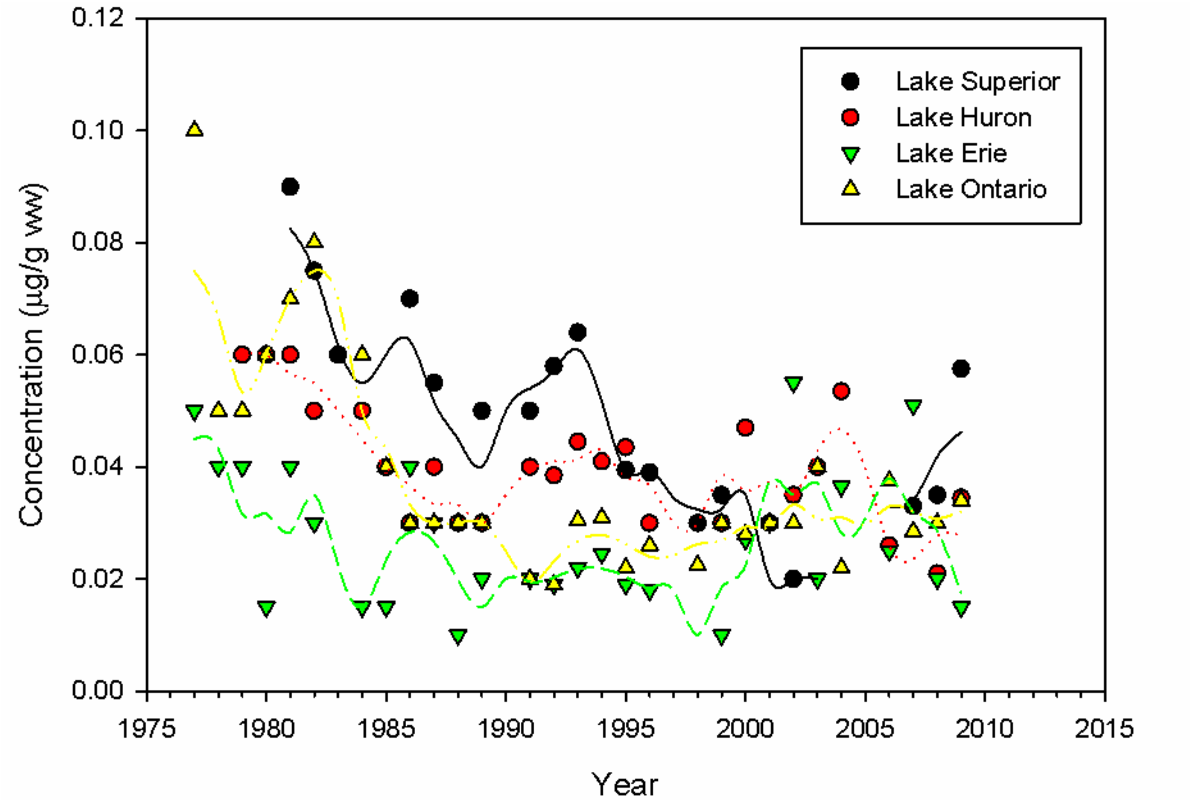

Figure 4. Median total mercury concentrations in composited Rainbow Smelt collected from the Canadian waters of the Great Lakes by Environment Canada. Lines denote 3 year moving average.
Source: Environment Canada and U.S. Environmental Protection Agency

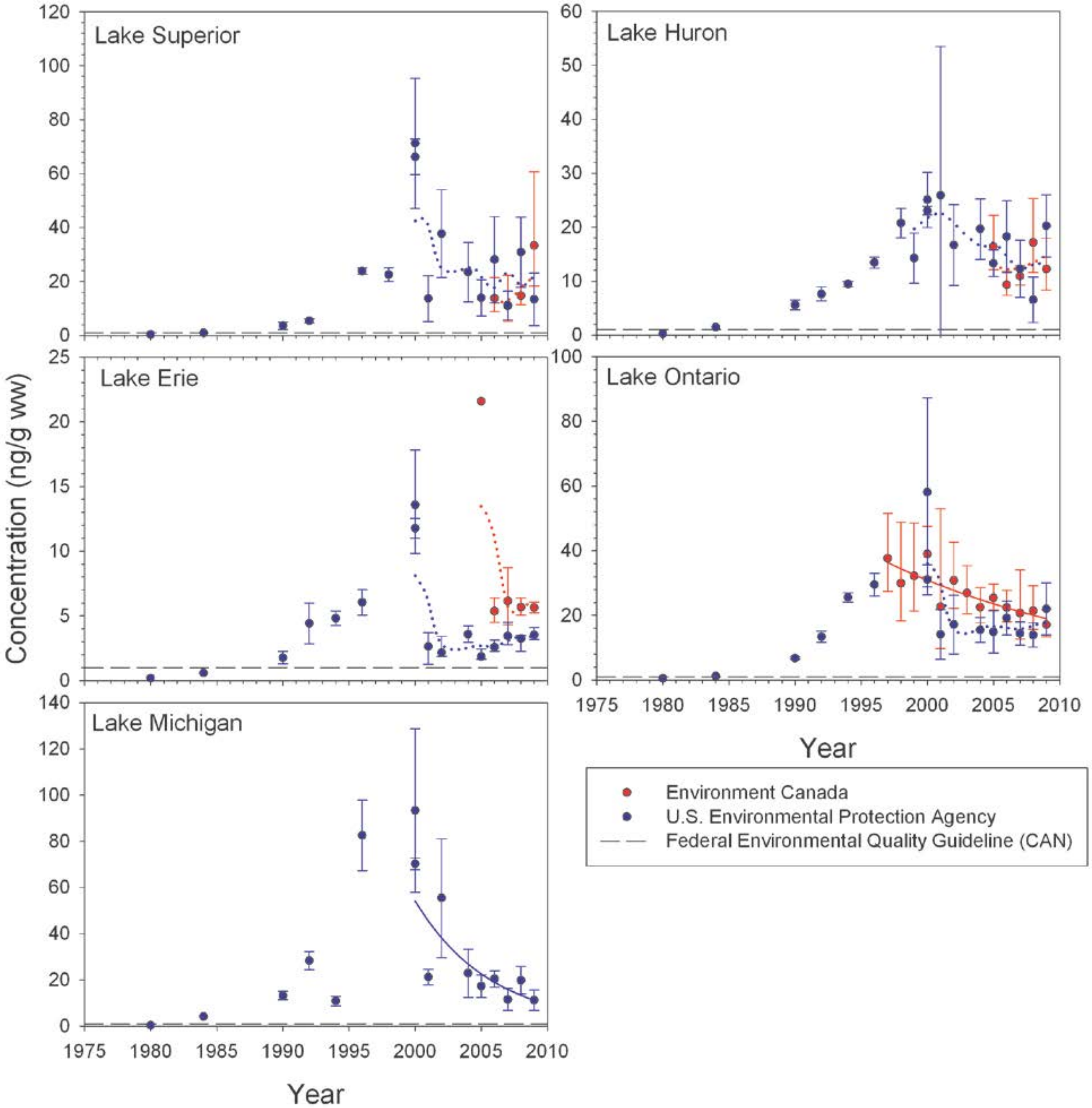

Figure 5. Mean (± stdev) penta-BDE concentrations in Great Lakes fish measured by Environment Canada, U.S. Environmental Protection Agency and Zhu & Hites (2004). Solid lines denote significant log-linear regressions. Dotted lines denote 3 year moving average when log-linear regression is not significant.
Source: Environment Canada and U.S. Environmental Protection Agency

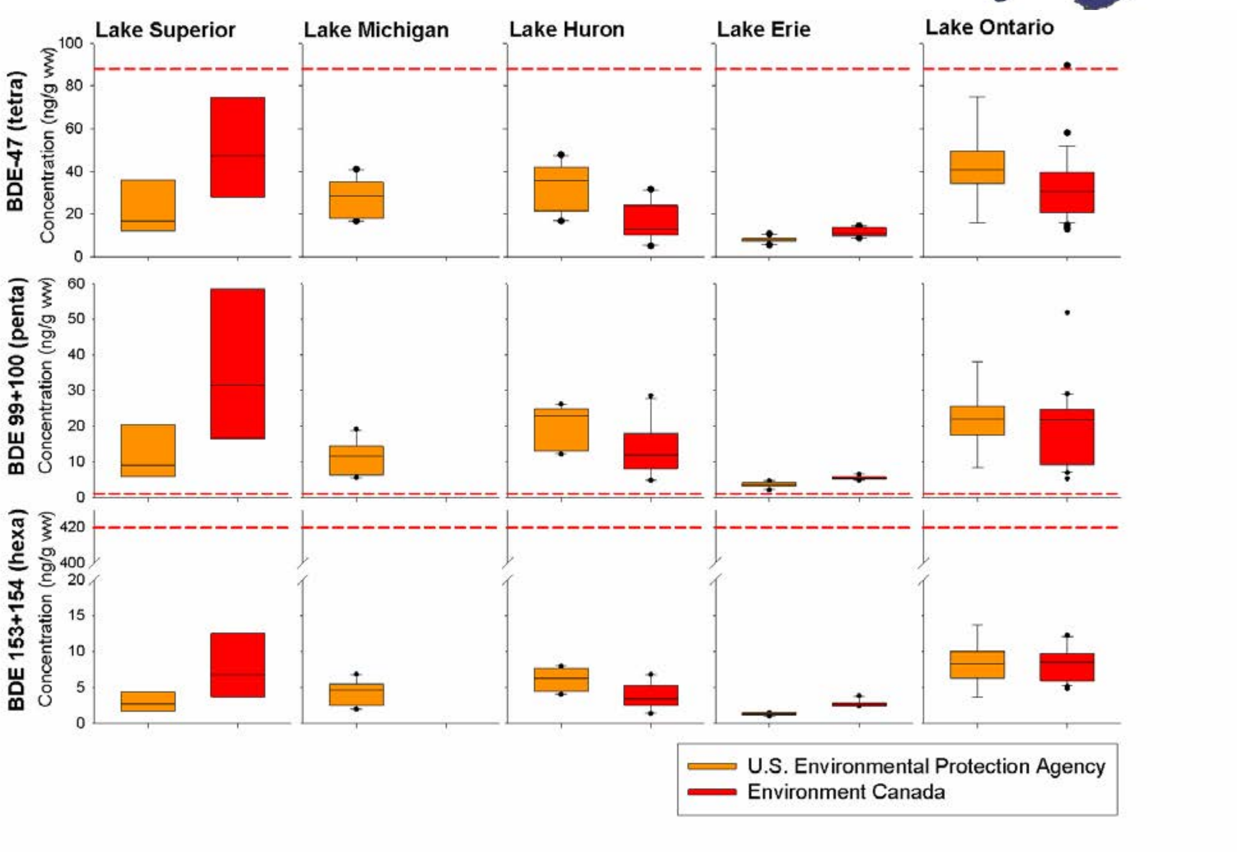

Figure 6. Concentrations of the dominant PBDE congeners (ng/g ww) in whole body Lake Trout and Walleye (U.S. EPA; Lake Erie) in each of the Great Lakes measured in 2009 relative to the Federal Environmental Quality Guidelines developed by Environment Canada (red dashed line).
Source: Environment Canada and U.S. Environmental Protection Agency

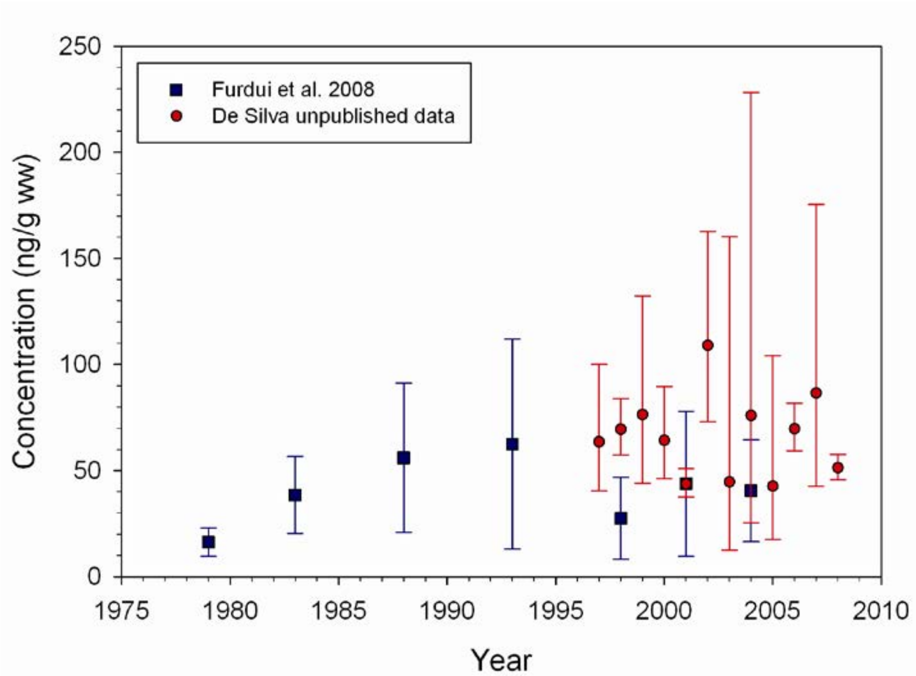

Figure 7. Temporal trends of PFOS concentrations (geometric mean ± 95% confidence interval) in Lake Ontario Lake Trout measured by Environment Canada (De Silva, unpublished data) and Ontario Ministry of the Environment (Furdui et al. 2008).
Source: Environment Canada and U.S. Environmental Protection Agency

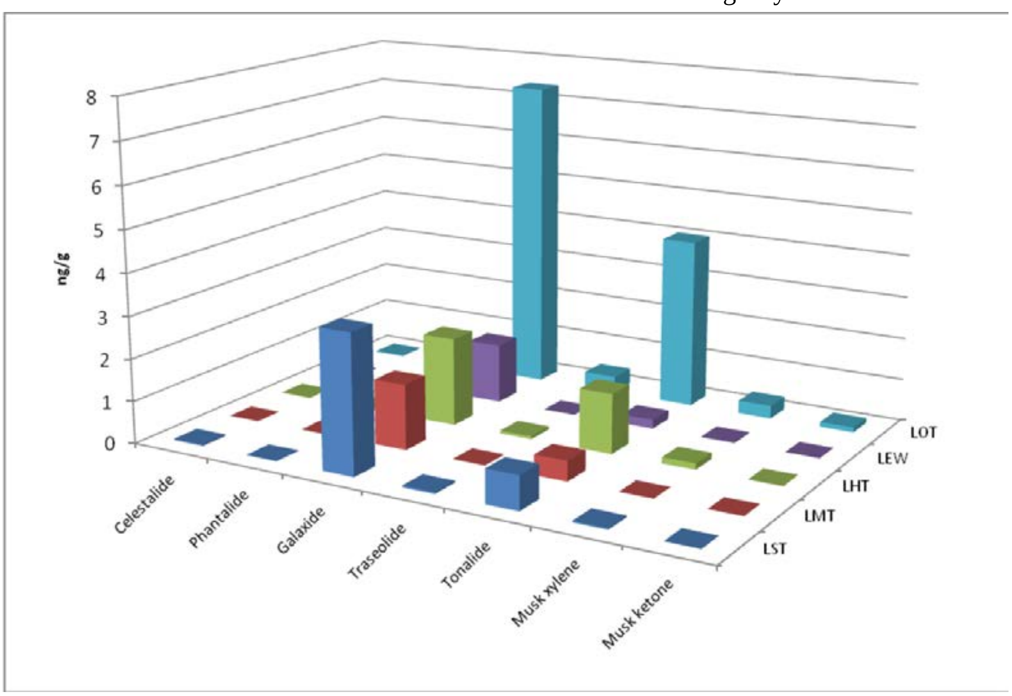

Figure 8. Average synthetic musk concentrations (ng/g ww) in whole body Lake Trout and Walleye (U.S. EPA; Lake Erie) in each of the Great Lakes measured in 2009.
Source: Environment Canada and U.S. Environmental Protection Agency

Contamination in Sediment Cores

Overall Assessment
Status: Fair
Trend: Improving
Rationale: Concentrations of legacy contaminants including PCBs and DDT are generally below guidelines in the Great Lakes and declining. Other contaminants such as the polybrominated diphenyl ethers (PBDEs) exhibit some exceedances of guidelines, particularly penta-BDE in Lake Ontario; however, temporal trends show recent declines as a result of management actions.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Unchanging
Rationale: Lake Superior is the largest, coldest and deepest of the Great Lakes; as a result, rates of decreases in concentrations of legacy contaminants are slow. However, typical offshore sediment contaminant concentrations are very low as atmospheric deposition is the primary source. Concentrations of some metals exceed the strictest sediment quality guidelines due to the nature of the watershed (pre-Cambrian shield) and historical regional sources associated with mining and smelting.

Lake Michigan
Status: Not Assessed
Trend: Not Assessed
Rationale: Not Assessed

Lake Huron
Status: Good
Trend: Improving
Rationale: Lake Huron is similar to Lake Superior from a sediment contamination viewpoint, as the lake is large, cold and deep with atmospheric deposition as the primary source of most contaminants. Typical sediment contaminant concentrations are very low. As with Superior, concentrations of some metals exceed the strictest guidelines due to the natural geochemistry of the watershed (pre-Cambrian shield) that results in loadings of compounds such as mercury.

Lake Erie
Status: Fair
Trend: Improving
Rationale: Lake Erie exhibits a definitive spatial gradient in contamination with decreasing concentrations from the western basin to the eastern basin, and from the southern area to the northern area of the central basin. This spatial distribution in Lake Erie is influenced by industrial activities in the watersheds of major tributaries, including the Detroit River, and areas along the southern shoreline. The shallow nature of the western basin results in resuspended contaminated bottom sediment continuing to influence suspended sediment quality in the water column, while sediment quality in the eastern basin continues to be classified as excellent.

Lake Ontario
Status: Fair
Trend: Improving
Rationale: Lake Ontario continues to exhibit the poorest sediment quality of all the Great Lakes. The greatest frequency and magnitude of exceedances of sediment quality guidelines is for polychlorinated dibenzo-*p*-dioxins and dibenzofurans. This legacy contamination issue is the result of historical industrial activities in the Niagara River watershed; however, current levels of dioxin contamination represent a 70 percent decline from peak levels in the 1970s. Trends in most legacy chemicals in Lake Ontario point toward improvement in sediment quality over time.

Purpose

- To assess the occurrence, distribution and fate of chemicals in Great Lakes sediments;
- To infer potential harm, or pressure, caused by contaminated sediments to Great Lakes aquatic ecosystems;
- To assist in identification of sources of chemicals to the Great Lakes.
- The Contamination in Sediment Cores indicator is used in the Great Lakes indicator suite as a Pressure indicator in the Pollution and Nutrients top level reporting category.

Ecosystem Objective
The Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human health, animal or aquatic life (Great Lakes Water Quality Agreement (GLWQA) Article IIId, United States and Canada 1987). The GLWQA and the Great Lakes Binational Toxics Strategy both state the virtual elimination of toxic substances to the Great Lakes as an objective.

Ecological Condition
Bottom sediment contaminant surveys conducted in the Great Lakes from 1968 – 1974, from 1997 – 2002 and more recent surveys provide information on the spatial distribution of contaminants, the impacts of local historical sources and, in concert with sediment cores, the response to management initiatives. Contaminants across several chemical classes are measured in both surface sediment and sediment cores. The measured contaminants with the highest occurrences, causes of degradation of sediment quality and fish consumption restrictions are:

- Mercury
- PCBs
- Dioxins
- HCB
- Total DDT
- Lead
- PAHs
- Dioxins and Furans

The spatial distribution of mercury contamination in Great Lakes sediments generally represents those of other toxic compounds, both other metals and organics such as PCBs, as accumulation of a broad range of contaminants on a lake-by-lake basis can be the result of common sources, e.g., chlor-alkali production. The highest concentrations of mercury in sediments of lakes Michigan, St. Clair, Erie and Ontario are observed in offshore depositional areas characterized by fine-grained sediments (Figure 1). In the case of lead, the degree of contamination in Lake Michigan is similar to Lake Ontario. Contaminant concentrations are generally correlated with particle size; hence the distribution of mercury is not only a function of loadings and proximity to sources, but of substrate type and bathymetry. Mercury contamination is generally quite low in lakes Huron, Michigan and Superior and higher in lakes St. Clair, Ontario and the western basin of Lake Erie. There is a gradient in contamination in Lake Erie with decreasing concentrations from the western basin to the eastern basin, and from the southern area to the northern area of the central basin. The spatial distribution in Lake Erie is influenced by industrial activities in the watersheds of major tributaries, including the Detroit River, and areas along the southern shoreline. Sources and loadings of mercury to Lake Huron appear to have been reduced to the point that no apparent spatial pattern exists. Current sediment contamination is substantially lower than peak levels that occurred in the mid – 1950s through the early 1970s. Connecting channels including the Niagara, lower Detroit and upper St. Clair Rivers are associated with historical mercury cell chlor-alkali production; these areas were also intensively industrialized and were primary sources of a variety of persistent toxics to the open lakes, including PCBs. Localized areas of highly contaminated sediment, and/or hazardous waste sites may continue to act as sources of contaminants and influence spatial distributions. Conversely, local sources may no longer be predominant, and spatial patterns may now reflect resuspension, intra-lake mixing and deposition of existing sediment inventories. In this case, further declines would be expected as contaminants are deposited and buried.

Status of Contaminants in Sediment

Sediments in the Great Lakes generally represent a primary sink for contaminants, and can act as a source through resuspension and subsequent redistribution. Conversely, burial in sediments also represents a primary mechanism by which contaminants are sequestered and prevented from re-entering the water column.

Comparisons of surficial sediment contaminant concentrations with sub-surface maximum concentrations indicate that contaminant concentrations have generally decreased by more than 35 per cent, and, in some cases, by as much as 80 per cent over the past four decades (Table 1).

Sediment concentrations can also be assessed against guideline values established for the protection of aquatic biota, e.g., Canadian Sediment Quality Guidelines Probable Effect Level (PEL, CCME, 1999). These guidelines can be applied as screening tools in the assessment of potential risk, and for the determination of relative sediment quality concerns. For metals, PEL guideline exceedances were frequent in Lake Ontario for lead, cadmium and zinc. Guideline exceedances were rare in all of the other lakes, with the exception of lead in Lake Michigan where the PEL (91.3 μg/g) was exceeded at over half of the sites. There were no PEL (277 ng/g total PCBs) guideline exceedances for PCBs in any of the Great Lakes sediments.

The presence of new persistent toxic substances represents a potential threat to the health of the Great Lakes ecosystem. These compounds include perfluoroalklated compounds (PFCs) and brominated flame retardants (BFRs), the latter of which are heavily used globally in the manufacturing of a wide range of consumer products and building materials. The BFRs have been found to be bioaccumulating in Great Lakes fish and in breast milk of North American women. While end of the pipe discharges may not be responsible for ongoing contamination, modern urban/industrial centres can act as diffuse sources of current inputs. Sediment core profiles of brominated diphenyl ethers (BDEs) and PFCs in Lake Ontario suggest that accumulation of these chemicals has recently peaked, or continues to increase (Figure 2). The Lake Ontario BDE profile indicates a leveling off of accumulation in the past decade, presumably as a result of voluntary cessation of production of these compounds in North America. However, the deca-substituted BDE 209 is the predominant congener in sediment, and is still currently used. Despite these trends, maximum concentrations of many BFRs and PFCs remain well below maximum concentrations of contaminants such as DDT and PCBs observed in past decades.

Assessment of the occurrence and fate of newer compounds has been incorporated into sediment assessment programs. PFCs are a broad range of substances that have attracted much scientific and regulatory interest in recent years as a result of their detection globally in humans and wildlife. PFCs are routinely detected in precipitation and air in urban and rural environments. These compounds have a myriad of applications, but have been primarily used as soil and liquid repellents for papers, textiles and carpeting. Production of PFCs as stain repellents in carpets historically exceeded $1 billion annually. Two classes of PFCs, the perfluoroalkyl sulfonate acids (PFSAs), particularly perfluorooctane sulfonate (PFOS), and the perfluorocarboxylates, particulary perfluorooctanoic acid (PFOA), are the most commonly measured PFCs; these compounds are highly stable and persistent in the environment, and are potentially toxic. PFCs have been detected in environmental samples far from urban areas, including remote areas such as the Canadian Arctic. The physical and chemical properties of PFCs are different from many other semi-volatile pollutants that can significantly influence their pathways through the environment.

Concentrations of PFCs in sediments of Great Lakes tributaries are highest in urbanized and/or industrialized watersheds. In general levels of perfluoroalkyl sulfonate acids and PFOS in tributaries (Figure 3) and open waters of the Great Lakes are slightly higher than the perfluorocarboxylates with the highest levels of PFCs generally found in areas of Lake Ontario and the western end of Lake Erie and the Detroit River corridor. There is a gradient toward increasing PFC contamination from the upper Great Lakes (Superior and Huron) to the lower Great Lakes (Erie and Ontario) for both tributary and open-lake sediments (Figures 3 and 4). Concentrations of PFCs in open-lake sediments are driven not only by proximity to sources, but physical processes and bathymetry as well. The highest PFC concentrations in open-lake sediments were found in Lake Ontario. The spatial distributions of PFCs in Lake Ontario are fairly consistent across the lake, which is primarily due to lake currents that evenly distribute suspended particles and across the three major depositional basins.

The spatial distributions of PFCs in Great Lakes sediments are heavily influenced by shoreline-based urban and industrial activities, which in some cases stand in contrast to distributions of legacy contaminants such as PCBs. These results suggest that large urban areas can act as diffuse sources of PFCs associated with modern industrial and consumer products, and therefore management action should focus on prevention of pollutant emissions from consumer and industrial products.

Management Challenges/Opportunities

Management efforts to control inputs of historical contaminants have resulted in decreasing contaminant concentrations in the Great Lakes open-water sediments for the standard list of chemicals. However, chemicals such as BFRs and current-use pesticides may represent emerging issues and potential future stressors to the ecosystem. These results corroborate observations made globally, which indicate that large urban centers act as diffuse sources of chemicals that are heavily used to support our modern societal lifestyle.

Linkages

Sediment contamination affects both water quality and aquatic dependent life. Sediment is a source of mercury and other toxic chemicals to enter the water column. These chemicals are components of the indicators in the top level categories of Water Quality, Aquatic Dependent Life, Fish & Wildlife, and Restoration & Protection. Relevant indicators include “Toxic chemicals in offshore waters”, water quality as measured by contaminants in whole fish, water birds, and bald eagles, “Fish disease occurrences,” and “Sediment remediation.”

Comments from authors

Long-term research and monitoring programs are valuable tools for demonstrating effectiveness of remedial actions and management initiatives, as well as acting as indicators of emerging issues. Government agencies in both the United States and Canada are formulating plans for future sediment core work, including the requirements for adequate numbers of samples to enable an accurate assessment of both spatial distributions and temporal trends.

In order to properly assess Lake Michigan, the sediment indicator team needs a consistent U.S. partner. Over the years, U.S. EPA has typically provided a member, however the turnover has been high and in recent years Canadian sediment indicator team had no support. As a result, an assessment of Lake Michigan without the input from the U.S. perspective was not undertaken.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	x					
2. Data are traceable to original sources	x					
3. The source of the data is a known, reliable and respected generator of data	x					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	x					
5. Data obtained from sources within the U.S. are comparable to those from Canada		x				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				

Acknowledgments

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Information Sources

Environment Canada Great Lakes Fact Sheet. Polybrominated diphenyl ethers in sediments of tributaries and open-water areas of the Great Lakes. Catalogue No. En84-70/2009E.

Environment Canada Great Lakes Fact Sheet. Perfluoroalkyl compounds in sediments of tributaries and open-water areas of the Great Lakes. ISBN No. 978-1-100-145025-4.

Environment Canada Great Lakes Fact Sheet. Contaminants in sediments of Canadian tributaries and open-water areas of the lower Great Lakes. ISBN No. 978-0-662-46896-7.

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Source: Environment Canada.

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Source: Environment Canada and USEPA.

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Source: Environment Canada and Ontario Ministry of the Environment.

Figure 3. Total PFSAs perfluoroalkyl sulfonate acids (PFSAs) and perfluorooctane sulfonate (PFOS) concentrations in surficial sediments in tributaries of the Great Lakes.
Source: Environment Canada and the Ontario Ministry of the Environment.

Figure 4. Total PFSAs perfluoroalkyl sulfonate acids (PFSAs) and perfluorooctane sulfonate (PFOS) concentrations in surficial sediments of open-water areas of the Great Lakes.
Source: Environment Canada and the Ontario Ministry of the Environment.

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Estimated percentage declines in sediment contamination

Parameter	Lake Ontario %Reduction	Lake Erie %Reduction	Lake St. Clair %Reduction	Lake Huron %Reduction	Lake Superior %Reduction
Mercury	73	37	89	82	0
PCBs	37	40	49	45	15
Dioxins	70	NA	NA	NA	NA
HCB	38	72	49	NA	NA
Total DDT	60	42	78	93	NA
Lead	45	50	74	43	10

Table 1. Estimated percentage declines in sediment contamination in the Great Lakes (1970 – 2010) based on comparison of surface sediment concentrations with maximum concentrations at depth in sediment cores.
Source: Environment Canada

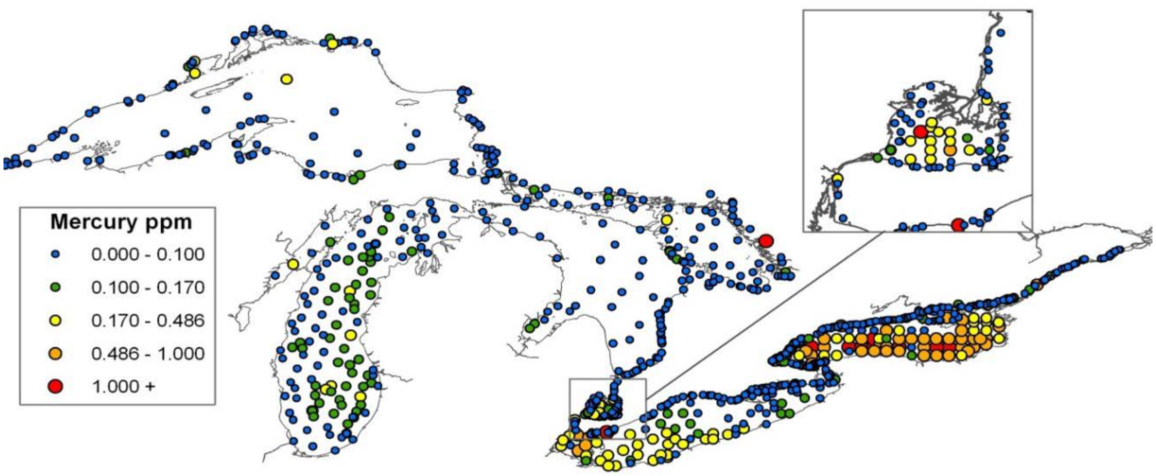

Figure 1. Spatial distribution of mercury contamination in surface sediments in open-lake areas and tributaries of the Great Lakes.
Sources: Environment Canada and USEPA.

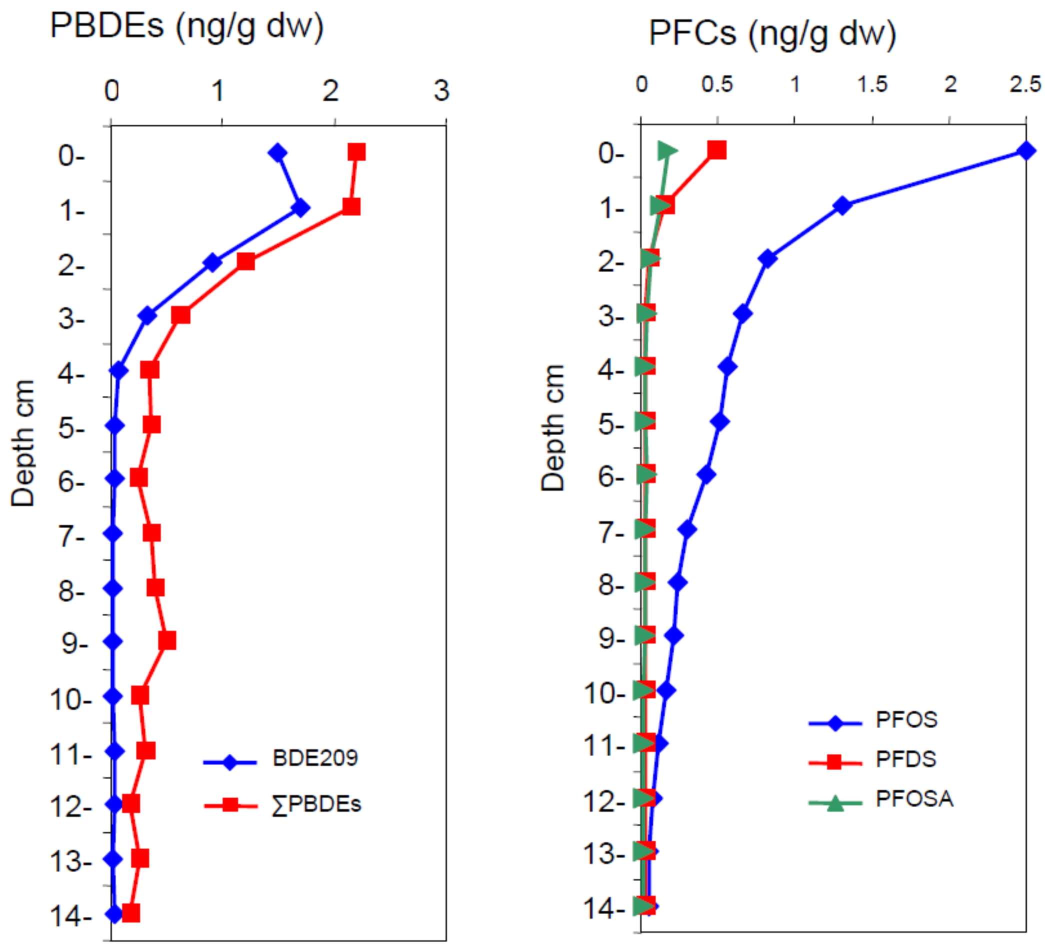

Figure 2. Core profiles of perfluoroalkyl compounds (PFCs) and polybrominated diphenyl ethers (PBDEs) in sediment cores from the central (Mississauga Basin) basin of Lake Ontario.
Sources: Environment Canada and Ontario Ministry of the Environment.

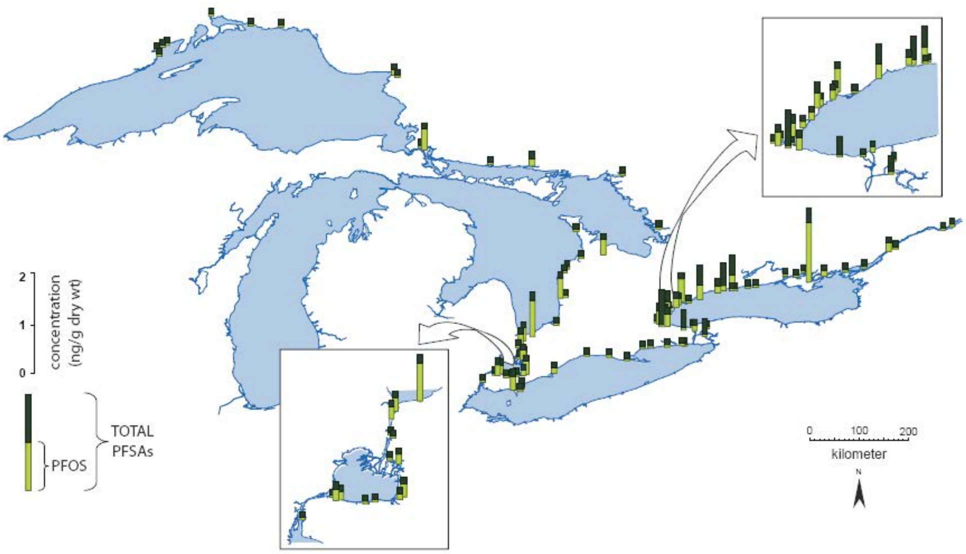

Figure 3. Total PFSAs perfluoroalkyl sulfonate acids (PFSAs) and perfluorooctane sulfonate (PFOS) concentrations in surficial sediments in tributaries of the Great Lakes.
Source: Environment Canada and the Ontario Ministry of the Environment.

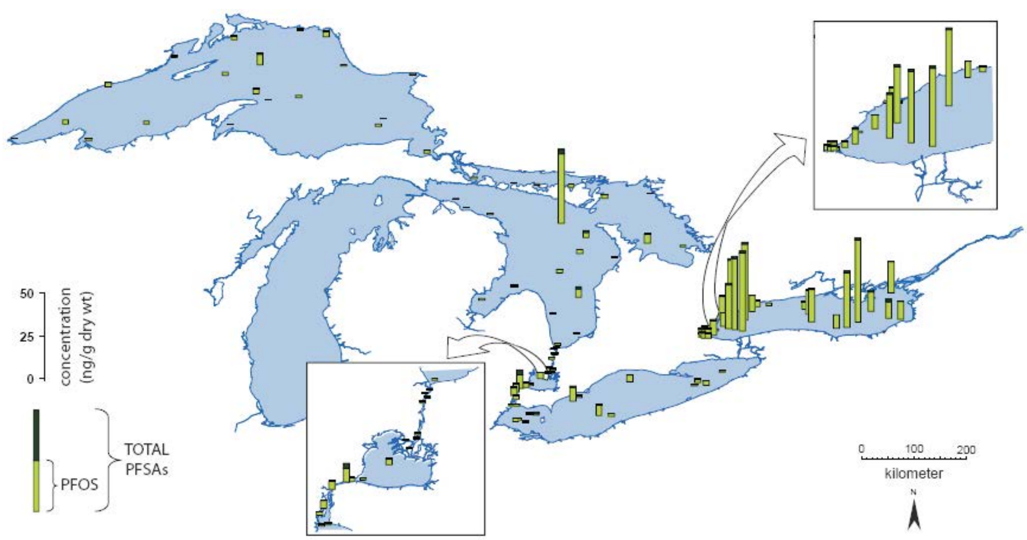

Figure 4. Total PFSAs perfluoroalkyl sulfonate acids (PFSAs) and perfluorooctane sulfonate (PFOS) concentrations in surficial sediments of open-water areas of the Great Lakes.
Source: Environment Canada and the Ontario Ministry of the Environment.

Diporeia

Overall Assessment
Status: Poor
Trend: Deteriorating
Rationale: Abundances of the benthic amphipod *Diporeia* spp. continue to decline in Lake Michigan, Lake Huron, and Lake Ontario. Abundances in Lake Superior are variable but overall trends are stable. Diporeia are currently extirpated or very rare in Lake Erie.

Lake-by-Lake Assessment

Lake Superior
Status: Good
Trend: Unchanging
Rationale: Long- term monitoring of populations in deeper regions of the lake indicate that, although substantial interannual variability can occur, there are not directional trends in abundances of *Diporeia* in the lake. Other studies have shown abundances in shallower regions remain high.

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: *Diporeia* abundances continue to decline in Lake Michigan. A lakewide survey in 2010 indicated that *Diporeia* are now rarely found at depths < 90 m (297 ft.) over the entire lake (Fig. 1). At depths > 90 m, abundances in 2010 were lower by 66 % compared to abundances found in 2005. While the trend remains downward at these deeper depths, more intensive temporal surveys (yearly) indicate that the rate of decline has slowed in recent years.

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: *Diporeia* abundances continue to decline in Lake Huron. The most recent survey lakewide survey occurred in 2007, and abundances were lower by 93 % compared to a similar survey in 2000. Long-term monitoring of abundances on a more limited spatial scale indicated that in 2009 *Diporeia* were rarely found at sites < 90 m, and abundances at sites > 90 m were trending downward.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: Because of shallow, warm waters, *Diporeia* are naturally not present in the Western and most of the Central basins. *Diporeia* declined in the Eastern basin beginning in the early 1990s and have not been found since 1998.

Lake Ontario
Status: Poor
Trend: Deteriorating
Rationale: *Diporeia* abundances continue to decline in Lake Ontario. Based on limited sampling in 2009 – 2010, abundances were 97 % lower than abundances found in 1995. In 2010, *Diporeia* were completely gone from most areas of the lake at depths less than 150 m, and were absent for the first time at a deep mid-lake site (Fig. 2). It is obvious that the deep, offshore region of Lake Ontario is no longer providing a

refuge for *Diporeia*. Limited spatial data indicated a population was still surviving near the Niagara River at depths between 80 and 110 m.

Purpose

- To provide a measure of the biological integrity of the offshore regions of the Great Lakes by assessing the abundance of the benthic macroinvertebrate *Diporeia*
- The *Diporeia* indicator is used in the Great Lakes indicator suite as a State indicator in the Aquatic-dependent life top level reporting category.

Ecosystem Objective

The ecosystem goal is to maintain a healthy, stable population of *Diporeia* in offshore regions of the main basins of the Great Lakes, and to maintain at least a presence in nearshore regions.

Ecological Condition

This glacial-marine relic was once the most abundant benthic organism in cold, offshore regions (greater than 30 m (98 ft) of each of the lakes. It was present, but less abundant in nearshore regions of the open lake basins, but naturally absent from shallow, warm bays, basins, and river mouths. *Diporeia* occurs in the upper few centimeters of bottom sediment and feeds on algal material that freshly settles to the bottom from the water column (i.e., mostly diatoms). In turn, it is fed upon by most species of Great Lakes fish; in particular by many forage fish species, which themselves serve as prey for the larger piscivores such as trout and salmon. For example, sculpin feed almost exclusively upon *Diporeia*, and sculpin are eaten by lake trout. Also, lake whitefish, an important commercial species, feeds heavily on *Diporeia*. Thus, *Diporeia* was an important pathway by which energy was cycled through the ecosystem, and a key component in the food web of offshore regions. The importance of this organism is recognized in the Great Lakes Water Quality Agreement: Supplement to Annex 1 – Specific Objectives (United States and Canada 1987).

On a broad scale, abundances are directly related to the amount of food settling to the bottom, and population trends reflect the overall productivity of the ecosystem. Abundances can also vary somewhat relative to shifts in predation pressure from changing fish populations. In nearshore regions, this species is sensitive to local sources of pollution.

Diporeia populations are currently in a state of dramatic decline in Lake Michigan (Figure 1), Lake Ontario (Figure 2), and Lake Huron, and they are completely gone or very rare in Lake Erie. The population in Lake Superior, although highly variable, remains unchanged. Initial declines were first observed in all lake areas within two to three years after zebra mussels (*Dreissena polymorpha*) or quagga mussel (*Dreissena bugensis*) first became established. These two species were introduced into the Great Lakes in the late 1980s via the ballast water of ocean-going ships. Reasons for the negative response of *Diporeia* to these mussel species are not entirely clear. One hypothesis is that dreissenid mussels are out-competing *Diporeia* for available food. That is, large mussel populations filter food material before it reaches the bottom, thereby decreasing amounts available to *Diporeia*. However, evidence suggests that the reason for the decline is more complex than a simple decline in food because *Diporeia* have completely disappeared from areas where food is still settling to the bottom and where there are no local populations of mussels. Also, individual *Diporeia* show no signs of starvation before or during population declines. Further, *Diporeia* and *Dreissena* apparently coexist in some lakes outside of the Great Lakes (i.e., Finger Lakes in New York).

Management Challenges/Opportunities

The continuing decline of *Diporeia* has strong implications to the Great Lakes food web. As noted, many fish species rely on *Diporeia* as a major prey item, and the loss of *Diporeia* will likely have an impact on these species. Responses may include changes in diet, movement to areas with more food, or a reduction in weight or energy content. Implications to populations include changes in distribution, abundance, growth, recruitment, and condition.

Recent evidence suggests that fish are already being affected. For instance, growth and condition of an important commercial species, lake whitefish, has declined significantly in areas where *Diporeia* abundances are low in Lake Michigan, Lake Huron, and Lake Ontario. Also, studies show that other species such as alewife, slimy sculpin, and bloater have been affected. Management agencies must know the extent and implications of these changes when assessing the current state and future trends of the fishery. Any proposed rehabilitation of native fish species, such as the re-introduction of deepwater ciscoes in Lake Ontario, requires knowledge that adequate food, especially *Diporeia,* is present.

Comments from the author(s)

Because of the rapid rate at which *Diporeia* populations have declined in many areas, and their significance to the food web, agencies committed to documenting trends should report data in a timely manner. The population decline has a defined natural pattern, and studies of food web impacts should be spatially well coordinated. Also, studies to define the cause of the negative response of *Diporeia* to *Dreissena* should continue and build upon existing information. With an understanding of exactly why *Diporeia* populations are declining, we may better predict what additional areas of the lakes are at risk. Also, by better understanding the cause, we may better assess the potential for population recovery if and when dreissenid populations stabilize or decline.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Figure 1. Distribution and density (number per square meter) of the amphipod *Diporeia* spp. in Lake Michigan in 1994/95, 2000, 2005, and 2010. Small crosses indicate location of sampling sites.

Source: Great Lakes Environmental Research Lab, National Oceanic and Atmospheric Administration. USA.

Figure 2. Distribution and density (number per square meter) of the amphipod *Diporeia* spp. in Lake Ontario in 1995, 2003, 2005, 2007, and 2009/10. Averages derived from all stations sampled that year; small crosses indicate stations not visited.

Source: Great Lakes Lab. for Fisheries & Aquatic Sciences, Fisheries and Oceans, Canada.

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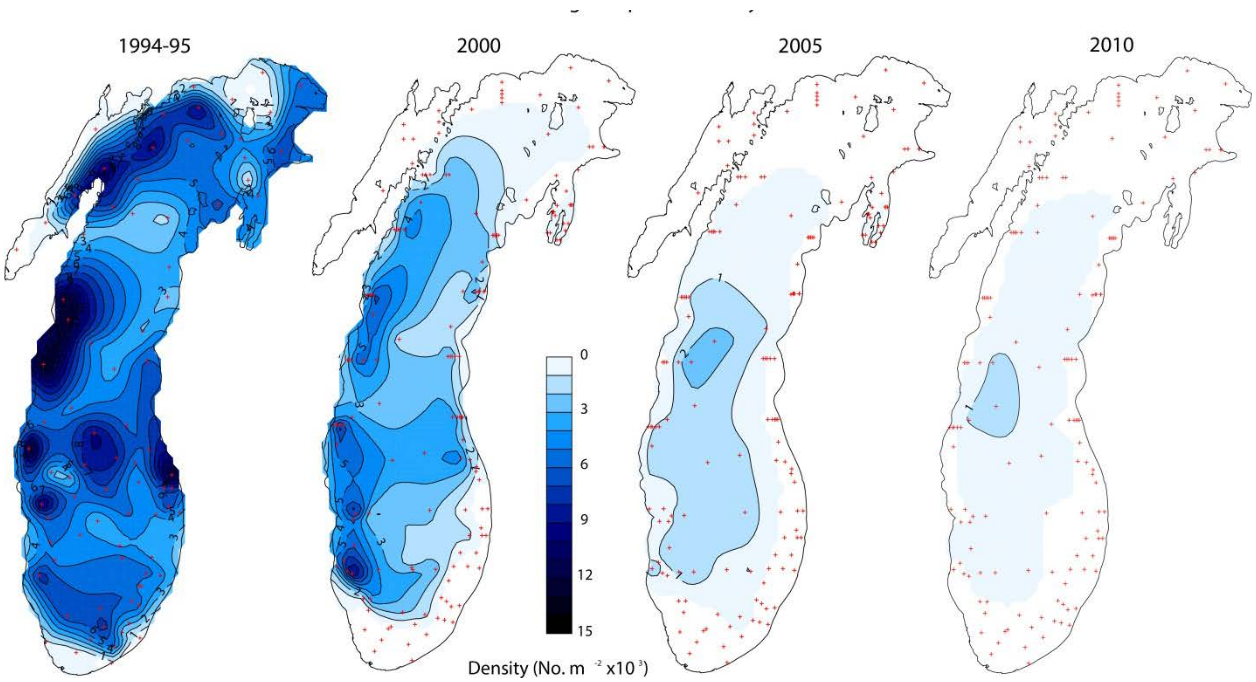

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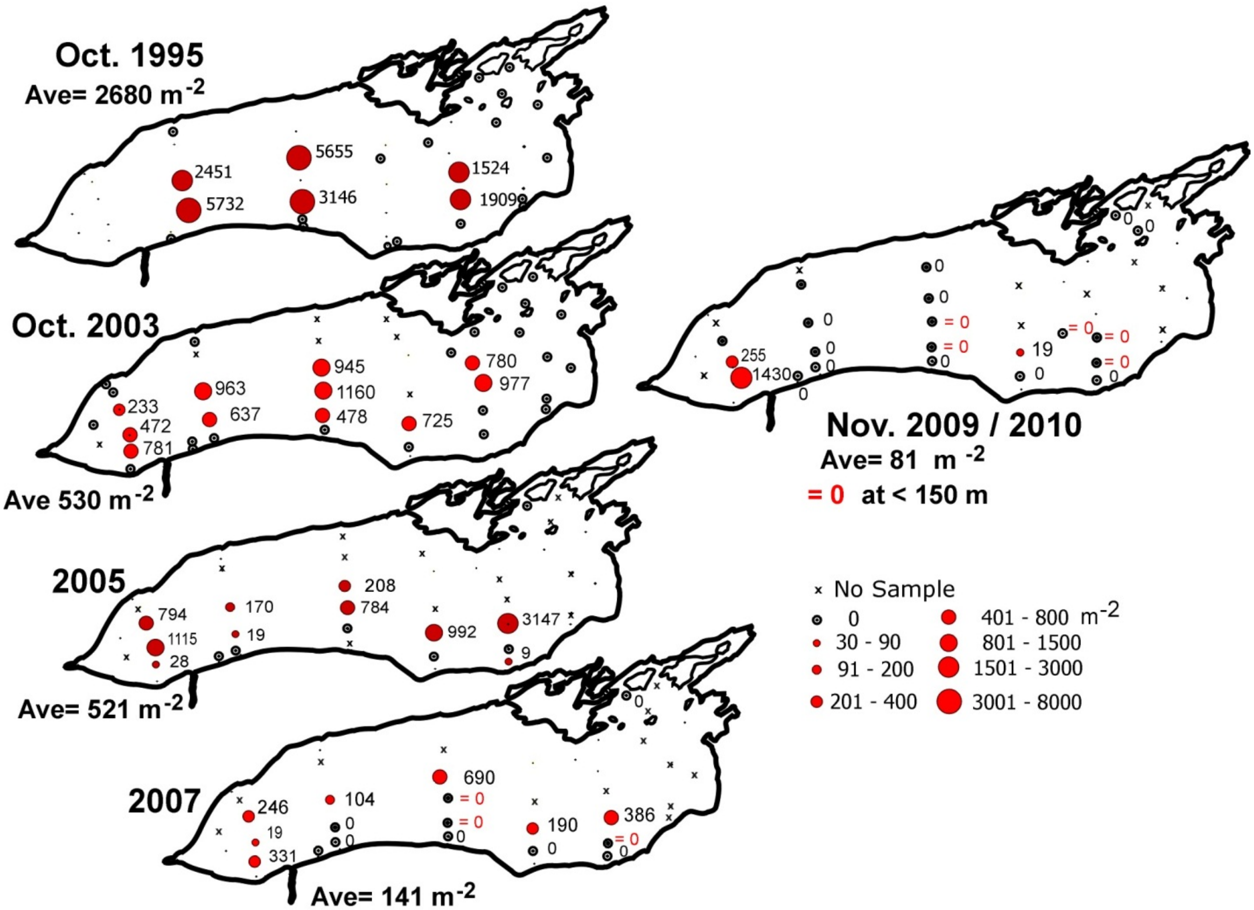

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Source: Great Lakes Lab. for Fisheries & Aquatic Sciences, Fisheries and Oceans, Canada.

Dreissenid Mussels – Zebra and Quagga mussels

Overall Assessment
Status: Fair
Trend: Deteriorating
Rationale: Over all the Great Lakes, dreissenid mussels are changing at various rates depending on the particular lake, and the particular area within a lake. Currently, quagga mussels (profunda phenotype) are replacing zebra mussels and reaching high abundances in some shallow, nearshore areas, and are also expanding into deep, offshore areas. In other shallow areas, quagga mussel populations (shallow phenotype) are stable and zebra mussels are still present. The offshore region comprises a relatively large proportion of many lakes where quagga mussels are still expanding at a rapid rate (i.e., Lakes Michigan, Ontario, and Huron). Therefore, the current overall assessment indicates a deteriorating status.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Unchanging
Rationale: Zebra mussels were first found in Duluth-Superior Harbor in 1989, and quagga mussels were found in the same area in 2005. Since then, spread and population growth of both dreissenid species has been minimal. Both species are most abundant and primarily confined in harbor areas or the nearshore areas of Lake Superior. Some zebra mussels, however, were found in 2009 in a bay of Isle Royale, and were also present in Thunder Bay harbor in 2001. Overall, population growth and spread of both species has been slow. It is believed that calcium concentrations in Lake Superior are too low to support high abundances.

Lake Michigan
Status: Poor
Trend: Deteriorating
Rationale: A recent survey throughout Lake Michigan (2010) indicated that the quagga mussel population expanded greatly since the last survey (2005), and that zebra mussels are now very rare. Based on yearly sampling just in the southern basin, the quagga mussel population at depths < 90 m has apparently stopped increasing and is beginning to decline, but is still increasing at depths > 90 m (Figure 1). Biomass is presently declining at < 50 m, but still increasing at > 50 m (Figure 2). Maximum biomass at < 50 m reached 45 g m^{-2} in 2008.

Lake Huron
Status: Poor
Trend: Deteriorating
Rationale: The last lake-wide survey of dreissenid populations in Lake Huron occurred in 2007. This survey indicated abundances of quagga mussels increased between 2003 and 2007, but zebra mussels decreased and were rarely found. Between 2003 and 2007, quagga mussels increased 1.6-4.0-fold at depths between 30 and 90 m in the main lake. Similar increases were found in Georgian Bay, but dreissenids were not found in North Channel. Biomass was not determined in any of these regions. Surveys in Saginaw Bay in 2008-2010 indicated that mean abundance and biomass had decreased 1.6-1.7 fold compared to 1991-1996. In addition, year-to-year variation in 2008-2010 was minimal, indicating that the population had perhaps stabilized at these lower levels. In 2008-2010 the population in Saginaw Bay consisted of 80% quagga mussels and 20% zebra mussels.

Lake Erie
Status: Fair
Trend: Undetermined
Rationale: The last lake wide survey in Lake Erie occurred in 2002. Mean abundances in that year were little changed since 1992 (2,025 m^{-2} in 2002 compared to 2,636 m^{-2} in 1992), but mean biomass increased 4-fold (24.7 g m^{-2} in 2002 compared to 6.8 g m^{-2} in 1992). Most dreissenid biomass (90%) occurs in the eastern basin. Populations in the central basin are limited because of seasonal hypoxia, and populations in the western basin are limited because of poor food quality (cyanophytes, inorganic particulates). Recent surveys (2005-2010) in the western basin indicate that dreissenid populations have fluctuated from year-to-year with no clear trends, and that quagga mussels have replaced zebra mussels as the dominant species (Figure 3). Recent trends in the eastern basin are unknown.

Lake Ontario
Status: Fair
Trend: Deteriorating
Rationale: Since 2007, *Dreissena* abundance has been stable or slowly increasing based on data from offshore surveys at depths beyond 30 m (Figure 4). Since 2000, all mussels collected in the offshore portions of Lake Ontario have been quagga mussels. Zebra mussels are restricted to shallow embayments such as the upper Bay of Quinte and inside Hamilton Harbor. Quagga mussels have slowly increased at depths beyond 100 m. Since 2008, they have been present in the deepest part of the lake (224 m), as well as at the middle of the lake. Densities are greatest nearest the south shore, often exceeding 5000 m^{-2}, but are as large as 400 m^{-2} at 150 m. The population in the east basin of Lake Ontario near Main Duck Island (35 m) has been stable since 2007, and is composed mostly of large individuals greater than 15 mm in length. There, the wet biomass of their soft tissue has ranged between 300 and 450 g m^{-2} (shell-free). Assuming dry weight is about 10% of wet weight, this is equivalent to 30-45 g m^{-2} dry weight and hence generally similar to the maximum of 45 g m^{-2} found at 31-50 m in southern Lake Michigan.

Purpose
- To track the status and trends of *Dreissena rostriformis bugensis* (quagga mussel) and *Dreissena polymorpha* (zebra mussel). Instability in dreissenid populations, as measured by abundance and biomass, results in uncertainties in resource management.
- The Dreissenid Mussels indicator is used in the Great Lakes indicators suite as a Pressure indicator in the Invasive Species top level reporting category.

Ecosystem Objective
Dreissenids are actively changing the integrity of Great Lakes ecosystems by altering nutrient and energy cycling, promoting nuisance algal blooms and benthic algae, and negatively impacting native species of invertebrates and fish. Such changes to ecosystem integrity create uncertainty in effective resource management. Thus, the indicator addresses the objective of maintaining healthy and sustainable ecosystems.

<u>Measure</u>
Ideally, specific measures to be reported are dreissenid abundances, biomass, size-frequency distributions, and length-weights. The latter two measures are essential for the most efficient determination of biomass, and also provide a basis for assessing the relative status of populations and individuals, respectively. As a minimum indicator, abundances of both zebra and quagga mussels should be reported. Spatial scales should be each lake, and any particular bay or basin within a lake. Often trends in zebra and quagga mussels can be quite different depending on environmental conditions. The entire suite of measurements listed above will be reported for additional scales.

At the minimum, spatially intensive studies of dreissenid abundance should be conducted once every five years in conjunction with other programs associated with the lake wide intensive monitoring program. More frequent sampling (yearly) is recommended in areas that are newly colonized or subjected to new perturbations, such as a new invader.

Status Justification
Good – no or few mussels with a slow rate of change
Fair – moderate abundance or now declining from a higher abundance or moderate abundance but slow rate of increase
Poor – high abundance and/or a fast increase

Endpoint
A quantitative endpoint has not yet been determined. A proposed endpoint of zero dreissenids is unrealistic. A working qualitative endpoint is the point in time and space in which a dreissenid population becomes stable, or varies within a given range. Such an endpoint will allow for the modeling of dreissenid population dynamics and inputs to predictive ecosystem models. Such models are a necessary precursor to effective resource management.

Ecological Condition
Dreissenid populations in the Great Lakes are presently in various stages of change. In many offshore regions, populations are increasing, but in some near shore regions populations seem to be stable or declining. While some year-to-year variability can be expected, a goal of this indicator is to determine at what level of abundance/biomass populations become stable and at equilibrium with the surrounding environment. Such levels, along with associated degrees of uncertainty, can then be used in predictive models to better manage Great Lakes resources.

Many sampling efforts have sought to provide data on population abundances and biomass. While abundances are the most common reporting measure of population status, biomass is more valuable for assessing ecological impacts and for input to predictive models. Biomass is calculated from the soft tissue of these organisms. Some protocols call for separating soft tissue from shell and directly determining soft tissue weight, while others determine the size frequency of the populations (shell length) and infer tissue biomass based upon a predetermined relationship between shell length and soft tissue weight. Data used to obtain biomass with the latter protocol can also be used to assess population dynamics and predict the direction of populations over time. For example, a population with a large number of individuals and a size distribution skewed toward smaller individuals demonstrates high recruitment and possibly low survivability (or if survivability is not compromised then it may illustrate recent colonization). In contrast, population showing a size-frequency distribution skewed towards larger individuals with fewer numbers suggests an aging population with relatively lower recruitment and greater survivability. Traditional population ecology suggests that stable populations move from a size-frequency distribution of low mean biomass towards one of higher mean biomass. As a population colonizes a new area, high resource availability promotes high recruitment. As resources are sequestered into the population, recruitment decreases with decreasing resource availability and mean biomass increases as fewer new (low biomass) individuals are added to the population and surviving members continue to grow.

Management Challenges/Opportunities
The main issue which compromises this indicator is the presence or absence of a commitment by agencies to monitor dreissenids on a regular basis. U.S. EPA Great Lakes National Program Office monitors benthos annually, but the spatial scope emphasizes deeper regions. The regular monitoring of Environment Canada does not include benthos. Sampling by Fisheries and Oceans Canada on Lake Ontario is sporadic. NOAA has supported dreissenid monitoring throughout Lakes Michigan and Huron every five years, and in the southern basin of Lake Michigan every year, but it is uncertain whether this support will continue.

Comments from the author(s)

Because of the rapid rate at which *Dreissena* populations have expanded in many areas, and because of the ability of dreissenids to cause ecosystem-wide changes, agencies committed to documenting trends should report data in a timely manner. Besides abundance, biomass should be routinely monitored. This allows comparisons across lakes and other food web components, and is most useful for predictive models. Since dreissenids are found on hard as well as on soft substrates, various sampling methods may be needed to truly assess population mass in a given lake or lake region.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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List of Figures

Figure 1. Mean (± SE) abundance (number per square meter) of the *Dreissena* population in each of four depth interval s at 40 stations in the southern basin of Lake Michigan between 1980 and 2010. The number of stations in each depth interval was 16-30 m = 12, 31-50 = 10, 51-90 m = 12, > 90 m = 6. solid circle/solid line = zebra mussel; open circle/dashed line = quagga mussel.
Source: Great Lakes Environmental Research Lab, NOAA

Figure 2. Mean (± SE) biomass (grams per square meter) of the *Dreissena* population in each of four depth intervals at 40 stations in the southern basin of Lake Michigan between 1980 and 2010. Biomass is given as shell-free dry weight. The number of stations in each depth interval was 16-30 m = 12, 31-50 = 10, 51-90 m = 12, > 90 m = 6. solid circle/solid line = zebra mussel; open circle/dashed line = quagga mussel.
Source: Great Lakes Environmental Research Lab, NOAA

Figure 3. Percentage of sites with *Dreissena* (top panel) and mean abundance of *Dreissena* (number per square meter) (bottom panel) in western Lake Erie between 1991 and 2010; n=30. Source: Great Lakes Science Center, USGS

Figure 4. Distribution and mean abundance (number per square meter) of the *Dreissena* population (zebra and quagga mussels) in Lake Ontario between 1995 and 2009. Small crosses indicate stations not visited. Ave. = average abundance for all stations sampled that year.
Source: Great Lakes Lab. for Fisheries & Aquatic Sciences, DFO

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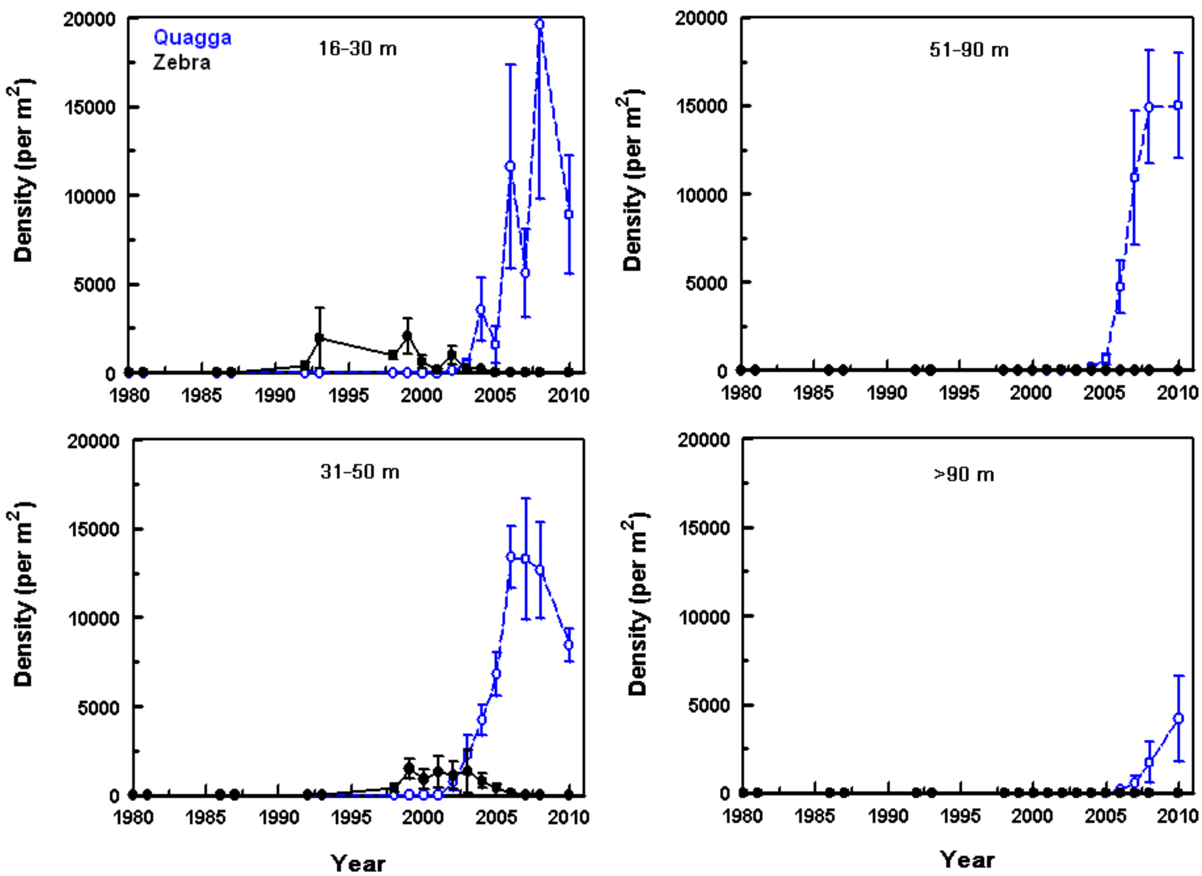

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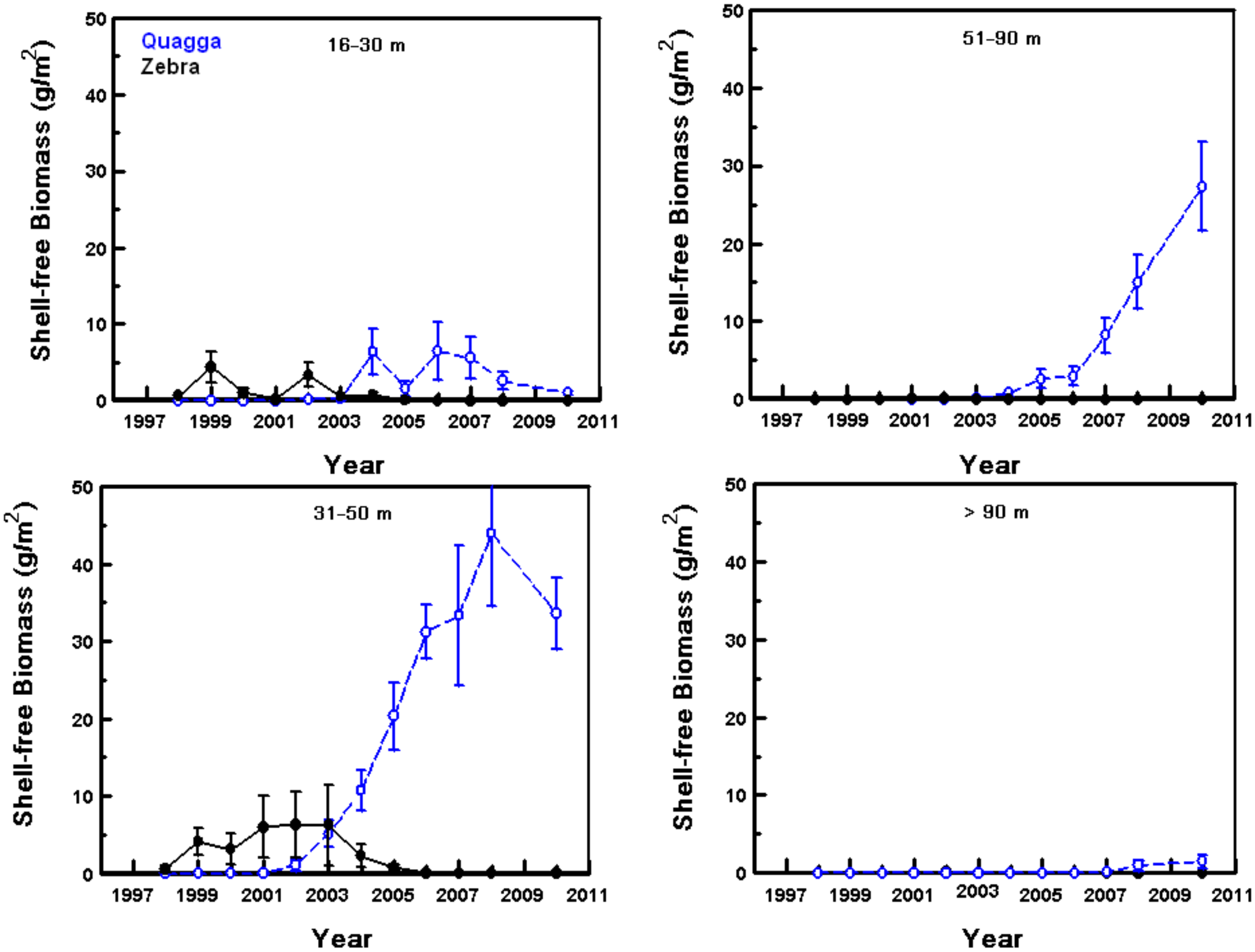

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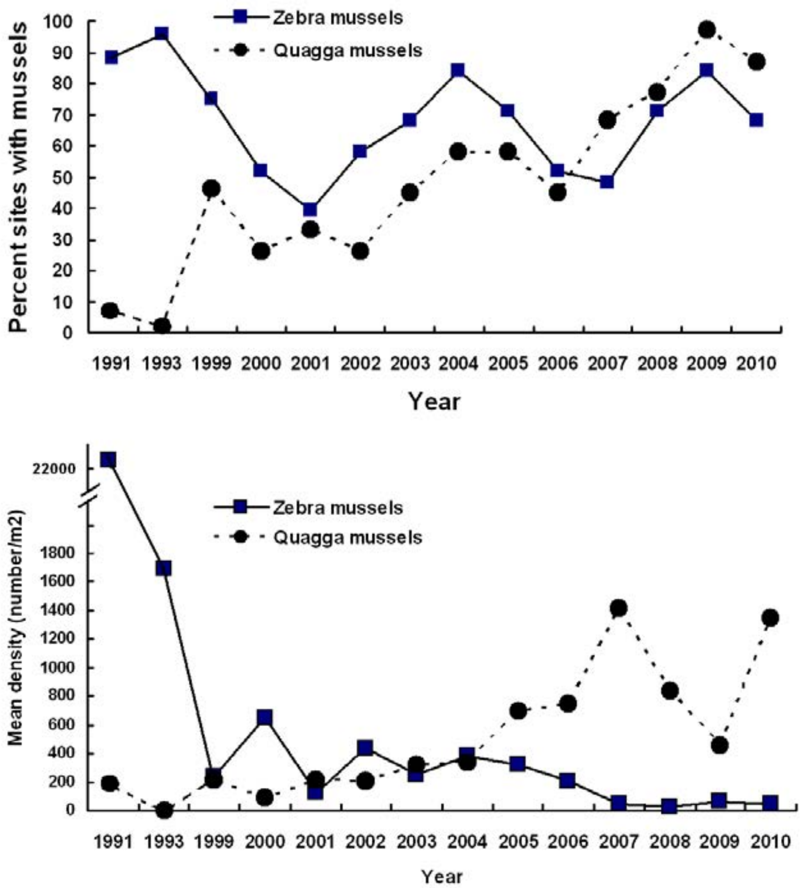

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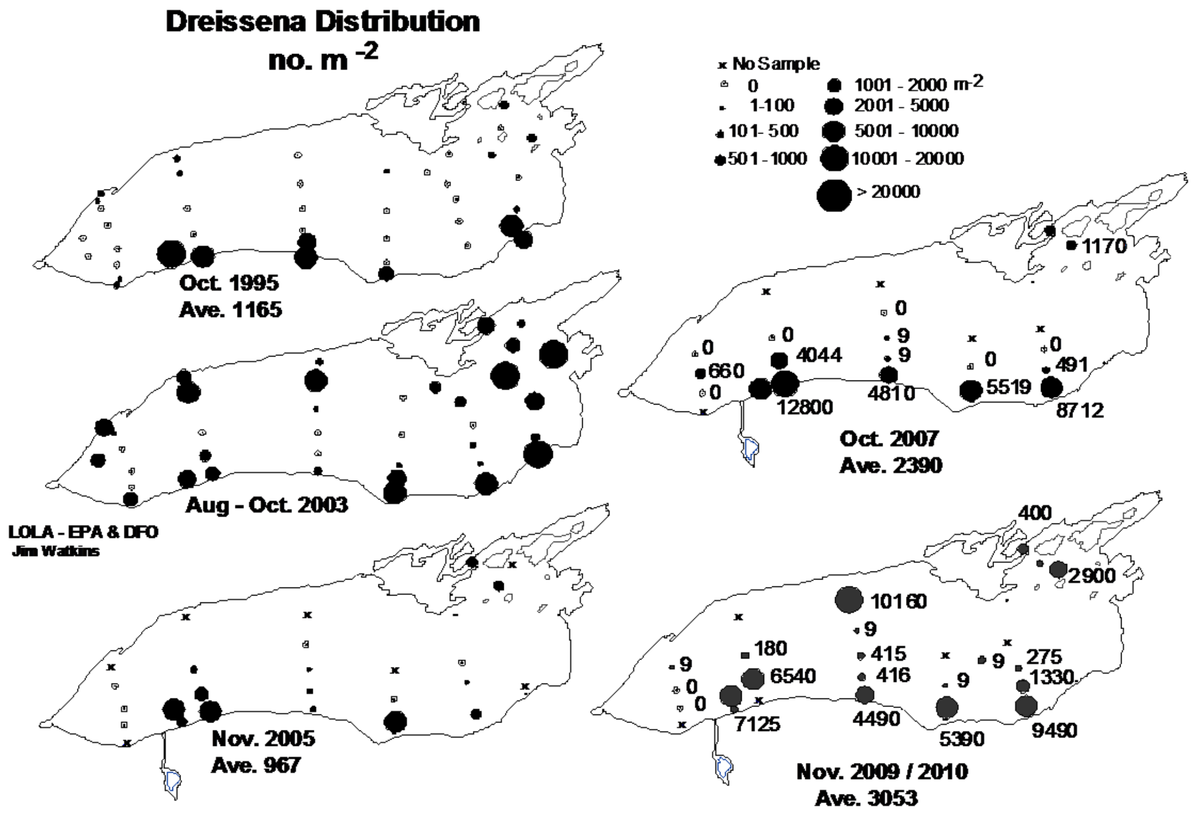
Source: Great Lakes Science Center, USGS



Fisheries and Oceans Canada
Pêches et Océans Canada

Figure 4. Distribution and mean abundance (number per square meter) of the *Dreissena* population (zebra and quagga mussels) in Lake Ontario between 1995 and 2009. Small crosses indicate stations not visited. Ave. = average abundance for all stations sampled that year.
Source: Great Lakes Lab. for Fisheries & Aquatic Sciences, DFO

Drinking Water Quality

Overall Assessment:
Status: **Good**
Trend: **Unchanging**
Rationale: **The overall quality of source and finished drinking water in the Great Lakes basin can be considered good. The potential risk of human exposure to the noted chemical and/or microbiological contents, and any associated health effect, is generally low.**

Lake-by-Lake Assessment
Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Other Spatial Scales
No other spatial scales were used in this indicator.

Purpose
- To evaluate the potential for human exposure to drinking water contaminants and the effectiveness of policies and technologies to ensure safe drinking water throughout the Great Lakes basin
- To evaluate the chemical and microbial contaminant levels in source and treated water.
- The Drinking Water Quality indicator is used in the Great Lakes indicator suite as an Impacts indicator under the Human Impacts top level reporting category.

Ecosystem Objective
Treated and source drinking water supplies in the Great Lakes basin should be free from harmful chemical and microbiological contaminants and should be safe to drink. This indicator supports the restoration and maintenance of the chemical, physical and biological integrity of the Great Lakes basin (GLWQA Annex 1, 2, 12 and 16).

Ecological Condition
Background
There are several sources of drinking water within the Great Lakes basin, including the Great Lakes themselves, smaller lakes and reservoirs, streams, ponds and groundwater (seeps and wells). These systems are vulnerable to contamination from several sources (chemical, biological, radioactive). Substances that may be present in source water include microbial contaminants (e.g. viruses and bacteria), inorganic contaminants (e.g. salts and metals), pesticides and herbicides, organic chemical contaminants (e.g. synthetic and volatile organic chemicals), and radioactive contaminants. After collection, source water undergoes a detailed treatment process prior to being sent to a distribution system where it is dispersed to consumers. The treatment process involves several basic steps, which are often varied and repeated depending on the condition of the source water. Source water can affect the finished water that is consumed. Good quality source water is an important approach to assuring the safety and quality of drinking water.

The information provided by the United States for this report focuses on finished, or treated, drinking water. There is currently no national drinking water database in the U.S. that includes source water data. In the United States, the Safe Drinking Water Act Reauthorization of 1996 requires all drinking water utilities to provide yearly water quality information to their consumers. To satisfy this obligation, U.S. WTPs produce an annual Consumer Confidence/Water Quality Report (CC/WQR). These reports provide information regarding source water type (i.e. surface water, groundwater), the availability of source water assessment and a brief summary of the drinking water systems susceptibility to potential sources of contamination, the water treatment process, contaminants detected in finished drinking water, and violations that occurred, and other relevant information. Records of the number and type of health based violations are also recorded in the nationwide U.S. EPA Safe Drinking Water Information System (SDWIS). Health based violations in the U.S. include: Maximum Contaminant Level (MCL) which is the highest level of a contaminant that is allowed in drinking water, the Maximum Residual Disinfectant Level (MRDL) which is the highest level of a disinfectant allowed in drinking water, and Treatment Technique (TT) which is a required process intended to reduce the level of contaminants in drinking water.

The data used for the Canadian component of this report was provided by the Ontario Ministry of the Environment (OMOE) and includes results from two program areas. Source water data is collected as part of the Drinking Water Surveillance Program (DWSP). The DWSP is a voluntary partnership program with municipalities that monitors source and treated water quality at over 100 systems in Ontario. The Drinking Water Management Division at OMOE provides information on adverse water quality incidents (AWQI). An AWQI is when a water sample exceeds the Ontario Drinking Water Quality Standards or when an operator observes unsafe water. The Ontario Drinking Water Quality Standards are described by the Maximum Acceptable Concentration (MAC), which is established for parameters that, when present above a certain concentration, have known or suspected adverse health effects. The Interim Maximum Acceptable Concentration (IMAC) is used for parameters when there is insufficient toxological data or it is not feasible for practical reasons to establish a MAC.

Status of Drinking Water in the Great Lakes Basin

Established drinking water standards were used to assess the quality of source and treated drinking water quality in the Great Lakes basin. Potential health effects may occur from long term exposure above these drinking water standards.

Source (Untreated) Drinking Water Quality

Nine chemical drinking water parameters that frequently result in water quality exceedences and which have potential health effects associated with exposure above the established MAC/IMAC, were selected to provide an assessment of source drinking water quality in Ontario from 2007 to 2009. As stated previously, no source water data was assessed in the U.S. due to the lack of centrally located source. The percentage of drinking water systems monitored through the DWSP where source water is below the MAC/IMAC was used as the metric.

Six of the nine chemical drinking water parameters were never detected above the MAC/IMAC in source waters (Table 1). These parameters included nitrate, nitrite, atrazine, arsenic, uranium and barium. Fluoride, lead and selenium were the only parameters that had concentrations exceeding the MAC/IMAC in source waters. Exceedences of these chemical parameters were only found in a few groundwater systems and may be the result of erosion of natural deposits and/or anthropogenic contamination. The percentage of sites and the actual drinking water systems with fluoride and selenium source water exceedences did not change over the time period (Table 1). Lead was the only parameter the percent of exceedences decreased over time, with none occurring in 2009 (Table 1).

Overall, source water quality is good in Ontario in regards to these selected chemical parameters. There were only four drinking water systems, all sourced from groundwater, where the MAC/IMAC was exceeded and at two of these sites the concentrations in treated and distributed water were below the MAC/IMAC.

Treated Drinking Water Quality

Treated drinking water was assessed for all community drinking water systems in U.S. Great Lakes basin counties and for all municipal residential drinking water systems in Ontario. Metrics were slightly different between countries due to differences in the way data is recorded and stored in their respective databases. In the U.S. the average percentage of drinking water systems and population that did not have any health based violations was used as metrics. In Ontario the percentage of drinking water systems that did not have any health based violations and the percentage of drinking water tests meeting standards were used as metrics.

In the U.S. the average percentage of drinking water systems and population that did not have any health based violations has remained mostly unchanged between 2007 and 2010, with the average percentage of community water systems with no exceedences consistently exceeding 90% (Figure 1). The percentage of the population with no violations was a little more variable but, on average, exceeded 90% (Figure 1). These numbers are similar to the national average in the U.S.

In Ontario the average percentage of drinking water systems that did not have any health based violations increased between 2004 and 2010 while the percentage of drinking water systems that met drinking water standards less that 99% of the time decreased (Figure 2). Over the past three years the percentage of drinking water systems with no exceedences has been fairly stable at around 65% and 96% of drinking water systems meet standards greater than 99% of the time. The average percentage of drinking water tests meeting standards in Ontario has increased slightly between 2004 and 2010 but has always exceeded 99.7% (Figure 3).

The proportion of health based exceedences caused by chemical, microbiological, radiological, disinfection by-products and treatment techniques differs between countries. The majority of exceedences in Ontario are microbiological while in the U.S. microbiological, chemical and disinfection by-product exceedences co-dominate (Figure 4). Another major difference between countries is that radiological parameters are responsible for 9% of exceedences in the U.S. while there were no radiological exceedences in Ontario (Figure 4). This large difference may be due to the small number of systems in Ontario that submitted results for radiological tests rather than higher concentrations in the U.S. The chemical category was comprised of different parameters for each county with some overlap. In Ontario most chemical exceedences were from fluoride and lead while in the U.S. most were from arsenic. Standards for fluoride and lead are stricter in Ontario which may be why there were more exceedences for these chemical there.

Summary

Based on the information provided from the OMOE DWSP, source water quality in Ontario can be considered good. It is important to note however that source waters as part of the DSWP are not currently analyzed for microbiological contamination, the largest contributor to health exceedences in Ontario. Treated drinking water quality in the U.S. and Canada can also be considered good. In the U.S. more than 90% of the population was never exposed to a health based violation while in Canada greater than 99.7% of all tests met drinking water standards.

Linkages

Drinking water quality may be negatively impacted by increases in nutrient, pesticide and bacterial loadings from tributaries, contamination in sediment, atmospheric deposition, land conversion, municipal wastewater and industrial loadings and runoff. These pressures result in changes to ground and surface water quality which may act as sources for drinking water. Improved wastewater treatment, sediment remediation and increased protected areas in response to these pressures may improve source drinking water quality.

Management Challenges/Opportunities

A more standardized, updated approach to monitoring contaminants and reporting data for drinking water needs to be established. Even though extensive lists of contaminants and their MCLs have been established in the U.S. and Ontario, newer parameters of concern might not be listed due to available resources or technology. Additionally, state monitoring requirements may differ, requiring only a portion of this list to be monitored.

Standardized monitoring and reporting, especially of source water in the U.S., would make trend analysis easier and provide a more effective assessment of the state of the ecosystem and the potential for health hazards associated with drinking water. By providing source water data, the origin of contamination at WTPs will be easier to identify as some utilize multiple sources of water. Inclusion of microbiological tests into source water assessments will be important to understand potential impacts to human health.

Comments from the author(s)

A concern for future efforts would be the comparability of metrics between countries. Focusing on the population that is impacted by drinking water quality exceedences, rather than the number of exceedences or number of systems with exceedences, will allow us to better evaluate the potential for human exposure to drinking water contaminants. Source waters may also be examined in the future to better understand where the contaminants are coming from.

Assessing Data Quality:

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Jeffrey C. May, Oak Ridge Institute for Science and Education, on assignment to the U.S. Environmental Protection Agency, Great Lakes National Program Office (GLNPO) 2006

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Source: U.S. EPA Safe Drinking Water Information System.
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Source: OMOE. 2011. Chief Drinking Water Inspector Annual Report 2009-2010.
Figure 3. Percentage of drinking water tests meeting standards (municipal residential drinking water systems) in Ontario.
Source: OMOE. 2011. Chief Drinking Water Inspector Annual Report 2009-2010.
Figure 4. Percentage of health based exceedences caused by chemical, microbiological, radiological, disinfection by-products and treatment technique parameters.
Source: U.S. EPA Safe Drinking Water Information System and OMOE. 2011. Chief Drinking Water Inspector Annual Report 2009-2010

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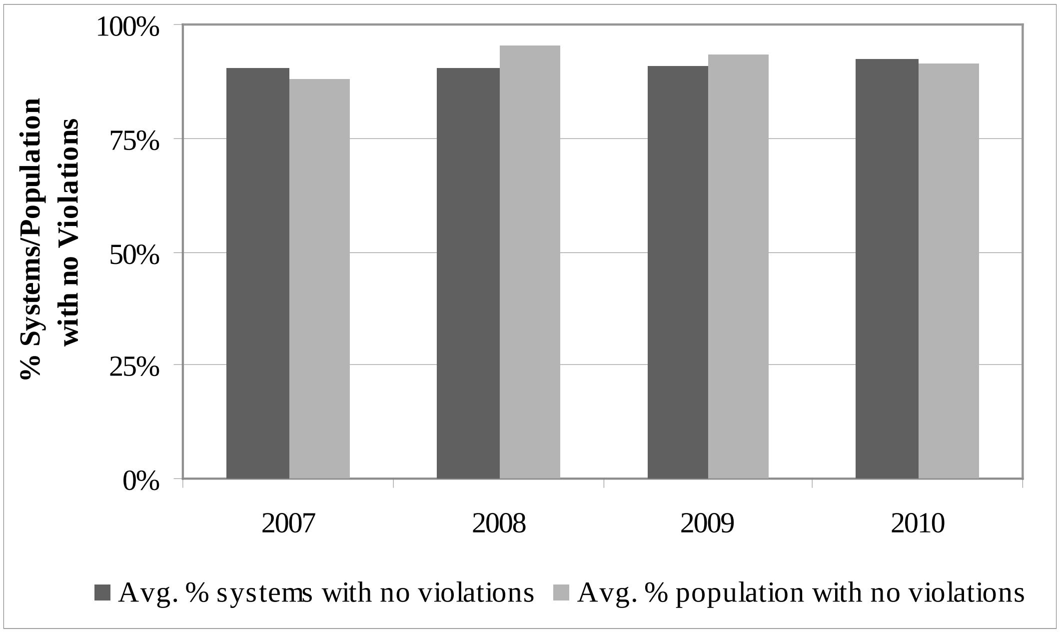
Percentage of DWSP sites where source water is below the MAC/IMAC.

	2007	2008	2009
Nitrate	100.00%	100.00%	100.00%
Nitrite	100.00%	100.00%	100.00%
Atrazine	100.00%	100.00%	100.00%
Arsenic	100.00%	100.00%	100.00%
Uranium	100.00%	100.00%	100.00%
Barium	100.00%	100.00%	100.00%
Fluoride	98.99%	98.91%	98.91%
Lead	98.99%	97.83%	100.00%
Selenium	98.99%	98.91%	98.91%

Table 1. Percentage of drinking water systems in the Great Lakes Basin (that are part of the DWSP in Ontario) where source water is below the MAC/IMAC for select chemicals.



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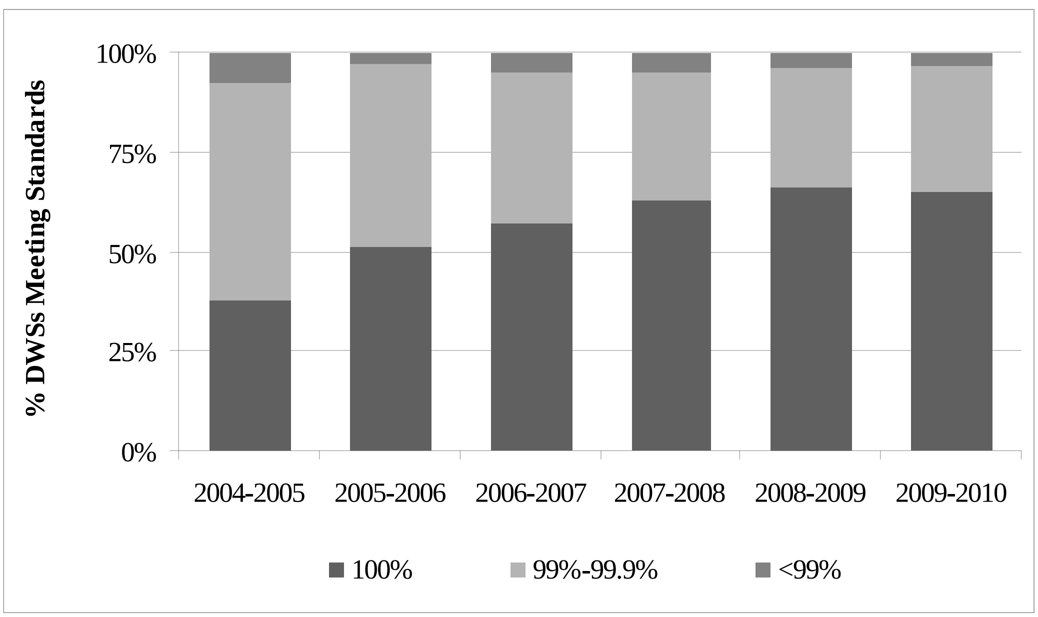

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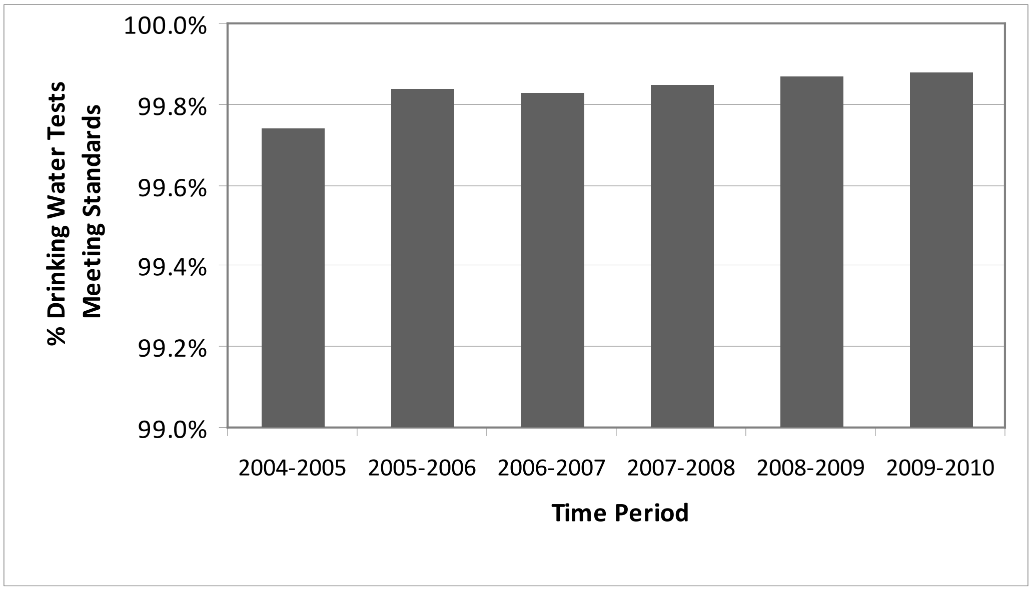
Source: OMOE. 2011. Chief Drinking Water Inspector Annual Report 2009-2010



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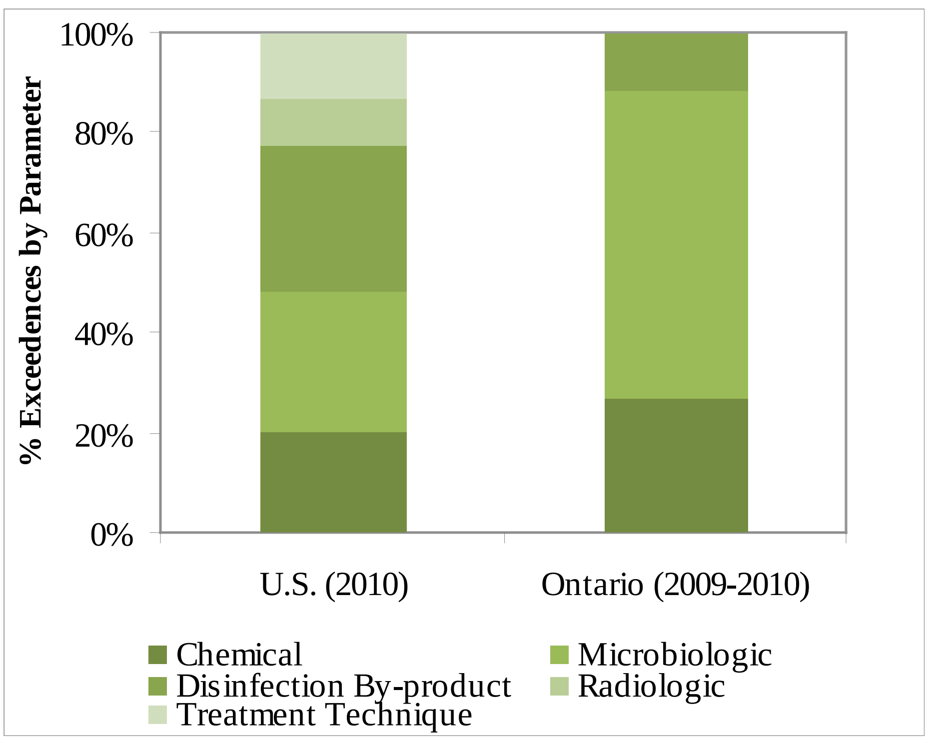

Figure 4. Percentage of health based exceedances caused by chemical, microbiological, radiological, disinfection by-products and treatment technique parameters.
Source: U.S. EPA Safe Drinking Water Information System and OMOE. 2011. Chief Drinking Water Inspector Annual Report 2009-2010

Economic Prosperity (Unemployment)

Overall Assessment
Trend: Undetermined
Rationale: Between 1976 and 2010, the overall unemployment rate fluctuated in response to socio-economic conditions, therefore identifying an expected but "undetermined" long-term trend. The short-term trend (2005 to 2010) is an increasing unemployment rate. Throughout the thirty-five year bracket, with the exception of 2008-2009 where it experienced a 3.0% increase, the annual rate of change has consistently remained within an approximate 2.0% difference.

Lake-by-Lake Assessment
Trends were not made on an individual lake basis.

Purpose
- To provide unemployment trends in the Great Lakes Region, as a representation of economic prosperity in the Great Lakes Region.
- The Economic prosperity indicator is used in the Great Lakes Indicator Suite as a driving force indicator under the economic/social category.

Ecosystem Objective
Economic prosperity in the Great Lakes region should be pursued with full regard to the purpose of the Great Lakes Water Quality Agreement, to restore and maintain the chemical, physical and biological integrity of the Great Lakes Basin Ecosystem.

Ecological Condition
The unemployment rates are based on data extracted from Statistics Canada and the United States Department of Labor (Bureau of Labour Statistics). The unit of analysis in this report is the unemployment percentage rate. This is the number of unemployed persons expressed as a percentage of the labor force. Estimates are in percentages, rounded to the nearest tenth. The data only considers persons in the civilian non-institutional population 15 years of age and over. The unemployment rate is reported for the whole of Ontario and the whole of each of the eight Great Lakes States, and is not limited specifically to the watershed of the Great Lakes.

As seen in Table 1, the unemployment rate ranges from a low of 4.2% (in 2000) to a peak of 10.6% (in 1983). Since 1976, unemployment in the Great Lakes region has experienced multiple periods of fluctuation in growth and decline (Figure 1). The short-term trend indicates that unemployment has been rising. In particular, from 2008 to 2009, the region experienced its largest fluctuation in growth yet of 3.0%, from 6.1% to 9.1% (Figure 2). Between 1976 and 2010, the Great Lakes Region has had an average unemployment rate of 6.6%. Other than the 2008 to 2009 unemployment change of 3.0%, the annual change in unemployment did not change by more than 2.0% in any other year.

Ontario and the eight U.S. Great Lakes States have experienced similar unemployment rate trends. As seen in Figure 3, the region has experienced wide fluctuations of unemployment. Specifically, in the eight U.S. States, the official unemployment rate in 2010 was 9.5%. These fluctuations mirror the region's overall pattern, whereby its annual rate of change is within an average of approximately 1.5%.

The United States reached a peak of official unemployment rate of 11.2% in 1982 and experienced its lowest unemployment rate of 4.0% nearly two decades after in 2000. During the Great Lakes region's highest unemployment year of 1983, the unemployment rate of the eight Great Lakes states was higher than the overall unemployment rate in the United States (Table 2 and Figure 4). However, as seen in Figure 4, the eight States have since managed to keep the official unemployment rate to equal or less than the overall national statistic. In 2000, the unemployment rate of the eight States was the same as the United States. Moreover, in the most recent 2010 unemployment data, the region was 0.1% less than the overall national unemployment figure.

Ontario also experienced wide fluctuations in its unemployment rate over the years. Ranges included a high unemployment rate of 10.9% in 1993, a low unemployment rate of 5.0% in 1988 and 1999, and a total unemployment in 2010 of 8.7%. In a national context, during the Great Lakes region's highest unemployment year of 1983, Ontario had a slightly lower number than the overall unemployment rate in Canada (Table 3 and Figure 5). This comparison was similar in the regional lowest unemployment rate year of 2000 wherein Ontario's unemployment rate was lower than Canada's overall. In the most recent unemployment data, however, Ontario has a slightly higher unemployment number than all of Canada.

As seen in Table 4 and Figure 6, there is no discernible unemployment rate pattern associated amongst the Great Lakes province and states. The states which consistently scored a high unemployment rate, particularly in 1983 and 2000, did not have a high unemployment rate in 2010. However, within the Great Lakes Region, Minnesota is consistently within the lower bracket of unemployment rates whereas Illinois frequently remains in the high end of the unemployment range. Michigan experienced the widest range of unemployment rates during low and peak periods contrasting with New York which experienced the smallest range of unemployment rates.

Linkages
The Great Lakes underpin regional economic prosperity and quality of life for the millions of residents in the eight U.S. States and Ontario. A significant fraction of the U.S. gross domestic product and over $150 billion in goods are generated annually in the Great Lakes region (Gesl 2006). Moreover, the lakes serve as commercial waterways, and supply water for agricultural and municipal uses (Gesl 2006). Unemployment is a key economic indicator when measuring an economy's strength and sustainability. Economic prosperity is a driving force behind most pressures on the environment, and can be considered as both a positive and negative force.

When the economy is performing well, there tends to be less conflict between economic development and maintaining the integrity of the environment (McGill Redpath Museum). Under a healthy economy where the unemployment rates are low or decreasing, there will be greater economic capabilities to provide research to monitor anthropogenic impacts and to develop and implement new methods for mitigating the associated consequences.

At the same time, when the economy is performing well, there tends to be increased use and development of natural resources. When economic prosperity is high there tends to be higher levels of consumer spending and home buying (Thorp, Muir and Zegarac 2000). These activities can increase pressures on the ecosystem through household and business waste generation, increased air pollution from transportation sources and accelerated land use changes (Thorp, Muir and Zegarac 2000). Residential development is the key category of land use change and its environmental impacts are widely recognized. Moreover, the proliferation of international trade treaties in support of increased economic prosperity over the last few decades has led to an increase in the global movement of goods. Increased transportation, particularly with Great Lakes and oceanic shipping traffic, has placed a strain on natural systems by facilitating the immigration of non-native species to new habitats, introducing pollutants into the aquatic ecosystem and altering and destroying coastal habitats (McGill University Redpath Museum).

Management Challenges/Opportunities
There are many linkages between economic prosperity and stresses to ecosystem health. Decision makers in the Great Lakes community should aim to maximize the positive and minimize the negative pressures of economic prosperity on the chemical, physical and biological integrity of the Great Lakes ecosystem.

Comments from the author(s)

Alternative and/or additional measures of economic prosperity should be examined for use in the SOLEC process. Unemployment is linked to economic prosperity; however, it may not be sufficient to represent other important aspects of economic prosperity, such as the level and distribution of income and wealth, poverty rates, income volatility and disparity, and economic security (Canadian Index of Well-Being).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Unemployment Percentage Rate

Year	Unemployment Percentage Rate in Ontario	Average Unemployment Percentage Rate in the Eight Great Lakes States	Unemployment Percentage Rate in the entire Great Lakes Region
1976	6.1	8.0	7.8
1977	6.9	7.2	7.2
1978	7.2	6.4	6.5
1979	6.6	6.4	6.3
1980	6.9	8.4	8.2
1981	6.6	9.1	8.8
1982	9.8	11.2	10.5
1983	10.4	11.0	10.6
1984	9.0	8.6	8.5
1985	7.9	8.0	7.8
1986	7.0	7.3	7.2
1987	6.1	6.3	6.4
1988	5.0	5.5	5.5
1989	5.0	5.3	5.3
1990	6.2	5.7	5.9
1991	9.5	7.0	6.9
1992	10.8	7.6	7.5
1993	10.9	6.8	6.8
1994	9.6	5.8	5.8
1995	8.7	5.2	5.3
1996	9.0	5.1	5.3
1997	8.4	4.8	4.9
1998	7.2	4.4	4.6
1999	6.3	4.2	4.5
2000	5.7	4.0	4.2
2001	6.3	4.8	4.9
2002	7.2	5.8	5.9
2003	6.9	6.2	6.1
2004	6.8	5.8	5.9
2005	6.6	5.4	5.6
2006	6.3	5.0	5.1
2007	6.4	5.1	5.2
2008	6.5	6.0	6.1
2009	9.0	9.6	9.1
2010	8.7	9.5	9.2

Table 1. Unemployment Percentage Rate Table in Ontario, Eight Great Lakes States and the Entire Great Lakes Region. Source: Statistics Canada and United States Department of Labor - Bureau of Labor Statistics

Unemployment Percentage Rate in the U.S. and the Great Lakes Region

Year	1983 (peak unemployment)	2000 (low unemployment)	2010 (current)
United States	9.60	4.0	9.6
Eight U.S. Great Lakes States	11.0	4.0	9.5

Table 2. Unemployment Percentage Rate in the United States and the Eight Great Lakes States
Source: United States Department of Labor – Bureau of Labor Statistics

Unemployment Percentage Rate in Canada and Ontario

Year	1983 (peak unemployment)	2000 (low unemployment)	2010 (current)
Canada	12.0	6.8	8.0
Great Lakes Province - Ontario	10.4	5.7	8.7

Table 3. Unemployment Percentage Rate in Canada and the Great Lakes Province (Ontario)
Source: Statistics Canada

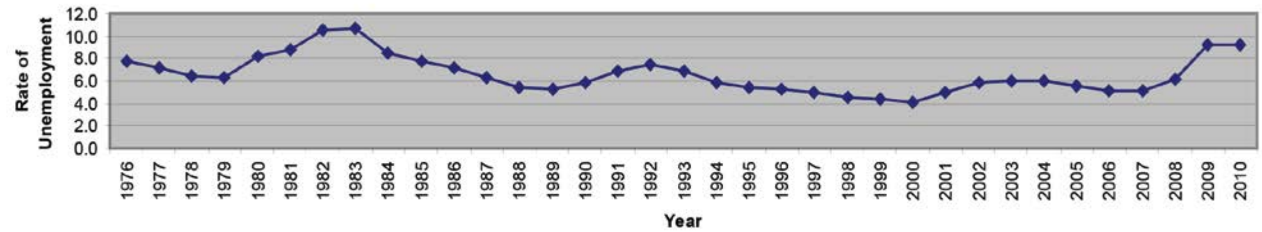

Figure 1. Total Unemployment Rate for the entire Great Lakes Region (Ontario and the eight U.S. Great Lakes States) from 1976 to 2010
Source: Statistics Canada and United States Department of Labor - Bureau of Labor Statistics

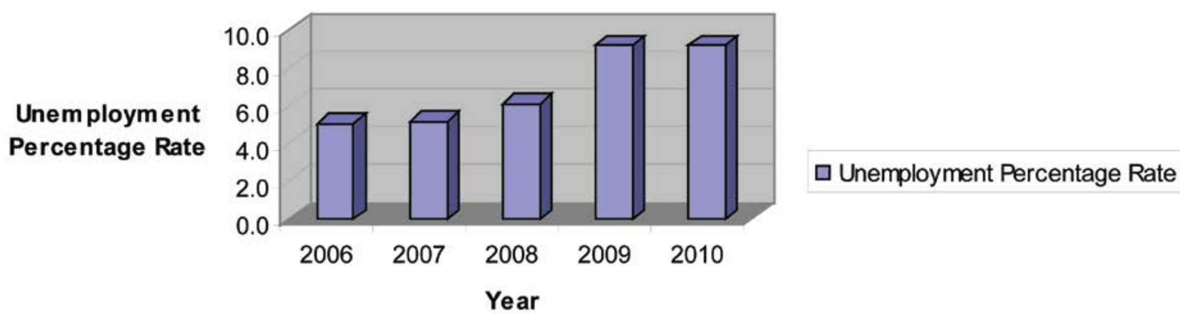

Figure 2. Short-Term Trend Analysis: Total Unemployment Rate for Great Lakes Region (Ontario and the Eight Great Lakes States from 2006 to 2010)
Source: Statistics Canada and United States Department of Labor - Bureau of Labor Statistics

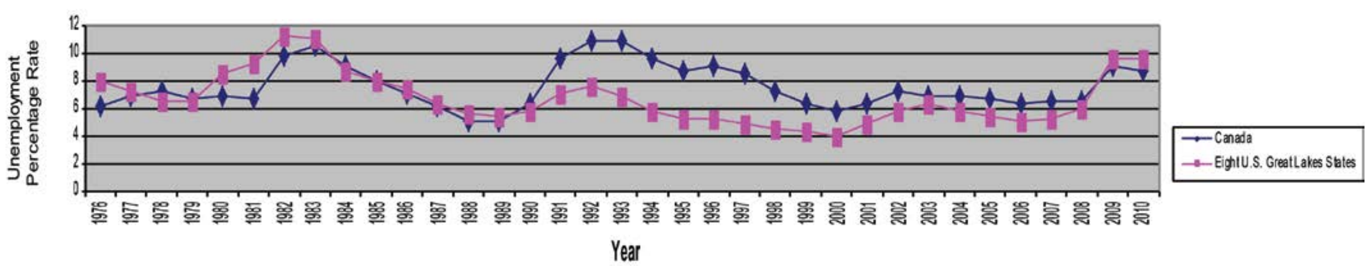

Figure 3. Total Unemployment Rate in the Eight Great Lakes States and Ontario from 1976 – 2010
Source: United States Department of Labor – Bureau of Labor Statistics

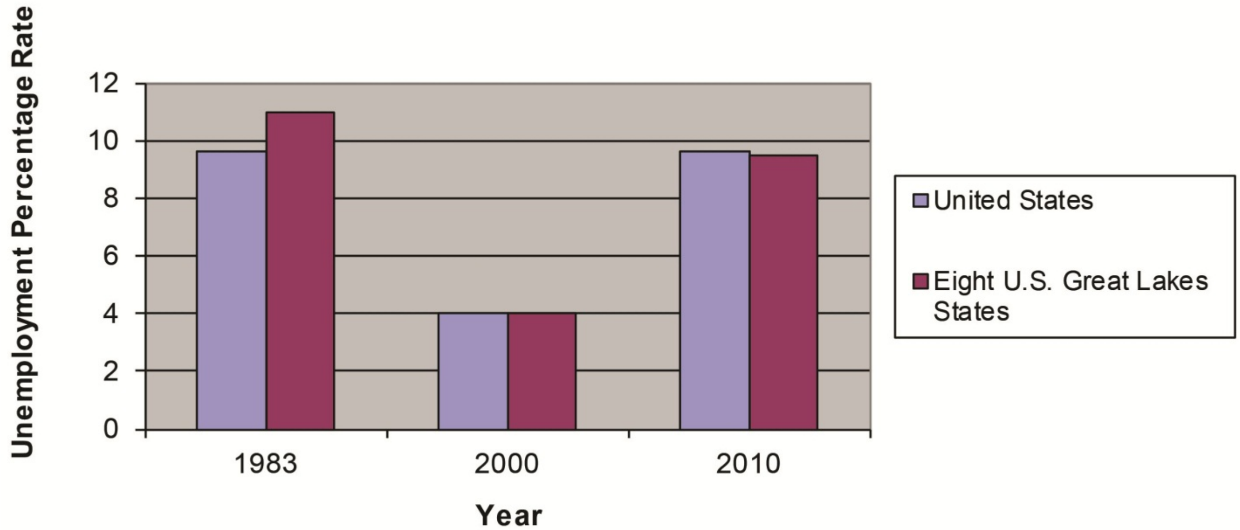

Figure 4. United States and Eight U.S. Great Lakes States: Low, Peak, and Current Years of Unemployment
Source: United States Department of Labor – Bureau of Labor Statistics

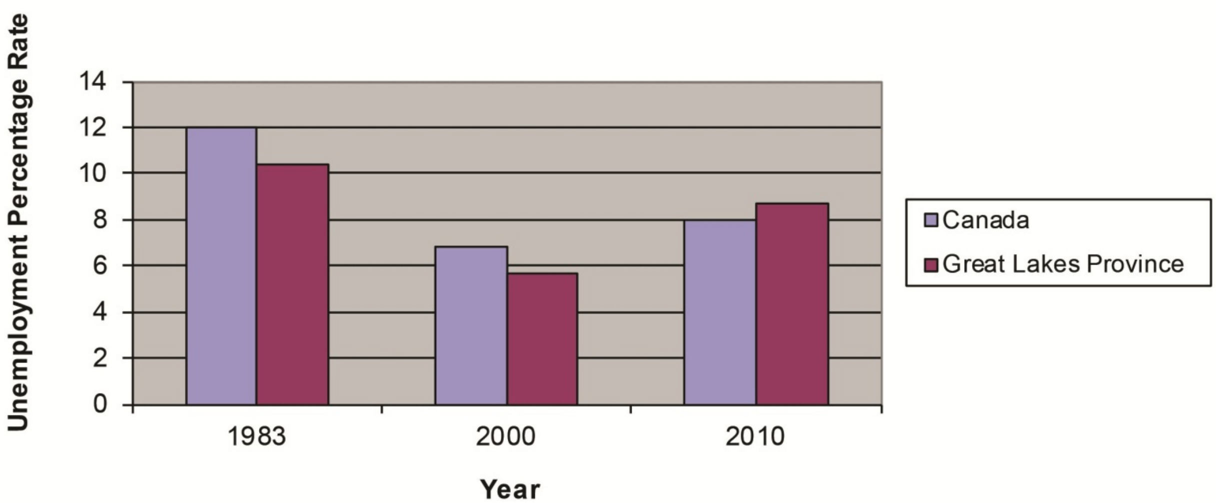

Figure 5. Canada and the Great Lakes Province (Ontario): Low, Peak, and Current Years of Unemployment
Source: Statistics Canada

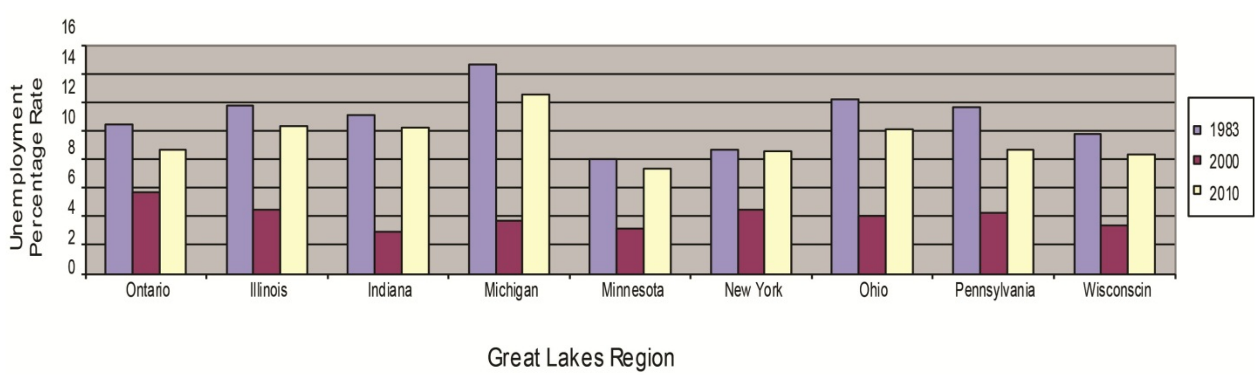

Figure 6. Ontario and the Eight Great Lakes States: Low, Peak, and Current Years of Unemployment
Source: Statistics Canada and United States Department of Labor - Bureau of Labor Statistics

Energy Consumption

Overall Assessment
Trend: Increasing
Rationale: The trend of total energy consumption in the eight Great Lakes States and Ontario has increased over the eighteen-year examined period. Between 1990 and 2008, energy consumption has increased 10.0%. However, the short term trend assessment of energy consumption from 2005-2008 illustrates that the total energy usage has decreased (a drop of 3.0% from 2005).

Lake-by-Lake Assessment
Trends were not made on an individual lake basis.

Purpose
- To provide energy consumption use trends in the Great Lakes region
- The energy consumption indicator is used in the Great Lakes indicator suite as a Driving Force indicator in the Economic/Social category

Ecosystem Objective
Resource conservation and minimizing the unnecessary use of resources are endpoints for ecosystem integrity. Impacts from energy consumption should be managed so that beneficial uses of the Great Lakes are not impaired, and pollution is controlled as outlined in Annex 2 and Annex 15 of the Great Lakes Water Quality Agreement.

Ecological Condition
In this report, the Great Lakes region is defined as the eight Great Lakes States and the province of Ontario. Energy consumption within the Great Lakes region is examined by data extracted primarily from the Statistics Canada, Natural Resources Canada, Canadian Industrial Energy End-Use Data and Analysis Centre, and the United States Information Administration. The unit of analysis for energy consumption is secondary energy use as reflected in Megawatts Hour (MWh).

Secondary energy is energy used by the final consumer. It includes energy used to heat and cool homes and workplaces, as well as to operate appliances, vehicles and factories. Table 1 lists the total secondary energy use in the Great Lakes States and Ontario from 1990 and 1995-2008. As seen in Table 1, in 2008, the total secondary energy consumption rate in the Great Lakes region is 8,247,276,452 MWh. Secondary energy does not include intermediate uses of energy for transporting energy to market or transforming one energy form to another; this is primary energy (State of the Great Lakes 2009; 294). This report will focus on examining the secondary energy usage in the Great Lakes region.

<u>A) Great Lakes Region as a whole (Ontario + Eight Great Lakes States)</u>
The energy consumption for the entire Great Lakes region has fluctuated over the eighteen-year period (Figure 1). Comparing the 1990 and 2008 total energy consumption data, the Great Lakes region total energy use grew by 10%. Within the four specific sectors, the industry sector is the most energy consuming sector in the Great Lakes region (Figure 2). However, the most recent data available from 2008 indicates that whereas in 1990 the industrial sector consumed 37% of the total energy, it has since decreased to 30.0% (Figure 3 & 4).The remaining three sectors, residence, transportation and commercial have increased their share of energy use by 1%, 3% and 3% respectively since 1990.

In examining the short-term trend analysis, the energy consumption from 2005 to 2008 shows a fluctuation range between a decline of 1.4% to an increase of 3.7%. There was a decrease in energy consumption from 2005 to 2006 (3.7 %); but in the next year (2006 to 2007), the consumption rate experienced an increase of 2.5% (Figure 5).

Returning to 2007-2008, the energy usage in the Great Lakes region decreased once again by another 1.0%, leaving the total energy consumption rate in 2008 as 8,247,276,452 MWh.

To obtain a greater understanding of the energy consumption rate within the region, population data from the U.S. Census and Statistics Canada have been included to examine the average energy use per person within the region (energy consumption per capita). In 1990, the total population within the Great Lakes region as defined in this report was 86,323,139 (Table 2).The total population's total energy consumption was 7,429,731,790 MWH/h, and its per capita usage was 87 MWh/per person/per year. It is worth noting that while the energy consumption has increased, per capita usage has dropped slightly. Compared to 1990, although the 2008 population in the Great Lakes region had an increase of 10.6%, its energy usage per capita declined by 3.4% to 84 MWh/per person per year.

B) Comparison between Ontario and the Eight Great Lakes States

The overall trends in energy consumption by sector were quite similar on both sides of the basin. In Ontario, the total secondary energy consumption by the four sectors in 2008 was 763,472,222 MWh (Table 3). The transportation sector accounted for the largest end user percentage of energy consumption at 32%. Energy consumption in the other three sectors was as follows: residence with 21%, commercial/institutional with 18% and industrial with 30% (Figure 6).

Total secondary energy consumption by the four sectors on the eight U.S. Great Lakes States in 2008 was 7,483,804,229 Megawatt hours (MWh) (Table 3). For the U.S Great Lakes States, the industrial sector was the largest consuming sector with 30% in 2008. The remaining three sectors account for 70% of the total, as follows: transportation and residential with 25% each and the commercial/institutional sector with 20% (Figure 6).

Linkages

Both Canada and the United States are among the world's top per capita electricity and energy consumers; consuming energy can cause a wide range of health and environmental impacts. Environmental impacts are caused by actions required to produce energy, including oil and gas exploration and development, coal mining, hydroelectric dams and reservoirs (Boyd 2001). According to a Stockholm Environment Institute report, current pressure exerted on the ecosystem as a result of energy generation and consumption is unsustainable (Persson and Noel 2010), As one of the main driving forces, energy consumption is triggering (direct and indirect) pressures on the ecosystem.

Energy consumption is a direct and indirect driving force behind many of the pressures on the Great Lakes. According to the United Nations Economic and Social Commission for Asia and the Pacifique (UNESCPA), energy consumption has a direct effect on greenhouse gas emissions, emission of air pollutants, acid precipitation and pollution of toxic substance (UNESCAP 2001). Consequently, these effects have a direct impact on biodiversity and the ecosystem.

There is, for example, a direct correlation between energy consumption and the emission of air pollutants. Burning fossil fuels can cause emission of air pollutants into the atmosphere and via atmospheric deposition on to land and water surfaces. Water is a "dangerously effective carrier of pollutants emitted into the air from the combustion of coal and other fossil fuels" (Krantzberg and Bassermann 2010). Rain transports pollutants to watersheds, lakes and rivers, and can therefore compromise water quality. For this reason, initiatives such as the UNEP global Mercury Partnership are calling for mercury global partnerships between governments and other stakeholders to reduce risks to human health and the environment from the release of mercury and its compounds to the environment from sources such as fossil fuel consumption (UNEP 1).

For other renewable energies such as hydroelectricity, solar power and wind power, the debate surrounding these usages has been controversial. While the use of renewable energy sources is considered more environmentally friendly and fairly economically feasible, it still elicits reactions from local communities and environmental policymakers on their limited benefits, potential tradeoffs and visual pollution.

In the case of hydroelectric power, while its usage is seen as more environmentally friendly, it does come at some environmental cost, particularly on water resources (Krantzberg and Bassermann 2010). Large hydro power can cause disruption in natural river cycles, which in turn affects the aquatic ecosystem, degrades upstream catchment areas and impacts crop productivity (Persson and Noel 2010). In addition, building hydroelectric damns often leads to the loss of forests, wildlife habitat, and species populations.

In the case of solar energy, use of toxic chemicals in the manufacturing of solar energy cells presents a problem both during use and disposal (IUCN 2008).

In the case of wind power, the usage of wind turbines has been controversial. On one hand, recent studies report that wind farms pose no serious environmental threats, and in some cases an off-shore wind-farm may even improve the marine ecosystem (Phadke 2010, and Bergman et al.2011). On the other hand, there are concerns that building wind turbines can result in ecosystem disruption in terms of habitat loss at large wind farms, and with rotors causing mortality of migratory birds (IUCN 2008).

Management Challenges/Opportunities
The linkages between energy use and stress on the Great Lakes health are outlined above. The Great Lakes community and decision makers should continue to support global, national, regional and local energy use conservation initiatives and, seek ways to minimize the stress that energy use and energy production can cause to the Great Lakes ecosystem.

Comments from the author(s)
In comparison to the Great Lakes region as defined in this report, the total energy use for the Great Lakes watershed would be less. Nonetheless, this data serves the indicator report's purpose well by illustrating a socio-economic trend that is a driving force behind many of the pressures on the Great Lakes conditions, and the socio-economic context is which decision-makers are working within. The investment required to breakdown energy use trends specifically for the Great lakes watershed boundary and/or on a lake-by-lake level would only be worthwhile should formal energy use conservation reduction targets be set for that defined geographic boundary.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Energy Consumption in the Great Lake Region

Year	Total Energy Use (MWh)	Residence	Commercial	Industrial	Transportation
1990	7,429,731,790	1,720,089,146	1,266,281,782	2,711,060,722	1,732,300,141
1995	7,953,728,327	1,881,985,073	1,430,974,398	2,791,232,982	1,849,535,875
1996	8,193,830,538	1,965,544,382	1,478,911,839	2,867,398,314	1,881,976,003
1997	8,188,486,379	1,889,090,097	1,494,270,762	2,884,634,732	1,920,490,789
1998	8,009,460,149	1,760,838,819	1,466,623,015	2,816,275,765	1,965,722,550
1999	8,296,601,235	1,878,856,669	1,535,890,162	2,840,141,925	2,041,712,479
2000	8,462,325,567	1,948,509,147	1,615,126,033	2,820,664,154	2,078,026,233
2001	8,134,622,104	1,899,472,020	1,610,799,287	2,585,355,733	2,038,995,064
2002	8,244,054,100	1,983,378,737	1,636,049,498	2,561,858,399	2,062,767,466
2003	8,338,580,794	2,030,464,961	1,639,774,499	2,581,586,950	2,086,754,383
2004	8,426,769,846	1,987,371,590	1,648,665,008	2,634,747,673	2,155,985,576
2005	8,472,930,380	2,052,945,322	1,649,586,013	2,575,162,448	2,195,236,598
2006	8,157,785,682	1,877,010,541	1,585,196,860	2,512,107,037	2,183,471,244
2007	8,364,775,670	1,998,980,762	1,641,411,359	2,530,691,551	2,193,691,997
2008	8,247,276,452	2,001,826,800	1,664,997,902	2,441,979,930	2,138,471,820

Table 1. Energy Consumption in the Great Lake Region from 1990, 1995-2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

Energy Consumption and Population within the Great Lakes Region

State/Province	Total Energy Consumption within the Great Lakes Region (1990)	Population within the Great Lakes Region (1990)	Total Energy Consumption within the Great Lakes Region (2008)	Population within the Great Lakes (2008)
Ontario	653,166,666	(1991) – 10,085,000	763,472,222	12,932,300
Illinois	1,055,466,152	11,430,602	1,198,279,684	12,842,954
Indiana	738,685,632	5,544,159	837,421,275	6,388,309
Michigan	832,058,075	9,295,297	855,269,304	10,002,486
Minnesota	407,456,708	4,357,099	580,016,955	5,230,567
New York	1,099,309,583	17,990,455	1,168,826,041	19,467,789
Ohio	1,125,979,052	10,847,115	1,155,286,158	11,528,072
Pennsylvania	1,085,505,936	11,881,643	1,142,889,252	12,566,368
Wisconsin	432,103,986	4,891,769	548,815,561	5,627,610
Total:	7,429,731,790	86,323,139	8,250,276,452	96,586,455

Table 2. Energy Consumption and Population within the Great Lakes Region (Ontario + 8 States).
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

Total Energy Consumption Rate

State/Province	Total Energy Consumption by State/Province(MWh)
Ontario	763,472,222
U.S. Basin Total (2008)	7,483,804,229
Illinois	1,198,279,683
Indiana	837,421,275
Michigan	855,269,304
Minnesota	580,016,955
New York	1,168,826,041
Ohio	1,155,286,158
Pennsylvania	1,142,889,252
Wisconsin	545,815,561

Table 3. Total Energy Consumption Rate by State/Province in 2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

Total Energy Consumption Rate from 2005 – 2008.

	2005	2006	2007	2008
Ontario	733,250,000	748,861,111	775,055,556	763,472,222
Illinois	1,218,794,659	1,169,969,019	1,198,836,519	1,198,279,684
Indiana	855,591,682	836,981,669	852,455,821	837,421,275
Michigan	929,504,206	879,682,124	880,971,636	855,269,304
Minnesota	550,709,848	543,353,764	559,003,759	580,016,955
New York	1,219,820,408	1,149,160,973	1,190,161,615	1,168,826,041
Ohio	1,189,194,481	1,143,475,394	1,186,820,605	1,155,286,158
Pennsylvania	1,185,150,100	1,149,922,957	1,176,475,196	1,142,889,252
Wisconsin	550,914,997	536,378,672	544,994,962	548,815,561

Table 4. Total Energy Consumption Rate from 2005 – 2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

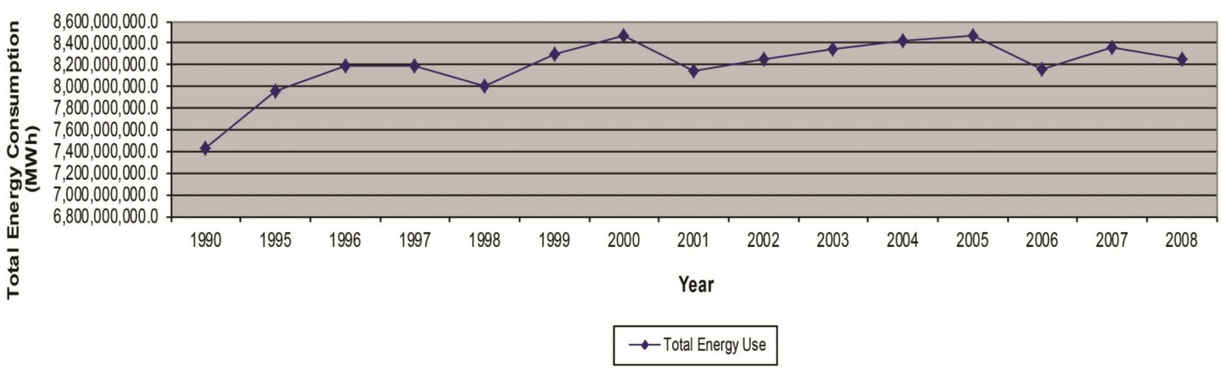

Figure 1. Total Energy Consumption in all Great Lake locations 1990, 1995-2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

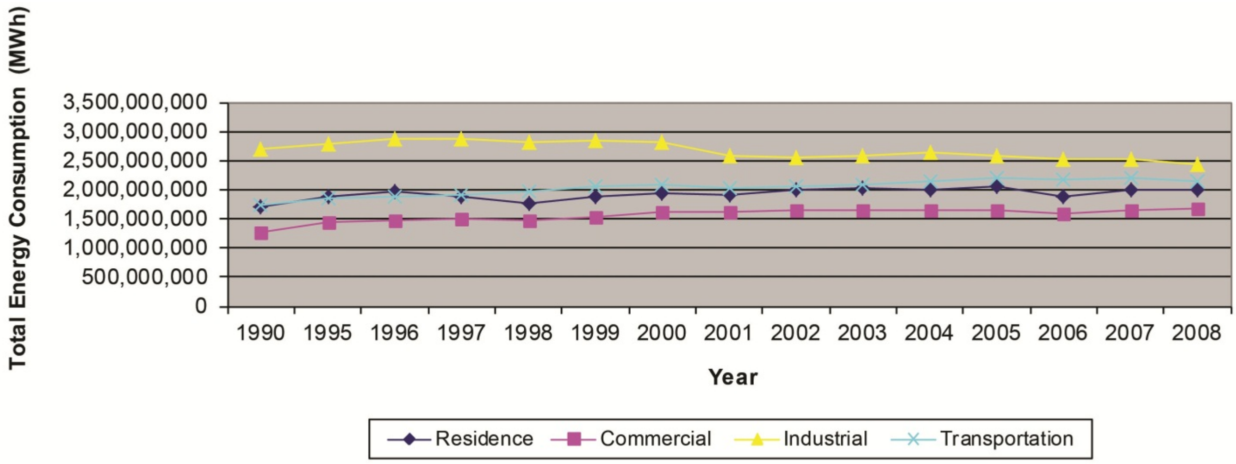

Figure 2. Total Energy Consumption by sector for all Great Lake locations 1990, 1995-2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

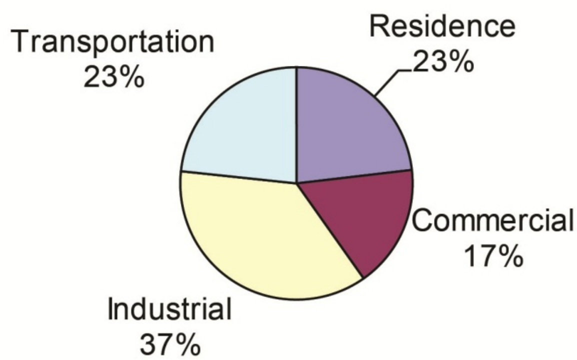

Figure 3. The percent contribution of each of the four sectors within the Great Lakes region in 1990.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

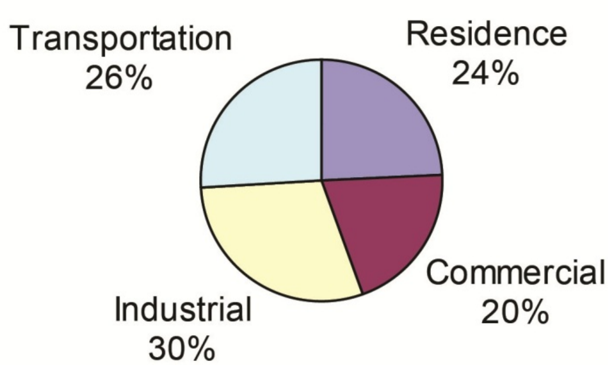

Figure 4. The percent contribution of each of the four sectors within the Great Lakes region in 2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

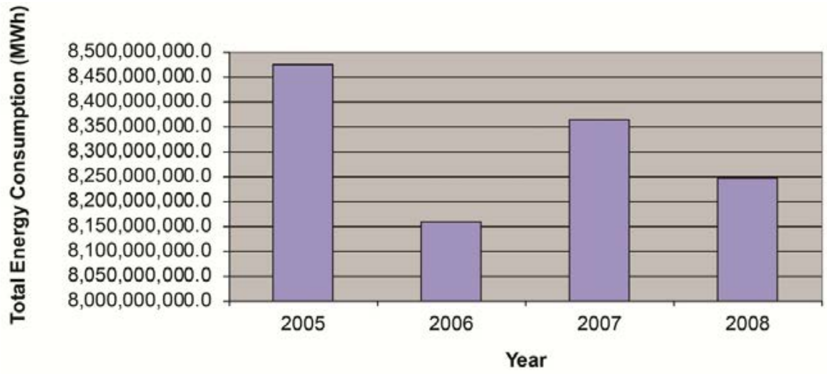

Figure 5. Total Energy Consumption in the Great Lakes in the Great Lakes States and Ontario, 2005-2008.
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

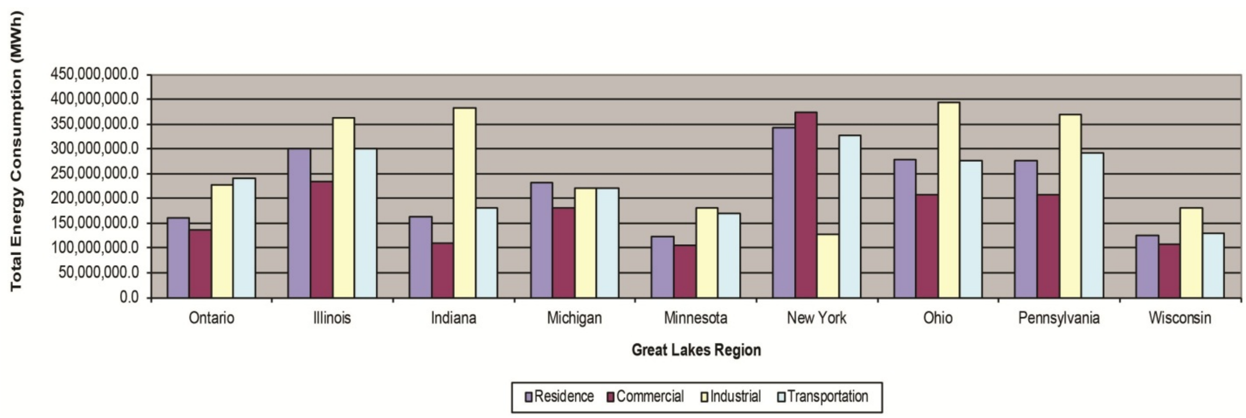

Figure 6. Comparison of Total Energy Consumption for Ontario and all Great Lakes States in 2008 (MWh).
Source: United States Energy Information Administration (EIA) 2010. Natural Resource Canada - Office of Energy Efficiency 2010.

Extreme Precipitation Events

Overall Assessment
Trend: Increasing
Rationale: Unavailable

Purpose

- To assess trends in precipitation and to examine the influence and impact(s) of climate change on the Great Lakes region.
- The Precipitation Events indicator is used in the Great Lakes indicator suite as a Pressure indicator in the Resource Use and Physical Stressors top level reporting category.

Ecosystem Objective

The ecosystem objective is to maintain the diverse array of Great Lakes coastal wetlands by allowing, as closely as possible, the natural seasonal and long-term fluctuations of Great lakes water levels. The alteration of frequency and magnitude of precipitation events may also affect such beneficial use impairments as 'Loss of Fish and Wildlife Habitat,' 'Degradation of Phytoplankton and Zooplankton Populations,' 'Degradation of Aesthetics,' 'Restrictions on Drinking Water Consumption or Taste and Odor Problems,' 'Eutrophication or Undesirable Algae,' 'Restrictions on Dredging Activities,' 'Degradation of Benthos,' and 'Degradation of Fish and Wildlife Populations' under Annex 2 of the Great Lakes Water Quality Agreement.

Ecological Condition

In recent decades the Great Lakes region has seen pattern of above average precipitation in both summer and winter months (Kling, 2003). From 1915 to 2004, total annual precipitation increased by 4.5 inches (Hodgkins et al., 2007). Although trends indicate increases in total precipitation, precipitation has not increased uniformly over the last one hundred years. For example, over the last 90, 70, and 50 years respectively, precipitation in March and February declined. Conversely, precipitation in April, May and July through December, over the same time periods, increased (Hodgkins et al., 2007). These finding highlight the seasonal shift in precipitation patterns.

The following figure showcases trends in average annual precipitation, in inches, over the Great Lakes providing support of an overall pattern of increasing total annual precipitation.

Looking forward, in low- and high- emission climate models scenarios, average annual total precipitation is expected to be slightly above long-term averages. It is also expected that annual average precipitation will increase by 10 to 20 percent by the end of century. In terms of temporal shifts in seasonal patterns of precipitations, winter and spring rains are expected to increase and summer rains decrease by up to 50 percent.

Over the course of the last five decades, the frequency of 24-hour and 7-day intense rainfall events have been high relative to the long-term average. Furthermore, findings based on models suggest an increase in both 24-hour and multiday heavy rain events over the next century. It is predicted that the frequency of such events may double by 2100 (Kling et al., 2003).

<u>Data Source</u>

Data from this report was generated using climate data from the National Oceanic and Atmospheric Administration (NOAA) climate divisions found in Table 1. These divisions were chosen based on an approximation of the boundaries of the Great Lakes basin.

Linkages
The impact of changes in the temporal distribution and magnitude of precipitation in the Great Lakes region will likely have an effect on the hydrologic system of the basin. As temperatures increase, evaporation as well is expected to increase. Additionally, an increase in surface water runoff will likely accompany an increase in total precipitation resulting in both positive and negative impacts on ecosystems. For ecosystems that rely on water level recharge during the winter season, the increase in winter precipitation may result in favorable impacts. Conversely, ecosystems that rely on summer recharge, such as some wetland ecosystems, may experience significant stress with decreases in summer precipitation (Wuebbles et al., 2004). Changes in runoff will also affect soil moisture. When compared to the long-term average from 1961-1990, soil moisture is expected to increase upwards of eighty percent during winter in some areas in the region and decrease regionally by upwards of thirty percent in the summer and fall. A shift in soil moisture may also promote the preference of crops and ecosystems that are reliant on recharge during the winter months (Kling et al., 2003). Groundwater recharge is also expected to increase as more rain falls when plants are dormant, leading to increased base flow in spring-fed streams and lakes, and surface flooding of areas with hydric soils.

Additional consequences of altered precipitation patterns include:
- Increased occurrence of flooding events
- Increased erosion and distribution of pollutants from upland sources
- Increased runoff during heavy rain events
- Increased groundwater recharge in winter and spring
- Decreases in fish and invertebrate production
- Disturbance of food web interactions and fish and insect life histories (Kling et al., 2003)
- Increased lake effect snow resulting in warmer surface waters and decreased ice cover (Burnett et al., 2003).

Management Challenges/Opportunities
The realm of response options to address climate change is classified into two categories, the first of which is adaptation, or “initiatives and measures designed to reduce the vulnerability of natural and human systems against actual or expected climate change effects” (Koslow, 2010). Although a wide range of adaptation strategies exist, there are significant financial, technological, cognitive, behavioral, political, social, institutional, and cultural constraints resulting in limited implementation and effectiveness of adaptive strategies (Bernstein et al., 2007). Adaptation is one way to deal with the knowledge gaps and uncertainty of climate change science (Patino, 2010). The Wisconsin Initiative on Climate Change Impacts (WCCI) recommends a risk management approach to impacts and adaptation. With confidence in seasonal changes, there is concern for spring high water events which will increase the threat of flooding from rivers, streams, and groundwater, and promote sanitary sewer overflows into waterways. Understanding the forecasted impacts and vulnerabilities is a first step toward implementing adaptation strategies (Liebl, 2011)

In the Great Lakes basin there has been significant progress in defining what adaptation means for conservation and restoration efforts in the region. For example, tools to help managers incorporate adaptation strategies into planning efforts have been developed by such organizations as the National Wildlife Federation, the Climate Adaptation Knowledge Exchange, regional Sea Grant offices, NOAA, and Natural Resources Canada to name a few (Koslow, 2010 and Natural Resources Canada). A few examples of projects or programs which have integrated adaptive strategies into management processes relevant to increased precipitation and altered distribution of precipitation events include the following:
- Wisconsin Imitative on Climate Change Impacts: The Wisconsin Imitative on Climate Change Impacts partnered with the Milwaukee Sewage Department on a project designed to provide estimates of the effects of altered precipitation patterns on sewage overflows to allow for better stormwater management.

- City of Chicago: The city currently utilizes green roofs as a means of reducing the amount of impervious surface and thus reducing stormwater runoff.
- City of Detroit: The City of Detroit uses green alleys, or concrete alleyways fitted with permeable pavement and open-bottom catch basins, to reduce stormwater runoff. Although only one alleyway has been built thus far, it is capable of holding up to a 10-year storm without water going into the storm drain (Koslow, 2010).
- Updating flood profiles to locate at risk areas (e.g., hazardous materials, wells and septic, roadways) can assist in prioritizing resource spending. Mapping hydric soils, regulating development of these lands, and restoring or enhancing existing ecological buffer zones can improve stormwater storage capacity and reduce downstream flood magnitudes. Collectively, enhancement of stormwater storage capacity and the disconnection of stormwater inputs to sanitary systems will reduce the frequency and magnitude of sanitary overflows in combined stormwater and sanitation systems (Liebl, 2011).

Adaptation is not explicit to infrastructure, but also to programs and policy. Adaptation in programs and policy calls for ongoing and permanent monitoring for re-assessment and adjustment (Policy Horizons Canada 2010). At minimum, programs and policy should embed mechanisms for adjustments informed by monitoring. Flood management and the protection of ground water resources will benefit from the restoration and enhancement of surrounding wetlands and open space (Adapting to Climate Change, NOAA 2010 & Liebl, 2011). However, areas of functional conservation will likely migrate or perish. To provide continued protection to these areas as they migrate with climate change requires particular mechanisms. Rolling easements, for example, are designed to promote the natural migration of shorelines. Defined by physical characteristics such as the line of vegetation, the delineation of the easement is adapted to change in accordance with changing water levels (Adapting to Climate Change, NOAA 2010).

The other way in which climate change can be addressed is through mitigation, or technological change and substitution that reduce resource inputs and emissions per unit of output (Koslow, 2010).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validate or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respectable generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Table 1. Climate Divisions
Source: NOAA

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Figure 1. Trends in Precipitation in the Great Lakes
Source: NOAA

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Climate Divisions

State	Climate Division
Minnesota	3,6
Wisconsin	1,2,3,6,9
Illinois	2
Indiana	1,2,3
Michigan	1,2,3,4,5,6,7,8,9,10
Ohio	1,2,3,4
Pennsylvania	10
New York	1,9,10

Table 1. Climate Divisions
Source: NOAA

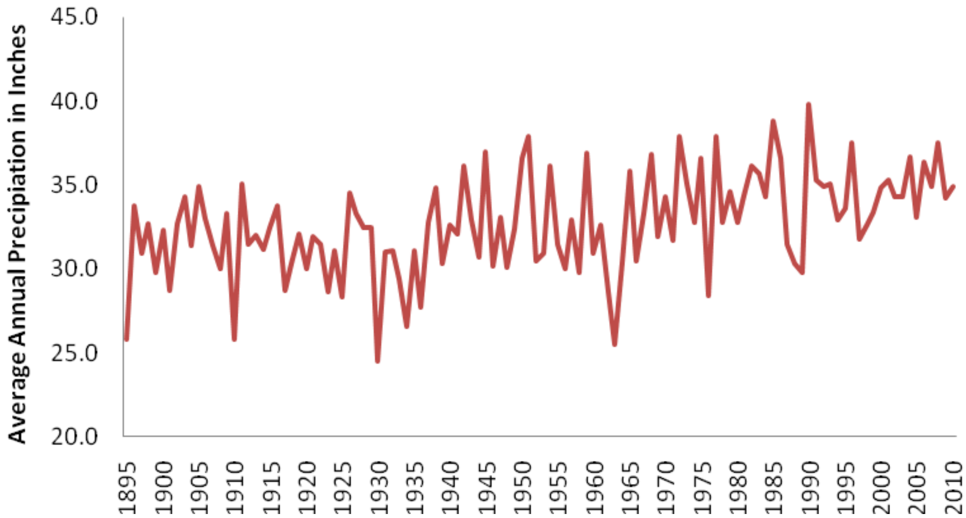

Figure 1. Trends in Precipitation in the Great Lakes
Source: NOAA

Fish Consumption Restrictions Advisory Rating Scale

Overall Assessment
Status: Fair
Trend: Undetermined
Rationale: U.S. Overall Average Score – 4.02, Ontario MOE Overall Average Score – 3.74. The Fish Consumption Advisory Rating Scale Indicator was created to categorize the different levels of risk to sensitive populations (children under 15 and women of child bearing age) from consuming certain fish species in each of the Great Lakes. The Indicator involves a five-level, Consumption Advisory Rating Scale that corresponds to the current contaminant levels in Great Lakes fish. Protective measures associated with each consumption advisory rating scale allows a flexible, graduated and appropriate response to the level of risk from consumption. The information used to conduct this analysis demonstrates that there are consumption advisories in all of the Great Lakes for a variety of species of fish that are driven by PCBs, mercury, dioxin, chlordane, mirex and toxaphene (Table 1). The level of the advisory varies according to the species, size and location of the fish. The average score for Lake Trout and Walleye (Lake Erie) (Figure 1 & 2) in the Great Lakes basin falls into the one meal per month to six meals per year category (Tables 2 & 3). Some locations and size classes allow for unlimited or 1 meal per week consumption of these fish while others are under do not eat advisories. Contaminant trends cannot be identified through this type of assessment.

Lake-by-Lake Assessment
Lake Superior
Status: Fair
Trend: Undetermined
Rationale: **U.S. Lake Average Score - 2.67, Ontario MOE Lake Average Score - 2.81.** The U.S. States of Minnesota, Wisconsin, and Michigan and the Province of Ontario issue consumption advice for fish from the waters of Lake Superior. Advisories in Lake Superior are driven by PCBs, dioxin, mercury, chlordane, and toxaphene with PCBs continuing to be the largest contributor (Table 1). Lake Superior fish consumption advisories for Lake Trout range between unrestricted or 1 meal per week for some small fish to do not eat for some large fish (Tables 2 & 3).

Lake Michigan
Status: Fair
Trend: Undetermined
Rationale: **U.S. Lake Average Score – 3.95.** The U.S. States of Michigan, Wisconsin, Illinois, and Indiana issue consumption advice for fish consumed from the waters of Lake Michigan. Advisories in Lake Michigan are driven by PCBs and chlordane with PCBs continuing to be the largest contributor (Table 1). Lake Michigan fish consumption advisories for Lake Trout range from 1 meal per month to do not eat (Tables 2 & 3).

Lake Huron
Status: Poor to Fair
Trend: Undetermined
Rationale: **U.S. Lake Average Score – 5, Ontario MOE Lake Average Score - 3.70.** The U.S. State of Michigan and the Province of Ontario issue consumption advice for fish consumed from the waters of Lake Huron. Advisories in Lake Huron are driven by PCBs, dioxin, and mercury with PCBs continuing to be the largest contributor (Table 1). Lake Huron fish consumption advisories for Lake Trout range

between unrestricted or 1 meal per week in small fish to do not eat in large fish (Tables 2 & 3). Please note that a far less diverse data set was used in the creation of a lake average, for the U.S., due to the fact that only the state of Michigan borders Lake Huron.

Lake Erie
Status: Fair
Trend: Undetermined
Rationale: **U.S. Lake Average Score - 3.5, Ontario MOE Lake Average Score – 3.74 (Lake Trout) 1.86 (Walleye).** The U.S. States of Michigan, Ohio, and Pennsylvania and the Province of Ontario issue consumption advice for fish consumed from the waters of Lake Erie. Advisories in Lake Erie are driven by PCBs, dioxin, and mercury with PCBs continuing to be the largest contributor (Table 1). Lake Erie fish consumption advisories for Lake Trout in both the U.S. and Canada range between the 1 meal per month advice category to 6 meals per year (Tables 2 & 3).

Lake Ontario
Status: Poor
Trend: Undetermined
Rationale: **U.S. Lake Average Score – 5, Ontario MOE Lake Average Score 4.54.** The U.S. State of New York and the Province of Ontario issue consumption advice for fish consumed from the waters of Lake Ontario. Advisories in Lake Ontario are driven by PCBs, dioxin, mercury and mirex with PCBs continuing to be the largest contributor (Table 1). Lake Ontario fish consumption advisories for Lake Trout range between unrestricted or 1 meal per week for some small fish in Ontario to do not eat (Tables 2 & 3). Please note that a far less diverse data set was used in the creation of a lake average, for the U.S., due to the fact that only the state of New York borders Lake Ontario.

For more information on the fish consumption advice for species not included in this assessment, please visit: http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/states.cfm or www.ontario.ca/fishguide

Purpose

- To assess the restrictive nature of fish consumption advisories issued in the Great Lakes.
- To determine what contaminants are driving consumption advisories in the Great Lakes.
- To infer potential effects to human health through consumption of contaminated fish.
- The Fish Consumption Restrictions indicator is used in the Great Lakes indicators suite as an Impact indicator in the Human Impacts top level reporting category.

Ecosystem Objective

Fish in the Great Lakes ecosystem should be safe to eat and consumption should not be limited by contaminants of human origin. Reductions in the number and severity of fish consumption restrictions will reflect an improvement in environmental quality and the potential for reduced exposure to contaminants from consumption of Great Lakes fish. This indicator supports Annexes 1, 2 and 12 of the GLWQA.

Ecological Condition

History and Background

Since the 1970s, there have been declines in the levels of many PBT chemicals in the Great Lakes basin due to bans on the use and/or production of harmful substances and restrictions on emissions. However, because of their ability to bioaccumulate and persist in the environment, PBT chemicals continue to be a significant concern. Historically, PCBs have been the contaminant that most frequently limited the consumption of Great Lakes sport fish. In some areas, dioxins/furans, mercury, and toxaphene (Lake Superior) do contribute to restrictive fish consumption advisories.

Annex 2 of the Great Lakes Water Quality Agreement (United States and Canada 1987) requires Lakewide Management Plans (LaMPs) to define "…the threat to human health posed by critical pollutants… including their contribution to the impairment of beneficial uses." Both the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (Great Lakes Sport Fish Advisory Task Force, 1993) and the Guide to Eating Ontario Sport Fish (OMOE 2007) are used to assess the status of the ecosystem by comparing contaminant concentrations in fish to levels that result in consumption advice. Contaminants upon which consumption advisories are based in Canada and the U.S. include PCBs, dioxin/furans, mercury, toxaphene, chlordane and mirex (Tables 2 & 3).

Contaminant concentrations in sport fish from both the OMOE program and the U.S. Great Lakes State programs determine the advised maximum consumption frequency of fish meals. Both countries calculate and issue their own advice (Tables 2 & 3). In 2009, the Great Lakes National Program Office's Great Lakes Fish Monitoring and Surveillance Program eliminated the sport fish analysis portion of its program and refocused its efforts on identifying emerging chemicals in whole fish. In lieu of trend monitoring data, both countries are presenting information on the number and level of Fish Consumption Advisories. The tracking of the number of advisories for common species, Lake Trout and Walleye, and chemicals over time will allow for sufficient identification of the status of the environment over time.

<u>Measure</u>

To numerically quantify fish consumption advisories in the Great Lakes, a metric was created that scores the level of advisories. Scores on a scale of 1 to 5 were given based on the level of consumption advisories for the sensitive population (women of child-bearing age and children under 15) across all size classes of Lake Trout in each state and province (Table 4). Lake Trout was chosen because it is a top predator fish and represents a 'worst case scenario' for fish consumption advisories. The average score across all states and provinces for a lake was used as the measure.

To increase uniformity between advisories issued by the states and Canada, advisories were broken down by fish length and scored in increments of 2". For states that do not specify a minimum or maximum class size in their advice, information was broken out into sizes according to that state's fish regulations between 6 and 30 inches.

The status of each lake was determined based on the average lakewide score. Good is a lakewide score of <2. Fair is a lakewide score of 2 to 4. Poor is a lakewide score >4. The target for this indicator is a lakewide score of 1 for each lake and for the entire Great Lakes basin, indicating that there are no fish consumption advisories.

<u>Fish Consumption Restrictions in the Great Lakes</u>

Fish consumption advisories for Lake Trout and Walleye in the Great Lakes range from unrestricted consumption to do not eat advisories. Although U.S. and Canadian data cannot be directly compared due to differences in the way consumption advisories are issued, they do follow similar patterns in terms of the levels of consumption restrictions in the individual Great Lakes. Consumption advisories for Lake Trout are most restrictive in Lakes Ontario and Huron and least restrictive in Lake Superior (Figures 1 & 2). All lakes have do not eat advisories for at least some size classes of Lake Trout.

Differences in advisories within and between lakes reflect different levels of contaminant concentration in the air and sediment as well as differences in sampling regimes and locations between the states and Ontario. PCBs continue to drive most fish advisories despite the fact that they were banned in the U.S. and Canada in the 1970s. This is likely due to large amounts of PCBs still persisting in the environment and being released from old electrical equipment. However, it is noteworthy that the PCB levels in Great Lakes fish have declined substantially since the 1970s (Figure 3).

Linkages

Fish consumption restrictions may be the result of pressures such as contamination in sediment, atmospheric deposition, pesticides in tributaries and industrial loadings. Contaminants from these sources bioaccumulate in fish and can result in restrictive fish consumption advisories. The number and level of restrictive fish consumption advisories may decrease over time as the result of sediment remediation and industrial efficiencies or may increase as a result of, for example, higher contaminant levels and/or changes in methods of calculating advisories (e.g., incorporation of new science on toxicity of contaminants).

Management Challenges/Opportunities

Health risk communication is a crucial component to the protection and promotion of human health in the Great Lakes. Enhanced partnerships between states and tribes involved in the issuing of fish consumption advice and U.S. EPA headquarters will improve U.S. commercial and non-commercial fish advisory coordination. In Canada, acceptable partnerships exist between the federal and provincial agencies responsible for providing fish consumption advice to the public.

At present, PCBs, mercury, and chlordane are the only PBT chemicals that have uniform fish advisory protocols across the U.S. Great Lakes basin. The Great Lakes Sport Fish Advisory Task Force is currently drafting additional uniform PBT advisories in order to limit confusion of the public that results from issuing varying advisories for the same species of sport fish across the basin.

In order to best protect human health, increased monitoring and reduction of PBT chemicals need to be made a priority. In particular, monitoring of contaminant levels in environmental media and biomonitoring of human tissues need to be addressed, as well as assessments of frequency and type of fish consumed. In addition, improved understanding of the potential negative health effects from exposure to PBT chemicals is needed.

Comments from the author(s)

Differences in the way consumption advisories are developed in the U.S. and Canada means that data cannot be directly compared between the two countries. Differences exist in terms of the contaminant concentrations used to determine consumption restrictions, the number of sample sites, frequency of sampling, and years of data that advisories are based on. For example, sample collection and release of advice for the Ontario MOE and the Great Lakes States may be on different schedules. Lake Trout were selected for this indicator as they are top predator fish and therefore reflect a 'worst case scenario' for fish consumption restrictions and are not representative of all fish. Collection and analysis, for both countries, are subject to availability of funds and change with time.

An increased focus on emerging chemicals is occurring in monitoring programs in the United States and Canada. While the Great Lakes National Program Office no longer collects or analyzes sport fish fillets, the Office has instituted an Emerging Chemicals Surveillance Program in whole fish that looks to identify the presence or absence of emerging chemicals of interest and will inform State monitoring and advisory programs. 2011 will be the first year of this program and results will be shared through various outlets, including SOLEC, as they are received.

The Ontario Ministry of the Environment continues to monitor contaminants of long term concern such as PCBs, dioxins/furans, mercury and organochlorine pesticides. Recently, the ministry has started analyzing some chemicals of emerging concern for the Great Lakes environment such as polybrominated diphenylethers (PBDEs), perfluorinated compounds (PFCs) and polychlorinated naphthalene (PCNs) in selected fish samples.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		x				

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
2. Data are traceable to original sources		x				
3. The source of the data is a known, reliable and respected generator of data		x				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		x				
5. Data obtained from sources within the U.S. are comparable to those from Canada					x	
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				

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Information Sources

Sport Fish Consumption Advisory Programs
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Wisconsin Department of Natural Resources - http://dnr.wi.gov/fish/consumption/
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Table 1. Contaminants on which the fish advisories are based on by lake for Canada and the United States.
Source: Compiled by U.S. EPA, Great Lakes National Program Office
Table 2. Consumption limits set by the Guide to Eating Ontario Sport Fish (based on Health Canada TDIs).
* Women of childbearing age and children under 15

Source: Ontario Ministry of the Environment (2011)
Table 3. Consumption limits set by the Great Lakes Sport Fish Advisory Task force. *Women of childbearing age and children under 15
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Figure 3. Long-term trends of total-PCB in Great Lakes lake trout.
Source: Data were adopted for skin-on lake trout fillets samples from Lake Michigan from Stow et al. 2004 and for skin-off lake trout fillet samples from the other lakes from Bhavsar et al. 2007.

Last Updated
Some content was updated for the 2011 document.
Last complete updated was for the *State of the Great Lakes 2009* report

Contaminants Responsible for Advisories*

Lake/ State or Province	PCB	Dioxin	Mercury	Chlordane	Mirex	Toxaphene
Superior/Michigan	x	x	x	x		
Superior/Wisconsin	x		x			
Superior/Minnesota	x		x			
Superior/Ontario	x	x	x			x
Huron/Michigan	x	x	x			
Huron/Ontario	x	x	x			
Erie/New York	x					
Erie/Ohio	x		x			
Erie/Pennsylvania	x					
Erie/Michigan	x	x	x			
Erie/Ontario	x	x	x			
Ontario/New York	x	x			x	
Ontario/Ontario	x	x	x			
Michigan/Illinois	x			x		
Michigan/Michigan	x	x	x	x		
Michigan/Indiana	x		x			
Michigan/Wisconsin	x		x			

Table 1. Contaminants listed in state/provincial fish consumption advisories. *Not all states/provinces issue advisories for all of the listed contaminants.
Source: Great Lakes states and Ontario Ministry of the Environment

Table 2a Advised meals per month for general population

Advised meals per month	PCBs (ppm)	Mercury (ppm)	Chlordane (ppm)	Mirex (ppm)	Photomirex (ppm)	Toxaphene (ppm)	PFOS (ppm)	Dioxin/DL-PCBs (ppt)
8	<0.105	<0.61	<0.059	<0.082	<0.015	<0.235	<0.080	<2.7
4	0.105-0.211	0.61-1.23	0.059 - 0.117	0.082-0.164	0.015-0.031	0.235-0.469	0.080 - 0.160	2.7 - 5.4
2	0.211-0.422	1.23-1.84	0.117 - 0.235	0.164-0.329	0.031-0.061	0.469-0.939	0.160 - 0.320	5.4 - 10.8
1	0.422-0.844	-	0.235 - 0.469	0.329-0.657	0.061-0.122	0.939-1.877	0.320 - 0.640	10.8 - 21.6
Do not eat	>0.844	>1.84	>0.469	>0.657	>0.122	>1.877	>0.640	>21.6

Table 2b Advised meals per month for sensitive* population

Advised meals per month	PCBs (ppm)	Mercury (ppm)	Chlordane (ppm)	Mirex (ppm)	Photomirex (ppm)	Toxaphene (ppm)	PFOS (ppm)	Dioxin/DL-PCBs (ppt)
8	<0.105	<0.26	<0.059	<0.082	<0.015	<0.235	<0.080	<2.7
4	0.105 - 0.211	0.26-0.52	0.059 - 0.117	0.082 - 0.164	0.015 - 0.031	0.235 - 0.469	0.080 - 0.160	2.7 - 5.4
Do not eat	>0.211	>0.52	>0.117	>0.164	>0.031	>0.469	>0.160	>5.4
Do not eat	>0.211	-	>0.117	>0.164	>0.031	>0.469	>0.160	>5.4
Do not eat	>0.211	>0.52	>0.117	>0.164	>0.031	>0.469	>0.160	>5.4

*Women of child-bearing age and children under 15.

Table 2. Consumption limits set by the Guide to Eating Ontario Sport Fish (based on Health Canada TDIs).
Source: Ontario Ministry of the Environment (2011)

Consumption limits

Consumption Advice Groups*	Concentration of PCBs (ppm)	Concentration of Hg (ppm)	Concentration of Chlordane (ppm)
Unrestricted Consumption	0 – 0.05	0 <= 0.05	0 - 0.15
2 meals/ week		> 0.05 <= 0.11	
1 meal/ week	0.06 – 0.2	>0.11 <= 0.22	0.16 - 0.65
1 meal/ month	0.21 – 1.0	>.22 <= 0.95	0.66 - 2.82
6 meals/ year	1.1 – 1.9		2.82 - 5.62
Do not eat	>1.9	>0.95	>5.62

* Women of childbearing age and children under 15

Table 3. Consumption limits set by the Great Lakes Sport Fish Advisory Task force.
Source: Great Lakes Sport Fish Advisory Task Force (PCB Protocol 1993, Mercury Protocol 2007, Chlordane Discussion Paper)

Consumption advisory scores

Consumption Advisory	Score
Unrestricted (8 meals / month)	1
1 meal/week (4 meals / month)	2
1 meal/month	3
6 meals/year	4
Do not eat	5

Table 4. Consumption advisory scores used to calculate metric for the Fish Consumption Restrictions Indicator
Source: U.S. Environmental Protection Agency and Ontario Ministry of the Environment

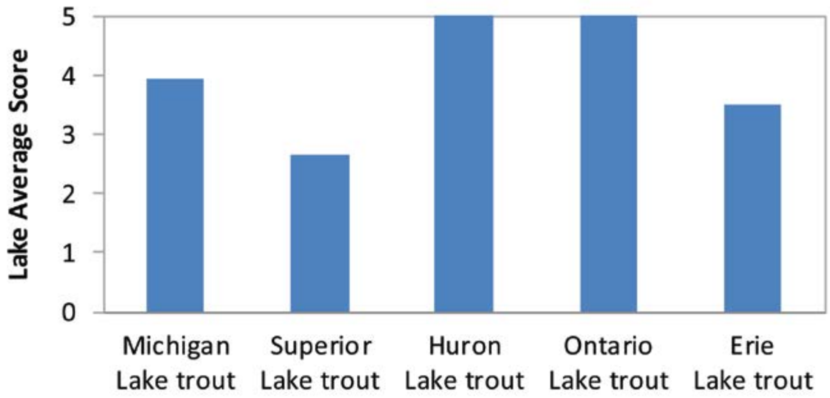

Figure 1. U. S. Fish Consumption Advisory Rating Scale
Source: U.S. State Consumption Advisory Programs. Compiled by U.S. EPA, Great Lakes National Program Office

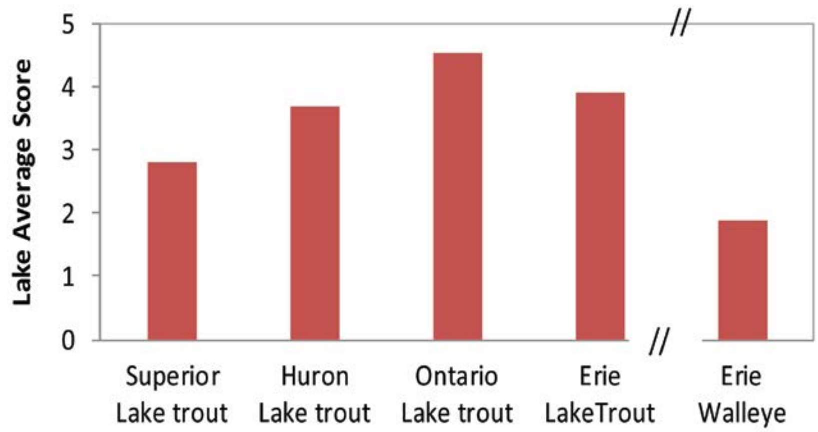

Figure 2. Canada Fish Consumption Advisory Rating Scale
Source: Ontario Ministry of the Environment. Compiled by U.S. EPA, Great Lakes National Program Office

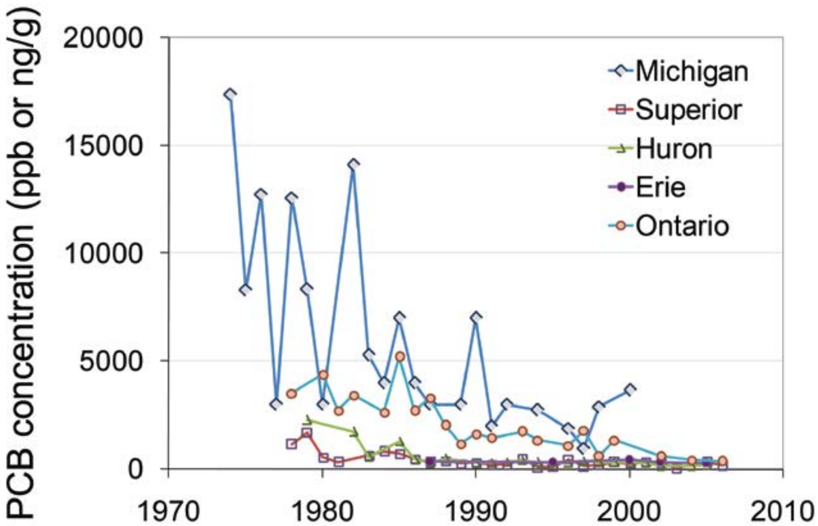

Figure 3. Long-term trends of total-PCB in Great Lakes lake trout.
Source: Data were adopted for skin-on lake trout fillets samples from Lake Michigan from Stow et al. 2004 and for skin-off lake trout fillet samples from the other lakes from Bhavsar et al. 2007.

Forest Cover

Overall Assessment
Component 1: Percent of forested lands within a watershed
Status: Fair
Trend: Improving
Rationale: Forested lands are a large percentage of land area within the Lake Superior basin (85%), a moderate amount in the Lake Michigan, Huron and Ontario basins (49% - 61%) and low in the Lake Erie basin (20%) based on satellite imagery. Trends in forest cover, based on forest inventory data or remote sensing, suggest that forest cover is only changing slowly in all basins. However, it is important to note that the forest cover trends being seen in the Great Lakes basin are quite small. Changes in forest types, composition and localized decreases in forest cover remain a concern.

Component 2: Percent of forested lands within riparian zones
Status: Fair
Trend: Undetermined
Rationale: Similar to total forest cover, forested cover types in the riparian zone of water bodies is high in the Lake Superior basin, moderate in the Lake Michigan, Huron and Ontario basins and low in the Lake Erie basins. Adequate, consistent long-term data is not available to assess trends.

Lake-by-Lake Assessment
Lake Superior
Component 1: Percent of forested lands within a watershed
Status: Good
Trend: Improving
Rationale: The Lake Superior basin has a high forest cover (85%) and low rates of agriculture and development (3.2%). These data suggest that there is unlikely to be long-term impairment of water quality.

Component 2: Percent of forested lands within riparian zones
Status: Good
Trend: Undetermined
Rationale: With 96% of the riparian zones of water bodies in the Lake Superior basin having forest cover, these waters are likely to be well protected. Insufficient data is available to assess trends.

Lake Michigan
Component 1: Percent of forested lands within a watershed
Status: Fair
Trend: Improving
Rationale: There is considerable variation in the watersheds draining into Lake Michigan, Generally there is high forest cover in the northern watersheds, while southern watersheds have low forest cover.

Component 2: Percent of forested lands within riparian zones
Status: Fair
Trend: Undetermined
Rationale: Northerly watersheds have high forest cover in riparian zones, while southern watersheds have significant agricultural activity in riparian zones that may decrease water quality and ecosystem integrity. Insufficient data is available to assess trends.

Lake Huron

Component 1: Percent of forested lands within a watershed

Status: Good

Trend: Improving

Rationale: Most northerly watersheds have a high level of forest cover with the watersheds, while more southerly ones have low forest cover. There is some potential in southerly watersheds to have impairments in water quality and ecosystem integrity.

Component 2: Percent of forested lands within riparian zones

Status: Fair

Trend: Undetermined

Rationale: Watersheds in the southern portion of the basin have moderate levels of agriculture and forests in the riparian zones which could lead to impairments in water quality and ecosystem integrity.

Lake Erie

Component 1: Percent of forested lands within a watershed

Status: Poor

Trend: Deteriorating

Rationale: Lake Erie has the lowest coverage by forests in the lake basin and the highest percentage of agricultural and developed lands. There is a large potential for water quality problems and risks to ecological integrity.

Component 2: Percent of forested lands within riparian zones

Status: Poor

Trend: Undetermined

Rationale: A high level of agricultural activities and a low proportion of forest cover in riparian zones suggests heightened threat to water quality and ecosystem integrity

Lake Ontario

Component 1: Percent of forested lands within a watershed

Status: Fair

Trend: Deteriorating

Rationale: Most watersheds in the Lake Ontario basin have low forest covers and significant proportions of the land area in agricultural activities with the associated risks to water quality.

Component 2: Percent of forested lands within riparian zones

Status: Fair

Trend: Undetermined

Rationale: Moderate levels of forest and agricultural covers in riparian zones in the Lake Ontario basin suggest there is moderate risk to water quality and ecosystem integrity.

Purpose

- This indicator describes the forest cover that is required to perform the hydrologic functions and host the organisms and essential processes that are necessary for supplying high quality water and protecting the physical integrity of the watershed.
- The Forest Cover indicator is used in the Great Lakes indicator suite as a State indicator in the Landscape and Natural Processes top level reporting category.

Ecosystem Objective

To have a forest composition and structure that most efficiently conserves the natural ecological diversity of the region.

Ecological Condition

This indicator includes two components:

- Percent of forested lands within watershed by lake basin, over time.
- Percent of forested lands within riparian zones by watershed, over time.

Component 1 summarizes the percent of forested lands by watershed within each lake basin. Decades of research and monitoring have shown that water draining forested watersheds is of high quality, as measured by sediment yields, nutrient loadings, contaminant concentrations and temperatures. Forest cover also contributes to many other ecosystem services, including controlling soil erosion, increasing groundwater infiltration, stabilizing shorelines and mitigating storm run-off. Leaf litter and woody debris provide critical food and habitat for fish and other aquatic wildlife.

In general, an increase in forest cover improves water quality. Ernst (2004) in a small survey of municipal water systems, showed that water treatment costs can be directly related to the degree of forest cover in the source watershed. The function she developed suggests that treatment costs are lowest at levels of forest cover above ~60%. Other studies have been less successful in discovering empirical relationships between forest cover and the economics of municipal water supplies. For the purposes of this report, and subject to further discussion, we have used the following end-points in assessing the status and trends of Great Lakes watersheds: Good = >60% forest cover by lake basin; Fair = 30 – 60% forest cover by lake basin: and Poor = <30% forest cover by lake basin.

Figure 1 shows the tertiary watersheds draining into the Great Lakes and their level of forest cover. There is a strong N-S gradient evident in the degree of forest cover as would be expected given a similar gradient in population and agricultural activity. In the Lake Superior basin, 85% of the land area is forested (Table 1), with only minor amounts of development and agriculture. In all the other basins, forests have been replaced by development and agriculture, comprising 29% in the Lake Huron basin, ~45% in the Lake Michigan and Ontario basin and 78% in the Lake Erie basin (Table 1). However, it must be noted that within any given basin, there are watersheds with adequate to good forest cover.

Assessing trends in the forest cover indicator has proven difficult. Whereas the status of forest cover can be readily assessed through analysis of carefully checked and referenced satellite data, these data are usually available for single points in time. For this report, we have employed data for the US portions of the lake basins from forest inventory programs that can provide a time series up to 30 years and for the Canadian portions of the basins from satellite imagery for 2009 and 2011. Table 3 shows that in the US portion of all lake basins, there is a trend towards increasing forest cover, whereas there are mostly weak trends towards decreasing forest cover in the Canadian portion of the basins.

Component 2 summarizes the area of riparian zones (30 metre buffer around all surface waters) that is forested within each lake basin. Where watersheds have experience large land-use changes due to agricultural activities or urban and suburban development, increased forest coverage within a riparian zone can mitigate many of the potentially harmful impacts on water bodies. Forested riparian zones can decrease the amount of surface runoff to water bodies (reducing erosion), mitigate nutrient loadings from fertilizer application and other non-point source pollutants and increases the capacity of the ecosystem to store water. Riparian zones can also important sources of energy and material to aquatic systems and help regulate water temperatures.

The end-points for this component have been defined as: Good = >80% forest cover in riparian zones; Fair = 50 – 80% forest cover in riparian zones; and Poor = <50% forest cover in riparian zones.

This component was assessed by creating a 30 m buffer around all waterbodies in the National Hydrology Dataset (US) and using it as a mask on the NLDC or Landcover 2008 data layers. On a lake basin level, the proportion of forest cover in riparian zones parallels that of the forest cover in the watersheds (Table 2). The Lake Superior basin has 96% of its riparian zones identified as forested, while only 31% of riparian zones in the Lake Erie basin are forested, with Lakes Michigan, Huron and Ontario being intermediate. Also similar to the forest cover component, agriculture and development are the competing land uses. There is also substantial variation at the tertiary watershed level with each of the lake basins (Figure 2). The northern watersheds have much higher rates of forested riparian zones than watersheds in the south, where there is much greater development and agriculture.

Trend analysis is not presently possible for this component. What is required is a time series of properly classified satellite imagery over a long enough time period (>20 years) in order to identify trends with any degree of reliability.

Linkages
The well-documented ability of forested lands to produce high quality water and for forested riparian areas to protect water resources has linkages to many other indicators. In particular, forest cover and forested riparian areas contribute directly to reducing nutrient, and other non-point source pollutant, loadings to the tributaries and lakes and ameliorate the effects of atmospheric deposition. Indirectly, the high quality water emanating for forested areas supports diverse aquatic communities. Climate change, through its effects on forest composition and function and on local hydrological processes is likely to affect the ability of forests to produce high quality water, although the magnitude and direction of these affects are not well known. For example, the decline to total annual runoff in many Great Lakes basins may lead to increased concentrations of nutrients and contaminants in tributary waters. Also, changes in forest composition, due human activities (eg. forest management) or natural agents (eg. emerald ash borer), may affect water quality and/or quantity.

Management Challenges/Opportunities
The increasing recognition of the benefits of forest cover in general and forested riparian areas in particular is leading to changes in regional planning that preserve forest cover. The increasing adoption of forest management certification standards (eg. Forest Stewardship Council) is increasing the deployment of best practices to protect water resources in managed forests. However, there remain many opportunities for improvement. The application of Integrated Watershed Management is not widely practiced and governance structures to support IWM are only slowly developing.

Comments from the author(s)
Estimating forest cover by remote sensing is widely used and generally reliable. However, many of the available datasets do not contain the long time series needed to adequately assess trends. Regular assembly of cross-border data sets are needed to measure changes in forest cover and to understand the drivers of change. Forest inventory data (eg. USFS FIADB) is also useful but Canada lacks an equivalent system. There also remains the challenge of integrating both forest inventory systems and remote sensing data across jurisdictions due to differences in goals and methodologies.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				X		
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				

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List of Tables

Table 1. Percentage of land cover types by lake basin. Cover types were identified from Landsat satellite imagery for 2006 (US) and 2008 (Ontario), forest includes areas classisfied forest and treed wetlands.
Sources: National Land Classification Database (US) and Landcover 2008 (MNR, Forest Evaluations and Standards Sections)
Table 2. Percent of forest cover in riparian zones. Data based of summing cover types in a 30 m buffer around all water bodies.
Sources: National Land Classification Database (US) and Landcover 2008 (MNR, Forest Evaluations and Standards Sections)
Table 3. Change in forest cover within Great Lake Basins.
Notes: For US estimates of Superior Huron and Michigan the change was based of 2005 and 2009 data and for Erie and Huron 2005 and 2010 data
Sources: US basins based on analysis of USFS FIA plots and for Canada a comparison of 2009 and 2011 satellite images.

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Figure 1. Percent forest cover in tertiary watersheds (HUC8 in US and 4 digit in Ontario) of the Great Lakes. Forest cover was estimated from satellite imagery and includes a variety of forest types (i.e. deciduous, conifer, mixed) and treed wetlands.
Source: U.S. National Land Cover Database NLCD 2006 and Ontario Landcover 2008
Sources: US NLCD 2006 and Ontario Landcover 2008)
Figure 2. Percentage of riparian zones with tertiary watersheds identified as forested.
Source: U.S. National Land Cover Database 2006 and Ontario Landcover 2008

Last Updated

State of the Great Lakes 2011

Percentage of land cover types by lake basin

	Superior	Michigan	Huron	Erie	Ontario
Forest	85.0	49.1	61.0	19.6	49.1
Agriculture	1.7	35.1	24.6	61.0	35.5
Developed	1.5	10.3	4.4	17.3	8.3
Water	10.4	3.0	7.4	1.0	4.6
Wetland	1.0	2.3	0.9	0.8	1.9

Table 1. Percentage of land cover types by lake basin. Cover types were identified from Landsat satellite imagery for 2006 (US) and 2008 (Ontario), forest includes areas classified forest and treed wetlands.
Source: National Land Classification Database (US) and Landcover 2008 (MNR, Forest Evaluations and Standards Sections)

Percent of forest cover in riparian zones

	Superior	Michigan	Huron	Erie	Ontario
Forest	96.0	63.4	72.7	30.9	63.0
Agriculture	0.8	23.4	19.9	54.5	25.6
Urban	0.9	7.7	3.0	11.7	5.7
Wetland	1.6	5.0	2.0	2.7	5.1

Table 2. Percent of forest cover in riparian zones. Data based on summing cover types in a 30 m buffer around all water bodies.
Source: National Land Classification Database (US) and Landcover 2008 (MNR, Forest Evaluations and Standards Sections)

Percent change in forest cover within Great Lake Basins

Basin	USA	Canada
Superior	0.43	-0.01
Michigan	1.26	
Huron	0.47	-0.3
Erie	0.92	-3.52
Ontario	0.39	-1.96

Table 3. Percent change in forest cover within Great Lake Basins.
Notes: For US estimates of Superior Huron and Michigan the change was based of 2005 and 2009 data and for Erie and Huron 2005 and 2010 data
Source: US basins based on analysis of USFS FIA plots and for Canada a comparison of 2009 and 2011 satellite images.

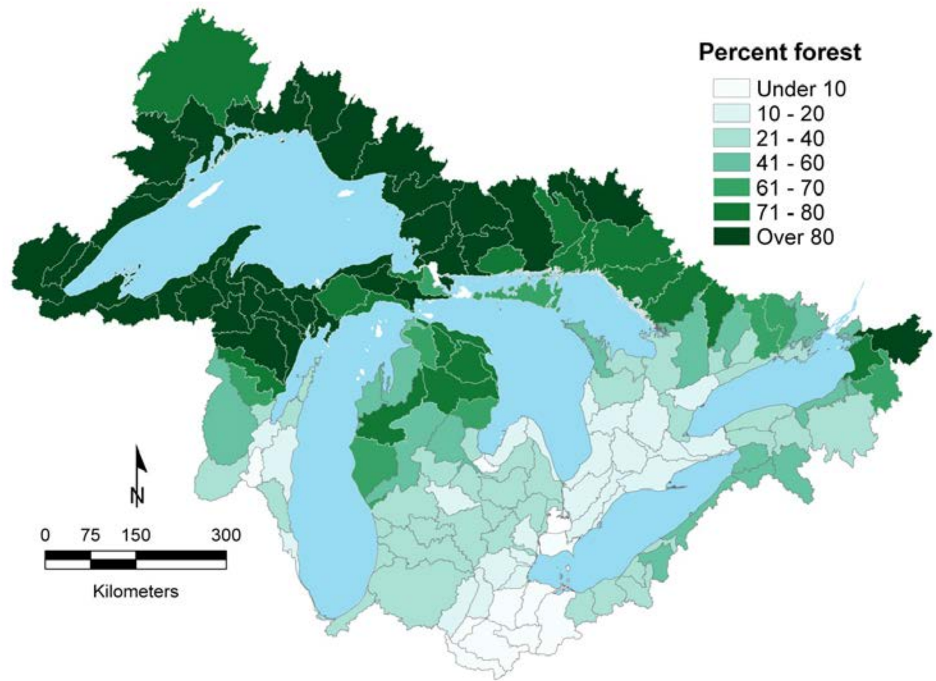

Figure 1. Percent forest cover in tertiary watersheds (HUC8 in US and 4 digit in Ontario) of the Great Lakes. Forest cover was estimated from satellite imagery and includes a variety of forest types (i.e. deciduous, conifer, mixed) and treed wetlands.
Source: U.S. National Land Cover Database 2006 and Ontario Landcover 2008

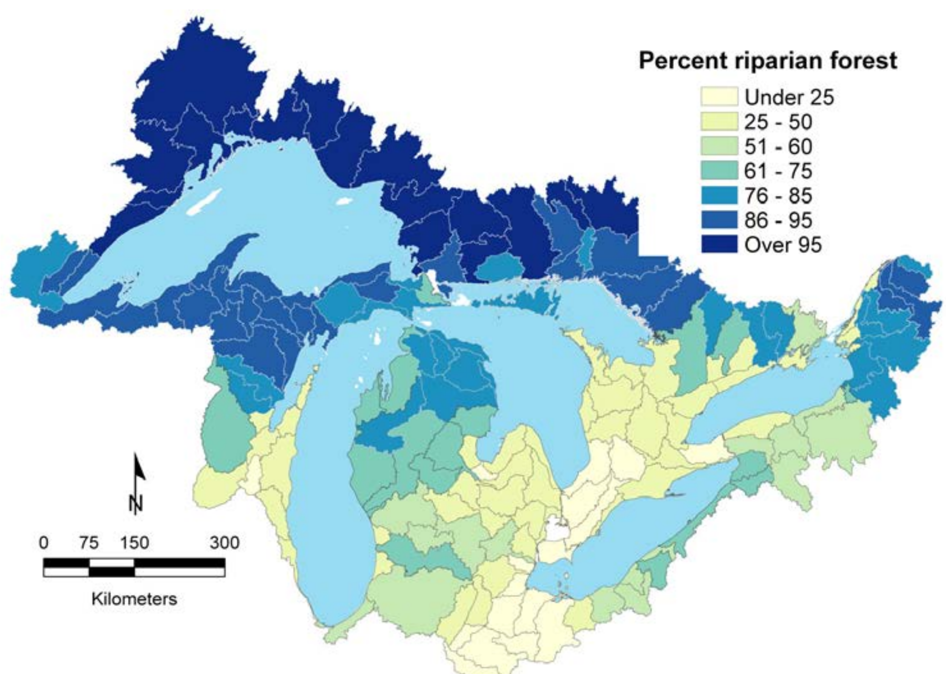

Figure 2. Percentage of riparian zones with tertiary watersheds identified as forested.
Source: U.S. National Land Cover Database 2006 and Ontario Landcover 2008

Greenhouse Gas Emissions

Overall Assessment
Trend: Undetermined
Rationale: Between 1990 and 2008, the long-term trend of greenhouse gas emissions in the Great Lakes region was increasing. In 2009, however, the region experienced its largest annual drop in emissions, resulting in the region's lowest greenhouse gas emission in nineteen years.

Lake-by-Lake Assessment
Trends were not made on an individual lake basis.

Purpose
- To provide greenhouse gas emissions trends in the Great Lakes region
- The greenhouse gas emissions indicator is used in the Great Lake indicator suite as a driving force indicator in the Economic/Social category

Ecosystem Objective
A reduction in greenhouse gas emissions will contribute to achieving and maintaining environmental benefits, such as beneficial uses of the Great Lakes, as outlined in Annex 2 of the Great Lakes Water Quality Agreement.

Ecological Condition
The greenhouse gas emissions presented are reflective of the emissions for the Great Lake region as defined in this report (the whole Ontario as well as the whole of the eight Great Lakes States). Greenhouse gas emissions estimates are extracted from Environment Canada (National Inventory Report) and the United States Environmental Protection Agency. In this report, the unit of analysis is million metric ton of carbon dioxide (CO_2). The data only considers emissions from carbon dioxide (CO_2) within the energy sector and the burning of fossil fuels, and not CO_2 emissions from other sources or from other greenhouse gases such as methane and nitrous oxide. While these sources are important and significant in calculating the total greenhouse gas emissions, they are not included in this report due to a lack of consistent data availability in the United States. Nonetheless, the measure in this report accurately illustrates the trends of greenhouse gas emissions in the Great Lakes region.

A) Great Lakes Region as a whole (Ontario and Eight Great Lakes States)
The total greenhouse gas emissions for the entire Great Lakes region (Ontario and the eight States) have fluctuated over the nineteen-year period (Table 1 and Figure 1). The long-term trend of the region is undetermined after the significant drop in greenhouse gas emission in 2009. Currently, when comparing the emission data from 1990 to 2009, the overall region has decreased by 1.7%. Despite the overall decrease in emission from 1990 to 2009, the region's long-term emissions trend has always been increasing. In fact, when comparing the 1990 emissions with 2008, the region increased by 6.8%. It was not until 2009 where emissions experienced the biggest decline of 8.3%, likely in response to difficult overall economic conditions. In examining the short-term trend, the region experienced fluctuation. More specifically, as seen in Figure 2, greenhouse gas emissions decreased by 4.0% from 2005 to 2006. While the region experienced a growth of 2.2% in its subsequent year, greenhouse gas emissions rate decreased again by 2.8% in 2008. In 2009, the region continued to decrease and had the biggest decline of 8.3%, resulting in the region's lowest greenhouse gas emission in nineteen years. Given the continuous fluctuation in the region, the short-term trend is undetermined.

B) Comparison between Ontario and Eight Great Lakes States
In Ontario, the total emission in 2009 was approximately 124.5 $MMTCO_2$ (Table 1). Since 1990, Ontario's emission has decreased by 0.6% with a yearly fluctuation rate range from a decline of 12.5% to a growth of 6.5%

(Table 1 & Figure 4). In a national context, Ontario's greenhouse gas emission in 2009 represents 25.3% of the total emissions in Canada, a decrease of 5.0% from Ontario's 1990 national share (Environment Canada: Canada National Inventory Report) (Table 2). In the United States, the total emissions in the eight Great Lakes States in 2009 were 1441.7 MMTCO2 (Table 1). This has increased by 1.8 % since 1990. The annual fluctuation rate over the years has ranged from a decline of 8.0% to a decline of 3.7% (Figure 3 and Figure 4). In a national context, the eight great lakes states represent 26.2% of the total emissions in the United States in 2009, a decrease of 2.6% from the region's 1990 national share (U.S. Environmental Protection Agency) (Table 3).

To obtain a greater understanding of greenhouse gas emissions within the region, the population data in 2009 have been included to examine the average greenhouse gas emissions per person. As gathered from the U.S. Census and Statistics Canada, the total population in 2009 within the Great Lakes region was 96,978,002 and total greenhouse gas emissions were 1566.1 MMTCO2(Table 4). That year, emissions usage per capita was 16.2 MMTCO2 (Table 4). From 1990 to 2009, the Great Lakes region has experienced a 2.3% decrease in its overall greenhouse gas emissions per capita (Table 4 and 5).

Linkages

Emissions of greenhouse gases from human activities are causing climate change on a global scale. Most greenhouse gas emissions are caused by the burning of fossil fuels for energy and by industrial processes such as petroleum refining and cement manufacturing (Boyd 2001). While the dominant greenhouse gas is carbon dioxide (CO2), other principal greenhouse gases that enter the atmosphere and are derived from human activities include methane released from landfills and agriculture, nitrous oxide from fertilizers, and fluorinated gases from industrial processes (EPA 2011.

Climate change is a major threat to the ecosystem with both direct and indirect effects on biological systems. Direct effects include increased temperature and increased CO2 levels associated with global climate change (Clark and Sullivan 2007). These direct effects cause other indirect effects, such as changes to hydrologic cycles (precipitation and evaporation), changes in precipitation patterns, floods, and water shortages (Clark and Sullivan 2007).

Other examples include lower water levels and an impact on the areal extent and diversity of shoreline wetlands (Alden and Mortsch 2004). Fluctuations in water levels within wetlands will likely cause changes in nutrient levels and may also enable the release of toxic metals such as mercury (Clark and Sullivan 2007).

The Great Lakes region has already started experiencing this warming effect and as additional warming occurs, a range of ecological changes and effects on wildlife are expected, with the most significant effects on aquatic and other species dependent on water bodies for breeding and feeding (Clark and Sullivan 2007). Changes in water temperature, water levels and flows, precipitation, air temperature, timing and duration of ice break up and disturbance hazards have all placed additional stress in the basin (Alden and Mortsch 2004). Higher air temperatures change the distribution and health of aquatic and terrestrial plants and animal species (Alden and Mortsch 2004). The geographic distribution of numerous fish species is likely to be altered. Under a climatic warming, both northern and southern boundaries of species' ranges in the Great Lakes region will shift northward. As a result, the fish communities of the Great Lakes will be altered due to invasion of warm water species and local extirpation of cool water and coldwater species (Mandrak 1989). The rise in water temperature will also enhance the growth of undesirable species (such as algal blooms). In many lakes, including Lake Michigan, changes in speciation are likely as water temperatures increase and water levels decline. Cold-water species such as salmonids (e.g. coho salmon and lake trout) will be under increased stress. Temperature increases also lowers oxygen levels in the summer, creating "dead zones" which cannot support life and if dead zones persist, they can give rise to toxic algal blooms, damaging fisheries and create risks to human health (Clark and Sullivan 2007).

Management Challenges/Opportunities

There are many linkages between greenhouse gas emissions and stresses to ecosystem health. Great lakes community and decision makers should continue to support global, national, regional and local efforts to reduce greenhouse gas emissions.

Comments from the author(s)

In Canada, the Canadian National Inventory Report uses CO2 equivalent (CO2eq) as its official metric measure to examine greenhouse gases. The CO2eq value is calculated by multiplying the amount of the gas by its associated global warming potential. CO2eq is a more accurate way of displaying and understanding the emissions from various greenhouse gases and from various sectors. For more information on the official Canadian GHG data, table 6 outlines the CO2 emissions used in this report and the official GHG data (CO2eq) extracted from the National Inventory Report and utilized by the Canadian Environmental Sustainability Indicators.

In comparison to the Great Lakes region, the total greenhouse gas emissions for the Great Lakes watershed would be less. Nonetheless, this data serves the indicator report's purpose well by illustrating a trend that is a driving force behind many of the pressures on Great Lakes conditions. The investment required to break-down greenhouse gas emission trends specifically for the Great Lakes watershed boundary and/or on a lake-by-lake level would only be worthwhile if formal emission reduction targets are set for that defined geographic boundary.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Acknowledgments

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Table 2. Ontario's Percent of National Greenhouse Gas Emissions – 1990 and 2009
Source: Environment Canada. 2011. *National Inventory Report*

Table 3. Great Lakes State's percent of national greenhouse gas emissions (energy sector) - 1990 and 2009
Source: United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.*

Table 4. 1990 Per Capita Greenhouse Gas Emissions (energy sector)
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.* Environment Canada and United States Environmental Protection Agency, *State of the Great Lakes 2011, Human Population*

Table 5. 2009 Per Capita Greenhouse Gas Emissions (energy sector)
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009*, and Environment Canada and United States Environmental Protection Agency, *State of the Great Lakes 2011, Human Population*.

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Figure 2. Short-term Trend: Total Greenhouse Gas Emissions in the Great Lakes Region's Energy Sector, 2005-2009.
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Figure 3. Comparison of Greenhouse Gas Emissions in the Energy Sector in the Great Lakes States and Ontario, 1990-2009.
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.*

Figure 4. Total Greenhouse Gas Emissions from 1990-2007 (Energy Sector in Ontario and 8 U.S. Great Lakes States).
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency (EPA). 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.*

Last Updated
State of the Great Lakes 2011

Annual Greenhouse Gas Emissions

Year	Ontario's Total Emissions (MMTCO2)	U.S. Great Lakes States Total Emissions (MMTCO2)	Entire Great Lakes Region Total Emissions (MMTCO2)
1990	125.2	1467.6	1592.8
1991	123.8	1450.1	1573.9
1992	127.2	1456.1	1583.2
1993	119.9	1485.8	1605.7
1994	120.2	1489.6	1609.8
1995	123.4	1516.4	1639.8
1996	130.3	1573.9	1704.3
1997	137.1	1588.7	1725.9
1998	140.1	1550.6	1690.8
1999	147.3	1577.9	1725.2
2000	157.6	1624.3	1781.8
2001	151.7	1563.9	1715.6
2002	156.0	1579.8	1735.8
2003	160.1	1604.8	1764.9
2004	151.1	1622.9	1774.0
2005	153.6	1638.3	1791.8
2006	144.9	1574.8	1719.6
2007	152.0	1605.8	1757.8
2008	142.2	1566.3	1708.4
2009	124.5	1441.7	1566.1

Table 1. Annual Greenhouse Gas Emissions in the Great Lakes Region's Energy Sector, 1990-2009
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.*

Ontario's percent of National greenhouse gas emissions

State/Province	Ontario's Greenhouse Gas Emissions (MMTCO2)	Total Greenhouse Gas Emissions in Canada (MMTCO2)	Greenhouse Gas Emissions in National Context
Ontario (1990)	125.2	412.5	30.3%
Ontario (2009)	124.5	490.1	25.3%

Table 2. Ontario's percent of National greenhouse gas emissions – 1990 and 2009
Source: Environment Canada. 2011. *National Inventory Report*

Great Lakes States' percent of National greenhouse gas emissions

State/Province	Eight Great Lakes States Greenhouse Gas Emissions (MMTCO2)	Total Greenhouse Gas Emissions in US (MMTCO2)	Greenhouse Gas Emissions in National Context
Eight Great Lakes States (1990)	1467.6	5099.7	28.8%
Eight Great Lakes States (2009)	1441.7	5505.2	26.2%

Table 3. Great Lakes States' percent of National greenhouse gas emissions (energy sector) - 1990 and 2009
Source: United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.*

1990 Per Capita Greenhouse Gas Emissions

State/Province	Total Greenhouse Gas Emissions in the Great Lakes Region (1990) – MMTCO2	Population within the Great Lakes Region (1990)	Per Capita 1990
Ontario	125.2	10,085,000	12.4
Illinois	194.9	11,430,602	17.1
Indiana	205.3	5,544,159	37.0
Michigan	180.4	9,295,297	19.4
Minnesota	79.6	4,357,099	18.3
New York	208.8	17,990,455	11.6
Ohio	246.8	10,847,115	22.8
Pennsylvania	265.5	11,881,643	22.4
Wisconsin	86.2	4,891,769	17.6
Total:	1592.8	86,323,139	18.5

Table 4. 1990 Per Capita Greenhouse Gas Emissions (energy sector)
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.* Environment Canada and United States Environmental Protection Agency, *State of the Great Lakes 2011, Human Population*

2009 Per Capita Greenhouse Gas Emissions

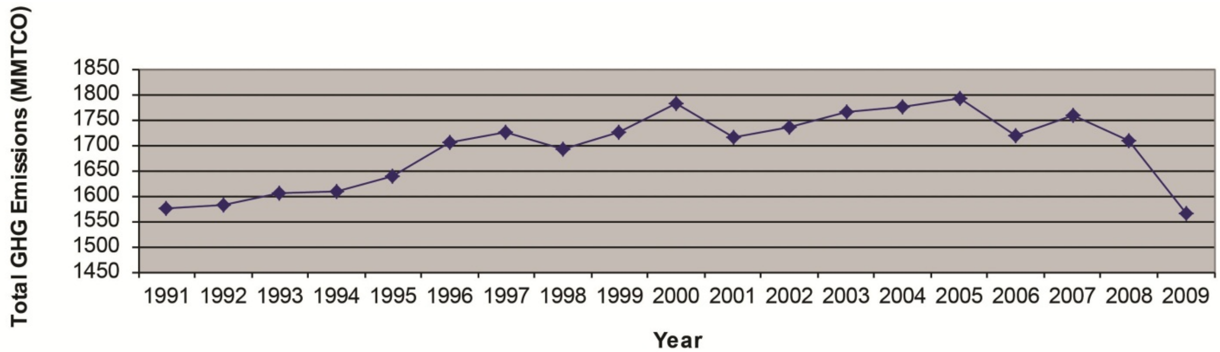
State/Province	Total Greenhouse Gas Emissions in the Great Lakes Region (2009) MMTCO	Population within the Great Lakes (2009)	Per Capita 2009
Ontario	124.5	13,064,900	9.5
Illinois	226.4	12,910,409	17.5
Indiana	205.5	6,423,113	32.0
Michigan	164.2	9,969,727	16.5
Minnesota	92.2	5,266,214	17.5
New York	176.9	19,541,453	9.1
Ohio	236.8	11,542,645	20.5
Pennsylvania	243.4	12,604,767	19.3
Wisconsin	96.3	5,654,774	17.0
Total:	1566.1	96,978,002	16.2

Table 5. 2009 Per Capita Greenhouse Gas Emissions (energy sector)
Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency. 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009,* and Environment Canada and United States Environmental Protection Agency, *State of the Great Lakes 2011, Human Population*.

Ontario's CO2 emissions compared to GHG

Year	CO2 Emissions in Ontario (MMTCO2)	Official GHG Emissions in Ontario (MMTCO2eq)
1990	125.2	176.5
1991	123.8	176.2
1992	127.2	180.1
1993	119.9	170.7
1994	120.2	172.6
1995	123.4	177.3
1996	130.3	184.7
1997	137.1	190.3
1998	140.1	189.6
1999	147.3	194.4
2000	157.6	204.2
2001	151.7	196.7
2002	156.0	202.9
2003	160.1	206.8
2004	151.1	200.8
2005	153.6	202.1
2006	144.9	193.7
2007	152.0	199.6
2008	142.2	189.6
2009	124.5	165.1

Table 6. Ontario's CO2 emissions compared to GHG emissions from 1990 to 2009
Source: Environment Canada. 2011. *National Inventory Report*



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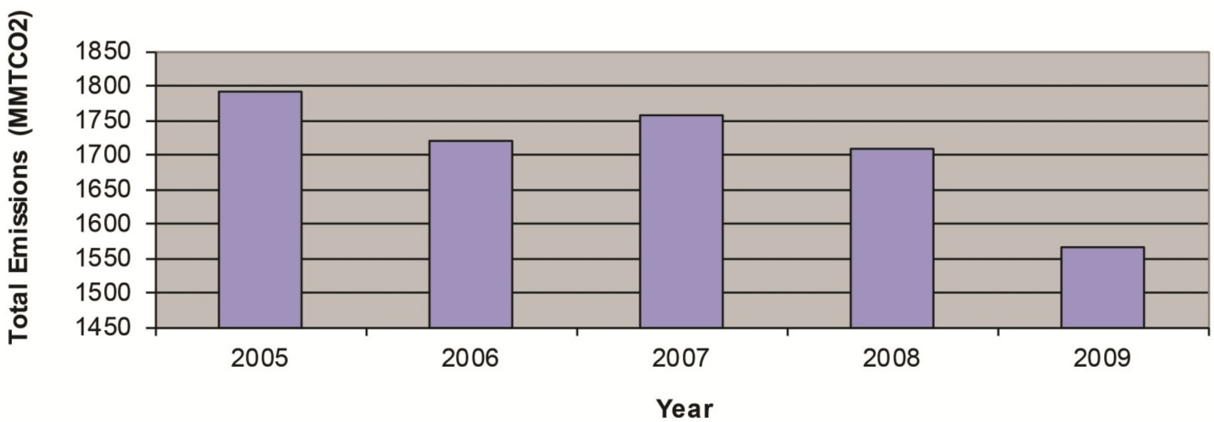

Figure 2. Short-term Trend: Total Greenhouse Gas Emissions in the Great Lakes Region's Energy Sector, 2005-2009.
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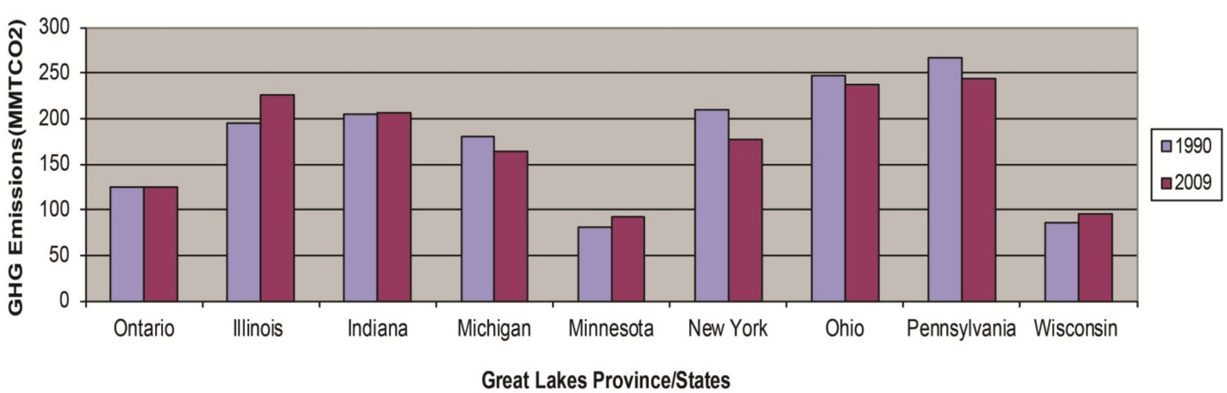

Figure 3. Comparison of Greenhouse Gas Emissions in the Energy Sector in the Great Lakes States and Ontario in 1990 and 2009.
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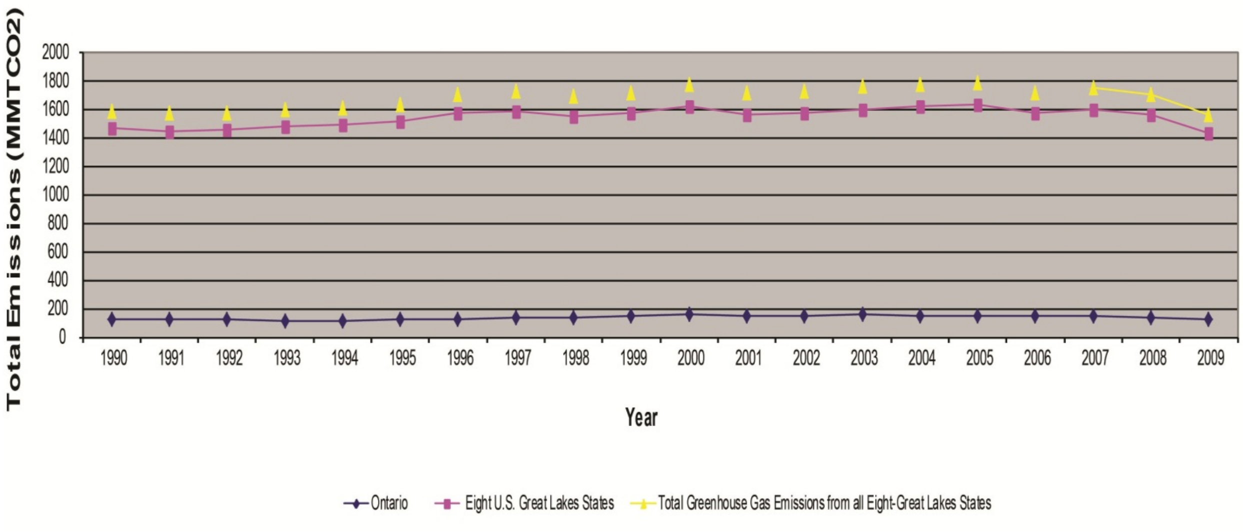

Figure 4. Total Greenhouse Gas Emissions from 1990-2009 (Energy Sector in Ontario and 8 U.S. Great Lakes States).

Source: Environment Canada. 2011. *National Inventory Report*, and United States Environmental Protection Agency (EPA). 2011. *State CO2 Emissions from Fossil Fuel Combustion 1990-2009.*

Hardened Shorelines

Overall Assessment
Status: Undetermined
Trend: Undetermined
Rationale: An overall assessment is not possible as information allowing a direct comparison to previous hardened shoreline indicator status is only available for the Lake Ontario shoreline.

Lake-by-Lake Assessment

Lake Superior
Status: Undetermined
Trend: Undetermined
Rationale: Available information does not allow a direct comparison to previous hardened shoreline indicator status.

Lake Michigan
Status: Undetermined
Trend: Undetermined
Rationale: Available information does not allow a direct comparison to previous hardened shoreline indicator status.

Lake Huron
Status: Undetermined
Trend: Undetermined
Rationale: Available information does not allow a direct comparison to previous hardened shoreline indicator status.

Lake Erie
Status: Undetermined
Trend: Undetermined
Rationale: Available information does not allow a direct comparison to previous hardened shoreline indicator status.

Lake Ontario
Status: Poor
Trend: Deteriorating
Rationale: Updated (2001-2002) shoreline classification datasets for Lake Ontario indicate that approximately 63.0% of the shoreline has less than 40% hardening which is below the poor threshold of 70%. While the percent of shoreline in the "no protection" category was comparable to the previous SOLEC update (NOAA, 1997), reductions in the "minor protection" category were offset by increases in the "moderate protection" and "major protection" categories suggesting a potential trend towards increased overall shoreline hardening in some areas. There is uncertainty in the trend analysis due to variations in input datasets as discussed further below.

Purpose

- To assess the amount of shoreline altered by the construction of shore protections, such as sheet piling, rip rap and other erosion control shore protection structures.
- To infer the potential harm to aquatic-dependent life, water quality and natural processes from conditions created by shore protections.

- The Hardened Shoreline indicator is used in the Great Lakes indicator suite as a Pressure indicator in the Resource Use and Physical Stressors top level reporting category.

Ecosystem Objective
Impacts from hardened shorelines should not impair the physical, biological or chemical integrity of the Great Lakes as reflected in Annex 2 of the Great Lakes Water Quality Agreement – restoration and protection of beneficial uses.

Ecological Condition
Measure
The amount (kilometres/miles) of shoreline that has been hardened through construction of sheet piling, rip rap and other erosion control shore protection structures. Shoreline reaches are categorized using descriptions from the baseline shoreline classification dataset and include highly protected (70-100%), moderately protected (40-70%), minor protection (15-40%), no protection (< 15%), non-structural protection, and unclassified.

Note: measure does not include artificial coastal structures that are extend out into the waters, such as jetties, groynes, breakwalls, piers, etc.

Endpoint
The reference values for basinwide and lakewide scales are as follows.
Good = >80% of the shoreline has minor to no protection (i.e. 0-40% hardened shoreline measure categories).
Fair = 70-80% of the shoreline has minor to no protection (i.e. 0-40% hardened shoreline measure categories).
Poor = < 70% of the shoreline has minor to no protection (i.e. 0-40% hardened shoreline measure categories).

Trend determination will be based on no net increase in the percent of shoreline in the highly protected and moderately protected categories. The defined endpoint is intended to support an assessment of relative change over time and represents an initial suggestion for establishing preferred conditions. However, further discussion and refinement of the endpoint categories is required to reflect improved understanding of shoreline hardening and ecosystem impacts. The Status Justification section below outlines some of the challenges with attempting to define reference conditions for hardened shorelines.

Status Justification
There is limited documentation on specific shoreline hardening objectives, particularly at the basinwide and lakewide scales. The proposed end-point values for a hardened shoreline status assessment provide a descriptive point of reference using the baseline SOLEC estimates of the extent and intensity of shoreline hardening. Various environmental services can be impacted by shoreline hardening including changes or reductions in aquatic habitat, alterations in sediment transport, and changes in nearshore groundwater-lake interactions (see Province of Ontario, 2001). There are a variety of challenges in defining appropriate end-point values regarding shoreline hardening. In particular, a refined end-point assessment should reflect the differing quality and quantity of environmental services being provided (or not provided) by differing shoreline locations (e.g. pollution filtration, fish habitat, etc.) and weight the necessity and amount of the shoreline services required to achieve established ecosystem goals relative to the extent and impact of various shoreline hardening activities. However, the ecological services provided by natural shorelines and the impacts of hardened shorelines are difficult to measure as they often relate to many complex, long-term, and interdependent ecological processes (such as pollution filtration and sediment transport), in addition to more immediate and observable effects such as habitat and habitat loss. There are also variations in the extent to which certain types of shoreline hardening activities actually impact various ecological services based on the age, quality, and design characteristics of the shoreline structures. The current end-point categories only provide a general estimate of the extent and intensity of shoreline hardening and do not reflect an assessment of the relative sensitivity to shoreline hardening on each lake. The selected endpoints account for the fact that some shoreline

hardening already exists on the Great Lakes and is likely to be maintained into the future. The trend assessment captures the relative change in the percent of shoreline with >40% hardening.

For the purpose of this report, an overall undetermined reference value has been selected for the basinwide assessment due to the lack of a standardized dataset on many of the lakes that can be directly compared to the baseline conditions established for the Great Lakes/SOLEC hardened shoreline indicator. Where updated datasets do exist, they tend to be limited in geographic scope (i.e. they do not cover a full lake basin) or there are issues in matching the existing hardened shoreline indicator categories. The baseline conditions, as represented in the 2009 Great Lakes/SOLEC hardened shoreline indicator report, are provided in Table 1 for reference.

Lake Ontario does have a full dataset that can be compared with the baseline conditions indentified in previous SOLEC reporting based on NOAA 1997 data. The updated dataset was developed in 2001 and 2002 to support the International Joint Commission's (IJC's) International Lake Ontario – St. Lawrence River Regulation Study. A similar methodology was utilized to classify the full U.S. and Canadian Lake Ontario shoreline based on the type and extent of shoreline hardening (see Stewart, 2002) with the results summarized in the Flood and Erosion Prediction System (FEPS) database (see Baird, 2005). The dataset was used to model water level impacts on shoreline structure lifespan and as a result, there are small gaps where direct comparisons to the baseline data set are difficult. In particular, there were some instances where the percent of very low quality shoreline structures was not identified as they were not included in the water level impact modeling. In the case of the SOLEC comparison, these areas were identified within the unclassified category, even though there was likely some shoreline hardening occurring. It should also be noted that the updated Lake Ontario classification dataset utilized a higher resolution shoreline delineation than was used in the baseline conditions unidentified in previous Great Lakes/SOLEC reporting. As a result, the classified shoreline extent is greater for the updated dataset. Finally, the updated dataset estimates the percent hardened shoreline using standard 1 km reaches along the full shoreline whereas the baseline dataset categorized reaches of variable (and generally greater) length.

Table 2 provides the length of shoreline in the baseline and updated (2001-2002) datasets along with the percent of shoreline within the various percent hardening categories for Lake Ontario. The percent of shoreline within the moderately (40 to 70% hardened) and major (>70% hardened) categories increased by 9.8 and 1.7 %, respectively while the percent of the shoreline within the minor (15 to 40% hardened) and no protection categories (<15% hardened) was reduced by 12.8%. The extent of shoreline in the minor and low protection categories is below the poor threshold established in the endpoint discussion and resulted in the poor status classification. The results suggest that there has been an increase in the amount of shoreline hardening since the baseline dataset was established in the late 1980s and a deteriorating trend was identified. However, since the overall length of categorized shoreline increased due to the refined shoreline delineation, there is uncertainty as to whether the identified change represents a true increase or a difference in dataset methodologies. Figure 1 provides maps of both the baseline Lake Ontario shoreline hardening categorization and the updated Lake Ontario data.

Linkages

Hardening shorelines can result in the loss of habitat, further erosion of unprotected properties adjacent to the structure, water quality degradation and the interruption of natural shoreline processes including reduced downdrift sediment transport.

Management Challenges/Opportunities

Shoreline hardening is generally implemented to stabilize shorelines and/or protect existing or planned infrastructure from erosion and flooding. Past high water conditions resulted in increased demand for shoreline hardening activities, although projects were often undertaken on a case-by-case basis without considering potential ecological consequences or impacts to adjacent property owners. The ecological impacts are not only difficult to quantify as a monetary equivalent, but difficult to perceive without an understanding of sediment transport along the lakeshores.

The importance of the ecological process of sediment transport needs to be better understood as an incentive to reduce new shoreline hardening. An educated public is critical to ensuring wise decisions about the stewardship of the Great Lakes basin ecosystem, and better platforms for getting understandable information to the public are needed.

Opportunities exist to identify particular shoreline functions that need to be maintained and where shoreline hardening is deemed necessary, to implement structures that are compatible with the ongoing ecosystem and sediment transport functions. There are also opportunities to modify existing shoreline hardening features to enhance identified ecosystem functions or even to remove certain shoreline hardening features altogether where other methods exist to reduce vulnerabilities (e.g. moving vulnerable infrastructure away from eroding shorelines).

Comments from the author(s)
There is uncertainty in undertaking direct comparison between the original hardened shorelines dataset previously reported and the more recent Lake Ontario dataset. In particular, the categorization is based on shoreline reaches which are defined differently in both datasets. The original dataset uses shoreline reaches of variable length whereas the more recent Lake Ontario data uses fixed 1 km shoreline reaches. It is possible that the large increase in highly hardened shorelines between the two datasets reflects a general reduction in reach length and not an overall increase in shoreline hardening. In addition, the overall shoreline lengths vary between the two datasets due to the base shoreline mapping used in the classifications. The recent Lake Ontario dataset uses a higher resolution shoreline delineation and includes certain features such as embayments that may not have been included in the original medium resolution shoreline delineation from the baseline hardened shoreline dataset. Since the indicator is based on a relative difference in the percent of shoreline within various categories, it is still possible to make some comparisons. However, it should be recognized that direct comparisons between data sets will be highly uncertain without using a common baseline shoreline delineation and comparable reach lengths. Finally, the baseline dataset is not clear on the transition between percent protected categories. For example, a shoreline reach that is 70% hardened could fall within either the 40% to 70% category or the 70% to 100% category. More explicit transitions were used for the categorization of the updated dataset.

There are opportunities for future updates to the hardened shorelines SOLEC indicator. Updated high resolution aerial imagery exists for much of the Great Lakes shoreline and oblique imagery has been recently collected or is planned to be collected for much of the U.S shoreline of the Great Lakes. With the information, it will be possible to use existing reach delineations and update the percent of shoreline hardening. Any efforts to update existing datasets should ensure that classification methodologies are similar to past efforts (e.g. as used for the updated Lake Ontario shoreline classification) and standardized reach delineations are utilized.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin			X			
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			

Clarifying Notes:

1. There is documentation prepared as part of the IJCs International Lake Ontario – St. Lawrence River Study (see Stewart, 2002). The classification itself was undertaken by private contractors with considerable experience in shoreline classification procedures. However, there is no formal validation methodology for undertaking this type of shoreline classification
2. The data can be traced to original sources
3. The classification itself was undertaken by private contractors with considerable experience in shoreline classification procedures
4. The geographic scale for the updated information only covers Lake Ontario and cannot be used for Great Lakes Basin wide assessments
5. The procedure for identifying hardened shorelines was applied consistently on both the Canadian and U.S. shorelines of Lake Ontario. However, the identification and interpretation of hardened shorelines was influenced by the imagery and input datasets which varied around the shoreline in terms of age and resolution (see Stewart, 2002). The specific age and quality of input imagery used for individual shoreline reaches are not identified.
6. The identification and interpretation of hardened shorelines was influenced by the imagery and input datasets which varied around the shoreline in terms of age and resolution. As mentioned previously, the variation in reach length and detail of shoreline delineation between the baseline dataset and the updated Lake Ontario data result in uncertainty in the overall status and trends analysis regarding hardened shorelines

Acknowledgments

Authors:
Mike Shantz, Environment Canada, Burlington, ON. (2011)

Information Sources

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Last Updated
State of the Great Lakes 2011

Baseline Great Lakes/SOLEC hardened shoreline classification

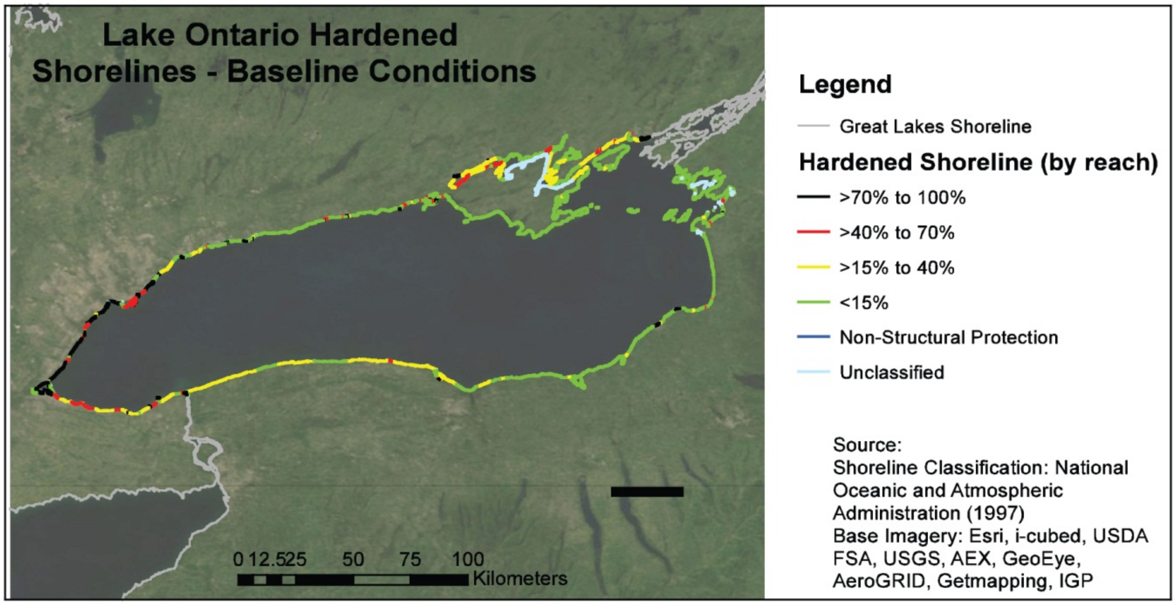
Lake/ Connecting Channel	Heavily Protected (%) (>70% protected)	Moderately Protected (%) (40-70% protected)	Minor Protection (%) (15-40% protected)	No Protection (%) (<15% protected)	Non-structural Protection (%)	Unclassified (%)	Total Shoreline (km)
Lake Superior	3.1	1.1	3	89.4	0.03	3.4	5080
St. Marys River	2.9	1.6	7.5	81.3	1.6	5.1	707
Lake Michigan	8.6	2.9	30.3	57.5	0.1	0.5	2713
Lake Huron	1.5	1.0	4.5	91.6	1.1	0.3	6366
St. Clair River	69.3	24.9	2.1	3.6	0.0	0.0	100
Lake St. Clair	11.3	25.8	11.8	50.7	0.2	0.1	629
Detroit River	47.2	22.6	8.0	22.2	0.0	0.0	244
Lake Erie	20.4	11.3	16.9	49.1	1.9	0.4	1608
Niagara River	44.3	8.8	16.7	29.3	0.0	0.9	184
Lake Ontario	10.2	6.3	18.6	57.2	0.0	6.2	1772
St. Lawrence River	12.6	9.3	17.2	54.7	0.0	6.2	2571

Table 1. Baseline Great Lakes/SOLEC hardened shoreline classification used for 2011 assessment based on information provided in 2009 SOLEC indicator report
Source: National Oceanic and Atmospheric Administration (1997)

Comparison of baseline Great Lakes/SOLEC hardened shoreline classification and updated classification

	Baseline SOLEC Classification	Updated Lake Ontario Classification
Length of Shoreline Categorized (km)	1772.0	2444.3
1. Heavily Protected (%)(>70% protected)	10.2	20.0
2. Moderately Protected (%)(40-70% protected)	6.3	8.0
3. Minor Protection (%) (15-40% protected	18.6	5.7
4. No Protection (%) (<15% protected)	57.2	57.3
5. Non-structural Protection (%)	0.0	0.1
6. Unclassified (%)	6.2	8.8

Table 2. Comparison of baseline Great Lakes/SOLEC hardened shoreline classification and updated (2001-2002) hardened shoreline classification for Lake Ontario
Source: Baseline SOLEC data from National Oceanic and Atmospheric Administration (1997) and updated Lake Ontario data from Stewart (2002) and Baird (2005)



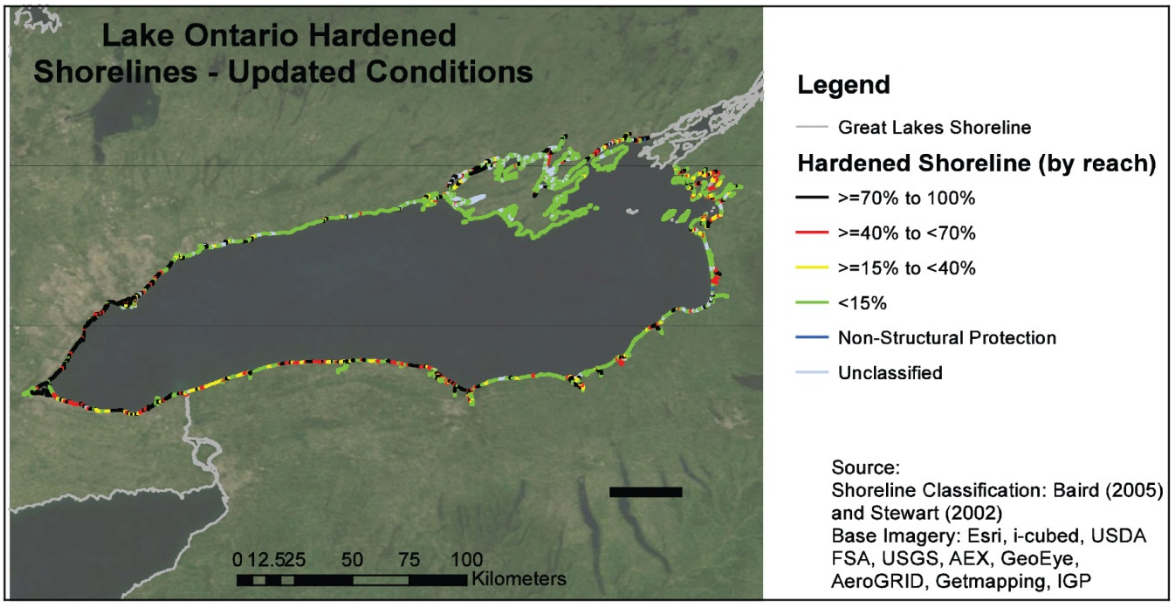


Figure 1. Maps of baseline Great Lakes/SOLEC hardened shoreline classification and updated (2001-2002) hardened shoreline classification for Lake Ontario
Source: Baseline Great Lakes/SOLEC data from National Oceanic and Atmospheric Administration (1997) and updated Lake Ontario data from Stewart (2002) and Baird (2005)

Harmful Algal Blooms (HABs)

Overall Assessment
Status: **Fair to Poor**
Trend: **Unchanging or Deteriorating**
Rationale: **Overall, there are too few data and no systematic monitoring programs to enable a rigorous quantitative evaluation of the conditions and trends for HABs in the Great Lakes. However, the existing data and anecdotal evidence suggest that nearshore and offshore zones are disparate, and should be assessed separately. The status of the Upper Great Lakes is generally good in the deeper offshore waters. The status is either unchanged or deteriorating in the shallower basins and/or nearshore areas, particularly in the lower lakes (Erie, Ontario) which are experiencing frequent outbreaks of HABs and nuisance algal blooms (NABs) as both planktonic and attached algae.**

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Unchanging or Undetermined
Rationale: There is very little quantitative current information on HABs in Lake Superior. Severe HABs outbreaks have not been documented recently in this lake and cyanobacterial biomass remains mostly at low levels in those cases where it has been evaluated. An occasional local impairment may occur near shoreline development.

Lake Michigan
Status: Fair
Trend: Unchanging/Deteriorating
Rationale: Offshore waters are generally good but cyanobacteria blooms are reported in some coastal regions in eutrophic embayments such as Green Bay, Muskegon Bay and in many of the river mouths along the eastern shore. Shoreline and beach fouling by *Cladophora* represent a source of bacteria for beaches and groundwater. Trapped bacterial flora during their growth provides substrate for further bacterial activity during decay.

Lake Huron
Status: Fair
Trend: Unchanging (offshore), Deteriorating (some nearshore regions)
Rationale: Lake Huron is generally oligotrophic in most areas, but experiences potentially toxic HABs occur in some nearshore areas, notably Saginaw and Sturgeon Bay which develop toxic summer outbreaks of planktonic *Anabaena* and *Microcystis aeruginosa*.

Lake Erie
Status: Fair to Poor
Trend: Deteriorating
Rationale: Lake Erie is the most heavily impaired by planktonic HABs, particularly in the last two years where satellite images of extensive surface blooms of *Microcystis* and other HABs have been posted on many websites (e.g. NOAA). Toxic and nuisance planktonic (*Microcystis; also Anabaena*, *Planktothrix and Aphanizomenon*) HABs are a particular concern in the western basin, often originating in the southwest (Maumee Bay and Sandusky Bay) and it is argued that October 2011 saw one of most severe planktonic HABs on record in the Great Lakes, covering most of west and central basins. Areas of the west basin also experience significant benthic NABs of the cyanobacteria *Lyngbya wollei*. The Central

basin of Lake Erie has large outbreaks of planktonic HABs; notably near Cleveland, where they may extend significant distances alongshore or in a northern direction into the offshore waters, and recently reported during the past few years along the northern shoreline between Point Pelee and Port Stanley or further eastward. Offshore water in the Eastern basin is high in quality and experiences very few planktonic blooms, but erratic but significant planktonic outbreaks have been reported in nearshore areas of this basin, notably near Erie and Long Point. However, many nearshore areas of the East Basin have significant impairment from attached *Cladophora* beds, despite low ambient nutrient levels

Lake Ontario

Status: Fair

Trend: Deteriorating (some nearshore areas); improving/unchanging (offshore areas)

Rationale: Offshore waters are generally good however blooms of cyanobacteria and related impairments (toxins, taste-odour compounds) occur on an annual basis in some nearshore areas, notably the Bay of Quinte, Sodus Bay, Rochester embayment, Hamilton Harbour and the Greater Toronto region, causing advisories and beach closures in some of these areas. In many nearshore areas, dense beds of attached *Cladophora* have led to extensive beach closures, fouling and other issues

Purpose

- To assess the potential harm to human, other organisms or ecosystems from planktonic or benthic/attached algal blooms.

Ecosystem Objective

Waters should be safe for drinking (>25 million people rely on the Great Lakes for drinking water), and for recreational use, and substantially free from toxic and/or high abundances of noxious cyanobacteria or algae that may harm human, animals or ecosystem health or have other harmful effects. While cyanobacteria produce a wide variety of toxins, hepatotoxic microcystins (MCs) are the most persistent and common cyanotoxins currently reported across the Great Lakes, and are generally produced by one of several species of *Microcystis, Anabaena* or *Planktothrix*. Other cyanobacterial toxins such as anatoxin-a have been found in embayments but are rare in occurrence thus this indicator focuses on a single class of MC toxins. Nontoxic bloom events are also of concern, however. Recently, winter blooms of the diatom *Aulacoseira* have been reported, which may contribute to the severity of the summer anoxia in the central basin. Benthic/littoral cyanobacteria such as *Lyngbya* or eukaryotic algae - particularly *Cladophora* and *Spirogyra* - show widespread occurrence in the nearshore zone and represent a different type of threat to the ecosystem. However some of the root causes of benthic HABs (elevated nutrients) are similar to the root cause of pelagic HABs. A combined metric enables monitoring for changes in both general types of blooms.

Ecological Condition

Background

Harmful cyanobacterial and/or algal* blooms (HABs) are a global issue in eutrophic waters with high anthropogenic (and/or natural) nutrient loading (e.g. Hallegraeff 1993). HABs are differentiated from 'non-harmful' blooms by their qualitative impacts on, or threats to: i) water quality, biota or physico-chemical characteristics; ii) health risks from toxins or heightened microbial activity; iii) aesthetics or recreation (Pearl 1988). Prior to remediation in the late 1970s, HABs were a major problem in many offshore and nearshore areas in the Great Lakes (e.g. Watson and Boyer 2008) where concerns focused on reduced aesthetics, taste-odour (T&O), foodweb structure, beach/intake/net fouling and economic impacts. Lake-wide remediation efforts initiated in the 1980s were mainly directed towards the reduction of point-source nutrient loading, and successfully mitigated many HAB impairments with progress largely gauged against the management reduction targets for Total Phosphorus (TP) and chlorophyll a (chl-a). Recently there has been a resurgence in algal blooms in the Lakes, with an additional new concern being their potential for the production of toxins*. Current management continues to target planktonic (subsurface) chl-a as a measure of total algal biomass and productivity, which is often a poor metric for these events.

(Notes - * algae here can be used to denote both eukaryotic algal taxa and cyanobacteria; ** Toxins were not recognized as a threat to the Great Lakes in the 1970s, but there is little historical data on their occurrence prior to their report in Lake Erie in the mid 1990s (Brittain et al., 2000). This perception of increased toxicity is based more on anecdotal evidence and reports may be biased by increasing public awareness, advances in analytical techniques, and increased monitoring.)

Most efforts are focused on visible HABs caused by planktonic toxic cyanobacteria, but HABs also can be caused by blooms of *Cladophora* and other benthic/littoral macroalgal proliferation. These benthic mats, along with planktonic outbreaks, have shown an apparent resurgence particularly in the lower Great Lakes. Because these events are often episodic, and vary seasonally and interannually in severity and spatial coverage, it is difficult to implement appropriate research, monitoring and management programs, particularly in large and complex waterbodies such as the Great Lakes where sampling is often subject to weather and vessel access. Blooms may not be restricted to the lakes themselves and have been reported in major embayments, tributaries and connecting channels.

Most algal blooms in the Great Lakes are reported in the nearshore areas, which are most prone to shoreline development issues, greater influx of nutrients and to some extent, increased public vigilance. The size of nearshore zones varies from ~1-10% in Superior to 60-90% in Erie, as does the influence of physical and climatic factors (runoff, erosion, thermal bar formation, upwelling/downwelling, alongshore/nearshore/offshore currents, circulation patterns, surface/ground water inputs, lake level regulation, ice formation, etc.). As a result, the nearshore zones are highly dynamic, and there is significant spatial-temporal variance in the areas supporting littoral and planktonic communities and offshore-nearshore material exchange.

HABs in the Great Lakes are caused by a variety of species. Major impairments to ecosystem services include: i) noxious/toxic metabolites (odour, toxins); ii) fouling (beaches, nets, intakes); iii) aesthetics and economic impacts including beach closures; vi) modified nutrient turnover and sequestration or translocation (via cell bound fractions) of nutrients; vii) increased bacterial activity; viii) adverse effects on food web integrity. Importantly their appearance is often associated with nearshore regions and this is poorly captured by the current LaMP targets – i.e. offshore nutrient and chl-a levels.

Key aspects of HABs

These are summarized in detail in Watson and Boyer 2008, but some key points are summarized below:

- HABs cause significant economic harm. Annual estimates vary, but range up to annual costs of $4.6 billion/yr (USA) in response monitoring, fisheries, tourism, public health & advisory, lost revenue & property value.
- Not all HABs are caused by cyanobacteria or resemble green paint or pea soup. They are caused by many species and vary in colour from green to red and brown.
- Algal blooms do not always show up as surface scums and can be hard to identify or anticipate. Some blooms are mixed through the water column, grow in deep water layers, under ice or as benthic/attached mats.
- Cyanobacteria produce many toxins which fall into three major categories, based on their activity: liver toxins (hepatotoxins), neurotoxins & dermal irritants. These toxins vary greatly in their chemical properties, stability and toxicity. Microcystins (hepatoxins; also carcinogens) are the most stable and prevalent across the Great Lakes. These toxins can persist in the water column after a bloom has died and disappeared.
- Toxins, taste and odour issues, visible blooms, cyanobacteria and algal biomass, and the abundance of chl-a may or may not be related. Toxins are odourless & colourless and there is often a very poor relationship between occurrence of toxins and T&O compounds. The two classes of compounds are derived from separate biochemical pathways. These compounds are produced by a number of different genera and cell and species-

specific variation in their production is common.

- Blooms are difficult to define, measure and predict.
- Blooms can show rapid changes in their spatial location and abundance.
- With calm conditions (or overnight), buoyancy-regulating cyanobacteria can float to the surface and be carried large distances by wind/waves. These may wash onshore, creating patches of very high toxin levels along beaches.
- Variations in analytical and sampling methods can lead to inconsistencies in the reported levels of these compounds.
- Fluorescence-based, cell counts and other abundance measures (e.g. molecular, biochemical) are often poorly correlated with each other and actual cell biomass due to wide variance in pigment content, photo-acclimation and cell composition. Taxonomic identification of many of the responsible species may be complex, leading to differences between analysts.

Additional Information

The term ‘algal bloom’ is a non quantitative descriptor for visible increases in free-floating or attached algal/cyanobacterial density, often manifested as scums, mats or water colour. Harmful algal blooms are differentiated as having harmful socioeconomic or ecological effects and may be caused by algal/cyanobacteria species belonging to many major taxonomic groups. The most concern is with HABs caused by cyanobacteria (CHABs), which include toxic blooms, caused by a subset of cyanobacterial species with the capacity to produce one or more toxins (neurotoxins, hepatotoxins or dermatotoxins) and currently are the only known sources of algal toxins in inland waters that directly affect humans. Detrimental health effects from benthic algal accumulations on the shore are more difficult to quantify but may result in socioeconomic and ecological damage (Table 1).

Great Lakes: current status of HABS

Toxins: The most commonly reported toxins in the Great Lakes and other waters are microcystins (MCs) produced by numerous cyanobacteria species; some of which (e.g. *Microcystis Anabaena* and *Planktothrix* spp.) bloom in the Lakes (e.g. Boyer 2007). In lakes Ontario and Erie, anatoxin-a and saxitoxins have been detected at high and low levels, respectively (Boyer 2007). While *Cylindrospermopsis* is present in Great Lakes and its surrounding watersheds, the toxin cylindrospermopsin previously associated with this genus has not been confirmed for these waterbodies. Analysis of numerous samples across the Great Lakes has shown no detectable levels of β-methylamino-l-alanine (BMAA), a toxin of emerging concern in some areas. The question of BMAAs and the link to Alzheimer’s continues to be debated. There are no data on the occurrence of lipopolysaccharides (LPS), produced by all cyanobacteria and widely believed to cause gastroenteritis, skin/eye irritations, hay fever, asthma and blistering (although this is debated; e.g. Stewart *et al*. 2006).

Taste and odour (T&O) impairment is widespread in the Great Lakes. T&O is most commonly caused by volatile organic compounds (geosmin, 2-methyisoborneol, β-cyclocitral and biogenic sulphides) released during the growth and decay of planktonic and benthic cyanobacteria, bacteria and algae. These compounds have no known human health effects, but can impart significant consumer alarm and treatment/economic costs and function in foodwebs as powerful chemical signals (e.g. Watson et al 2008a; Watson 2003).

Other issues i.e. benthic HABs (*Cladophora*, *Lyngbya, Chara*). Despite a significant reduction in these impairments in the 1980s-90s, there has been a significant resurgence in this problem which is now widespread in the lower lakes, notably in areas affected by a combination of diffuse shoreline or tributary influx of nutrients and colonised by dressenid mussels. The link among these factors to growth and biomass is, however, obscured by the dynamic physical nature of the nearshore zone, sloughing off and difficulties with sampling.

Great Lakes: current status of HABS in individual lakes

As noted above, there are no long term data or rigorous monitoring programs in place across most of the lakes, and only a qualitative assessment of the current status in each lake can be made.

Lake Superior: There is very little quantitative current information on HABs in Lake Superior. To our knowledge, severe HABs outbreaks have not been documented recently in this Lake. Algal biomass, especially for potentially toxic cyanobacterial species remains mostly at low levels, although there may be some local impairment near shoreline development. Localized, low toxicity blooms have been observed in the connecting channels across the Keweenaw Peninsula.

Lake Michigan: Cyanobacteria blooms are reported in some coastal regions in eutrophic embayments such as Green Bay, Muskegon Bay and in many of the river mouths along the eastern shore of Lake Michigan. Shoreline and beach fouling by *Cladophora* represent a source of bacteria for beaches and groundwater, trapping bacterial flora during their growth and providing substrate for further bacterial activity during decay.

Lake Huron: Lake Huron is generally oligotrophic in most areas, but experiences potentially toxic HABs occur in some nearshore areas, notably Saginaw Bay develops toxic summer outbreaks of *Microcystis aeruginosa*. These blooms appear to be genetically distinct with a greater MC production capacity than HABs populations of *M. aeruginosa* in western Lake Erie (Dyble *et al* 2008). Highest toxin levels occur in shallow regions with high TP concentrations. Blooms have been reported from Sturgeon Bay in 2006-07, but no recent data is available (Diep *et al*. 2006). Recently, complaints of fish-net fouling by attached chlorophytes have increased (*Spirogyra cf circumlineata*, *Stigeoclonium*; Watson and Milne, unpublished). Rotting mats of beached green macroalgae are increasingly impacting aesthetics, recreation and tourism along some shorelines, notably Saginaw and more recently, the S.E., largely caused by *Cladophora* and *Chara*, respectively, with the detection of human fecal indicators (*E. coli*, *Enterococcus*) and evidence of differential survival in the beached mats and in situ beds of the macroalgae (Lake Huron Binational Partnership 2008-2010 Action Plan 2008). *Cladophora* is more clearly associated with suspected nutrient discharge while *Chara* is more widespread and not clearly linked to local inputs (Howell *et al*. 2005).

Lake St Clair (LSC): St. Clair River/Lake St. Clair/Detroit River's status is Fair. Recent reports and surveys do not identify algal blooms as a problem across most of LSC, as also indicated by generally low chla levels (~3-5ug/L; Lake St. Clair Canadian Watershed Technical Report; Watson unpublished). However, recent satellite images and anecdotal reports indicate blooms in the SE region of Lake St. Clair near the mouth of the Thames River. *Lyngbya* mats have also been found in the western shoreline areas associated with macrophyte stands; also in the Detroit River (Trenton Channel) (Watson unpublished).

Lake Erie: Lake Erie is the most heavily impaired by planktonic HABs, particularly in the last two years where satellite images of extensive surface blooms of *Microcystis* and other HABs have been posted on many websites (e.g. NOAA). Toxic HABs and their causes are a particular concern and the focus of several recent studies (e.g. MERHAB-LGL, Stumpf et al. 2012).

General trends: Overall, the data indicate an apparent deterioration, and shifts in external/internal physical/ chemical/ biological regimes - notably in the western basin of Lake Erie. These are not easily assessed using current monitoring methods and measures, particularly where basin-wide averages and/or surface (1m) chl-a are considered (Ghadouani & Smith 2005). Studies suggest an increase in the severity of blooms in the western basin and some nearshore areas of the north shore (Point Pelee, Rondeau Bay, Long Point), and a decline in overall chl-a and total and/or eutrophic species biomass in the offshore regions of the central and eastern basins. Pre-remedial cyanobacteria populations were predominated by Nitrogen-fixers (*Aphanizomenon, Anabaena*), while many of the recent blooms have been dominated by non nitrogen-fixers, notably *Microcystis* and *Planktothrix* spp., suggesting changes in nutrient supply or dreissenid activity. Nevertheless, significant blooms of nitrogen-fixing populations of *Anabaena* (cf *lemmermanni*) occur in both western and eastern basins (Watson, unpublished).

Immense surface blooms (>20 km^2) have been recorded in the western basin of Lake Erie near the Maumee and Sandusky Rivers (e.g. Rinto-Kanto *et al*. 2005; Stumpf et al 2012). Microcystins (MCs) are the most common cyanobacterial toxins measured in Lake Erie. Data from 2000–2004 measured a wide range in MC levels from detection limits (in 2002) to >20µg/L (in 2003). Toxicity is not restricted to the western basin: in 2003, highest MC concentrations were measured from Maumee, Long Point Bay and Sandusky Harbour. Neurotoxins (anatoxin–a, saxitoxin, neosaxitoxin) occurred at or near detection limits in the open lake waters. Samples collected across the lake between 2003 & 2008 showed the greatest proportion of samples (72-77%) with detectable MC levels from the western basin (Figure 1), although only ~5% had levels above 1µg/L.

Toxins are not always produced by the same species, by the dominant taxa, or on a consistent basis. *Microcystis* blooms from Maumee have shown 5-100% variance in genetic potential for MC production. Recent molecular work has shown that blooms upstream in the Maumee R. are not a source of toxic *Microcystis* spp. to western basin of Lake Erie, but the two populations arise independently (Kutovaya *et al* 2010). In fact *Planktothrix* can be the major source of MC toxins in Maumee Bay and Sandusky Harbor where cyanobacteria populations are dominated by non-toxin producers (e.g. *Aphanizomenon, Anabaena*; Rinto-Kanto *et al*. 2005; Boyer 2007). Most impairment occurs at shorelines and beaches and can be manifested as fish/bird kills. Lyngbyatoxins (inflammatory/vesicatory and tumour-promoting) were not detected in the mats of *Lyngbya wollei* proliferating in the Maumee and Detroit Rivers.

Cylindrospermopsis raciborskii, first identified in Sandusky Bay 2005, may develop localized biomass but to date, cylindrospermopsin or deoxycylindrospermopsin has been detected in these areas. The highly variable morphology of this and other species may lead to misidentification as an *Aphanizomenon issatchenkoi* or *Rhaphidiopsis curvata*.

Geosmin and 2-methylisoborneol (MIB) are likely the cause of annual musty-muddy odour problems in drinking water in supplies in the western basin (e.g. Toledo). Significant odour is produced by extensive rotting mats of shoreline attached algae. The planktonic cyanobacterial taxa which are currently problematic in Lake Erie (*Microcystis** and the local strain of *Planktothrix*) do not produce these or other T&O compounds which commonly impair drinking water supplies. (*Note – *Microcystis* produces ß-cyclocitral; however, this is rapidly removed by most water treatment methods.)

Severe impairments by thick mats of the cyanobacterium *Lyngbya wollei* reported in the mouth of the Maumee River (western basin) at sites with high ambient P in the overlying water between 2006-09 appear to have abated this past year (Watson *et al*. 2008b; Western Lake Erie Waterkeeper Association unpublished). Extensive mats of attached green algae, notably *Cladophora* are showing an increase in abundance along some northern shorelines, although there are no recent data (post 2008) available on distribution.

Lake Ontario: Blooms of cyanobacteria and related impairments (toxins, taste-odour compounds) occur on an annual basis in some nearshore areas, notably Areas of Concerns (AOCs) of Lake Ontario. Sporadic outbreaks of high MC levels and cyanobacteria blooms have been recorded in Hamilton Harbour, Bay of Quinte, Oswego Harbor and most recently, Sodus Bay (Watson and Boyer 2008, Watson *et al*. 2010a,b; Boyer unpublished). Spatial and temporal levels of MCs in the Bay of Quinte, Hamilton Harbour, Oswego Harbor (now delisted) and the Rochester Embayments indicate periods of severe impairment of nearshore sites by windblown accumulations of toxic material, where MC levels can reach levels in excess of 500 µg/L. Microcystins and toxigenic *Microcystis* are also commonly found in many of the nearshore regions and embayments that span the northern Coast of New York State (Hotto *et al*, 2007). While microcystins are certainly the toxin of most concern in Lake Ontario, recent surveys indicate the widespread occurrence of low concentrations of anatoxin-a in nearshore embayments (Boyer 2007; Yang 2007, Boyer unpublished). The organism responsible for anatoxin-a production is currently unidentified. Other toxins (saxitoxins and cylindrospermopsin) are rare.

Studies have identified three T&O patterns over the past 5 years which are caused by geosmin and/or 2-MIB. Recently, there have been no severe T&O impairments to drinking water in intakes from Lake Ontario, although there have been anecdotal reports of T&O from the St Lawrence River (J. Ridal, personal communication) . Benthic algal impairment continues to be major problem in many areas, with issues of plant intake and beach fouling (Higgins *et al*. 2008). Severe impairment is also manifested by benthic mats of the cyanobacteria *Lyngbya* cf. *wollei* and epiphytic *Gloeotrichia* recently identified in the St. Lawrence River near the confluence of nutrient-rich tributaries (Vis *et al*. 2008). As with the Maumee populations, these mats of *Lyngbya* are non-toxic but show high geosmin production, likely the source of extensive drinking water T&O impairment in the Montreal area.

Linkages
Increasing nutrient inputs from diffuse and point sources, climate change (severe storm events, differences in insulation/harmful irradiation, ice-cover and mixing), and invasive species (e.g. dreissenid mussels) in the Great Lakes may lead to increased frequency, distribution and severity of both nearshore (attached/benthic) and offshore algal blooms and favour the predominance of cyanobacteria.

Management Challenges/Opportunities
There are a number of issues that relate to the effectiveness of monitoring and applying this indicator:

There is a critical need for a coordinated, interagency monitoring program, which employs standard methods; different sampling regimes and analytical protocols employed by individual studies affect data comparability and interpretation of long-term trends.

Basin-wide seasonal means, used widely to gauge trophic levels, do not resolve temporal/spatial differences in biomass and taxa, and thus cannot identify problem areas and/or potential drivers.

Littoral/benthic, epiphytic and meroplanktic algal populations are not addressed by most sampling programs, yet can account for a high proportion of algal productivity, or represent seed beds where surface blooms originate.

Alternative measures of algal abundance and productivity are often poorly correlated, as are measures of light regime. Chl-a continues to be a target measure for management, yet there are often poor correlations among chl-a, total algal biomass and levels of impairment. Secchi depth estimates visible light attenuation, which can differ significantly (seasonally and spatially) from PAR extinction.

Toxins should be systematically investigated, particularly in high risk source-waters, using regular monitoring at recreational areas and intake zones, mid-late summer spatial surveys during high risk periods and an alert level framework such as developed by the World Health Organization (Watzin *et al*. 2006). More effective criteria for T&O would include regular measures of the most problematic compounds (e.g. geosmin, MIB) in source waters and municipal supplies, and comparison against their odour threshold levels.

Nutrient levels may, or may not predict toxin or odour outbreaks. Blooms are often local and inshore in origin and can spread over considerable areas as surface scum.

Incidental reports, media releases and websites may inflate or misrepresent these issues. Most attention is focused on surface scum, which inevitably bias samples and perceived severity.

Comments from the authors
There are few long term data collected on HABs and more specifically, toxins, in the Great Lakes, making trend analysis difficult. Differences in sampling regimes and analytical protocols (e.g. surface or integrated sampling; taxa enumeration; toxin analyses) utilized in past studies affects the ability to compare data and determine long term trends in toxins and bloom occurrences. Attention is most often focused on shoreline scums or algal material visible

at the surface, particularly for inland waters where many reported blooms are caused by attached macroalgae (*Cladophora*, *Lyngbya*) or large, buoyancy-regulating cyanobacteria. These buoyancy-regulating taxa can produce rapid surface accumulations from populations through the mixed layer or deep living/benthic populations. Concentrated surface scums appear, disappear and migrate rapidly with changes in vertical mixing, currents and wind activity. These can produce rapid changes in toxin levels along a waterfront or cover extensive areas in large lakes, and are difficult to sample, quantify or predict. Beach and shoreline sampling programs require multiple sub-sites to capture this envelope of spatial/temporal variance in risk and impairment, which are poorly represented by basin-wide seasonal means. Sampling regimes in the Great Lakes are often sparse (both temporally and spatially) and are likely to miss spatial and temporal peaks in cyanobacterial/algal abundance.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization			x			
2. Data are traceable to original sources		x				
3. The source of the data is a known, reliable and respected generator of data			x			
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin					x	
5. Data obtained from sources within the U.S. are comparable to those from Canada		x				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report				x		

Clarifying Notes: See notes under '**Management Challenges/Opportunities' and 'Comments from the authors'.** The sources of data are varied and in many cases, use different sampling and analytical methods. Monitoring in the lower lakes is generally good but monitoring in the upper lakes Michigan, Huron and Superior is sparse and largely reactive

Acknowledgments

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Figure 1. Lake Erie: percent of all samples collected between 2003-2009 with detectable levels of MC toxins. Source: Greg Boyer, SUNY; unpublished

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HABs Impairments

Impairment	Mechanisms	Affected agents
Drinking/recreational water integrity	Taste and odour, poor aesthetics	Drinking/recreational water
Source water quality and function	Anoxia from decaying material Reduced water transparency etc.	Multiple ecosystem (fish and wildlife; internal nutrient loading etc); Tourism/ recreational; property value
Fouling	Industrial intakes Fish nets Beaches/shorelines	Drinking/hydro/other industries; aquaculture/tourism/ recreational; waterfront and property value
Elevated shoreline and beach bacterial/ pathogen levels	Entrain/facilitate growth of pathogenic microbiota	Tourism/ recreational; property value
Biomagnification (toxins, taste)	Tainted fish /shellfish State of the Great Lakes 2011 *report*sh/other	Recreational/food/aquaculture; ecological (foodweb transfer)
Ecological	Multiple; include cell/tissue damage, growth inhibition, teratogenic, toxigenic (toxins, irritants, shading, allelopathic interactions, inadequate food quality, etc)	Multiple foodweb levels

Table 1. HABs Impairments - Socioeconomic and Ecological
Qualitative assessment only at this point; could be developed into more quantitative measures.

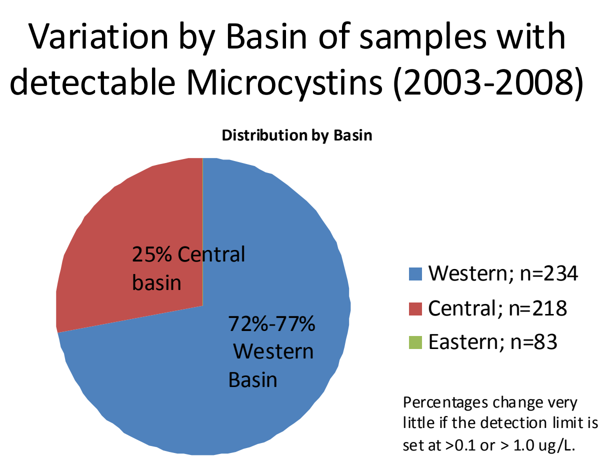

Figure 1. Lake Erie: percent of all samples collected between 2003 & 2009 with detectable levels of MC toxins. Source: Greg Boyer, SUNY; unpublished

Human Population

Overall Assessment

Trend: **Increasing**

Rationale: The long-term trend (1971 to 2006) of the total population in the Great Lakes region is increasing. Compared to 1971, the population increased by 14.0% in 2006. The short-term trend from 2001 to 2006 indicates that the total population in the Great Lakes region has increased by 1.8%.

Lake-by-Lake Assessment

Lake Superior

Trend: Decreasing

Rationale: Human population around Lake Superior has decreased by 5.0% over the long-term. The short-term trend indicates a continued decline; more specifically, from 2001 to 2006, Lake Superior's population decreased by 1.3%.

Lake Michigan

Trend: Increasing

Rationale: Human population around Lake Michigan has been increasing over the years. The long-term trend indicates a growth of 11.3%, and a short-term trend from 2001 to 2006 shows continued growth of 0.7%.

Lake Huron

Trend: Increasing

Rationale: From 1971 to 2006, human population around Lake Huron has consistently been increasing. Since 1971, the long-term trend indicates a substantial growth of 24.1%. Likewise, the short-term trend shows a continual increase of 2.7% from 2001 to 2006.

Lake Erie

Trend: Increasing

Rationale: Both long-term and short-term trends in Lake Erie indicate that human population is increasing. From 1971 to 2006, human population increased by 3.1% From 2001 to 2006, human population increased by 0.4%.

Lake Ontario

Trend: Increasing

Rationale: Human population around Lake Ontario has consistently been increasing. The long-term trend since 1971 indicates that population has increased by 29.8%. Similarly, the short-term trend from 2001 to 2006 indicates a continued increase of 5.0%.

Purpose

- To assess the current human population trend in the Great Lakes region
- The Human Population indicator is used in the Great Lakes indicator suite as a Driving Force indicator in the Economic/Social category

Ecosystem Objective

The human population should be living and working with full regard to the purpose of the Great Lakes Water Quality Agreement, to restore and maintain the chemical, physical and biological integrity of the Great Lakes Basin Ecosystem.

Ecological Condition
In this report, the Great Lakes basin is defined as the watershed of the Great Lakes.

Measures

There are different approaches to determine the human population of the Great Lakes basin. A range of population estimates for the Great Lakes basin are often cited by different organizations and reports (Table 1). In this report, it was initially a challenge to properly compare the Canadian and American population datasets because the U.S. population numbers in the Great Lakes are not available by watershed. In addressing the issue, one potential approach was to identify and include every county that falls fully or partially in the Great Lakes basin. However, the problem with this approach was that whether the county was 1.0% or 100% in the Great Lakes basin, the entire population number would be included in the estimate. Consequently, this resulted in an overestimate of the U.S. population in the Great Lakes region. Another challenge in this approach was the fact that there are many counties that fall in more than one lake basin; in which case, the analysis required to accurately portray the lake-by-lake estimates is difficult.

A ratio approach uses GIS analysis to calculate that if only 1.0% of a county's boundary falls in the Great Lakes Basin, then only 1.0% of the county's population would be included. This ratio approach does have a number of limitations. For example it assumes that each county has an evenly distributed population. That is not always the case and the ratio approach can underestimate human population where a county falls only partially in the Great Lakes basin but has a population centre(s) within the basin. This approach also does not accurately reflect the significant population in Illinois that resides outside the Great Lakes basin but is serviced by Lake Michigan's drinking water.

The adjusted-ratio approach, used in this report, reflects a review of the population identified for each U.S. county. Every county with a population over 100,000 people (and 40,000 people for the Lake Superior Basin) was examined to ensure the population calculated in the ratio approach accurately reflected the distribution of the county's population. In the end, the population ratio of eight counties were adjusted to accurately reflect the population centers and in the Chicago area four counties were selected and adjusted to represent the total population of Illinois serviced with drinking water.(Table 2).

Total Populations in the Great Lakes Region (Ontario and Eight Great Lakes States)

The total population in the Great Lake basin in 2006 has increased to 38,968,987 (Table 3). As seen in Figure 1, the population growth from 1971 to 1986 was small. From 1986 to 1991, however, the region experienced its largest population growth of 5.7%. Since then, the region's population numbers continued to grow steadily and from 1996 to 2001, the region had its second largest population growth of 4.3%. In examining the long-term trend, the region's population increased 14.2% since 1971 (Figure 2). In the short-term trend, from 2001 to 2006, the Great Lakes region experienced a small increase of 1.8% (Figure 3).

In 2006, 33.2% of Canadians lived in the Great Lakes Basin, and 9.4% of Americans lived in the Great Lakes Basin.

Within the entire Great Lakes region, Ontario experienced the largest population increase. From 1971 to 2006, Ontario's population increased by 37.4% (Figure 4). The short-term trend from 2001 to 2006 indicated Ontario's population had grown by 6.5% (Figure 5, Table 3). Five U.S. Great Lakes States also experienced population growth, although their growth was not as evident as Ontario's. Indiana had the highest population growth amongst the eight states with 17.4%, following by Wisconsin with 11.7%, Michigan with 11.0%, Pennsylvania with 4.0% and Illinois with 3.3% (Figure 4). Minnesota, New York and Ohio, on the other hand, experienced decreases in their population. In particular, Minnesota decreased the most with an 8.2% decline, followed by Ohio with a decline of 4.8% and New York with 4.0% decline (Figure 4).

Each of the Great Lakes
The total population around each Great Lake and associated watersheds between 1971to 2006 has fluctuated over time (Table 4).

Around Lake Superior, the human population has decreased by 5.0% from 1971 to 2006 (Figure 6). With the exception of 1971-1976 and 1991-1996 where the population increased slightly, Lake Superior has consistently experienced a declining population. In 1981 to 1986, Lake Superior had its largest population decline of 5.6% (Figure 6). The short-term trend from 2001 to 2006 indicates that the population continues to decline; the population has decreased by 1.3%. In proportion to the entire Great Lake Basin, only 1.5% of the total human population in the Great Lakes Basin lives around the Lake Superior basin, and this percentage has decreased by 0.4% since 1971 (Figure 7 & 8).

Around Lake Michigan, the human population has increased by 11.3% from 1971 to 2006 (Figure 6). With the exception of 1991-1996, Lake Michigan has consistently had an increasing population. In particular, from 1996 to 2001, the population growth was 6.0% (Figure 8). The short-term trend from 2001 to 2006 indicates an increase of 0.7% (Figure 8). In proportion to the entire Great Lake basin, 34.7% of the total human population lived around Lake Michigan in 1971 (Figure 7). As of 2006, Lake Michigan's total population portion in the basin dropped slightly to 33.6% (Figure 8). In both 1971 and 2006, Lake Michigan had the largest population percentage in the basin.

Around Lake Huron, the human population has consistently been growing. The long-term trend indicates that Lake Huron's human population has increased by 24.1% since 1971 (Figure 6). From 1986 to 1991, Lake Huron had its largest population increase of 8.5% (Figure 6). The short-term trend shows a continued growth and .from 2001 to 2006, the population increased by 2.7%. Lake Huron basin's human population was 7.3% of the total population in the Great Lake Basin in 1971 (Figure 7). As of 2006, Lake Huron contained 8.0% of the total population in the basin (Figure 8).

Around Lake Erie, the human population has increased by 3.1% over the long term (Figure 6). However, unlike other Great Lakes where their human population has either been increasing or decreasing relatively consistently, Lake Erie's population trend has fluctuated greatly. From 1971 to 1986, the population decreased steadily. From 1986 to 1991, the population increased significantly by 3.6%. In 1996the population decreased once again and since then, the population has grown again. The short-term trend in Lake Erie indicates an increase of 0.4% from 1996 to 2000. In proportion to the entire Great Lake region, Lake Erie and Lake Michigan used to have the greatest share of population within the basin. In 1971, Lake Erie held 35.4% of the entire population for the Great Lake Basin (Figure 7). In 2006, however, the population had declined by 4.1% to 31.4% of the Great Lake Basin population (Figure 8).

Around Lake Ontario, human population has consistently increased. The long-term trend of indicates an increase of 29.8% since 1971, the largest long-term population growth among the Great Lake basins. Lake Ontario experienced its largest population increase from 1986 to 1991 with 7.7% (Figure 6). The short-term trend, from 2001 to 2006, indicates continued growth of 5.0% (Figure 6). In proportion to the entire Great Lake basin, as of 2006, 25.2% of the total human population fell within Lake Ontario's basin. In comparison to its 1971 proportion to the other Great Lake basins, human population in Lake Ontario's basin increased by 4.6% (Figure 7 and 8).

Linkages
Humans are a key driving force in the overall impact on the environment. Emphasis should be placed on ensuring humans are working, playing and living sustainably. Further analysis in population trends, consumption rate and population density are areas that can help understand and calculate the different impacts humans have on the environment.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Source: United Status Census Bureau and Statistics Canada

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Population Estimate Approaches

Approach	Estimates
Great Lakes and St. Lawrence River Region. (Whole of Ontario, Quebec and Eight Great Lakes States)	Total: 103,359,687 Ontario: 12,665,330 Quebec: 7,631,600 Eight Great Lakes States: 83,062,787
Great Lakes Region (Whole of Ontario and Eight Great Lakes States)	Total: 95,718,087 Ontario:12,665,330 Eight Great Lakes States: 83,062,787
Great Lakes Basin (All U.S. counties that are fully or partially located in the basin - overestimate approach)	Total: 42 868 987 Ontario: 10,879,768 Eight Great Lakes States: 31,989,219
Great Lakes Basin (Ratio of U.S. county within the basin = ratio of population attributed to the basin - underestimate approach, especially due to Chicago area)	Total: 32 629 828 Ontario: 10,879,768 Eight Great Lakes States: 21,750,060
Great Lakes Basin (U.S. county adjusted ratio approach used in this report)	Total: 38,968,987 Ontario: 10,879,768 Eight Great Lakes States: 28,089,219

Table 1. Population Estimate Approaches (Year: 2006).
Source: United Status Census Bureau and Statistics Canada

Counties Adjustment

County	Adjustment Rationale
Cook County, DuPage County, Will County and Lake County, Illinois	These ratios were adjusted to account for the approximate 6.4 million people in Illinois that receive drinking water from Lake Michigan in 2010, according to the Chicago Metropolitan Agency for Planning
La Porte County, Indiana	Accounting for Michigan City
St. Joseph County, Indiana	Accounting for South Bend and surrounding area
Marquette County Michigan	Accounting for Marquette
St. Louis County, Minnesota	Accounting for Duluth, and some iron-range communities (e.g. Hoyt Lakes)
Erie County, Pennsylvania	Accounting for City of Erie, and coastal townships from Springfield to Northeast
Douglas County, Wisconsin	Accounting for City of Superior and surrounding area
Kenosha County, Wisconsin	Accounting for City of Kenosha
Racine County, Wisconsin	Accounting for City of Racine and surrounding area

Table 2. Counties Adjustment.
Source: United Status Census Bureau and Statistics Canada

Total Population in the Great Lakes States and Ontario

	1971	1976	1981	1986	1991	1996	2001	2006
Illinois	6,021,260	5,938,855	5,829,213	5,831,514	6,014,380	5,917,302	6,268,708	6,226,965
Indiana	945,833	961,748	975,880	981,281	1,071,477	1,033,124	1,116,641	1,145,015
Michigan	8,988,758	9,135,800	9,228,640	9,146,124	9,844,548	9,547,821	10,019,923	10,100,700
Minnesota	222,844	223,376	223,587	204,558	200,190	203,282	207,846	204,577
New York	3,570,221	3,541,288	3,457,816	3,420,398	3,444,814	3,511,654	3,476,534	3,428,569
Ohio	4,242,702	4,160,853	4,105,531	4,036,441	4,069,454	4,066,331	4,101,553	4,037,445
Pennsylvania	224,262	234,963	234,483	231,536	232,468	233,111	235,324	233,669
Wisconsin	2,396,147	2,408,192	2,410,832	2,418,094	2,562,540	2,529,981	2,658,063	2,712,278
Ontario	6,813,337	7,317,524	7,650,414	8,064,667	8,950,267	9,555,896	10,168,222	10,879,768
Total Population	33,425,364	33,922,599	34,116,395	34,334,613	36,390,138	36,598,502	38,252,815	38,968,987

Table 3. Total Population in the Great Lakes States and Ontario from 1971 to 2006.

Source: United Status Census Bureau and Statistics Canada

Total Population around each Great Lake

	1971	1976	1981	1986	1991	1996	2001	2006
Superior	621,342	636,166	634,723	599,218	597,198	604,314	597,908	590,295
Michigan	11,612,395	11,704,666	11,747,052	11,780,684	12,509,795	12,220,287	12,999,125	13,095,085
Huron	2,454,075	2,616,270	2,711,185	2,721,926	2,973,575	2,998,756	3,147,612	3,233,157
Erie	11,836,856	11,743,266	11,592,423	11,465,682	11,894,835	11,879,720	12,169,921	12,217,235
Ontario	6,900,696	7,222,230	7,431,013	7,767,104	8,414,735	8,895,424	9,338,248	9,833,214
Total for All	33,425,364	33,922,599	34,116,395	34,334,613	36,390,138	36,598,502	38,252,815	38,968,987

Table 4. Total Population around each Great Lake and associated watersheds from both Ontario and Great Lake States from 1971 to 2006.
Source: United Status Census Bureau and Statistics Canada

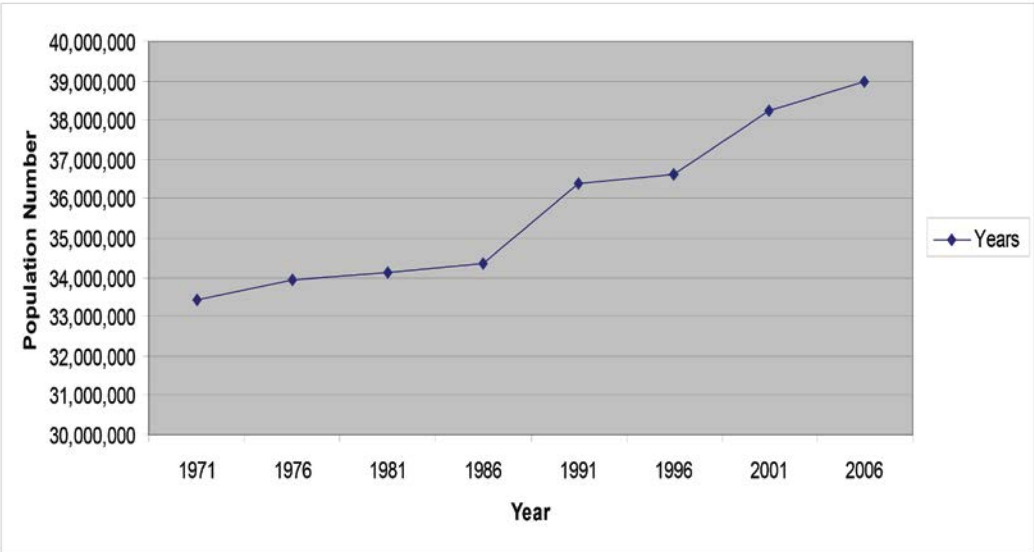

Figure 1. Total Population in the Great Lakes Region from 1971 to 2006.
Source: United Status Census Bureau and Statistics Canada

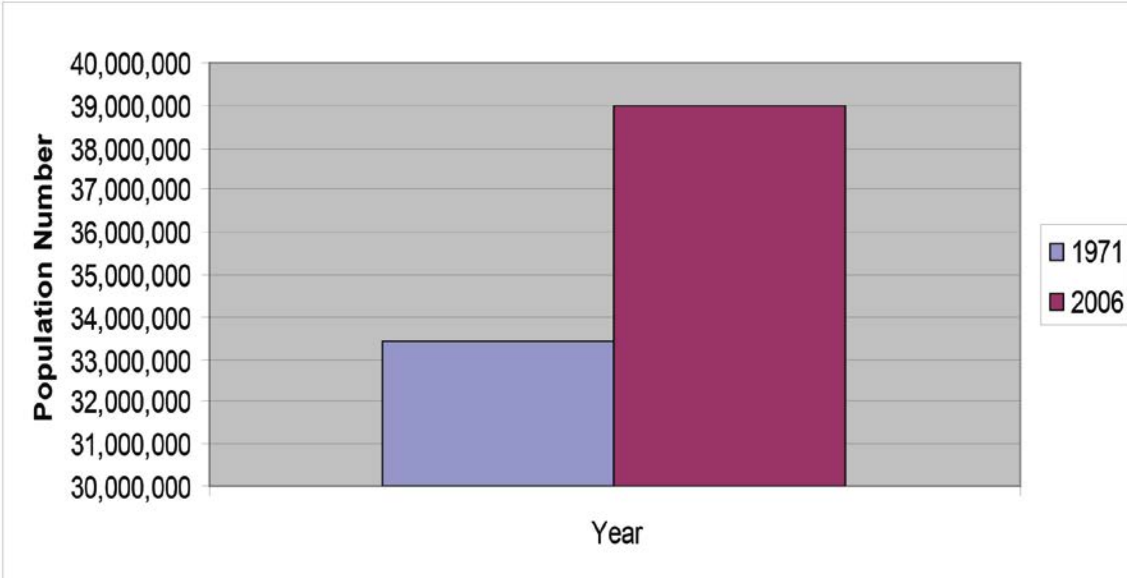

Figure 2. Long-Term Trend Comparison of the Great Lakes Region between 1971 and 2006.
Source: United Status Census Bureau and Statistics Canada

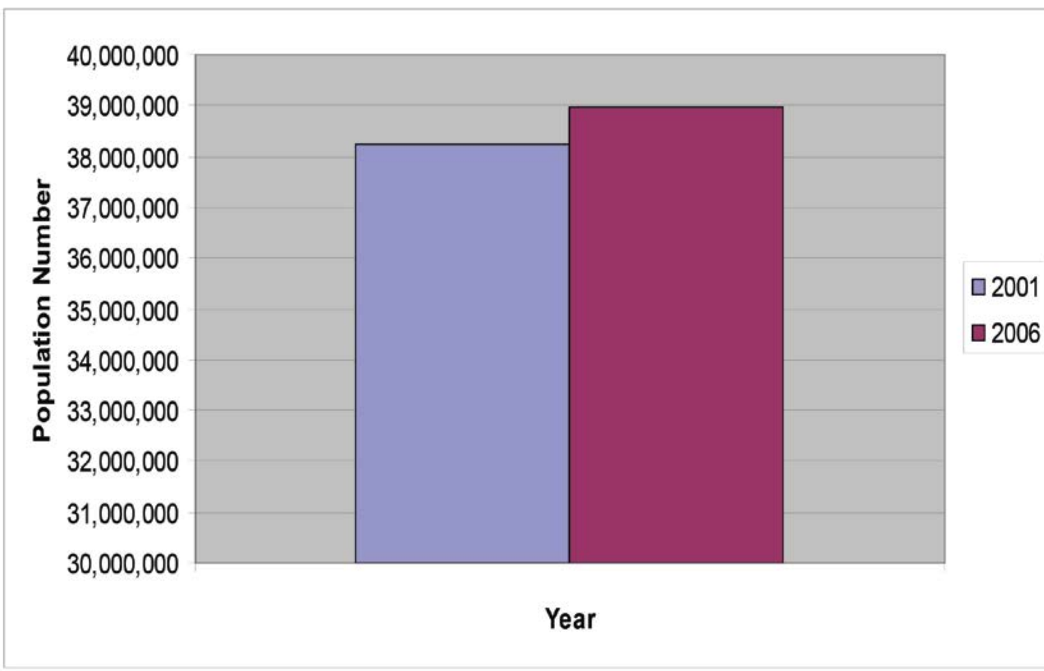

Figure 3. Short-Term Trend Comparison of the Great Lakes Region from 2001 to 2006.
Source: United Status Census Bureau and Statistics Canada

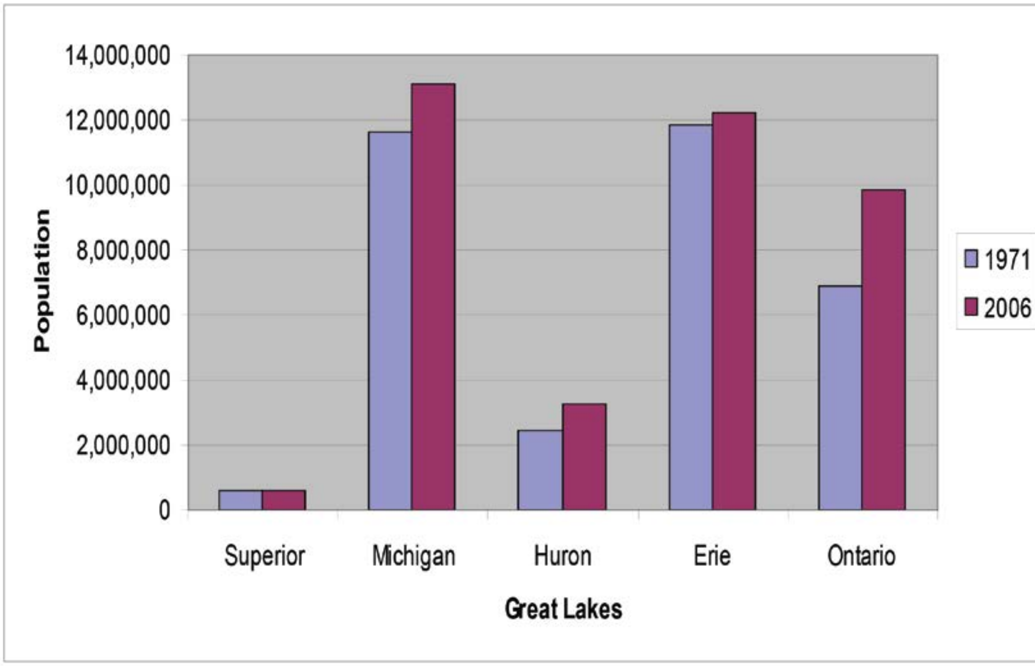

Figure 4. Comparison of the population around each of the Great Lakes and associated watershed in both the eight of the Great Lakes states and Ontario in 1971 to 2006.
Source: United Status Census Bureau and Statistics Canada

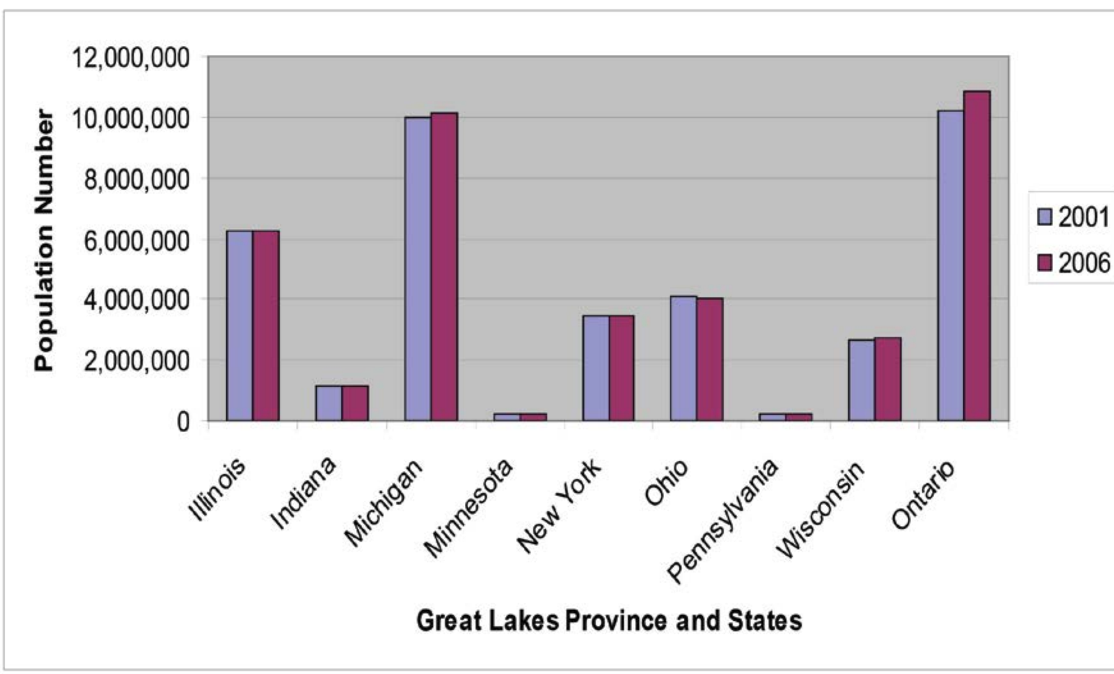

Figure 5. Comparison of the Population in the Great Lakes States and Ontario in 2001 and 2006.
Source: United Status Census Bureau and Statistics Canada

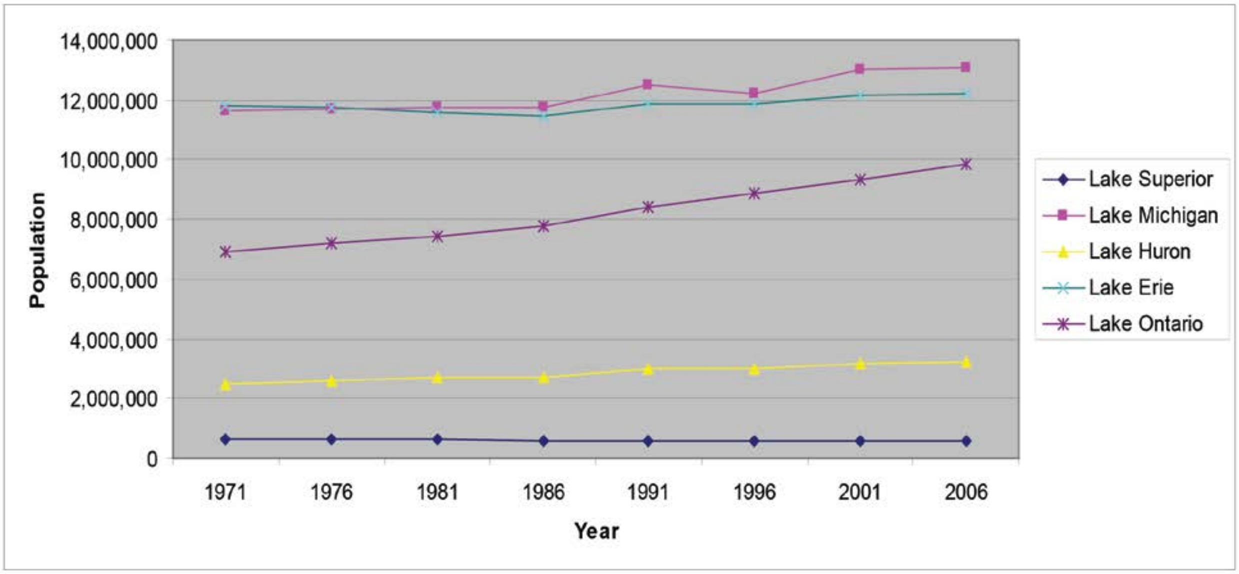

Figure 6. Total Population around each Great Lake and Associated Watersheds from both Ontario and the Great Lakes States in 1971 to 2006.
Source: United Status Census Bureau and Statistics Canada

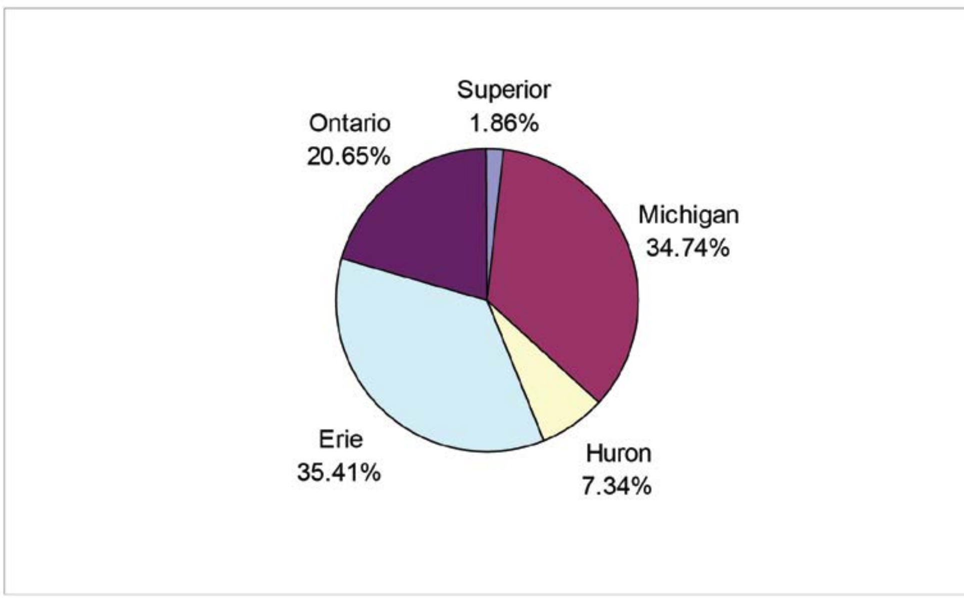

Figure 7. Percentage of the Human Population Found in Each Great Lake and Associated Watershed in the Great Lakes Region in 1971.
Source: United Status Census Bureau and Statistics Canada

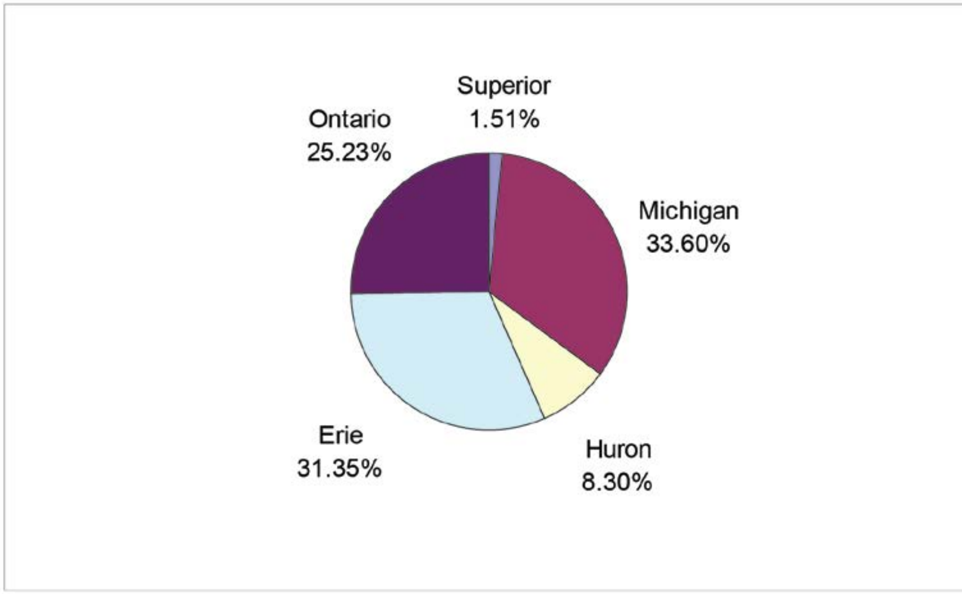

Figure 8. Percentage of the Human Population Found in Each Great Lake and Associated Watershed in the United States in 2006.
Source: United Status Census Bureau and Statistics Canada

Ice Duration on the Great Lakes

Editor's Note (2009)
This indicator was last updated in 2007. Since that time, re-evaluation of the information presented suggests that the trend would be better represented as Unchanging rather than Deteriorating. Also, this report represents only one indicator relevant to the analysis of climate change in the Great Lakes basin, and extrapolation to generalized conclusions about climate change is not warranted.

Much additional information about climate change and links to supporting web pages are available through:

Environment Canada: http://www.ec.gc.ca/climat-climate/default.asp?lang=En&n=E584B5CF-1 or http://www.ec.gc.ca/climat-climate/default.asp?Lang=Fr&n=E584B5CF-1

U.S. Environmental Protection Agency: http://www.epa.gov/climatechange/

Great Lakes Information Network: http://www.great-lakes.net/envt/refs/cchange.html

Overall Assessment
Status: Mixed (Fair)
Trend: Deteriorating (with respect to climate change)

Lake-by-Lake Assessment
Individual lake basin assessments were not prepared for this report.

Purpose

- To assess the ice duration, and thereby the temperature and accompanying physical changes to each lake over time, in order to infer the potential impact of climate change.
- The Ice Duration indicator is used in the Great Lakes indicator suite as a State indicator in the Landscape and Natural Processes top level reporting category.

Ecosystem Objective
This indicator is used as a potential assessment of climate change, particularly within the Great Lakes basin. Changes in water and air temperatures will influence ice development on the Lakes and, in turn, affect coastal wetlands, nearshore aquatic environments, and inland environments.

Ecological Condition
Background
Air temperatures over a lake are one of the few factors that control the formation of ice on that surface. Colder winter temperatures increase the rate of heat released by the lake, thereby increasing the freezing rate of the water. Milder winter temperatures have a similar controlling effect, only the rate of heat released is slowed and the ice forms more slowly. Globally, some inland lakes appear to be freezing up at later dates, and breaking-up earlier, than the historical average, based on a study of 150 years of data (Magnuson et al. 2000). These trends add to the evidence that the earth has been in a period of global warming for at least the last 150 years.
The freezing and thawing of lakes is a very important aspect to many aquatic and terrestrial ecosystems. Many fish species rely on the ice to give their eggs protection against predators during the late part of the ice season. Nearshore ice has the ability to change the shoreline as it can encroach upon the land during winter freeze-up times. Even inland systems are affected by the amount of ice that forms, especially within the Great Lakes basin. Less ice on the Great Lakes allows for more water to evaporate and be spread across the basin in the form of snow. This can have an effect on the foraging animals (such as deer) that need to dig through snow during the winter in order to obtain food.

Status of Ice Duration on the Great Lakes
Observations of the Great Lakes data showed no real conclusive trends with respect to the date of freeze-up or break-up. A reason for this could be that due to the sheer size of the Great Lakes, it wasn't possible to observe the

whole lake during the winter season (at least before satellite imagery), and therefore only regional observations were made (inner bays and ports). However, there were enough data collected from ice charts to make a statement concerning the overall ice cover during the season. There appears to be a decrease in the maximum ice cover per season over the last thirty years (Fig. 1).

The trends on each of the five Great Lakes show that during this time span the maximum amount of ice forming each year has been decreasing, which correlated to the average ice cover per season observed for the same time duration (Table 1). Between the 1970s and the 1990s there was at least a 10% decline in the maximum ice cover on each lake, nearly 18% in some cases, with the greatest decline occurring during the 1990s. Since a complete freeze-up did not occur on all the Great Lakes, a series of inland lakes (known to freeze every winter) in Ontario were examined to see if there was any similarity to the results in the previous studies. Data from Lake Nipissing and Lake Ramsey were plotted (Fig. 2) based on the complete freeze-over date (ice-on date) and the break-up date (ice-off date). The freeze-up date for Lake Nipissing appears to have the same trend as the other global inland lakes: freezing over later in the year. Lake Ramsey however, seems to be freezing over earlier in the season. The ice-off date for both however, appear to be increasing, or occurring at later dates in the year. These results contradict what is said to be occurring with other such lakes in the northern hemisphere (Magnuson et al. 2000).

The satellite data used in this analysis can be supplemented by on-the-ground citizen-collected data. The IceWatch program of Environment Canada's Ecological Monitoring and Assessment Network and Nature Canada have citizen scientists collecting ice-on and ice-off dates of lakes throughout the Ontario portion of the Great Lakes basin. These volunteers use the same criteria for ice-on and ice-off as does the satellite data, although the volunteers only collect data for the portion of the lake that is visible from a single vantage point on the shore. The IceWatch program began in 2000 as a continuation of a program run by the Meteorological Service of Canada. Data from this program date back to the 1850s. An analysis of data from this database and the Canadian Ice Database (Canadian Ice Services/Meteorological Service of Canada) showed that ice break-up dates were occurring approximately one day earlier every seven years between 1950 and 2004 for 341 lakes across Canada (Futter, unpublished data). The data from IceWatch are not as comprehensive as the satellite-collected data, but they do show some trends in the Great Lakes basin. From two sites with almost 100 years of data, Lake Nipissing is shown to be thawing later in the season (Fig. 3). IceWatch data from near Lake Ramsey indicate that lakes have been freezing later over the past 30 years.

Pressures

Based on the results of Figure 1 and Table 1, it seems that ice formation on the Great Lakes should continue to decrease in total cover if the predictions on global atmospheric warming are true. Milder winters will have a drastic effect on how much of the lakes are covered in ice, which in turn, will have an effect on many aquatic and terrestrial ecosystems that rely on lake ice for protection and food acquisition.

Management Implications

Only a small number of data sets were collected and analyzed for this study, so this report is not conclusive. To reach a level of significance that would be considered acceptable, more data on lake ice formation would have to be gathered. While the data for the Great Lakes is easily obtained from 1972 through the present, smaller inland lakes, which may be affected by climate change at a faster rate, should be examined. As much historical information as is available should be obtained. This data could come from IceWatch observers and the IceWatch database from throughout the Great Lakes basin. The more data that are received will increase the statistical significance of the results.

Comments from the author(s)

Increased winter and summer air temperatures appear to be the greatest influence on ice formation. Currently there are global protocols, which are being introduced in order to reduce the emission of greenhouse gases.
It would be convenient for the results to be reported every four to five years (at least for the Great Lakes), and quite

possibly a shorter time span for any new inland lake information. It may also be feasible to subdivide the Great Lakes into bays and inlets, etc., in order to get an understanding of what is occurring in nearshore environments.

Acknowledgments
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Heather.Andrachuk@ec.gc.ca.
All data analyzed and charts created by the author.

Information Sources

Magnuson, J.J., Robertson, D.M., Benson, B.J., Wynne, R.H., Livingston, D.M., Arai, T., Assel, R.A., Barry, R.G., Carad, V., Kuusisto, E., Granin, N.G., Prowse, T.D., Stewart, K.M., and Vuglinski, V.S. 2000. Historical trends in lake and river ice covering the Northern Hemisphere. Science 289(9):1743-1746.

Ice charts obtained from the National Oceanic and Atmospheric Administration (NOAA) and the Canadian Ice Service (CIS).

Data for Lake Nipissing and Lake Ramsey obtained from Walter Skinner, Climate and Atmospheric Research, Environment Canada-Ontario Region.

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Table 1. Mean ice coverage, in percent, during the corresponding decade.
Source: National Oceanic and Atmospheric Administration.

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The red line represents the percentage of maximum ice cover and the blue line represents the date of maximum ice cover.
Source: National Oceanic and Atmospheric Administration.
Figure 2. Ice-on and ice-off dates for Lake Nipissing (red line) and Lake Ramsey (blue line).
Data were smoothed using a 5-year moving average.
Source: Climate and Atmospheric Research and Environment Canada.
Figure 3. Ice-off dates and trend line from 1900-2000 on Lake Nipissing.
Source: Ecological and Monitoring Assessment Network (EMAN).

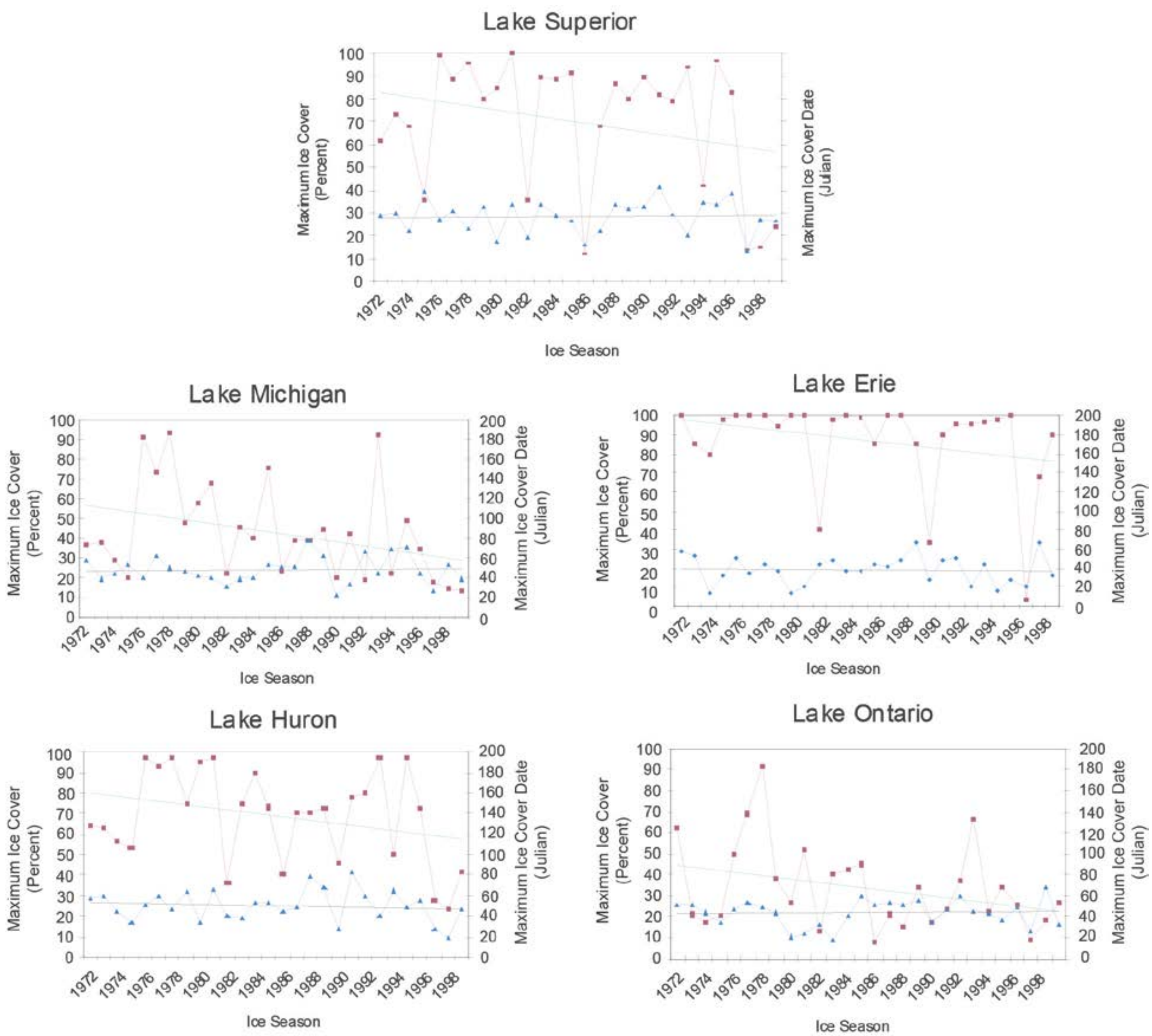
Last Updated

State of the Great Lakes 2007
The “Mixed” status term used in the 2009 report were replaced with the “Fair” status term to be consistent with definitions used for the 2011 reporting cycle.

Mean ice coverage

Lake	1970-1979	1980-1989	1990-1999	1970s to 1990s
Erie	94.5	90.8	77.3	-17.2
Huron	71.3	71.7	61.3	-10.0
Michigan	50.2	45.6	32.4	-17.8
Ontario	39.8	29.7	28.1	-11.7
Superior	74.5	73.9	62.0	-12.6

Table 1. Mean ice coverage, in percent, during the corresponding decade.
Source: National Oceanic and Atmospheric Administration.



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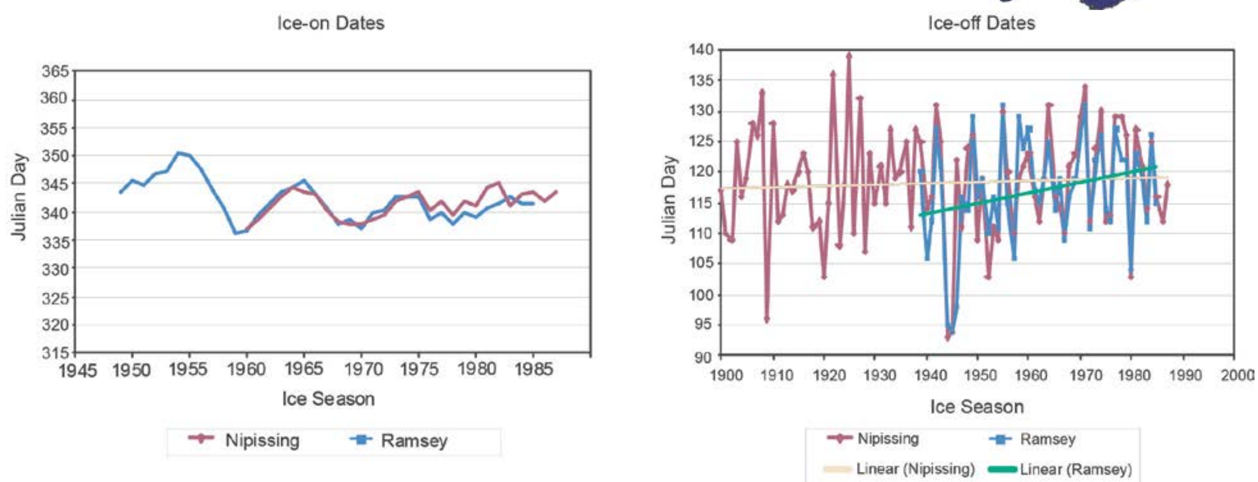

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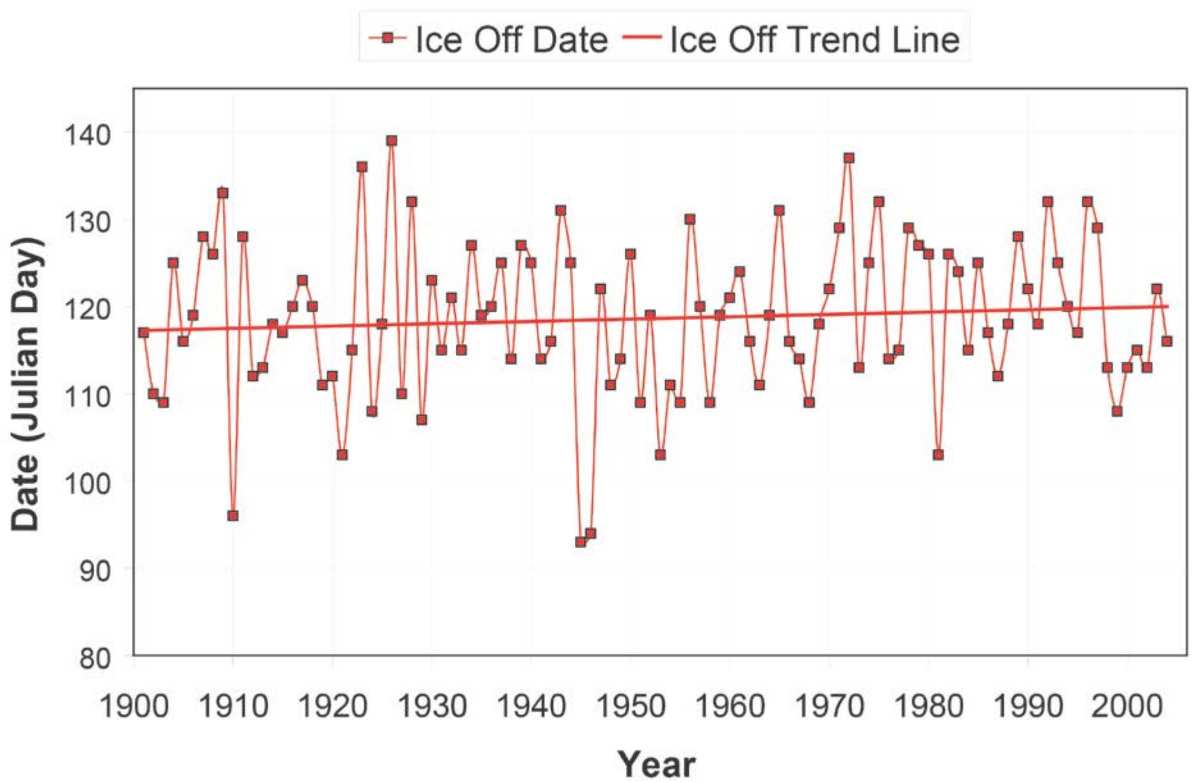

Figure 3. Ice-off dates and trend line from 1900-2000 on Lake Nipissing.
Source: Ecological and Monitoring Assessment Network (EMAN).

Inland Water Quality Index

Overall Assessment
Status: Fair
Trend: Undetermined
Rationale: The average Water Quality Index (WQI) value for 95 Canadian tributaries to the Great Lakes was 70/100.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Undetermined
Rationale: Average WQI value for 9 tributaries was 80/100.

Lake Michigan
Status: Undetermined
Trend: Undetermined

Lake Huron
Status: Good
Trend: Undetermined
Rationale: Average WQI value for 29 tributaries was 83/100.

Lake Erie
Status: Fair
Trend: Undetermined
Rationale: Average WQI value for 18 tributaries was 45/100.

Lake Ontario
Status: Fair
Trend: Undetermined
Rationale: Average WQI value for 33 tributaries was 66/100.

Other Spatial Scales
St. Lawrence River
Status: Good
Trend: Undetermined
Rationale: Average WQI value for 6 tributaries was 81/100.

Purpose
- To communicate the overall water quality status of Great Lakes tributaries with the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI).
- To infer the influence of land use activities on the surface water quality of streams in the Great Lakes basin.
- To provide context for the effects of tributary water quality on Great Lakes aquatic ecosystems, particularly the nearshore.
- The Inland Water Quality Index indicator report is used in the Great Lakes indicator suite as a Pressure indicator in the Pollution and Nutrients top level reporting category.

Ecosystem Objective

This indicator supports the objective of ensuring that surface waters in the Great Lakes basin are of a quality that is protective of aquatic life.

Ecological Condition

Measure

The WQI (CCME 2011*b*) provides a mathematical framework for synthesizing water quality monitoring results for multiple samples and parameters into a single value representing overall water quality conditions at a given site. The WQI is based on three measures (factors) of compliance with water quality criteria (guidelines and objectives) for the protection of aquatic life. The first factor (scope) measures the percentage of the number of parameters that comply with water quality criteria. The second factor (frequency) measures the percentage of individual water quality tests that comply with criteria. The third factor (magnitude) measures by how much criteria are exceeded. The three factors are combined into a single unitless value between 0 and 100 where higher numbers indicate better water quality. Computation of the WQI is described in detail in CCME (2001*a*,*b*). The sensitivity of the WQI to user-driven variations in formulation and application has been studied by Khan et al. (2004), Davies (2006), Gartner Lee Limited (2006), Statistics Canada (2007), de Rosemond et al. (2009), and Kilgour and Associates Limited (2009).

For this SOLEC indicator, WQI values were calculated using measurements of total concentrations of eight water quality parameters: ammonia (unionized), chloride, copper, iron, nitrate, nitrite, phosphorus and zinc (Table 1). Water quality data (2002-2009) were acquired from the Ontario Provincial Water Quality Monitoring Network (OMOE 2011). The most downstream monitoring site on each stream draining to the Great Lakes was selected, including tributaries to the Great Lake connecting channels and the St. Lawrence River. The most recent four years of results were used for the index calculations. For most (83/95) sites the 2006-2009 data were used. The 2002-2005 data were used for some (12/95) sites that were monitored infrequently (< 10 samples) between 2006 and 2009. Sources of the water quality criteria include CCME water quality guidelines for the protection of aquatic life (CCME 2011*a*) and the Ontario interim provincial water quality objective for total phosphorus (OMOE 1994).

Endpoint

The WQI calculates a value between 0 and 100 for each monitoring site. The developers of the WQI recommended fitting the calculated values into five categories that describe water quality conditions: Excellent (95-100); Good (80-94); Fair (65-79); Marginal (45-64); and Poor (0-44). The category range describes sites where the water quality complies with water quality criteria virtually all of the time (Excellent) or hardly any of the time (Poor).

For this SOLEC indicator, the five original categories developed by CCME were dissolved into three descriptive categories: Good (80-100), Fair (45-79) and Poor (0-44).

Background

The Provincial Water Quality Monitoring Network (PWQMN) collects stream water quality information from hundreds of sites across Ontario in partnership with Ontario's Conservation Authorities. Most of these sites are located in the Great Lakes basin, and many are located at or near the outlets of tributaries to the Great Lakes. Stream water samples from each site are collected approximately monthly and delivered to the Ontario Ministry of the Environment's laboratory where they are tested using consistent analytical methods for a consistent set of water quality parameters. Parameters are selected to indicate the influence of land used activities on stream water quality. For example, chloride is measured as an indicator of the influence of salt loading from winter de-icing. Field measurements including water temperature and pH are also taken at the time of sample collection using portable water quality meters. A complete set of water quality data (2002-2009) for all stream monitoring sites is available on the Ontario Ministry of the Environment public website (OMOE 2011).

Status of Water Quality in Great Lakes Tributaries

The overall water quality status of tributaries to the Great Lakes can be described as Fair (WQI_{avg}=70, n=95). 39%, 48% and 13% were categorized as having Good, Fair and Poor water quality, respectively (Figures 1 and 2).

Good water quality was found in certain tributaries to Lakes Superior, Huron and Ontario and the St. Lawrence River. Poor water quality was found in certain tributaries to Lakes Erie and Ontario. The WQI values at individual sites ranged from 7.6 (Sturgeon River, Lake Erie) to 100 (Montreal and Michipicoten Rivers, Lake Superior; Mississagi and Serpent Rivers, Lake Huron).

On a lake-by-lake basis (Figure 2), tributaries to Lake Superior (WQI_{avg}=80, n=9), Lake Huron (WQI_{avg}=83, n=29) and the St. Lawrence River (WQI_{avg}=81, n=6) can be described as having Good water quality. Tributaries to Lake Erie (WQI_{avg}=45, n=18) and Lake Ontario (WQI_{avg}=66, n=33) had Fair water quality.

Linkages

Calculated WQI values show a statistically significant negative association with two measures of watershed development: percent watershed area occupied by human land uses and road density (Figure 3). This suggests that overall water quality in Great Lakes tributaries, as represented by WQI values, is influenced by human land uses where minimally developed watersheds have the highest WQI values.

The WQI values indicate the potential for substances in stream water to impact aquatic life based on compliance with water quality criteria. However, the values are not a direct measure of impacts to aquatic communities, such as changes in fish and benthic invertebrate communities. The WQI values also infer the potential for discharge from tributaries to impact the Great Lakes, particularly at the tributary mouths and nearby nearshore areas.

Management Challenges/Opportunities

The WQI was developed to communicate water quality information to general audiences. It is not intended to replace rigorous technical analysis of water quality data for water resources management.

The water quality of many Great Lakes tributaries has been monitored since the 1960s. Calculation of WQI values for historical monitoring data is possible and could support an assessment of trends in the WQI over time. However, some of the anticipated challenges include: inconsistent laboratory methods and detection limits over time and incomplete datasets (missing parameters, missing years).

The WQI could be applied to water quality results from U.S. tributaries to the Great Lakes depending on the availability of the data. An anticipated challenge is that WQI results are not directly comparable between jurisdictions where different water quality parameters and criteria are used. This will be the case for any index.

Comments from the author(s)

The CCME WQI is used extensively in Canada, most notably for the annual Canadian Environmental Sustainability Indicators report (Environment Canada 2011). The WQI has also been used and adapted by some of Ontario's Conservation Authorities for their watershed report cards. OMOE currently does not use the WQI for reporting; however, given its widespread use, the author accepts that it is a logical starting point for developing an indicator of Great Lakes tributary water quality for SOLEC.

The strengths and weaknesses of the WQI have been, and continue to be, discussed. A few reports on the sensitivity of the WQI are posted on the CCME website. The Gartner Lee Limited (2006) report is particularly helpful in understanding the nuances of the WQI.

Most of the monitoring sites in the Ontario PWQMN are purposefully located in populated areas and areas where water quality impacts from varying land uses are known or expected. Minimally-impacted reference watersheds are likely under-represented in this SOLEC indicator.

The sites selected for this SOLEC indicator likely under-represent the upper Great Lakes, especially Lake Superior. A redundancy analysis or similar approach could be considered for future iterations of this indicator to omit some sites from the lower Great Lakes such that each of the Lakes is more equally represented.

Human influence is not the only cause of exceedances of water quality criteria. Parameters can exceed their respective criteria in areas that are naturally rich in a given nutrient or metal. No considerations for naturally-occurring elevated concentrations of some parameters were made in the WQI calculations.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Clarifying Notes: Water quality data for U.S. tributaries to the Great Lakes were unavailable for WQI calculations.

Acknowledgments
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Information Sources

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Information on the Ontario Provincial Water Quality Monitoring Network (PWQMN) – including a map of monitoring sites can be found here: http://www.ene.gov.on.ca/environment/en/monitoring_and_reporting/provincial_water_quality_monitoring_network/index.htm.

PWQMN monitoring sites (ESRI ArcGIS shapefile), 2002-2009 results (Microsoft Access and Excel) and metadata are posted on the MOE public website here: http://www.ene.gov.on.ca/environment/en/resources/collection/data_downloads/index.htm.

The WQI Calculator (Microsoft Excel, v1.1, 2011), user's manual and technical report can be downloaded here: http://www.ccme.ca/ourwork/water.html?category_id=102.

List of Tables

Table 1. Water quality criteria for the eight indicators used in the CCME Water Quality Index (WQI) calculations.
Source: Ontario Ministry of the Environment

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Source: Ontario Ministry of the Environment
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Source: Ontario Ministry of the Environment

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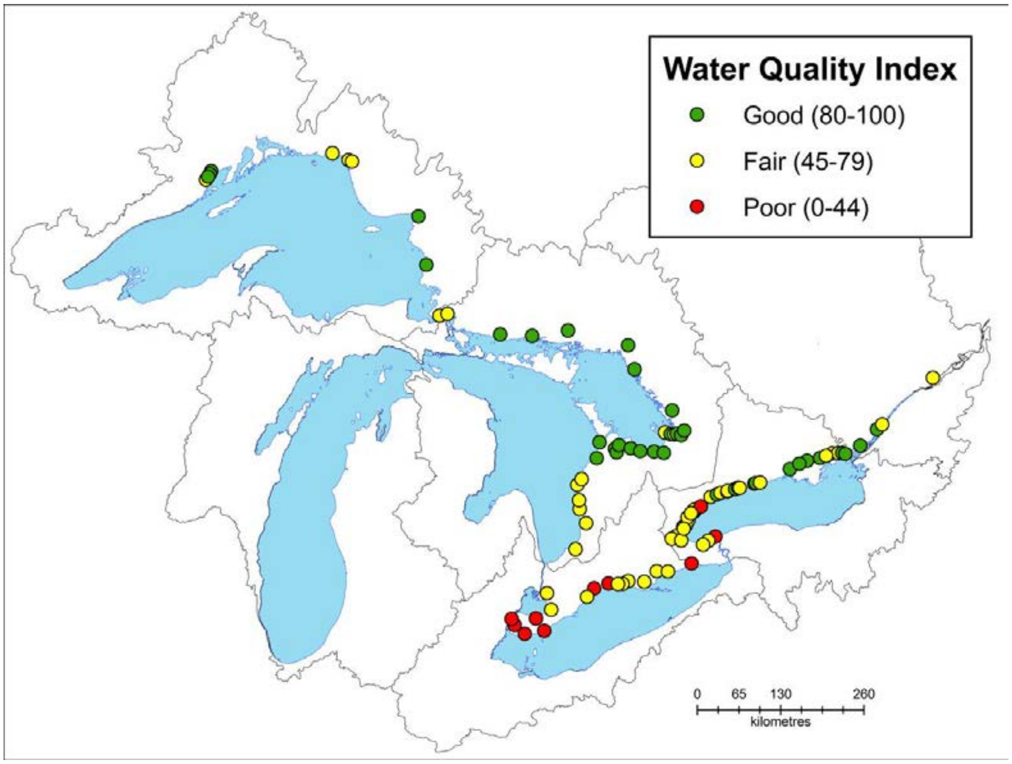
Water quality criteria

Indicator	Criterion	Source
Ammonia (unionized)	0.0152 mg L^{-1}-N	CCME
Chloride	110 mg L^{-1}	CCME (draft)
Copper	2 μg L^{-1} at water hardness of 0-120 mg L^{-1}-$CaCO_3$ 3 μg L^{-1} at water hardness of 120-180 mg L^{-1}-$CaCO_3$ 4 μg L^{-1} at water hardness of >180 mg L^{-1}-$CaCO_3$	CCME
Iron	300 μg L^{-1}	CCME
Nitrate	2.9 mg L^{-1}-N	CCME
Nitrite	0.06 mg L^{-1}-N	CCME
Phosphorus	0.03 mg L^{-1}	OMOE
Zinc	30 μg L^{-1}	CCME

Sources: CCME = Water quality guidelines for the protection of aquatic life (CCME 2011*a*); OMOE = Interim provincial water quality objective (OMOE 1994).

Table 1. Water quality criteria for the eight indicators used in the CCME Water Quality Index (WQI) calculations.
Source: Ontario Ministry of the Environment



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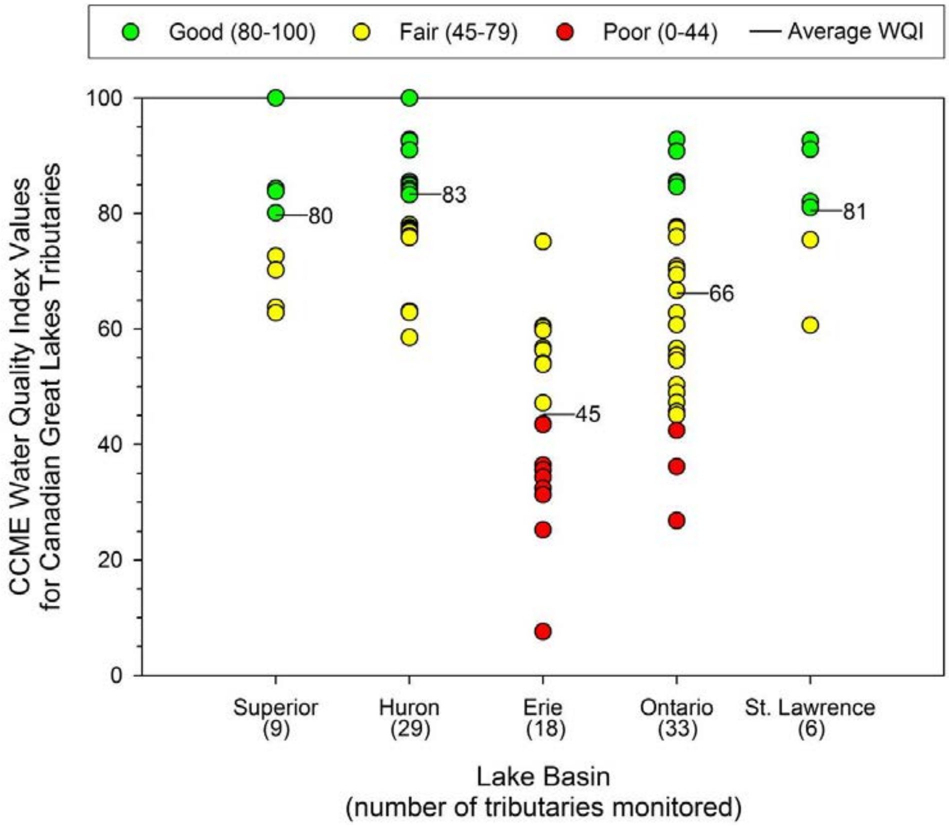

Figure 2. CCME Water Quality Index (WQI) values for Canadian Great Lakes tributaries by lake basin. Source: Ontario Ministry of the Environment

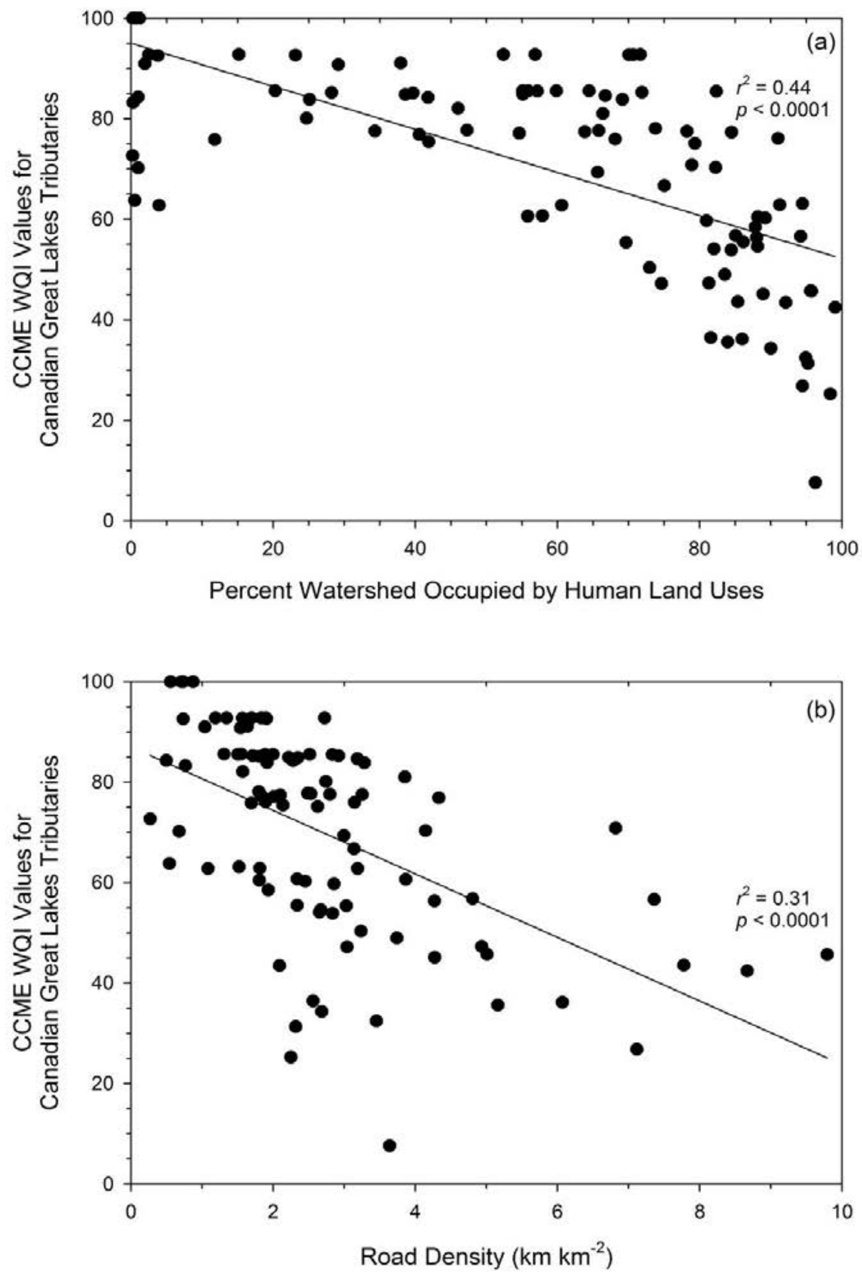

Figure 3. CCME Water Quality Index (WQI) values for Canadian Great Lakes tributaries (n=95) versus (a) percent watershed occupied by human land uses and (b) road density.
Source: Ontario Ministry of the Environment

Land Cover

Overall Assessment:
Status: **Mixed**
Trend: **Undetermined**
Rationale: **Low-intensity development increased 33.5%, road area increased 7.5%, and forest decreased 2.3% from 1992 to 2001. Agriculture lost 210,000 ha (520,000 acres) of land to development. Approximately 50% of forest losses were due to management and 50% to development**

Lake-by-Lake Assessment:
Lake Superior
Status: Good
Trend: Undetermined
Rationale: Lowest conversion rate of non-developed land to developed and highest conversion rate of non-forest to forest. Of the 4.2 million ha (10.4 million acre) watershed area in the U.S. basin, 1,676 ha (4141 acres) of wetland, 6,241 ha (15,422 acres) of agricultural land, and 14,300 ha (35,336 acres) of forest land were developed between 1992 and 2001.

Lake Michigan
Status: Mixed
Trend: Undetermined
Rationale: Intermediate to high rate of land development conversions. Of the 1.2 million ha (3.0 million acre) watershed area, 9,724 ha (24,028 acres) of wetland, 78,537 ha (193,624 acres) of agricultural land, and 57,529 ha (142,157 acres) of forest land were developed between 1992 and 2001.

Lake Huron
Status: Fair
Trend: Undetermined
Rationale: Second lowest rate of conversion of land to developed. Of the 4.1 million ha (10.1 million acre) watershed area in the U.S. basin, 4,314 ha (10,660 acres) of wetland, 17,881 ha (44,185 acres) of agricultural land, and 17,730 ha (43,812 acres) of forest land were developed between 1992 and 2001.

Lake Erie
Status: Poor
Trend: Undetermined
Rationale: Highest conversion rate of non-developed to developed area. Of the 5.0 million ha (12.4 million acre) watershed area in the U.S. basin, 3,352 ha (8,283 acres) of wetland, 52,502 ha (129,735 acres) of agricultural land, and 27,869 ha (68,866 acres) of forest land were developed between 1992 and 2001.

Lake Ontario
Status: Mixed
Trend: Undetermined
Rationale: Intermediate to high conversion rate of non-developed to developed land use coupled with the lowest rates of wetland development. Of the 3.4 million ha (8.4 million acre) watershed area in the U.S. basin, 458 ha (1,132 acres) of wetland, 24,883 ha (61,487 acres) of agricultural land, and 20,670 ha (51,076 acres) of forest land were developed between 1992 and 2001.

Other Spatial Scales
This indicator pertains primarily to risk of degradation of the coastal margins and nearshore waters. The importance

of land use condition (especially as a source of nutrients and contaminants) declines with increasing distance away from the coastal margin since substances are typically transported by the water contributed by tributaries.

Purpose

- Assess the status of land cover within the Great Lakes basin
- Infer the potential impact (risk of degradation) of land cover and land cover change on Great Lakes ecosystem health
- The Land Cover indicator is used in the Great Lakes indicator suite as a State indicator in the Landscapes & Natural Processes category.

Ecosystem Objective

Sustainable development is a generally accepted land use goal for the Great Lakes basin. This indicator supports Annex 13 of the 1987 Great Lakes Water Quality Agreement (GLWQA).

Ecological Condition

A common land cover classification was developed to allow an integrated comparison of land use in both Canada and the U.S. between 1990 and 2001. This involved integrating the detailed but distinct classifications of the US system (24 land use classes as delineated by Wolter 2006) with the Canadian system (The Ontario Ministry of Natural Resources' Ontario Provincial Land Cover, consisting of 27 (in 1990) or 28 (in 2000) classes). The resulting unified assessment was comprised of 6 land classes (Developed, Agriculture, Grassland/ Shrubland, Forest, Wetland, Water (Ciborowski et al. 2011)). Using this common land cover classification for the year 2000, we calculated the total and proportional amounts of each land cover class by lake and across the Great Lakes Basin (Table 1).

There were large variations in proportional distribution of each type of land cover among lakes, with the Lake Superior basin being predominately forested (Fig. 1) and Lake Erie predominantly agricultural (Fig 2). Forest and Agricultural land uses were more evenly distributed in lakes Michigan (Fig. 3) and Ontario (Fig. 4). The relative amount of developed land ranged from a low of 2.1% in the Lake Superior basin to 13.4% in the Lake Erie basin. The large variation in land use among lakes reflects the underlying climatic and soil gradients across the Great Lakes Basin that have historically constrained the conversion of the native vegetation (forest or grassland) to agricultural land use.

Between two nominal time periods (1992 and 2001), the U.S. portion of the Great Lakes watershed has undergone substantial change in many key land use/land cover (LU/LC) categories. Of the total change that occurred (798,755 ha, 2.5% of watershed area), salient transition categories included a 33.5% increase in area of low-intensity development, 7.5% increase in road area, and a decrease of forest area by over 2.3%, the largest LU/LC category and area of change within the watershed. More than half of the forest losses involved transitions into early successional vegetation (ESV), and hence, will likely remain in forest production of some sort. However, nearly as much forest area was, for all practical purposes, permanently converted to developed land. Likewise, agriculture lost over 50,000 more hectares (125,000 acres) of land to development than forestland, much of which involved transitions into urban/suburban sprawl. Approximately 210,068 ha (81%) of agricultural lands were converted to development, and 16.3% of that occurred within 10 km of the Great Lakes shoreline.

LU/LC transitions between 1992 and 2001 within near-shore zones of the Great Lakes (0-1, 1-5, 5-10 km) largely paralleled those of the overall watershed. While the same transition categories dominated, their proportions varied by buffered distance from the lakes. Within the 0-1 km zone from the Great Lakes shoreline, conversions of forest to both ESV (9,087 ha, 5.0% of total category change (TCC)) and developed land (8,657 ha, 5.6% of TCC) were the largest transitions, followed by conversion of 3,935 ha (1.9% of TCC) of agricultural land to developed. For the 1-5 km zone inland from the shore, forest to developed conversion was the largest of the three transitions (17,049 ha, 11.0% of TCC), followed by agricultural to developed (14,279 ha, 6.8% of TCC) and forest to ESV (13,116 ha, 7.3% of TCC). Within the 5-10 km zone from shoreline, transition category dominance was most similar to the trend for the whole watershed, with 16,113 ha (7.7% of TCC) of agriculture converted to developed, 14,516 ha (8.0% of TCC) of forest converted to ESV, and 14,390 ha (9.3% of TCC) of forestland being developed by 2001. When all buffers from shoreline out to 10 km are combined, the forest to developed transition category was the largest (40,099 ha, 25.9% of TCC), followed by forest to ESV (36,726 ha, 20.3% of TCC), and agricultural to developed (34,328 ha, 16.3% of TCC).

Contrary to previous decadal estimates showing an increasing forest area trend from the early 1980s to the early 1990s, due to agricultural abandonment and transitions of forest land away from active management, there was an overall decrease (~2.3%) in forest area between 1992 and 2001. Explanation of this trend is largely unclear. However, increased forest harvesting practices in parts of the region coupled with forest clearing for new developments may be overshadowing gains from the agricultural sources observed in previous decades.

The distribution of land use classes for each Great Lake is shown in Figures 1-5. When analyzed on a lake-by-lake basis, Lake Michigan's watershed naturally has shown the greatest area of change from 1992 to 2001 (286,587 ha, ~2.5%), because its watershed is entirely within the U.S., and hence, the largest analyzed. Lake Michigan's watershed leads in all LU/LC transition categories but two: 1) miscellaneous vegetation to flooded and 2) ESV to forest (Fig. 3). When normalized by area, however, Lake Michigan's proportion of LU/LC change is intermediate when compared to the other Great Lakes watersheds on the U.S. side of the border. Although Lake St. Clair is not a Great Lake, and the U.S. part of its watershed is largely metropolitan (Fig. 2), Lake St. Clair's watershed shows the highest rates of change into development from wetland, ESV, agriculture, and forest sources.

Of the Great Lakes, Lake Erie's watershed (Fig. 2) shows the greatest proportion of land conversion to development (87,077 ha, 1.74%), while Lake Superior's watershed (Fig. 1) had the lowest proportion (20,351 ha, 0.48%). For example, Lake Erie's watershed had the highest proportion of agricultural land conversion to development. However, Lake Ontario's watershed (Fig. 4) showed the greatest proportion of forest conversion to development. Lake Superior's watershed reflects a high proportion of lands under forest management in that it has both the highest proportion of forest conversion to ESV and vice-versa. Lastly, Lake Huron's watershed (Fig. 5) had the highest proportion of wetlands being converted to development, followed closely by watersheds for Lake Michigan and Lake Erie.

Linkages

The importance of land use condition (especially as a source of nutrients and contaminants) is greatest at shorelines and coastal margins, and declines with increasing distance away from the shore since substances are typically transported by the water contributed by tributaries. Natural land cover is an indicator of good conditions because it incorporates nutrients into biomass and slows the rate of water runoff into the lakes, together with materials (sediments, pollutants) that the water transports.

Management Challenges/Opportunities

Rates of land use change provide an important integrated indicator of the degree and location of both loss and gain of natural lands, representing increases and reductions in the risks of degradation.

Comments from the author(s)

Land use changes estimated for the combined US-Canada data set between 1990 and 2000 are much more pronounced in the Canadian data set compared with the US data, with up to 10% change observed in certain categories. These changes are much greater than changes reported in the literature, and lead us to evaluate possible explanations for these differences. There are two sources of error. The first is registration error – maps not properly aligned in a common coordinate system (discussed in detail by Ciborowski et al. 2011). This can lead to displacement of images found on both maps. For example, a road running through a forest whose apparent position is offset between images is interpreted as a conversion from road to forest in on one part of the map, and a conversion from forest to road on another part. Since numerous map tiles are used to create the composite map for Canada, and the error across the map tiles appears to be non-uniform, each source image would have to be reviewed and corrected to remove the overall bias. The second, and likely more pronounced error, is the result of a change in criteria used to classify land use/land cover between 1990 and 2000. Ciborowski et al. (2011) document examples of where extensive areas mapped as ‘settlement/developed’ in 1990 are not present in the Yr 2000 map; those same areas in 2000 are mapped as forest depletion’. In other cases, roads mapped as ‘developed’ in 1990 are mapped as ‘open land’ in 2000. Yet another final example, shows an extensive area near Sudbury classified as ‘developed’ in 1990 but mapped as ‘early successional’ in 2001. The errors due to differences in classification criteria and registration between images preclude a meaningful assessment of land use change. To make such an assessment, we would recommend a reclassification of the source images from 1990, using the same criteria for the 2000 assessment (and that common criteria be developed and used for all successive interpretations of satellite data). This, coupled with the accurate georectification of the 1990 imagery, would allow an assessment of land use change compatible with the US land use change assessment conducted by Wolter, and ultimately integration across the Great Lakes Basin.

Assessing Data Quality:

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Peter Wolter, Department of Forest Ecology and Management, University of Wisconsin-Madison.

Contributors:
Members of the Great Lakes Environmental Indicators project - Gerald L. Niemi (Senior PI; NRRI, University of Minnesota Duluth), Nicholas P. Danz (University of Wisconsin – Superior), and Thomas Hollenhorst (US EPA, Mid-Continent Ecology Division National Health and Environmental Effects Research Laboratory, Duluth, MN 55804) contributed to formation of the research group that identified the need for this database. Scudder D. Mackey (Habitat Solutions NA) and Li Wang (University of Windsor) contributed to the cross-walking and amalgamation of Canadian and US-based information into a common dataset. Sandra E. George (Environment Canada, Burlington) and Mike Robertson (Ontario Ministry of Natural Resources, Peterborough, ON) were especially helpful in facilitating the licensing and acquisition of Canadian map data. The SOLEC coordinators Rob Hyde, Nancy Stadler-

Salt, Stacey Cherwaty-Pergentile (Environment Canada, Burlington, ON), and Paul Horvatin and Karen Rodriguez (US EPA GLNPO, Chicago, IL) provided the impetus for developing the concept paper on land cover that allowed us to assess the status of land cover within the Great Lakes basin, and to ultimately infer the potential impact (risk of degradation) of land cover and land cover change on Great Lakes ecosystem health.

The project on which these data were based was originally funded by the U.S. Environmental Protection Agency Science to Achieve Results (STAR) Estuarine and Great Lakes (EaGLe) program through funding to the Great Lakes Environmental Indicators (GLEI) and Reference Condition projects (U.S. EPA Agreements EPA/R-8286750 and EPA/R-82877701, respectively), and funding from the National Space and Aeronautics Administration (NAG5-11262). We additionally acknowledge funding from Environment Canada (Agreements KW405-09-1987-O and KW405-10-1831R-O) to update and expand the stress data across the entire Great Lakes Basin.

Information Sources:

Canadian LULC was derived from the Provincial Land Cover data sets: (http://www.lib.uoguelph.ca/resources/data_resource_centre/geospatial_data_resources/ontario_provincial_land_cover_database.cfm).

From 1990 and 2000; for 2000, the eastern portion of the basin south of the Canadian Shield was completed using the National Land and Water Information Service (NLWIS) coverage: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226330737632&lang=eng

U.S. LULC was based on Wolter and colleagues' work from the Great Lakes Environmental Indicators (GLEI) project (Wolter et al. 2006), which in turn were derived from the National Land Cover Dataset (NLCD).

Land cover classes and the crosswalking procedures necessary to integrate the US and Canadian databases into a common classification system are documented in Ciborowsi et al. (2011).

Ciborowski, J.J.H., G.E. Host, T.A. Brown, P. Meysembourg and L.B. Johnson. 2011. Linking Land to the Lakes: the linkages between land-based stresses and conditions of the Great Lakes. Background Technical Paper prepared for Environment Canada in support of the 2011 State of the Lakes Ecosystem Conference (SOLEC), Erie, PA. 47 p + Appendices.

Wolter, P., C.A. Johnston and G.J. Niemi. 2006. Land use land cover change in the Great Lakes basin 1992–2001. Journal of Great Lakes Research 32:607–628.

List of Tables:

Table 1. Total and relative area of land in the watershed of each Great Lake in each of six land cover classes in 2000 (Canada) and 2001 (US), and the entire Great Lakes Basin.
Source: Ciborowski et al. (2011).

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Figure 2. Distribution of land use across the Lake Erie basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes.
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Figure 3. Distribution of land use across the Lake Michigan in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes.
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Figure 4. Distribution of land use across the Lake Ontario basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes.
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Figure 5. Distribution of land use across the Lake Huron basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes.
Source: Ciborowski et al. (2011).

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Permissions and Links:
Permission to put graphics online: Yes.
Permission to link from SOLEC web site to other Agency site(s): N/A

	Lake Ontario		Lake Erie		Lake Huron		Lake Michigan		Lake Superior		Glreat Lakes	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Developed	5,828	9.3	10,732	13.4	6,926	4.9	11,799	10.1	2,660	2.1	37,948	7.2
Agriculture	22,099	35.3	52,844	65.9	33,702	23.9	42,364	36.2	1,733	1.4	15,274	29.0
Grassland/ Shrubland	2,023	3.2	696	0.9	2,452	1.7	3,193	2.7	1,242	1.0	9,608	1.8
Forest	27,280	43.5	13,032	16.2	76,640	54.4	38,516	32.9	95,818	76.7	251,285	47.8
Wetland	2,317	3.7	1,974	2.5	10,163	7.2	17,423	14.9	10,483	8.4	42,360	8.1
Water	3,116	5.0	965	1.2	11,107	7.9	3,627	3.1	13,060	10.4	31,874	6.1
Total	62,663	100.0	80,242	100.0	140,994	100.0	116,922	100.0	124,996	100.0	525,817	100.0

Table 1. Total and relative area of land in the watershed of each Great Lake in each of six land cover classes in 2000 (Canada) and 2001 (US), and the entire Great Lakes Basin.
Source: Ciborowski et al. (2011).

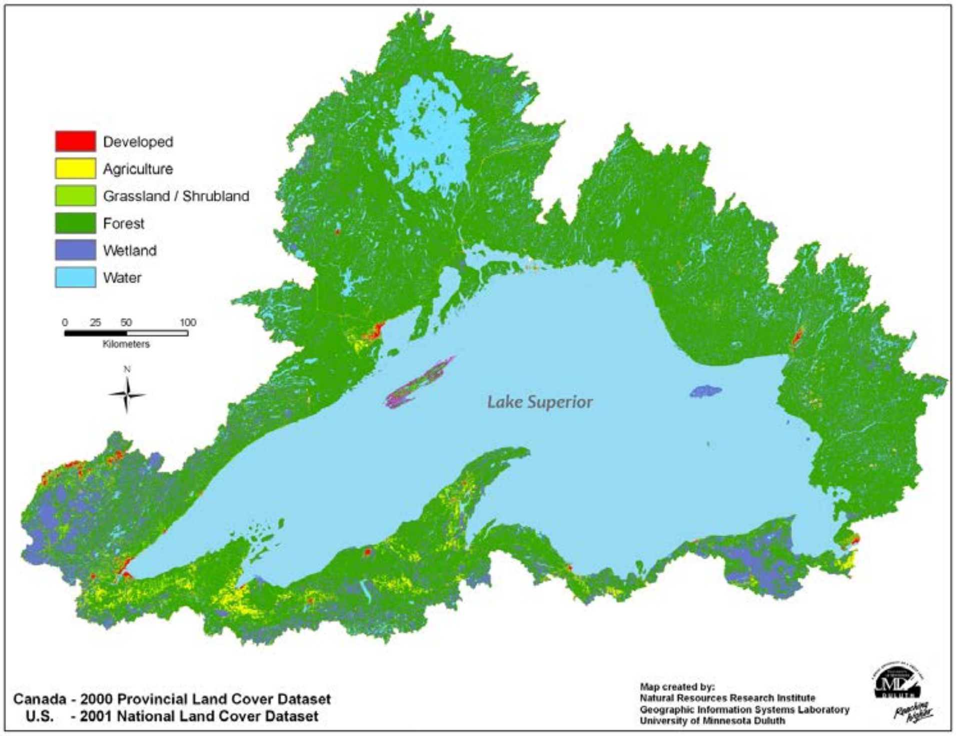

Figure 1. Distribution of land use across the Lake Superior basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes. Source: Ciborowski et al. (2011).

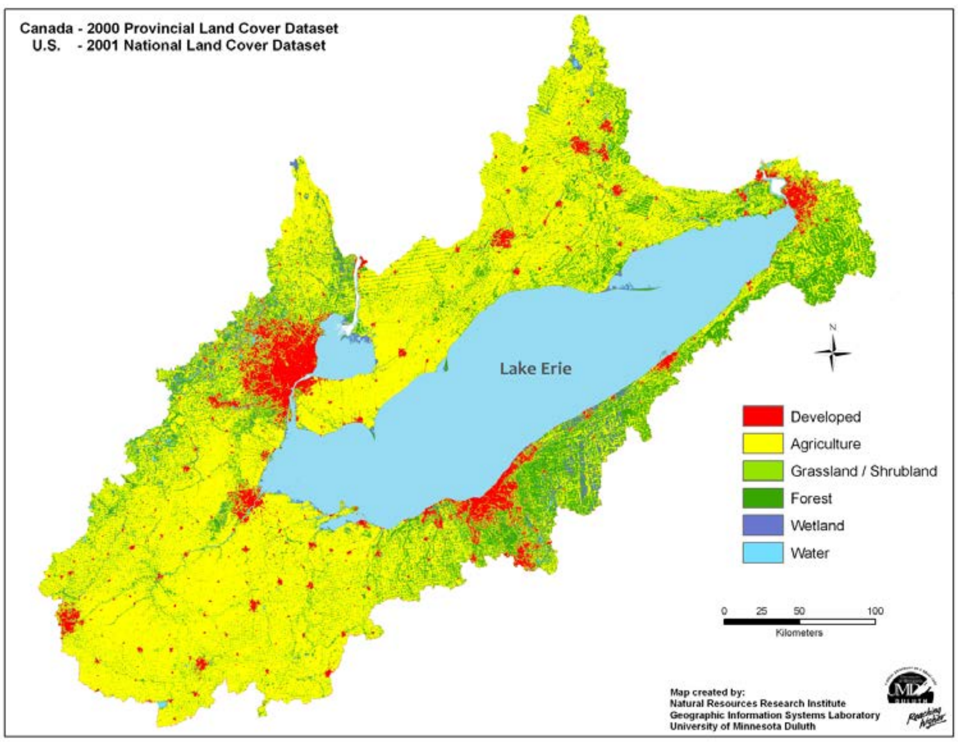

Figure 2. Distribution of land use across the Lake Erie basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes. Source: Ciborowski et al. (2011)

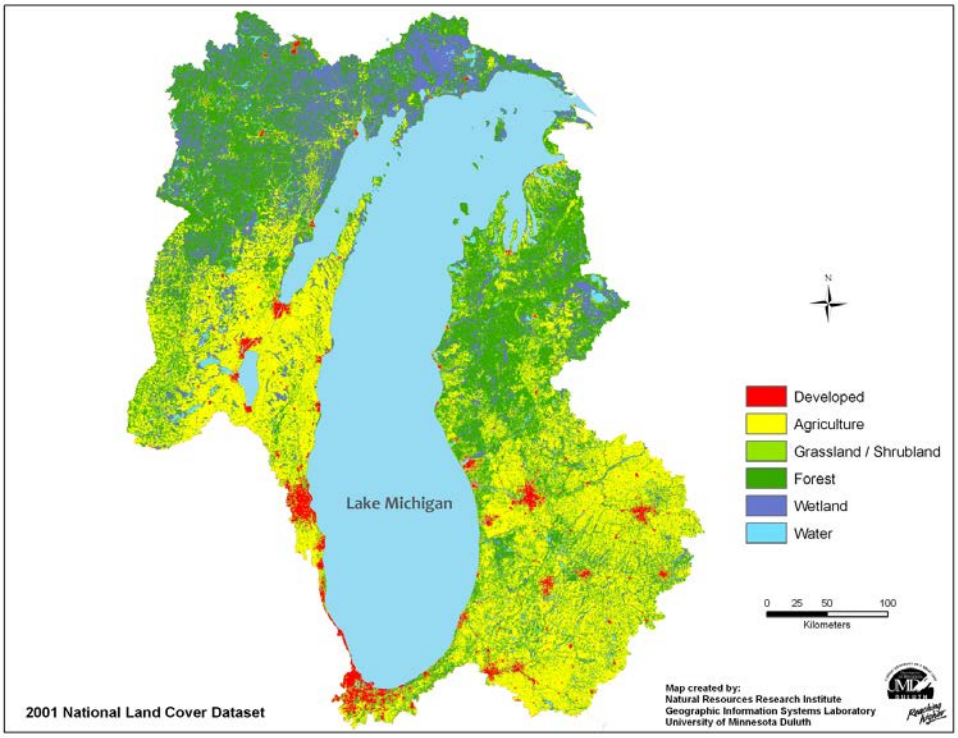

Figure 3. Distribution of land use across the Lake Michigan in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes. Source: Ciborowski et al. (2011)

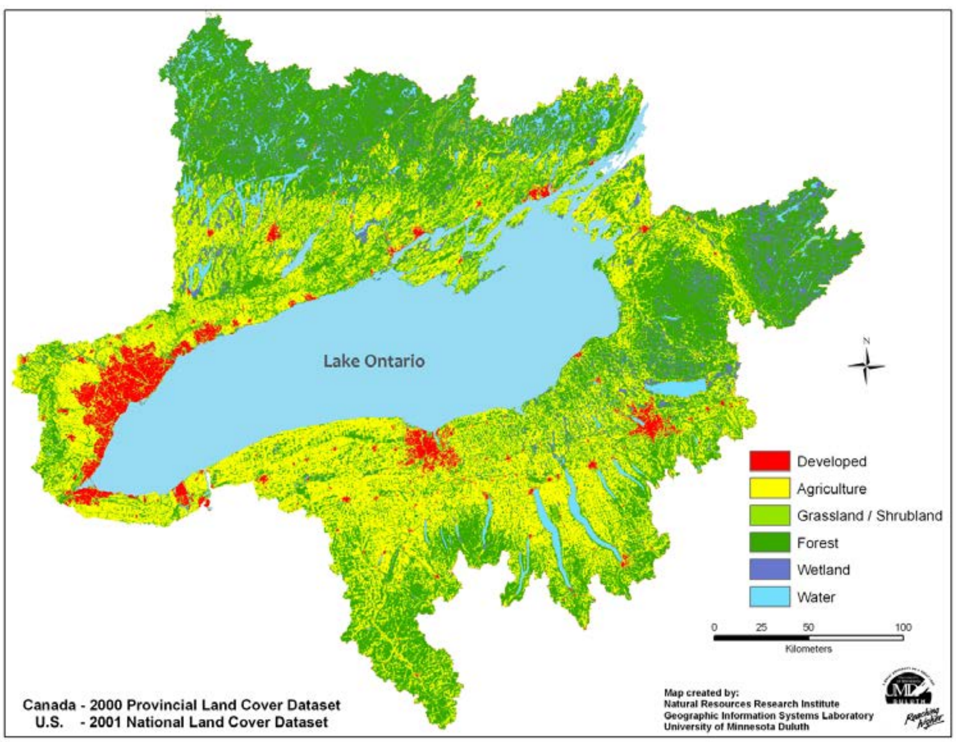

Figure 4. Distribution of land use across the Lake Ontario basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes. Source: Ciborowski et al. (2011).

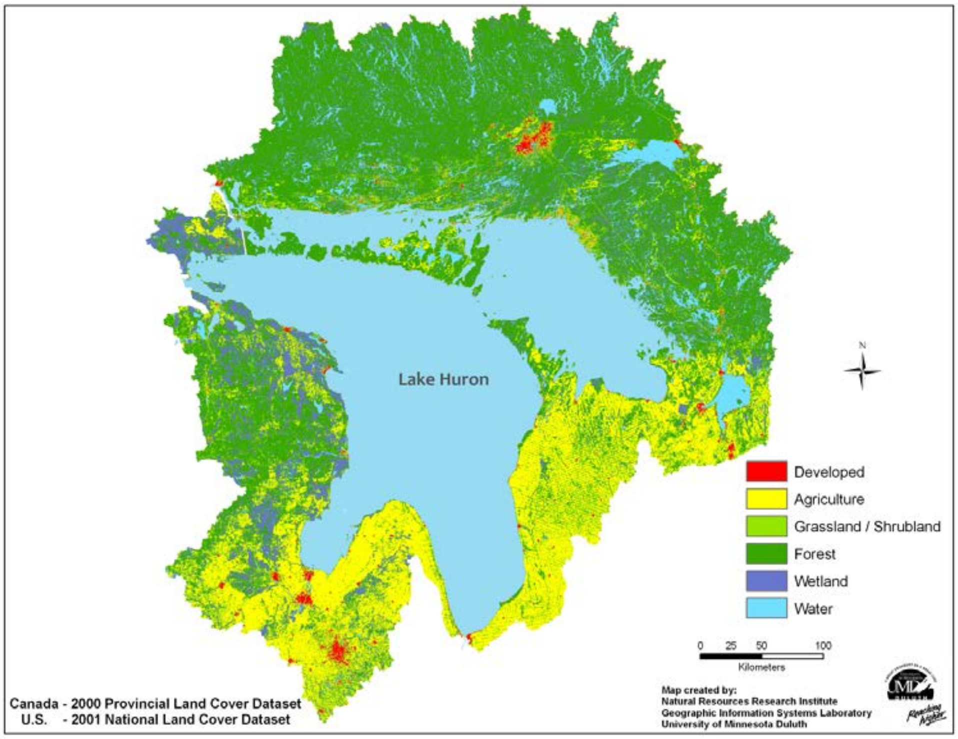

Figure 5. Distribution of land use across the Lake Huron basin in 2000 (Canada) and 2001 (US) colour-coded according to six land use classes.
Source: Ciborowski et al. (2011).

Lake Sturgeon

Overall Assessment
Status: Fair
Trend: Improving
Rationale: There are remnant populations in each basin of the Great Lakes, but few of these populations are large. Progress continues as agencies learn more about population status in many tributaries and the Great Lakes proper. Confirmed observations and captures of lake sturgeon continue to increase in all lakes. Stocking is contributing to increased abundance in some areas. There remains a need for information on some remnant spawning populations. Researchers are learning more about the juvenile life stage. In many areas habitat restoration is needed because spawning and rearing habitat has been destroyed or altered, or access to it has been blocked.

Lake-by-Lake Assessment
Lake Superior
Status: Fair
Trend: Improving
Rationale: Lake sturgeon abundance shows an increasing trend in a few remnant populations and in two rivers where stocked. Twenty-one Lake Superior tributaries historically supported lake sturgeon populations. Recent evidence of successful reproduction has been documented in ten tributaries.

Lake Michigan
Status: Fair
Trend: Improving
Rationale: Remnant populations persist in at least nine tributaries having unimpeded connections to Lake Michigan. Successful reproduction has been documented in eight of these rivers, and abundance has increased in a few in recent years. Active rehabilitation has been initiated through rearing assistance in two remnant populations, and reintroductions have been initiated in four rivers.

Lake Huron
Status: Fair
Trend: Improving
Rationale: Current lake sturgeon spawning activity is limited to five tributaries, four in Georgian Bay and the North Channel and one in Saginaw Bay. Abundant stocks of mixed sizes are consistently captured in the North Channel, Georgian Bay, southern Lake Huron and Saginaw Bay.

Lake Erie
Status: Fair
Trend: Improving
Rationale: Lakewide incidental catches since 1992 indicate a possible improvement in their status in lake Erie. Spawning occurs in four known locations in the basin, all located in the connecting waters between lakes Huron and Erie. The Huron Erie Corridor supports a robust population of all age classes. The western basin of Lake Erie, the Detroit River East of Fighting Island, the North Channel of the St. Clair River and Anchor Bay in Lake St. Clair appear to be nursery areas for juveniles and foraging areas for adults.

Lake Ontario/St. Lawrence River
Status: Fair
Trend: Improving

Rationale: Lakewide incidental catches since 1995 indicate a possible improvement in their status. Spawning occurs in the Niagara River, Trent River, and possibly the Black River. There are sizeable populations within the Ottawa and St. Lawrence River systems. Stocking for restoration began in 1995 in New York.

Purpose

- To assess the presence and abundance of lake sturgeon in the Great Lakes and their connecting waterways and tributaries
- To infer the health and status of the nearshore benthivore fish community that does, could or should include lake sturgeon

Ecosystem Objective

Conserve, enhance or rehabilitate self-sustaining populations of lake sturgeon where the species historically occurred and at a level that will permit all state, provincial and federal delistings of classifications that derive from degraded or impaired populations, e.g., threatened, endangered or at risk species. Lake sturgeon is identified as an important species in the Fish Community Goals and Objectives for each of the Great Lakes. Lake Superior has a lake sturgeon rehabilitation plan, and many of the Great Lakes States have lake sturgeon recovery or rehabilitation plans which call for increasing numbers of lake sturgeon beyond current levels.

Ecological Condition

Background

Lake sturgeon (*Acipenser fulvescens*) were historically abundant in the Great Lakes with spawning populations using many of the major tributaries, connecting waters, and shoal areas across the basin. Prior to European settlement of the region, they were a dominant component of the nearshore benthivore fish community, with populations estimated in the millions in each of the Great Lakes (Baldwin *et al*. 1979). In the mid- to late 1800s, they contributed significantly as a commercial species ranking among the five most abundant species in the commercial catch (Baldwin *et al*. 1979, Figure 1).

The decline of lake sturgeon populations in the Great Lakes was rapid and commensurate with habitat destruction, degraded water quality, and intensive fishing associated with settlement and development of the region. Sturgeon were initially considered a nuisance species of little value by European settlers, but by the mid-1800s, their value as a commercial species began to be recognized and a lucrative fishery developed. In less than 50 years, their abundance had declined sharply, and since 1900, they have remained a highly depleted species of little consequence to the commercial fishery. Sturgeon is now extirpated from many tributaries and waters where they once spawned and flourished (Figures 2 and 3). They are considered rare, endangered, threatened, or of watch or special concern status by the various Great Lakes fisheries management agencies. Their harvest is currently prohibited or highly regulated in most waters of the Great Lakes.

Status of Lake Sturgeon

Efforts continue by many agencies and organizations to gather information on remnant spawning populations in the Great Lakes. Most sturgeon populations continue to sustain themselves at a small fraction of their historical abundance. In many systems, access to spawning habitat has been blocked, and other habitats have been altered. However, there are remnant populations in each basin of the Great Lakes, and some of these populations are large in number (tens of thousands of fish, Figures 3-7). Genetic analysis has shown that Great Lakes populations are regionally structured and show significant diversity within and among lakes (DeHaan et al. 2006, Welsh et al. 2008).

Lake Superior

The fish community of Lake Superior remains relatively intact in comparison to the other Great Lakes (Bronte *et al*. 2003). Historic and current information indicate that at least 21 Lake Superior tributaries supported spawning lake sturgeon populations (Harkness and Dymond 1961; Auer 2003; Quinlan 2007). Successful reproduction was confirmed in the St. Louis River in spring 2011 through capture of larval fish. Lake sturgeons currently reproduce in 10 Lake Superior tributaries. The Lake Sturgeon Rehabilitation Plan for Lake Superior (Auer 2003) serves as the guiding document for agency activities. Populations in the Sturgeon River, Michigan, and Bad River, Wisconsin, meet rehabilitation plan criteria for self-sustaining populations (Auer 2003, Auer and Baker 2007, GLIFWC unpublished data, Quinlan 2007, Quinlan et al. 2010). Improvements in assessment techniques have provided better estimates of lakewide abundance (Auer and Baker 2007, Schram 2007, and GLIFWC unpublished data). The estimated combined spawning run population size in the Bad and White rivers, Wisconsin, was 844 individuals, 666 in the Bad River and 178 in the White River (Schloesser and Quinlan 2011). The estimated number of lake sturgeon in annual spawning run in the Sturgeon River, MI range from 350 to 400 adults (Auer and Baker 2007) , Stocking in the St. Louis (MN) and Ontonagon (MI) rivers have resulted in increases in abundance in localized areas. Genetic analysis has shown that lake sturgeon populations in Lake Superior are distinct from one another and significantly different from those in the other Great Lakes (Welsh et al. 2008).

Studies and assessments continue in key tributaries, embayments and nearshore waters including the Kaministiquia River, Ontario, Chequamegon Bay, Wisconsin, Batchawana and Goulais bays, Ontario, Pigeon Bay, Minnesota/Ontario in Keweenaw Bay and in nearshore waters off the Ontonagon River, Michigan (Quinlan et al. 2010). A key study on the Kaministiquia River, Ontario, examined the effect of conrolled flow regimes at Kakabeka Falls on the migratory behavior and reproductive response of lake sturgeon from 2002-2009 (Friday 2009). Habitat (substrate type and water depth) for adult and juvenile fish was geo-referenced and quantified using hydroacoustics in the Kaministiquia River, Ontario (Biberhofer and Prokopec 2005) and Bad River (Cholwek *et al*. 2005). Habitat preference of stocked sturgeon is being studied in the Ontonagon and St. Louis rivers using radio telemetry (Fillmore 2003, 1854 Authority unpublished data). Due to potential for overexploitation, sport fishing regulations in Ontario waters have been changed to eliminate harvest. There remains a prohibition of commercial harvest of lake sturgeon in Lake Superior. Regulation of recreational and subsistence/home use harvest in Lake Superior varies by agency.

In 2011, fishery agencies conducted a coordinated lakewide juvenile lake sturgeon index survey that will provide the most comprehensive data set to date for Lake Superior lake sturgeon. This effort targeted eighteen locations associated with all known current and historic lake sturgeon populations. Despite limited progress, challenges remain. Spawning runs are absent in 11 of 21 historic spawning tributaries, and only two populations meet targets identified in the 2003 Rehabilitation Plan. Overall, lake sturgeon abundance remains a small fraction of historical abundance, estimated at 870,000 (Hay-Chmielewski and Whelan 1997) and basic abundance and biological data is unavailable for a few stocks.

Lake Michigan

Sturgeon populations in Lake Michigan continue to sustain themselves at a small fraction of their historical abundance. An optimistic estimate of the lakewide adult abundance is less than 10,000 fish, well below 1% of the most conservative estimates of historic abundance (Hay-Chmielewski and Whelan 1997). Remnant populations currently are known to spawn in waters of at least nine tributaries having unimpeded connections to Lake Michigan (Schneeberger *et al.* 2005, Elliott 2008, Clapp *et al.* 2012). Two rivers, the Menominee and Peshtigo, appear to support annual spawning runs of 200 or more adults, six rivers, the Manistee, Muskegon, Grand, Kalamazoo, Fox and Oconto, appear to support annual spawning runs of between 20 and 100 adults, and smaller numbers of sturgeon in spawning condition have been captured or observed in the lower Mansitique and St. Joseph Rivers (Baker 2006; Elliott and Gunderman 2008; K. Smith, unpublished data). Successful reproduction has been documented in eight of these rivers, and age 0 juveniles can be captured regularly in many of these rivers. Recent recruitment estimates have been made from research efforts in the Peshtigo River indicating that in some years, several hundred fall recruits are produced from that system (Caroffino et al. 2007), and research and assessment efforts in the Manistee and Muskegon rivers indicate significant recruitment from those systems as well (K. Smith, MDNR, personal communication). In addition, abundance of spawners in some rivers appears to have increased in the last decade, indicating that increased recruitment may have been occurring for several years in some rivers. Some lake sturgeon have been observed during spawning times in a few other Lake Michigan tributaries such as the Cedar, Millecoquins and Boardman Rivers, and near some shoal areas where sturgeon are thought to have spawned historically, but it is not known if spawning occurs in these systems,. A large self-sustaining population exists in the Lake Winnebago system upstream of the lower Fox River. This population spawns in the Wolf and Upper Fox Rivers and supports an active winter recreational spear fishery. The upper Menominee River also supports two self-sustaining populations which are separated from each other and from the lower Menominee River population by several dams. These populations also support a very limited hook and line fishery in the fall of each year.

Active management in the form of reintroduction stocking and rearing assistance has been implemented in 7 Lake Michigan basin tributaries. Commencing in 2005, Lake sturgeon are being reared from eggs using streamside rearing facilities and stocked as fingerlings into the Milwaukee, Kewaunee, Cedar and Whitefish rivers where sturgeon have been considered extirpated for some time. Over the next 20 years, these reintroductions are intended to rebuild self-sustaining populations that use these rivers to spawn. Streamside rearing facilities are also being used to increase the survival of naturally produced eggs and larvae in the Manistee River (since 2003,Holtgren et al 2007) and in the Kalamazoo river since 2011. Stocking also has been conducted in the upper Menominee River for many years and in portions of the Winnebago system. Though limited recreational harvest is allowed in both the upper Menominee River and the Winnebago system, no harvest is allowed from other Lake Michigan tributaries or from Lake Michigan. Habitat evaluations have been conducted in many sturgeon tributaries within the Lake Michigan basin (Daugherty et al. 2008), and improvements in flow conditions and improved fish passage via dam removal of installation of fish passage is ongoing.

Lake Huron

Lake sturgeon populations continue to be well below historical levels. Spawning has been identified in the Garden, Mississaugi and Spanish rivers in the North Channel, in the Nottawasaga River in Georgian Bay and in the Rifle River in Saginaw Bay. Adult spawning populations for each of these river systems are estimated to be in the 10s and are well below rehabilitation targets (Hay-Chmielewski and Whelan 1997; Holey *et al*. 2000). Research in the Saginaw River Watershed in 2005 – 2007 indicated that lake sturgeon are no longer spawning in that watereshed, although sufficient spawning habitat does exist below the Dow Dam (Midland, MI) on the Tittabawassee River, and below Hamilton Dam (Flint, MI) on the Flint River. Also, creation of a rock ramp at the Chesaning Dam (Chesaning, MI) on the Cass river in 2010 now allows lake sturgeon passage and provides access to approximately 40 miles of high gradient quality spawning habitat above the former dam site. Research since 2007 on the St. Mary’s River system has yet to determine a spawning stock of Lake Sturgeon. Barriers in Michigan’s tributaries to Lake Huron continue to be a major impediment to successful rehabilitation in Lake Huron.

Stocks of lake sturgeon in Lake Huron are monitored primarily through the volunteer efforts of commercial fishers cooperating with the various resource management agencies. To date the combined efforts of researchers in U.S. and Canadian waters has resulted in over 7,000 sturgeon tagged in Saginaw Bay, southern Lake Huron, Georgian Bay and the North Channel, with relatively large stocks of mixed sizes being captured at each of these general locations. Tag recoveries, telemetry studies, and genetic collections indicate that lake sturgeon are moving within and between jurisdictional boundaries and between lake basins, supporting the need for more cooperative management between the states and between the U.S. and Canada. In October 2009 Ontario closed both commercial and recreational harvest of Lake Sturgeon. Regulation of recreational and subsistence/home use harvest in Lake Huron varies by agency and is largely unknown.

Lake Erie

Lake sturgeon populations continue to be well below historical levels with the exception of the stocks located in the Huron Erie Corridor which are close to historic levels. Spawning has been identified at four locations in the connecting waters between Lakes Huron and Erie (Manny and Kennedy 2002; Roseman et al. 2011) and is likely occurring in the upper Niagara River (B. Trometer, USFWS, pers. comm.). Tag recovery data and telemetry research indicate that a robust lake sturgeon stock of approximately 15,000 fish reside in the North Channel of the St. Clair River and Lake St. Clair (Thomas and Haas 2002, 2008). The North Channel of the St. Clair River, Anchor Bay in Lake St. Clair, the Detroit River (East of Fighting Island), and the western basin of Lake Erie have been identified as nursery areas as indicated by consistent catches in commercial and survey fishing gears. In the central and eastern basins of Lake Erie, lake sturgeon are scarcer with only occasional catches of sub-adult or adult lake sturgeon in commercial and research fishing nets. Survey work conducted in 2005 and 2006 indicated that no lake sturgeon spawning is taking place in the Maumee River (OH) although spawning and nursery habitat requirements would support a reintroduced population. An observed concentration of sturgeon in the spring of 2009 and the collection of 2 males in June 2011 outside the Buffalo Harbor suggest spawning is occurring in the area.

Research efforts will continue to focus on identifying new spawning locations, genetic difference between stocks, habitat requirements, and migration patterns. In October 2009 Ontario closed both commercial and recreational harvest of Lake Sturgeon. Regulation of recreational and subsistence/home use harvest in Lake Huron varies by agency and is largely unknown

Lake Ontario/St. Lawrence River

Lake Ontario has lake sturgeon spawning activity documented in three tributaries, the Niagara, Trent, and Black rivers. There is no targeted assessment of lake sturgeon in Lake Ontario, but incidental catches in research nets have occurred since 1997 (Ontario Ministry of Natural Resources 2004) and 1995 (Eckert 2004), indicating a possible improvement in population status. Age analysis of lake sturgeon captured in the lower Niagara River indicates successful reproduction in the mid-1990s. The New York State Department of Environmental Conservation initiated a stocking program in 1995 to recover lake sturgeon populations. Lake sturgeon has been stocked in the St. Lawrence River and some of its tributaries, inland lakes in New York, and the Genesee River. There are sizeable populations within the St. Lawrence River system, most notably Lac St. Pierre and the Des Prairies and St. Maurice Rivers. However, access is inhibited for many of the historical spawning grounds in tributaries by small dams and within the St. Lawrence River by the Moses-Saunders Dam.

Low numbers or lack of fish (where extirpated) is itself a significant impediment to recovery in many spawning areas. Barriers that prevent lake sturgeon from moving into tributaries to spawn are a major problem. Predation on eggs and newly hatched lake sturgeon by non-native predators may also be a problem. The genetic structure of remaining populations has been studied by university researchers and fishery managers, and this information will be used to guide future management decisions. With the collapse of the Caspian Sea sturgeon populations, black market demand for sturgeon caviar could put tremendous pressure on Great Lakes lake sturgeon populations. An additional concern for lake sturgeon in many of the Great Lakes is the ecosystem changes that are resulting from high densities of invasive species such as dreissenid mussels and round gobies and the presumed related spread of Botulism Type E which has produced die-offs of lake sturgeon in most years since 2001(Elliott and Gunderman 2008, Clapp et al. 2012).

Management Challenges/Opportunities

Lake sturgeon is an important native species that is listed in the Fish Community Goals and Objectives for all of the Great Lakes. Many of the Great Lakes states and provinces either have or are developing lake sturgeon management plans promoting the need to inventory, protect and restore the species to greater levels of abundance.

While overexploitation removed millions of adult fish, habitat degradation and alteration eliminated traditional spawning grounds. Current work is underway by state, federal, tribal, provincial and private groups to document active spawning sites, assess habitat condition and availability of good habitat, and determine the genetics of remnant Great Lakes lake sturgeon populations.

Several meetings and workshops have been held focusing on identifying the research and assessment needs to further rehabilitation of lake sturgeon in the Great Lakes (Holey *et al*. 2000, Zollweg *et al*. 2003, Quinlan *et al*. 2005, Boase *et al*. 2008) and a significant amount of research and assessment directed towards these needs has occurred in the last 10 years. Among these is the research to better define the genetic structuring of Great Lakes lake sturgeon populations, and genetics-based rehabilitation plans are being developed to help guide reintroduction and rehabilitation efforts being implemented across the Great Lakes. Research into new fish passage technologies that will allow safe upstream and downstream passage around barriers to migration also have been underway for several years. Many groups are continuing to work to identify current lake sturgeon spawning locations in the Great Lakes, and studies are being initiated to identify habitat preferences and recruitment levels for juvenile lake sturgeon (ages 0 to 2). Several agencies are also working in concert on reintroduction and rearing assistance programs to strengthen and reintroduce lake sturgeon into various waters where populations are lacking or at risk from further declines. This approach has recently been strengthened with completion of genetic stocking guidelines for the stocking of lake sturgeon in the Great Lakes (Welsh et al. 2010).

Comments from the author(s)

Research and development is needed to determine ways for lake sturgeon to pass man-made barriers on rivers. In addition, there are significant, legal, logistical, and financial hurdles to overcome in order to restore degraded spawning habitats in connecting waterways and tributaries to the Great Lakes. More monitoring is needed to determine the current status of Great Lakes lake sturgeon populations, particularly the juvenile life stage. Cooperative efforts between law enforcement and fishery managers are required as world pressure on sturgeon stocks will result in the need to protect large adult lake sturgeon in the Great Lakes.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		x				
2. Data are traceable to original sources	x					
3. The source of the data is a known, reliable and respected generator of data	x					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	x					
5. Data obtained from sources within the U.S. are comparable to those from Canada		x				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				

Acknowledgments

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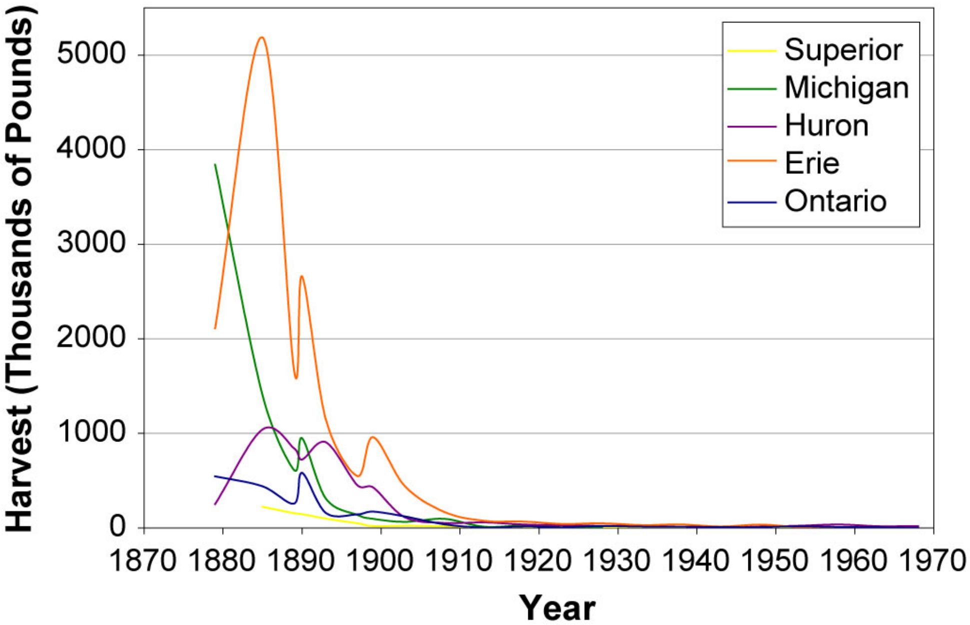

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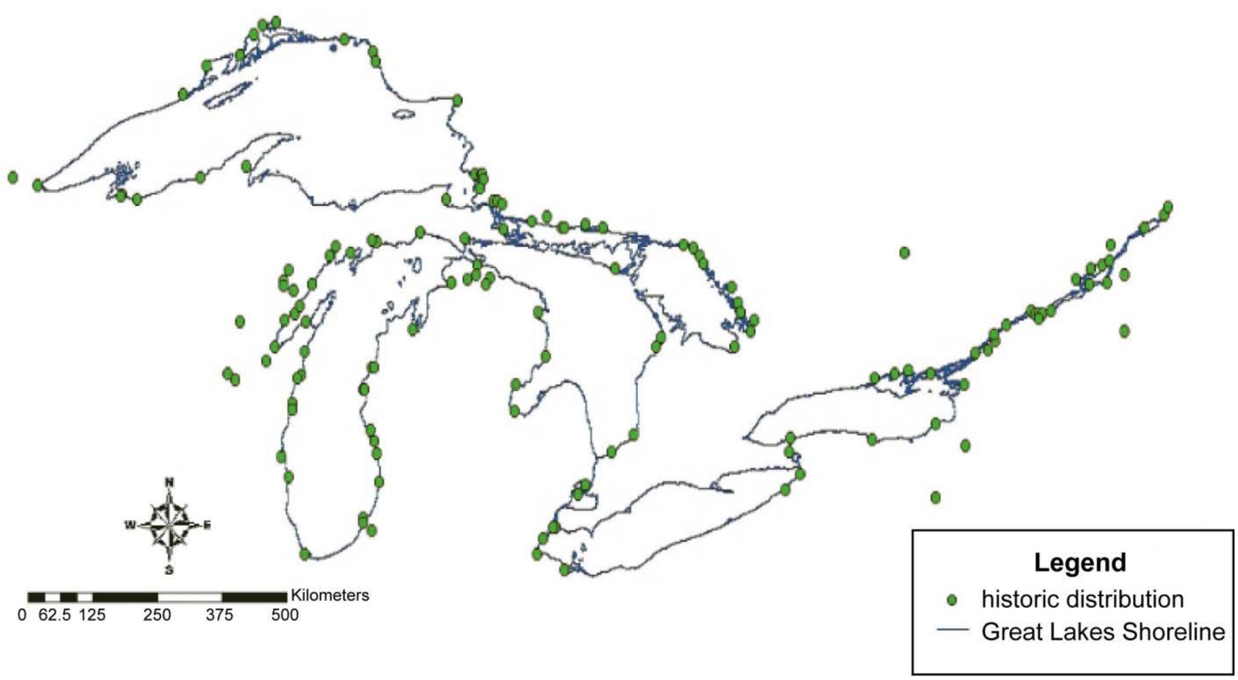

Figure 2. Historic lake sturgeon harvest from each of the Great Lakes.
Source: Zollweg *et al.* 2003

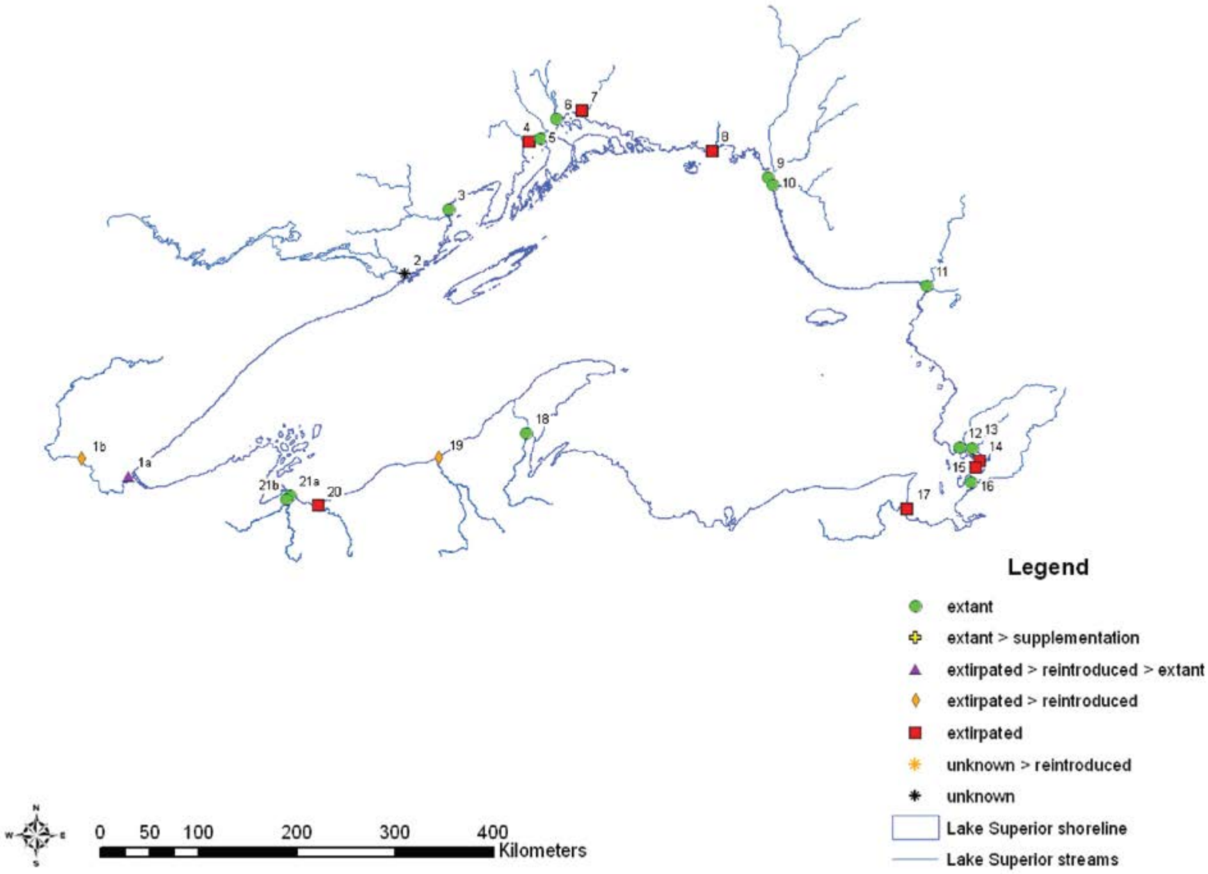

Figure 3. Lake sturgeon population status in Lake Superior in 2011.
Source: Lake Superior Lake Sturgeon Work Group

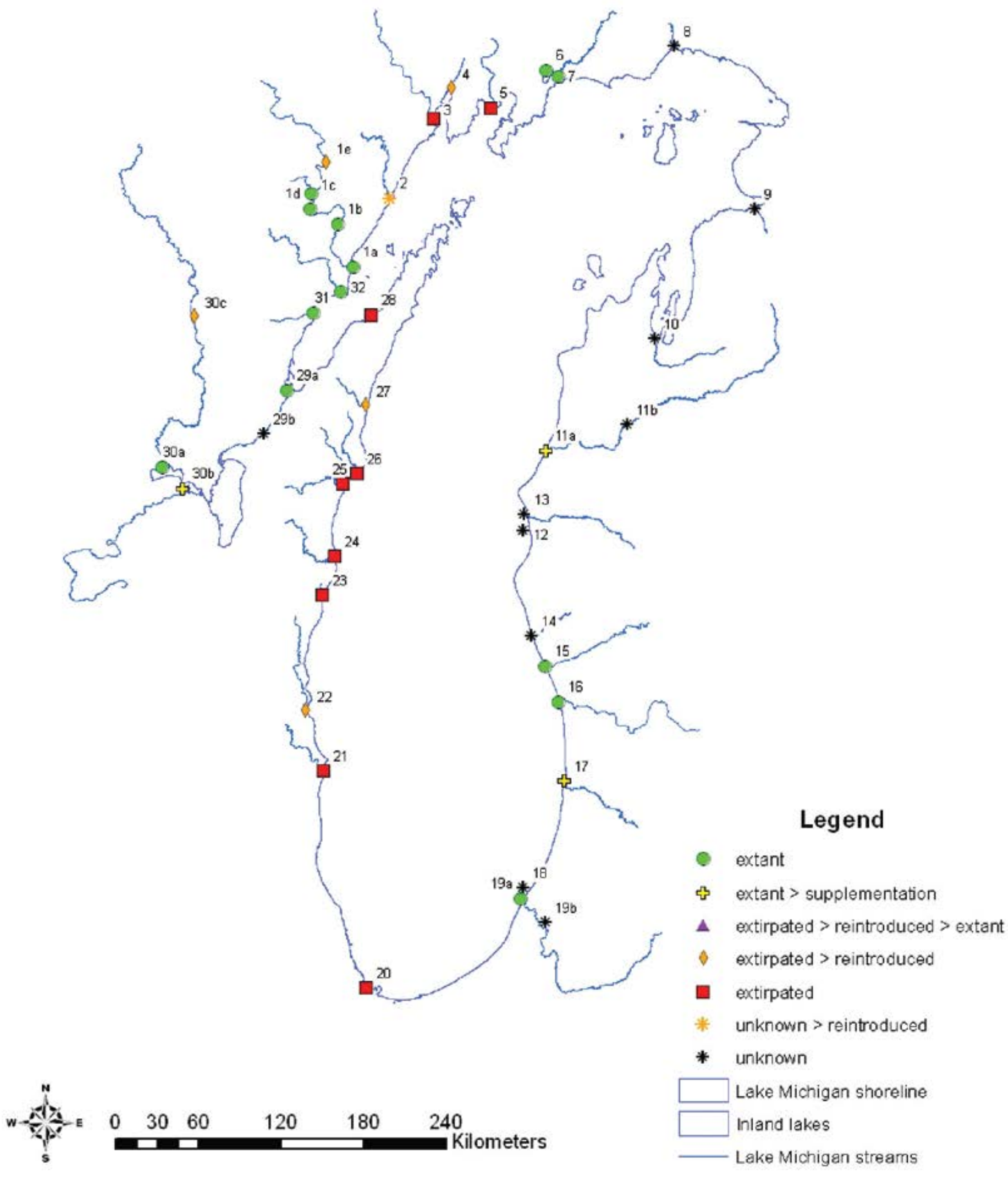

Figure 4. Lake sturgeon population status in Lake Michigan.
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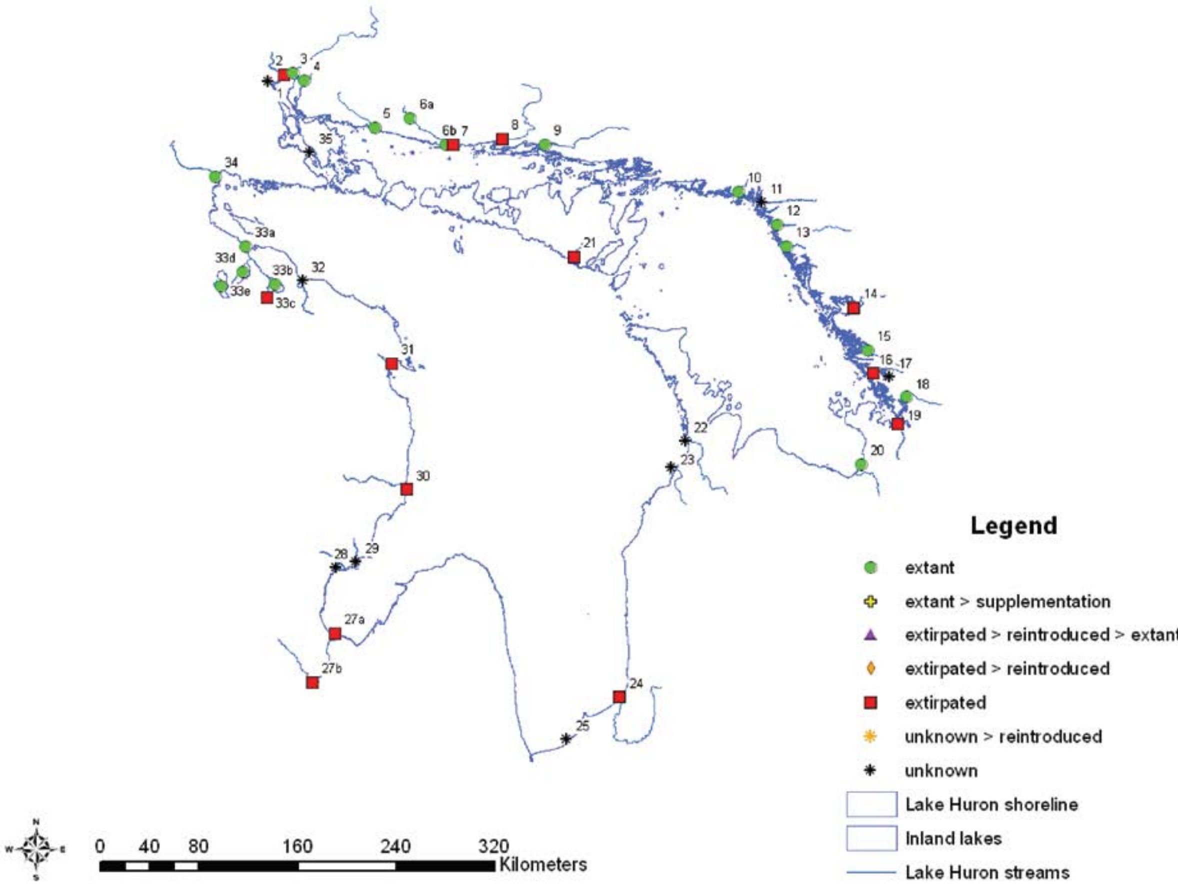

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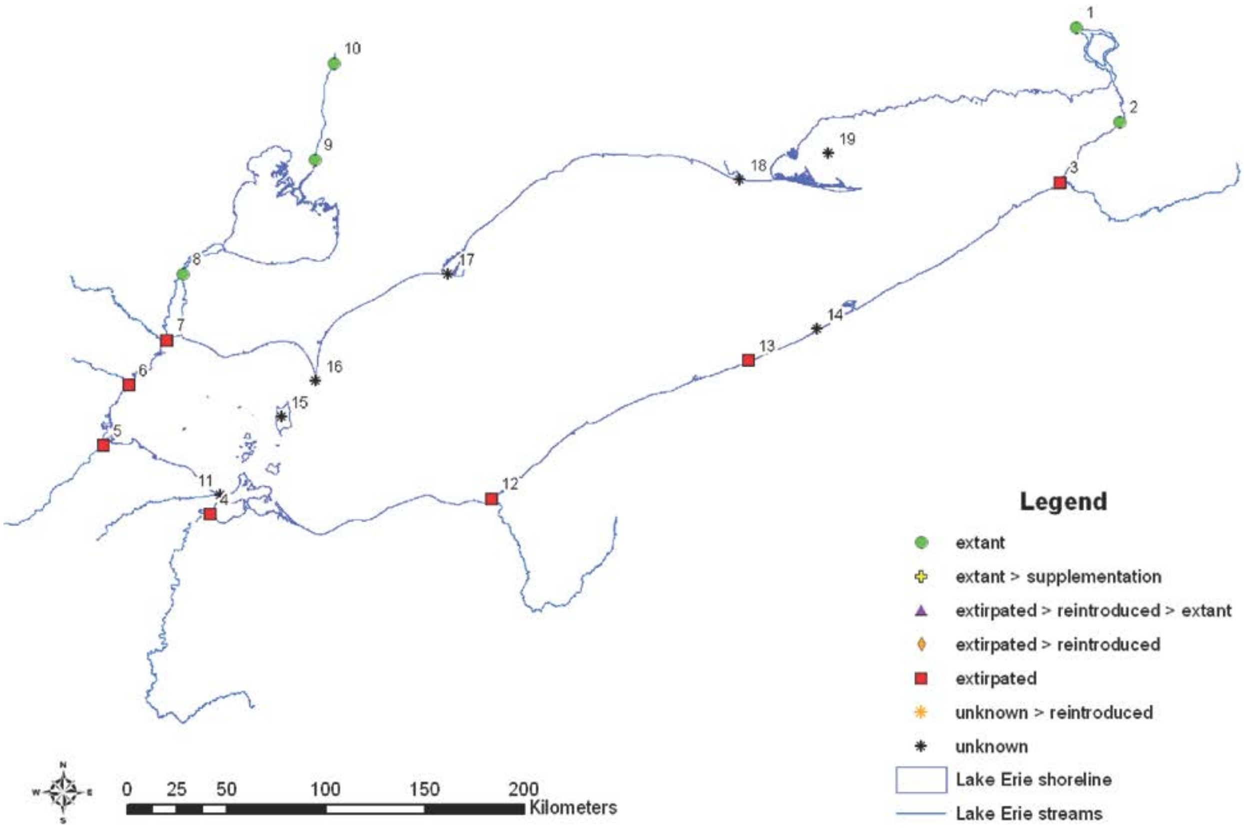

Figure 6. Lake sturgeon population status in Lake Erie.
Source: James Boase and Betsy Trometer, USFWS

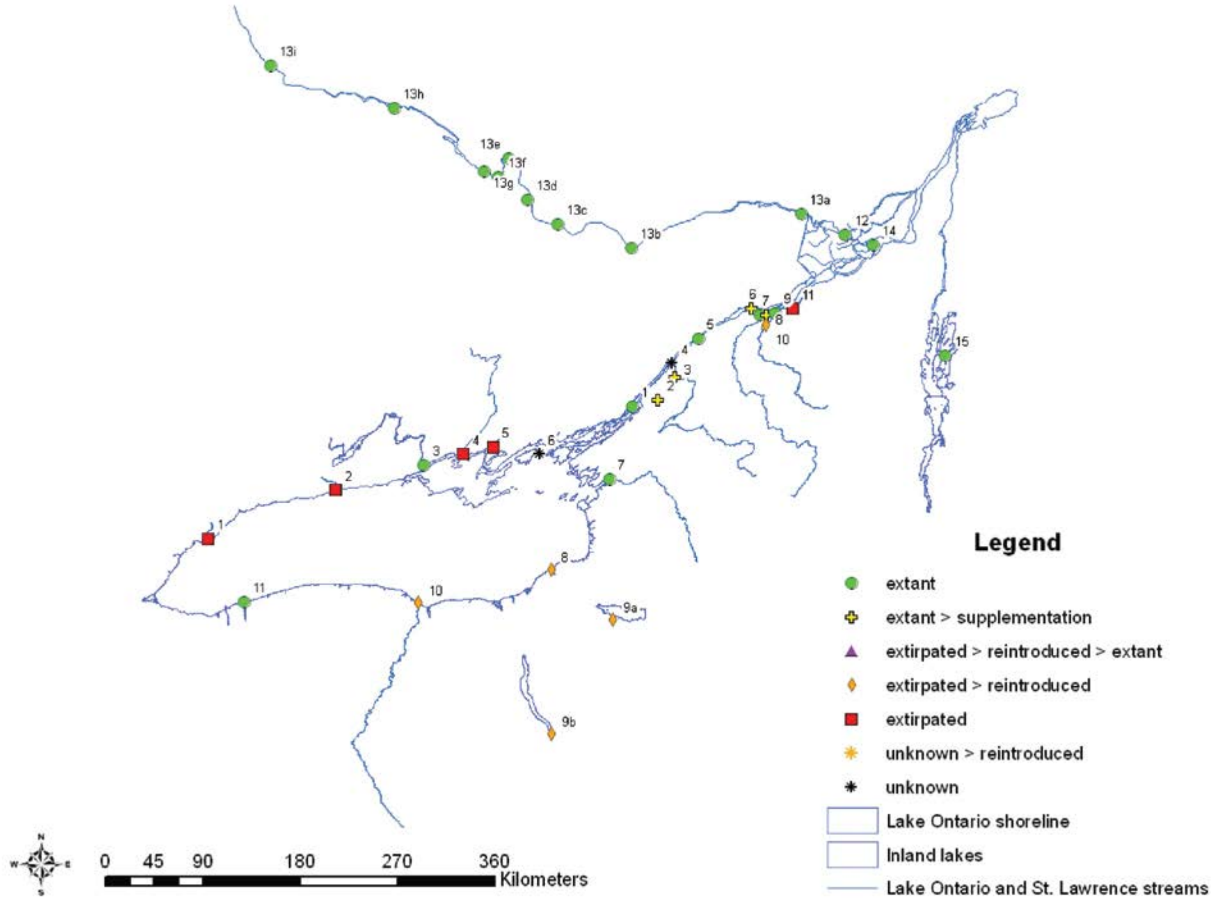

Figure 7. Lake sturgeon population status in Lake Ontario and St. Lawrence River
Source: New York Lake Sturgeon Working Group, and Tim Haxton, OMNR

Lake Trout

Overall Assessment

Status: Fair

Trend: Improving

Rationale: Self-reproducing populations are present only in Lake Superior and many smaller populations in Lake Huron. Populations in lakes Michigan, Erie, and Ontario are mostly below Great Lakes Fishery Commission Lake Committee target levels for relative abundance and natural reproduction is low. Some population increases are being observed with support of stocking and other rehabilitation efforts.

Lake-by-Lake Assessment

Lake Superior

Status: Good

Trend: Improving

Rationale: Natural reproduction of both nearshore (lean) and offshore (siscowet) populations is widespread and supports all populations. Most stocking has been discontinued and fisheries are well managed. Sea lamprey mortality has been increasing. All agencies committed to further restoration and conservation.

Lake Michigan

Status: Poor

Trend: Unchanging

Rationale: Little natural reproduction detected anywhere; no significant recruitment of wild fish to the population. Survival of stocked fished in northern Lake Michigan is poor due to high sea lamprey mortality and fishing resulting in inadequate parental stocks. Agencies are mixed on commitments to rehabilitation.

Lake Huron

Status: Fair

Trend: Improving

Rational: More than ten year classes of wild lake trout have been observed lake wide, and represent 20% survey catches and 33-60% of harvest in recent years. Abundant year classes of wild lake trout are now entering the adult portion of the population and their presence on the spawning grounds should help stimulate more natural reproduction. All agencies committed to further rehabilitation and conservation.

Lake Erie

Status: Poor

Trend: Deteriorating

Rationale: Sea lampreys predation continues to suppress adult stocks despite higher stocking numbers and improved recruitment of young stocked fish in recent years. Most agencies committed to further rehabilitation and conservation.

Lake Ontario

Status: Fair

Trend: Improving

Rationale: Sea lamprey predation was strongly related to a collapse in adult stocks during 2004-2005; however abundance has increased each year since 2007. Post-release survival of stocked fish and natural reproduction has remained low since the early 1990s. All agencies committed to further rehabilitation and conservation.

Purpose

- To estimate the relative abundance of both stocked and wild lake trout.
- To measure the success of rehabilitation through catch rates of wild fish
- To infer the control measures on fishing and sea lamprey predation through the age structure and abundance of mature fish.
- To infer the basic structure of the cold water predator community and the general health of the ecosystem
- The Lake Trout indicator is used in the Great Lakes indicator suite as a State of indicator in the Aquatic-dependent life top level reporting category.

Ecosystem Objective

Self-sustaining, naturally reproducing populations that support target yields to fisheries are the goal of the lake trout rehabilitation program. Target yields approximate historical levels of lake trout harvest or levels adjusted to accommodate stocked naturalized introduced predators such as Pacifique salmon. Targets, most centered on desired harvest expectations, are set by Lake Committees of the Great Lakes Fishery Commission in Fish Community Objectives (Horns *et al.* 2003, Eshenroder *et al.* 1999, DesJardin *et al.*1995, Ryan *et al.* 2003., Stewart *et al.* 1999), and are revised periodically. These targets are 1.8 million kg (4 million pounds) from Lake Superior, 1.1 million kg (2.5 million pounds) from Lake Michigan, 0.9 million kg (2.0 million pounds) from Lake Huron and 50 thousand kg (0.1 million pounds) from Lake Erie. Lake Ontario has no specific yield objective but has a population objective of 0.5 to 1.0 million adult fish that produce 100,000 yearling recruits annually through natural reproduction. The desired state will be for lake trout to serve as the primary top predator in Lake Superior and share this status with other native and established non-native predators in lakes Michigan, Huron, Erie and Ontario.

Ecological Condition

Measure

Trends in the relative abundance of stocked lean lake trout in lakes Huron, Michigan, Erie and Ontario, and wild lean lake trout in Lake Superior are displayed in Figure 1. Targets are set for most populations of lean lake trout as these are perceived to be biologically important to increase the probability of natural reproduction in lakes Huron, Michigan, Erie and Ontario and to maintain wild populations in Lake Superior. Target values are measured and expressed by relative abundances of all or a portion of the population in multiagency gill net surveys that are standardized within each lake. These measures are superior to harvest objectives, which are harder to evaluate and represent desired states that cannot no be easily tested for sustainability. Lake trout abundance dramatically increased in all the Great Lakes after initiation of sea lamprey control, stocking, and harvest control. Success to achieve population targets and ultimately to self-sustaining natural reproducing populations has been mixed among the lakes.

Endpoint

Desired states are populations that are self-sustaining through natural reproduction with minimal or no hatchery supplementation required, that support a sustainable harvest, and serve as a top predator. The resulting population size and sustainable yield compared to historical levels will likely be lower in most lakes since this apex trophic level is now shared by naturalized non-native predators that support a multi-billion dollar fishery.

Background

Historically lake trout were the keystone salmonine predator for most of the Great Lakes. Overfishing and predation by non-native sea lamprey, and to a limited extent other factors, destroyed nearshore lean populations and deep water siscowet lake trout populations, but many survived in Lake Superior and a few lean lake trout populations in Lake Huron (Lawrie and Rahrer 1972, Berst and Spangler 1972, Wells and McLain 1972, Hartman 1972, Christie 1972). Rehabilitation efforts through stocking and controls on fisheries and sea lamprey have been ongoing since the early 1960s (Hansen *et al.* 1995, Eshenroder *et al.* 1995, Holey *et al.* 1995, Cornelius *et al.* 1995, Elrod *et al.* 1995).

Status of Lake Trout

Lake Superior

Wild lean lake trout populations have recovered from collapse in the 1950s due to an aggressive recovery program employing sea lamprey suppression, stocking of hatchery fish, and fishery restrictions (Hansen *et al.* 1995, Bronte *et al.* 2003). Recovery began with the buildup of large populations of hatchery lake trout which was superseded by wild fish. The transition to wild lake trout dominance began in the 1980s in Michigan waters and was subsequently followed in Wisconsin, then most recently in Minnesota. In Michigan waters, abundance and recruitment of most lake trout populations are near historic high levels with some indications of density-dependent growth declines (Wilberg *et al.* 2003, Richards *et al.* 2004, Sitar *et al.* 2010). The latest progress in recovery was the cessation of most stocking in Minnesota waters.

Siscowet is the most abundant form of lake trout in Lake Superior occupying deep water areas and have recovered from depressed levels in the 1950s (Bronte and Sitar 2008, Ebener *et al.* 2010). Recent harvest is low, though emerging industrial interest in extracting omega-3 fatty acid from siscowets may develop a demand. Sea lamprey wounding rates on siscowets are high, though the mortality inflicted may not be higher than that experienced by lean lake trout (Moody *et al.* 2010). Similar to leans, siscowets are at high levels and experiencing density-dependent effects.

Currently, wild lake trout abundance has generally remained level. Fishing mortality has been controlled in most areas of Lake Superior through regulations. Despite continued sea lamprey management, wounding rates on lake trout in some areas have increased above target levels since 1995 (Sitar *et al.* 2010). In the near-term, some decline in lake trout abundance is expected due to density-dependence effects.

Lake Huron

Sea lamprey wounding rate has decreased since 2000 from more than 20 wounds per 100 fish to less than 10 wounds per 100 fish. Age-7 catch per 1000 ft of gillnet per million stocked has been stable between 0.45 and 1.4 since 1991, except for the year classes stocked in 2003 and 2004 when there were dramatic changes to lower food webs (oligotrophication) in Lake Huron that caused a substantial reduction in abundance of alewives. Alewives were an important food of lake trout prior to 2004, but have declined from over predation and poor recruitment, and are no longer available.. Growth declines over the last decade have caused age at recruitment to commercial fishery and fishery independent survey gear to increase from age 5 prior to 2006 to age 7 by 2009. Both these changes are likely due to the impacts of food-web changes (collapse of alewives) in combination with changes in seasonal and spatial distribution of juvenile lake trout.

Year classes of wild lake trout produced during 2003-2006 coincided with increasing older parental stocks and the reduction in consumption of alewives by adult lake trout suggesting that Thiamine Deficiency Syndrome (TDS) was a substantial impediment to rehabilitation of lake trout in Lake Huron. Reductions in TDS in combination with prior increases in abundance of adult lake trout and reductions in sea lamprey mortality created a fish community that was conducive to survival of larval lake trout and advancement of lake trout rehabilitation on Lake Huron.

Lake Michigan

Lake trout densities measured by spring assessment surveys remain below target in all management units and lake - wide. Few wild fish (with no fin clip) were recovered in assessment surveys (Bronte *et al.* 2007, Lake Trout Task Group 2010), which indicates that natural reproduction remains low even though fry from reproduction by stocked lake trout have been recovered (Jannsen *et al.* 2006). Recent events that should increase the probability of achieving the lake trout rehabilitation objectives include: 1) a revised implementation strategy for the rehabilitation of lake trout in Lake Michigan that concentrates stocking and other management efforts in the best habitat areas, 2) egg thiamin levels, thought be inadequate for hatching success and fry survival, have recently increased lakewide, and 3) sea lamprey numbers, which were above the targets levels for many years, have declined.

Elevated sea lamprey induced mortality, low adult stock size, and lack of sustainable reproduction (Bronte *et al.* 2003, 2007), continues to limit lake trout rehabilitation. Recommendations to advance recovery include minimizing adult mortality from fishing and lamprey, focus new hatchery production in refuge areas, restore a native forage base, and recast FCO for population characteristics rather than harvest levels.

Lake Erie

Directed efforts to restore lake trout in Lake Erie began in 1982. Recruitment of stocked fish was good but their survival to adulthood was poor due to excessive sea lamprey predation. Adoption of the original lake trout rehabilitation plan in 1985 (Lake Trout Task Group 1985) brought higher annual stocking targets, sea lamprey control, and standardized assessment programs to monitor the population. The lake trout responded quickly to the implementation of sea lamprey suppression and increased stocking, building a large population by 1990. However, these accomplishments were short lived as stocking numbers were reduced in 1996 due to concerns about a shortage of forage fishes (Einhouse *et al.* 1999) while at the same time sea lamprey control was relaxed (Sullivan *et al.* 2003). Adult lake trout abundance was quickly reduced to low levels by 2000 where it has since remained.

Overall lake trout abundance in Lake Erie has increased in more recent years due to adoption of a revised rehabilitation plan (Markham *et al.* 2008) that increased stocking numbers back to their original level. Recruitment of stocked fish, including Klondike strain lake trout, has been high. However, sea lamprey abundance remains high and above targets despite increased lampricide treatments, and this continues to suppress the adult lake trout population. Achievement of lake trout rehabilitation goals will continue to be hampered if sea lamprey abundance and wounding rates remain high and above target levels.

Lake Ontario

The abundance of hatchery-reared adult lake trout in Lake Ontario was relatively high during 1986-1998, but declined by more than 30% in 1999 due to reduced stocking and poor survival of stocked yearlings since the early 1990s (Elrod *et al.* 1995, Lantry and Lantry 2011). Adult abundance remained relatively stable during 1999-2004, but again declined by 54% in 2005 likely due to ongoing poor recruitment and mortality from sea lamprey predation. Enhanced control of sea lampreys and subsequent decreases in wounding on lake trout during 2008-2010 was followed by a sharp recovery in adult lake trout numbers that in 2010 was similar in abundance to 1999-2004 levels.

Although the abundance of adults reached a peak in 1986, appearance of naturally reproduced lake trout in assessment surveys occurred later after the abundance of large adult females exceeded target levels in 1992 (Lantry and Lantry 2011). Despite widespread catches of small numbers of natural recruits nearly every year during 1993-2010, a failure to achieve self-sustaining stocks has been attributed to the dense populations of alewives in Lake Ontario and an associated diet of lake trout that favors alewives (leading to Early Mortality Syndrome), the absence of suitable alternative deepwater preyfishes, and colonization of spawning reefs by invasive round gobies (Fitzsimons *et al.* 2003, Lantry *et al.* 2003, Schneider *et al.* 1997, Walsh *et al.* 2011). Recent meager prospects for restoration have been improved with the reappearance of deepwater sculpin in assessment catches (their abundance steadily increased during 2002-2010) (Lantry *et al.* 2007, Weidel *et al.* 2011) and the joint US and Canadian efforts currently underway to reestablish deepwater ciscoes. Both deepwater sculpin and deepwater ciscoes were historically important prey for lake trout.

Linkages

The rehabilitation of lake trout populations in the Great Lakes has linkages to sea lamprey, prey fish, and non-native species. Lake trout stocking and the building parental stocks would not be possible without sustained levels of sea lamprey control, as well as controls on fisheries. Non-indigenous alewives, while at lower levels now, still effect wild recruitment through predation on lake trout fry and contain high levels of thaiminase that lowers egg viability and fry survival in lake trout that consume mostly alewives. The lack of native pelagic and benthopelagic coregonines, lost to overfishing, habitat degradation and non-native invasions, is also hampering recovery as these lost species were conduits for offshore benthic and pelagic production to the nearshore environment and to lake trout as prey.

Management Challenges/Opportunities

Continued and enhanced sea lamprey control is required basin-wide to increase survival of lake trout to adulthood. New sea lamprey control options, which include pheromone systems that increase trapping efficiency and disrupt reproduction, are being researched and implemented, and hold promise for improved control. Continued and enhanced control on exploitation is being improved through population modeling in most Lakes. Stocking densities need to be increased in some areas, especially in Lake Michigan and possibly Lake Ontario. All lake trout in US waters are now receiving coded-wire tags that, when recaptured, will contribute substantially to the knowledge base for better rehabilitation options. The use of alternate strains of lake trout from Lake Superior could be candidates for deep, offshore areas not colonized by traditional strains used for restoration. Introduction of such strains has been initiated in Lake Erie, will start soon in Lake Ontario and are being considered for Lake Michigan. Direct stocking of eggs, fry, and yearling on or near traditional spawning sites should be used where possible to enhance colonization. The need to restore native forage fish, such as cisco and deepwater ciscoes, is gaining momentum and seen as an important requirement to aid in bringing lake trout back to self-sustainability. This activity will require careful consideration of the transfer of diseases among lakes as well as the development of rearing and stocking strategies.

Comments from the author(s)

Reporting frequency should be every five years. Monitoring systems are in place, but in most lakes the measures do not directly relate to stated harvest objectives. Lake trout population-objectives may need to be redefined as endpoints in units measured by the monitoring activities, and are being incorporated into restoration guides and plans. The data time series we present are based on important population targets that can be measured with current assessment activities.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		x				
2. Data are traceable to original sources		x				
3. The source of the data is a known, reliable and respected generator of data		x				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		x				
5. Data obtained from sources within the U.S. are comparable to those from Canada				x		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				

Acknowledgments

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List of Figures

Figure 1. Relative abundance of lake trout in the Great Lakes. The measurements reported vary from lake to lake, as shown on the vertical scale, and comparisons among lakes may be misleading. Overall trends over time provide information on relative abundances for all or part of the population.
Source: Data sources are from biological assessments conducted cooperatively by state, federal, tribal and provincial agencies, and are largely contained in non-peered reviewed reports to the Great Lakes Fishery Commission, Lake Committees., New York Department of Environmental Conservation, Ontario Ministry of Natural Resources, U.S. Fish and Wildlife Service and U.S. Geological Survey.

Last Updated

State of the Great Lakes 2011

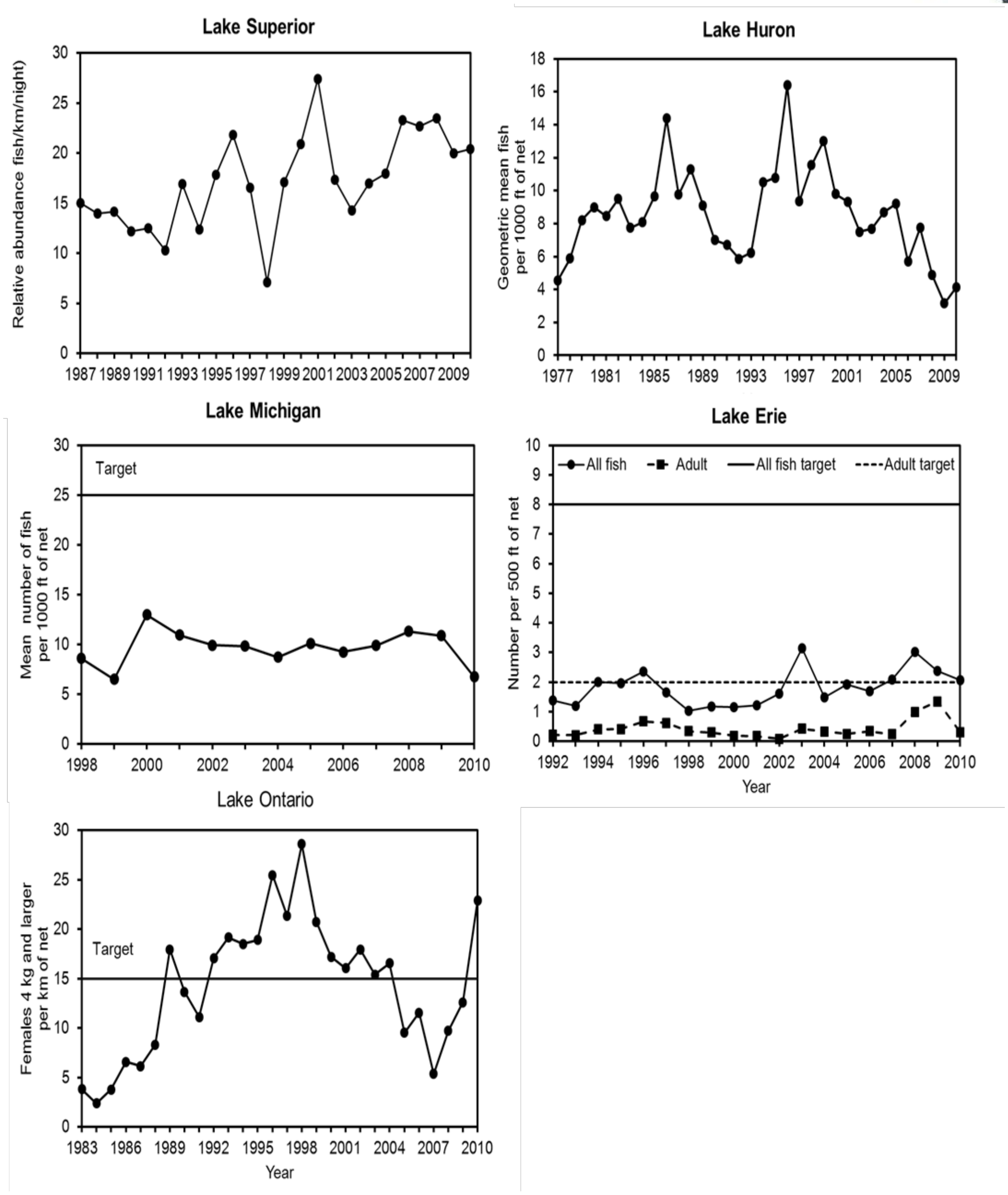

Figure 1. Relative abundance of stocked lake trout (wild fish in Lake Superior) in the Great Lakes. The measurements reported vary from lake to lake, as shown on the vertical scale, and comparisons among lakes may be misleading. Overall trends over time provide information on relative abundances for all or part of the population. Source: Data sources are from biological assessments conducted cooperatively by state, federal, tribal and provincial agencies, and are largely contained in non-peered reviewed reports to the Great Lakes Fishery Commission, Lake Committees ., New York Department of Environmental Conservation, Ontario Ministry of Natural Resources, U.S. Fish and Wildlife Service and U.S. Geological Survey.

Nutrients in Lakes

Overall Assessment

Status: Fair

Trend: Deteriorating

Rationale: In Lakes Michigan, Huron and Ontario, offshore total phosphorus concentrations are currently below targets but may be too low, negatively impacting lake productivity. Nearshore symptoms of nutrient enrichment persist. In Lake Erie, targets are frequently exceeded and conditions are deteriorating. Only in Lake Superior are offshore targets being met and conditions acceptable.

Lake-by-Lake Assessment

Lake Superior

Status: Good

Trend: Unchanging

Rationale: Targets have consistently been met, and offshore total phosphorus concentrations are similar to historic values, indicating acceptable conditions. There is no trend over time.

Lake Michigan

Status: Fair (below target)

Trend: Deteriorating (further below target)

Rationale: Offshore phosphorus concentrations are continuing to decrease and are meeting targets. However, concentrations have fallen to low levels and may be negatively affecting lake productivity (phytoplankton, zooplankton and fish production). In some nearshore areas, elevated phosphorus and/or invasive species are supporting nuisance algae growth.

Lake Huron

Status: Fair (well below target)

Trend: Deteriorating (further below target)

Rationale: Offshore phosphorus concentrations are continuing to decrease, and although concentrations are meeting targets, they may be too low and negatively affecting lake productivity. In certain areas of the nearshore, waters are experiencing nuisance algae growth.

Lake Erie

Status: Poor (above target)

Trend: Deteriorating

Rationale: Total phosphorus targets continue to be exceeded and trends indicate increasing concentrations. Excessive algal growth is apparent, particularly in the western basin but in the other basins also.

Lake Ontario

Status: Fair (below target)

Trend: Deteriorating (further below target)

Rationale: Offshore phosphorus concentrations are continuing to decrease to levels too low to support healthy offshore lake productivity. Many nearshore waters are experiencing nuisance algae, possibly fueled by locally-high phosphorus discharges, but also by invasive mussels which make phosphorus more readily available for algae.

Other Spatial Scales – Nearshore eutrophication

This indicator reports mainly on total phosphorus (TP) concentrations in the offshore. These offshore waters best indicate long-term trends because, in contrast to shallower, nearshore waters, they are less influenced by local pollutant discharges. As demonstrated here, offshore nutrient concentrations in most lakes have declined over time, and are meeting targets that were set during the 1980s, but may now be too low to support healthy levels of lake productivity.

At the same time as offshore TP concentrations are reaching unprecedented lows, large regions of the Great Lakes are experiencing nuisance algae problems. The extent of the algae problem seems to be of similar magnitude as was experienced in the 1970s (GLWI, 2005), despite significantly lower phosphorus loads since that time (Dolan 2010). In Lake Michigan, growth of the benthic alga *Cladophora* remains a problem, making some beaches unswimmable (Bootsma et al. 2004). *Cladophora* blooms appear to be most extensive in eastern Lake Erie, while the western Lake Erie basin is also plagued by the more toxic *Microcystis* algal blooms (Ouellette et al., 2006). In Lake Huron, the benthic alga Chara is flourishing on the east side and on the western side *Cladophora* is resurging (E.T. Howell, personal communication).

The causes of the algae resurgence are not clear, and may not be directly related to phosphorus discharges. Total phosphorus loads have declined over time and are currently meeting IJC targets in most areas of the Great Lakes (Dolan, 2010). An exception to this may be found in the western basin of Lake Erie, where an increase in loads of total phosphorus, and of soluble phosphorus in particular, has been observed over the last 10 years (Richards and Baker, 2006).

Purpose

- To assess nutrient concentrations in the Great Lakes.
- To support the evaluation of the nutrient loadings to the Great Lakes
- To support the evaluation of trophic status and food web dynamics in the Great Lakes
- The Nutrients in Lakes Indicator is used in the Great Lakes indicator suite as a State indicator in the Water Quality top level reporting category.

Ecosystem Objective

The goals of phosphorus control are to maintain an oligotrophic state and relative algal biomass of Lakes Superior, Huron and Michigan, to maintain algal biomass below that of a nuisance condition in Lakes Erie and Ontario, and to eliminate algal nuisance in bays and in other areas wherever they occur (IJC, 1978). The International Joint Commission (IJC) developed the following delisting guideline for eutrophication or undesirable algae: no persistent water quality problems (e.g., dissolved oxygen, depletion of bottom waters, nuisance algal blooms or accumulations, and decreased water clarity) attributed to cultural eutrophication.

Ecological Condition

Measure

To assess the nutrient concentrations in the open waters of the Great Lakes, offshore total phosphorus (TP) values in the spring will be compared to the GLWQA targets (see endpoints).

Endpoints

When total phosphorus load goals are met, the expected concentration of total phosphorus in the open waters of each lake are: Lake Superior - 5 µg/l, Lake Huron - 5 µg/l, Lake Michigan - 7 µg/l, Lake Erie Western Basin - 15 µg/l, Lake Erie Central Basin - 10 µg/l, Lake Erie Eastern Basin - 10 µg/l, Lake Ontario - 10 µg/l. However, the authors note that these endpoints do not take into account the effects of invasive mussels on phosphorus cycling in the lakes.

Status

The status of total phosphorus in the Great Lakes is monitored by the Canadian and United States federal governments. Both Environment Canada (EC) and the United States Environmental Protection Agency (USEPA) conduct ship-based cruises to collect water quality samples on the lakes. Methods for EC's Great Lakes Surveillance Program are described in Dove et al. (2009). Sampling and analytical procedures for GLNPO's Open Lake Water Quality Surveys is provided in GLNPO (2010). Briefly, EC conducts monitoring in each of the Great Lakes except Lake Michigan, which is located entirely within the United States. Each lake is generally monitored every second year, with several cruises conducted during that year. All regions (nearshore, offshore and major embayments) are monitored for the EC program. USEPA conducts one spring and one summer cruise on all waters except Georgian Bay, with stations located more along the central long axis of each lake. Here, we provide an update with respect to long-term trends in total phosphorus in each of the Great Lakes, and relate these trends to the nutrient status and ecosystem objectives.

For the purpose of presenting long-term trends, the data are restricted surface waters (top 3 m) at offshore locations (depth ≥ 50m for lakes Huron, Michigan and for Georgian Bay, depth ≥ 100m for Lake Ontario and depth ≥ 150 m for Lake Superior), with the exception of Lake Erie, which is relatively shallow and is therefore divided instead into three basins. Springtime concentrations generally represent the annual maxima, and are therefore presented.

The results of offshore total phosphorus concentrations are shown in Figure 1 for the upper Great Lakes (lakes Superior, Huron, Michigan and Georgian Bay) and in Figure 2 for the lower Great Lakes (lakes Erie and Ontario). Individual measurements are represented in these box plots. The solid line within each box is the median value; the lower and upper ends of the boxes are the 25^{th} and 75^{th} percentiles, respectively, and the whiskers show the minimum and maximum values.

In the 1970s, symptoms of eutrophication were evident in many regions of the Great Lakes and the Great Lakes Water Quality Agreement of 1978 set out the above targets for phosphorus loads and offshore phosphorus concentrations in order to meet the ecosystem objectives. Concerted efforts to reduce phosphorus loads to the Great Lakes started in the 1970s and were successful at reducing phosphorus concentrations and symptoms of eutrophication in the lakes (Stevens and Neilson, 1987). The best example is seen for Lake Ontario, where the spring TP concentrations declined from 21 µg/L in 1975 and were meeting the target of 10 µg/L by the early 1990s. Implementation of sewage treatment plant controls were successful in reducing the symptoms of eutrophication so that the nuisance levels of *Cladophora* growth, most apparent in the 1960s and 1970s, were controlled and were no longer problematic throughout most regions of the lakes by the 1980s (GLWI, 2005).

Despite the successes of these control measures, nuisance algae have resurged in nearshore regions, particularly in lakes Ontario, Erie and Michigan, and in certain areas of Lake Huron (Higgins et al., 2005; Auer et al., 2010). This has lead to assertions in the media that phosphorus concentrations and inputs to the Great Lakes must be once again increasing (CBC, 2011). However, in the offshore regions of lakes Ontario, Huron and Michigan, phosphorus levels have continued to decline, and the rate of the decline has accelerated starting in the 1990s. In Lake Ontario, for example, offshore TP has declined from target levels achieved in the early 1990s to levels well below target (Figure 2).

The weight of scientific evidence indicates that invasive Dreissenid mussels (zebra mussels *Dreissena polymorpha* and quagga mussels *Dreissena bugensis*), which have colonized all of the Great Lakes with the exception of Lake Superior, have dramatically altered phosphorus cycling (Hecky et al., 2004). Dreissenid mussels are efficient filters of particulates, with two results: 1) mussels take in particulate-bound nutrients and excrete soluble nutrient forms, thereby increasing the availability of phosphorus for uptake by algae in Great Lakes nearshore areas, and 2) nutrients are bound in mussel feces deposited in nearshore sediment, preventing the export of phosphorus to offshore regions. In this way, nuisance algae are able to thrive in the nearshore, and the offshore regions are deprived of nutrients. Invasive mussels are causing massive ecosystem change, including reductions in benthos, plankton and fish populations in the offshore, and yet they facilitate the growth of nuisance levels of benthic algae in the nearshore (Evans et al., 2011).

Lake Superior

The TP record in Lake Superior extends back to 1970 (Environment Canada) and 1992 (USEPA). The average offshore values of TP have remained below the 5 μg/L target value to maintain an oligotrophic state. Fewer than 4% of the 400+ individual data measurements have exceeded the target. The ecosystem objective to maintain an oligotrophic state and retain relatively low algal biomass is being met. There are few invasive mussels in Lake Superior (Grigorovich, 2008), so it has been spared the ecological impacts seen in most of the other Great Lakes.

There is no trend over time apparent in either the US or the Canadian datasets, indicating status is good and unchanging. The lack of a trend, however, does not necessarily indicate that Lake Superior's waters have not been impacted. Due to its long residence time and large volume, we might not expect to detect a trend for some time. As was demonstrated by Chapra et al. (2009) using chloride, significant loading increases would not be detectable in the lake for at least a decade. For a less conservative substance like phosphorus, the lake's assimilation could further mask impacts. Prudence is recommended in the management of phosphorus inputs here, as the lake's very long residence time and low productivity mean that recovery from impacts, once felt, would take many decades to achieve.

Lake Michigan

Data for Lake Michigan are only collected by GLNPO since this lake is located entirely within the United States. Average offshore TP values have ranged from 6 μg/L in 1976 (the first year of monitoring) to 3.1 μg/L in 2009, indicating a significant ($p<0.001$) decline of 0.072 μg/L·yr over the period of record. Average offshore values have been in compliance with the GLWQA target concentration of 7 μg/L in every year, and only 14 of the 391 individual measurements have exceeded the target concentration over the 1983 – 2007 period. None of the individual measurements have exceeded the target concentration since 1996. These data indicate that the status with respect to the existing indicator endpoints is good and improving. In our best judgment, however, the endpoint has been surpassed, to the detriment of offshore biological productivity. In the nearshore, nutrient inputs combined with invasive mussel effects appear to be causing a resurgence of nuisance benthic algae. In the offshore, the evidence indicates the mussel invasions have resulted in increased predation of plankton and reduced nutrients, resulting in decreased productivity of the fisheries (Mida et al., 2010; Evans et al., 2011).

Lake Huron

In Lake Huron, average TP values in the offshore have ranged from 5.6 to 1.7 μg/L (data from both programs). Both the GLNPO and EC data indicate significant long-term declines in TP. GLNPO has measured a 0.079 μg/L·yr decline between 1983 and 2009 ($p<0.001$). EC has measured a longer-term decline of 0.056 μg/L·yr between 1970 and 2009 ($p<0.05$). The trends appear to be more steep since 1990, with declines of 0.13 and 0.10 μg/L·yr according to the GLNPO and EC data, respectively. The recent (2009) values are extremely low (1.8 and 2.7 μg/L for USEPA and EC, respectively), indicating levels have fallen too far below the target concentration and are insufficient to support a healthy offshore biological community. Decreased phytoplankton production, loss of native benthos, and serious declines in alewife and lake whitefish have been observed since the introduction of dreissenid mussels (Evans et al., 2011).

In Georgian Bay (measured only by Environment Canada), the long-term trend in TP has followed that of Lake Huron quite closely. The average TP values in the offshore have ranged from 1.9 to 5.5 μg/L and have also generally been in compliance with the 5 μg/L target value. Cruise means exceeded the target in 1987 (5.5 μg/L) and 1993 (5.1 μg/L). The Georgian Bay data indicate a significant ($p<0.001$) decline in TP of 0.08 μg/L·yr between 1970 and 2009. The rate of decline has been steeper since 1990 (slope = -0.14 μg/L·yr, $p=0.002$), indicating the decline in TP has accelerated. The most recent (2009) offshore average value of TP (2.55 μg/L) is extremely low, indicating oligotrophic conditions with insufficient nutrients to support a healthy biological community.

Lake Erie
TP concentrations in the western basin of Lake Erie have been the highest and most variable observed in the dataset. Spring cruise means have ranged from 10.8 to 82.6 µg/L. Concentrations were highest during the 1970s, and have clearly declined over time, although they continue to be highly variable and the most recent values in the western basin are some of the highest observed (Figure 2). The EC data indicate TP in the western basin has declined by 0.8 µg/L·yr ($p=0.01$); the rate is 1.04 µg/L·yr ($p<0.001$) if the unusually high 2009 value is excluded. The GLNPO data indicate a slower decline of 0.442 µg/L·yr from 1974 to 2008, but the trend is not statistically significant ($p=0.12$). Average TP concentrations frequently exceed the 15 µg/L target, and individual measurements have exceeded this value about two-thirds of the time in each of the US and Canadian data sets. The most recent values for the western basin are very high, and are most similar to values observed in the 1970s (Figure 2).

Concentrations of TP in the central Lake Erie basin are lower than those observed in the western basin but are elevated compared to target values and have not declined significantly over the period of record. Linear regression of the EC data indicates a decline of 0.174 µg TP/L·yr, but the trend is not statistically significant ($p=0.068$). The GLNPO data indicate an initial decline of 0.6 µg TP/L·yr from 1974 through 1990 ($p=0.01$), followed by an increase of 0.25 µg TP/L·yr from 1990 to 2009, but this increase was marginally significant ($p=0.1$). The central basin data are highly variable, and spring cruise mean TP concentrations since 1970 have ranged from 7.5 to 31 µg/L. Concentrations are often elevated above the 10 µg/L target; similar to the western basin, individual measurements from the central basin have exceeded the target about two-thirds of the time in each of the US and Canadian data sets.

Concentrations in the deeper eastern basin tend to be the lowest and the least variable in Lake Erie. Spring cruise mean concentrations have ranged from 4.9 to 37 µg/L and have exceeded the 10 µg/L target concentration about 60% of the time since 1983. The EC data indicate a decline between 1970 and 2009 (slope = -0.31 µg/L·yr) that is moderately significant ($p=0.02$). The GLNPO data indicate a slower rate of decline of 0.082 µg TP/L·yr ($p<0.05$). There is some suggestion of a more recent increase, but the trend is not statistically significant.

Lake Ontario
The trend for Lake Ontario provides the most convincing illustration of the long-term decline of TP in the Great Lakes. Mean offshore concentrations in the 1970s exceeded 20 µg/L; recent data are well below the target of 10 µg/L. The EC data show a highly significant ($p<0.001$) decline of 0.433 µg/L·yr between 1970 and 2010. The rate of decline from 1986 to 2009 measured by GLNPO is a more modest 0.16 µg/L·yr ($p<0.0001$), and is similar to the rate from 1990 -2010 measured by EC (-0.15 µg/L·yr, $p<0.0001$).

Data from the last decade in particular indicate offshore total phosphorus concentrations are not sufficient to support a healthy foodweb. Similar to Lakes Michigan and Huron, the offshore targets have been surpassed, yet the ecosystem objectives to maintain the algal biomass below nuisance levels have not been met for the nearshore. Cladophora has been found widely distributed across nearshore areas with solid substrate (Wilson et al., 2006). The current concentrations of TP (USEPA = 5.18 µg/L in 2009; EC = 6.41 µg/L in 2010) have surpassed the offshore target of 10 µg/L by a wide margin. At the same time, offshore silica levels have surged higher, indicating that diatom populations have crashed in the offshore (Dove, 2010). Mills et al. (2006) found that phytoplankton have been depleted and epilimnetic zooplankton have declined to historic lows. These changes may be, in turn, limiting offshore fish productivity, as preyfish declines have also been noted (Gorman, 2009).

Linkages
Nutrients, in particularly phosphorus, control the productivity of the Great Lakes ecosystems. In sufficient quantities, nutrients provide for a productive foodweb and fishery; in excess, nutrients stimulate nuisance and harmful algal growth, and symptoms of eutrophication, such as noxious algal blooms, depleted oxygen and fish kills, can ensue.

Nutrients are contributed by tributary discharges, sediment resuspension, atmospheric deposition, urban and agricultural runoff and by municipal wastewater facilities. Important linkages exist between sources, their pathways and the nearshore receiving environment, which in turn contributes nutrients to the offshore regions. Increasing human populations inhabiting Great Lakes shorelines, projected to occur in the decades to come, may result in increased pressures to municipal wastewater loadings, nutrients in tributaries and even atmospheric deposition.

Management Challenges/Opportunities

The proliferation of dreissenid mussels in the nearshore, and the subsequent expansion of mussel populations to many regions of the offshore, has had profound impacts on the lake environment. Mussel filtration of lake water has altered the light environment so that light penetrates to deeper depths and enables algae to grow in areas previously uninhabitable. The presence of mussel shells provides algae with a hard substrate upon which to grow. Finally, mussels have altered nutrient cycling so that nutrients destined for the offshore are instead trapped in the nearshore where they are causing impairment, and depriving the offshore of sufficient nutrients to sustain a healthy food web.

An improved understanding of how Dreissenid mussel water filtration controls the availability of phosphorus for algae is required. Improved knowledge about loadings of nutrients, in their various forms, and the impacts of those loads to lake impairments would also assist in determining whether specific load reductions would be worthwhile.

Further controlling lake-wide phosphorus loads would be even more costly, and the reduction of nutrients in the offshore may be exacerbated. Management of invasive mussels, already established in the ecosystem, is a major challenge with no readily apparent solutions.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	×					
2. Data are traceable to original sources	×					
3. The source of the data is a known, reliable and respected generator of data	×					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	×					
5. Data obtained from sources within the U.S. are comparable to those from Canada		×				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	×					

Clarifying Notes:

Comparison of US and Canadian TP data indicates consistently lower values are obtained by the USEPA relative to Environment Canada. Statistical tests were performed for lakes Ontario and Huron, where some shared stations permit paired t-test comparisons. The results indicated significantly higher values obtained by EC compared to the USEPA ($p<0.001$). The differences amount to approximately 1.9 and 1.6 µg P/L for lakes Ontario and Huron, respectively. No significant difference was observed for laboratory quality assurance (filtered) samples over many years (1999-2008), indicating agreement between laboratory instruments used. The difference occurs independently of field sampling date and location and is likely due to differing sample digestion durations. Samples collected by Environment Canada are digested for a minimum of 30 minutes once digestor temperature has reached 121°C. Samples collected by the USEPA are digested for 30 minutes with the oven set to 121°C, but this includes time for the oven to reach high temperature. The longer digestion of EC samples may result in more complete breakdown of nutrients attached to particles and higher concentrations are measured.

Acknowledgments

Authors:

Alice Dove, Environmental Scientist, Water Quality Monitoring and Surveillance, Environment Canada.

Glenn Warren, Environmental Monitoring and Indicators Team Leader, Great Lakes National Program Office, USEPA.

Information Sources

United States data from Great Lakes National Program Office, United States Environmental Protection Agency, Chicago, Illinois.

Early (1970 – 1976) Lake Erie data from CLEAR (Center for Lake Erie Area Research) under contract to USEPA.

Canadian data from Great Lakes Surveillance Program, Water Quality Monitoring and Surveillance, Environment Canada, Burlington, Ontario.

Nearshore information provided by E.T. Howell, Ontario Ministry of the Environment

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List of Figures

Figure 1. Long-term Trend of Total Phosphorus in the Upper Great Lakes
Source: Environment Canada and USEPA - Great Lakes National Program Office

Figure 2. Long-term Trend of Total Phosphorus in the Lower Great Lakes
Source: Environment Canada, USEPA – Great Lakes National Program Office, and Center for Lake Erie Area Research (CLEAR)

Last Updated

State of the Great Lakes 2011

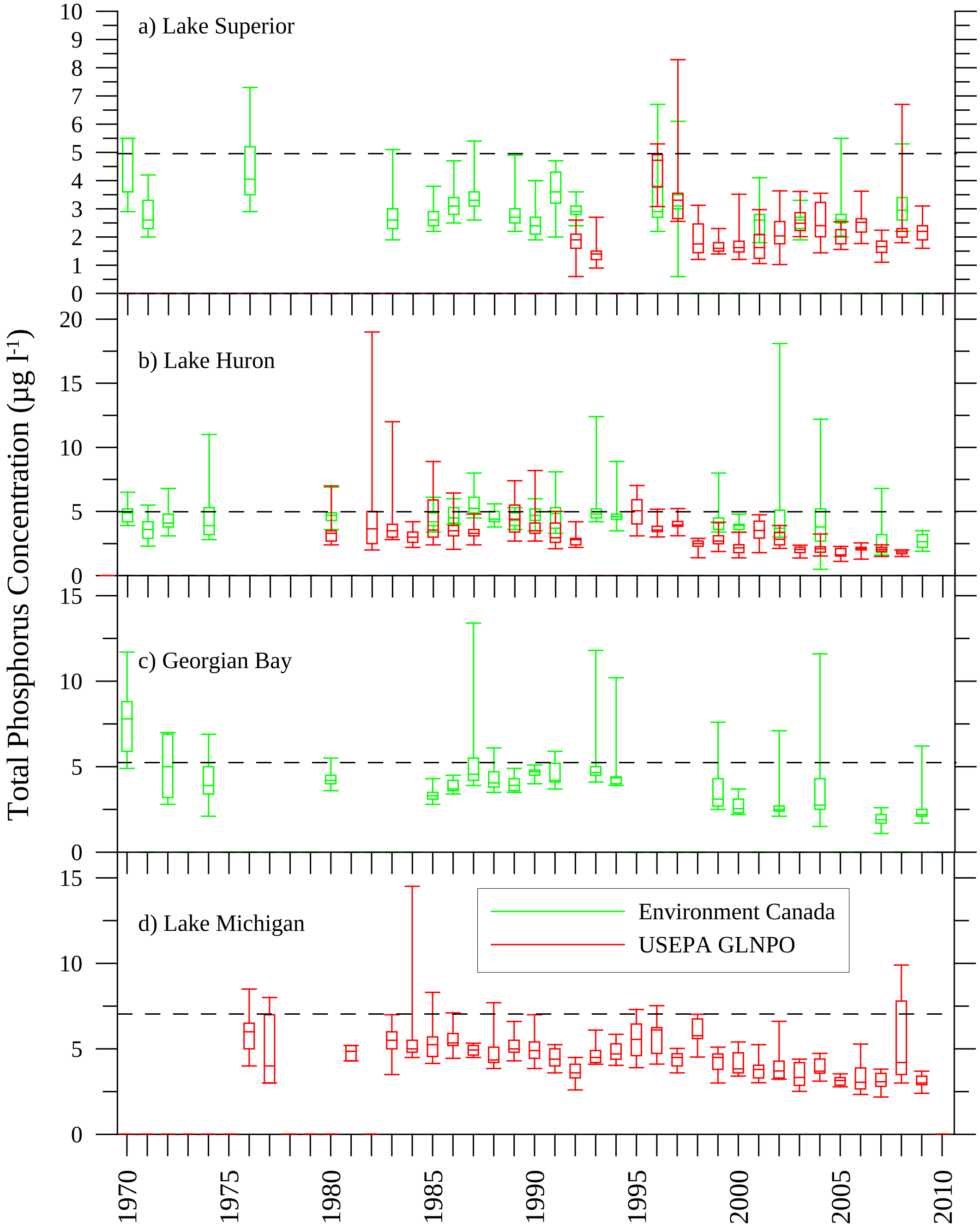

Figure 1. Long-term Trend of Total Phosphorus in the Upper Great Lakes
Source: Environment Canada and USEPA - Great Lakes National Program Office

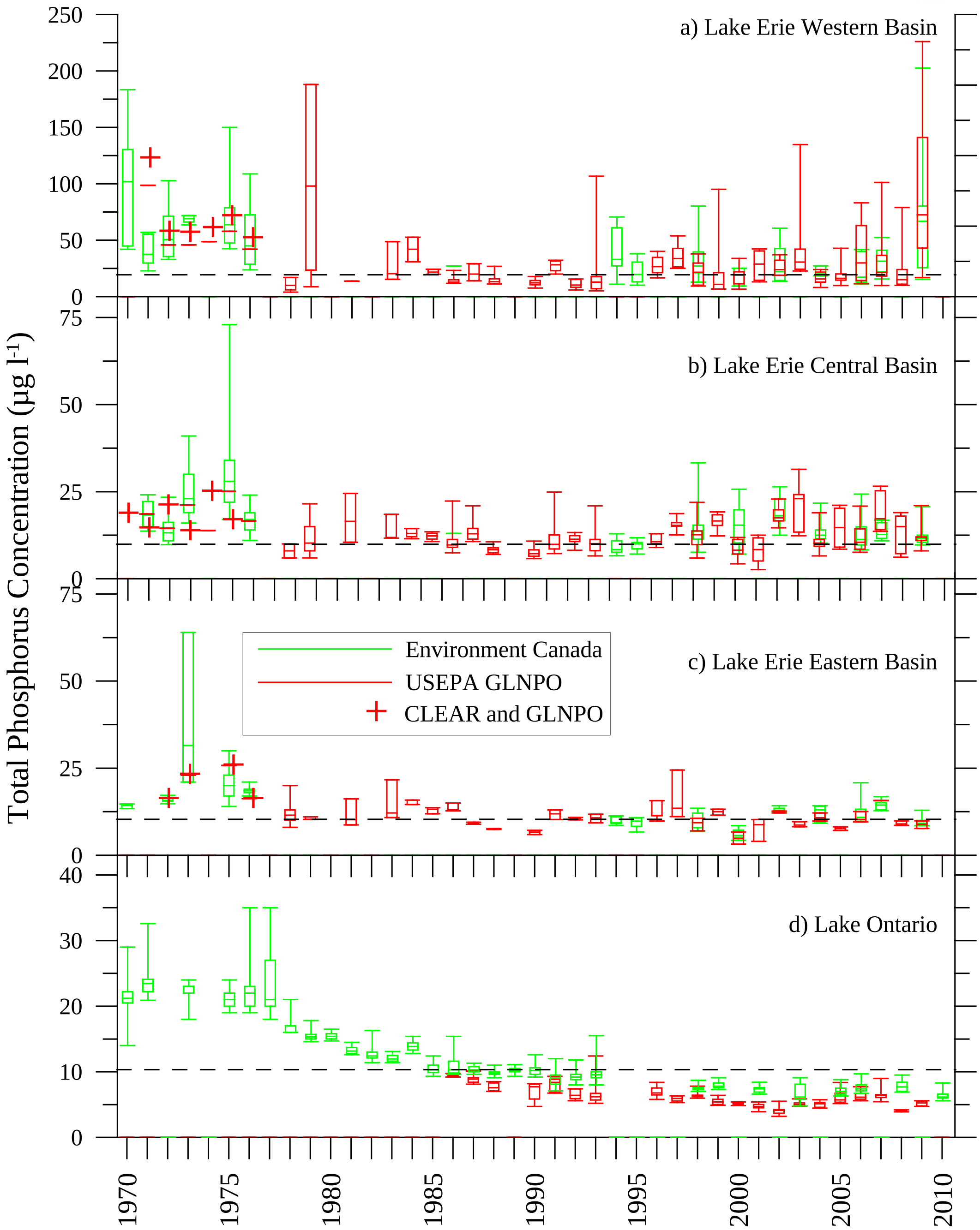

Figure 2. Long-term Trend of Total Phosphorus in the Lower Great Lakes
Source: Environment Canada, USEPA – Great Lakes National Program Office, and Center for Lake Erie Area Research (CLEAR)

Phytoplankton Populations

Overall Assessment
Status: Undetermined
Trend: Undetermined (changing)
Rationale: Reductions in the spring bloom are occurring in Lake Michigan, Lake Huron, and to a lesser extent in Lake Ontario, consistent with both oligotrophication and invasive species impacts. Cyanobacterial blooms are occurring with greater frequency in the western basin of Lake Erie.
*This assessment is based on historical conditions and expert opinion. Specific objectives or criteria have not been determined.

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Unchanging
Rationale: Changes in phytoplankton community size or seasonality, as measured by satellite-estimated chlorophyll a, have not been detected in Lake Superior. Current communities are indicative of an oligotrophic system.

Lake Michigan
Status: Fair
Trend: Undetermined (changing)
Rationale: A notable reduction in the spring bloom and a consequent diminution in seasonality has been seen in Lake Michigan. Lower levels of primary production could be reducing resource availability to higher trophic levels.

Lake Huron
Status: Fair
Trend: Undetermined (changing)
Rationale: The spring bloom largely disappeared in 2003; reductions in chlorophyll have been seen across all seasons since 2005. Coincident declines in zooplankton and benthos suggest impacts on higher trophic levels.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: While highly variable, no trends in chlorophyll have been noted for Lake Erie since the last report (2003). However, blooms of cyanobacteria, in some cases toxic, appear to have increased in frequency in the western basin in recent years.

Lake Ontario
Status: Fair
Trend: Undetermined (changing)
Rationale: There is some indication of declines in spring chlorophyll in the past ten years.

Purpose
- To directly assess phytoplankton species composition, biomass, and primary productivity in the Great Lakes
- To indirectly assess the impact of nutrient and contaminant enrichment and invasive non-native predators

on the microbial food-web of the Great Lakes

- The Phytoplankton Populations indicator is used in the Great Lakes indicator suite as a State indicator in the Aquatic-dependent life top level reporting category.

Ecosystem Objective

Desired objectives are phytoplankton biomass size and structure indicative of oligotrophic conditions (i.e. a state of low biological productivity, as is generally found in the cold open waters of large lakes) for Lakes Superior, Huron and Michigan; and of mesotrophic conditions for Lakes Erie and Ontario. In addition, algal biomass should be maintained below that of a nuisance condition in Lakes Erie and Ontario, and in bays and in other areas wherever they occur. There are currently no guidelines in place to define what criteria should be used to assess whether or not these desired states have been achieved.

Ecological Condition

This indicator assumes that phytoplankton populations respond in quantifiable ways to anthropogenic inputs of both nutrients and contaminants, permitting inferences to be made about system perturbations through the assessment of phytoplankton community size, structure and productivity. Internally consistent time series data on phytoplankton community size and composition have not been available since 2000. In their absence, assessments made in this report have been based on estimates of chlorophyll derived from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite imagery as well as on literature sources.

Major changes have occurred in the phytoplankton community of several Great Lakes since SOLEC 2003. The spring phytoplankton bloom in Lake Huron, which is the major episode of primary production in the lake, virtually disappeared in 2003 (Barbiero et al. 2011). Dramatic declines in cladoceran populations were seen that summer, along with overall declines in crustacean biomass (Barbiero et al. 2009). Declines in the spring bloom were also seen in Lake Michigan (Fahnenstiel et al. 2010, Barbiero et al. 2012) along with similar changes in zooplankton communities. Causal links, if any, between the reductions in the spring bloom and the coincident reductions in cladoceran biomass are not fully worked out at present. These changes represent a trend towards oligotrophication in Lakes Huron and Michigan, with the offshore waters of these two lakes now closely resembling those of Lake Superior in many respects (Barbiero et al. 2012). While this trend can be viewed in a positive light from a conservation perspective, it likely also represents an overall reduction in the carrying capacity of the two lakes.

In the western basin of Lake Erie, a number of large blooms of the nuisance cyanobacterium *Microcystis* have occurred since the last report (Vincent et al. 2004), and there is evidence that such blooms are becoming a yearly occurrence (Chaffin et al. 2011).

There is some evidence that the chlorophyll declines seen in Lake Ontario in the 1980s (Johengen et al. 1996) have continued in the past ten years (GLNPO, unpublished data), albeit at a reduced rate.

No assessment of "ecosystem health" is currently possible on the basis of phytoplankton data, since reference criteria and endpoints have yet to be developed.

Management Challenges/Opportunities

The two most important potential future pressures on the phytoplankton community are changes in nutrient loadings and continued introductions and expansions of non-native species. Increases in the magnitude and/or bioavailable fraction of phosphorus loading might result in both increases in phytoplankton community size, as well as shifts in phytoplankton community composition away from diatoms and towards other, potentially nuisance, taxa. Conversely, reductions in phosphorus loading might be expected to have the opposite effect. Continued expansion of dreissenid mussel populations could further reduce nutrient concentrations in offshore waters and contribute to the oligotrophication already seen in some of the lakes.

Comments from the author(s)

A highly detailed record of phytoplankton biomass and community structure has accumulated, and continues to be generated, through regular monitoring efforts. However, problems exist with internal comparability of these data. While efforts are currently underway to rectify this situation, consistent long-term data extending beyond 2000 are not currently available.

While the use of phytoplankton data to assess "ecosystem health" is conceptually attractive, there is currently no objective, quantitative mechanism for doing so. Reliance upon literature values for nutrient tolerances or indicator status of individual species is not recommended, since the unusual physical regime of the Great Lakes makes it likely that responses of individual species to their chemical environment in the Great Lakes will vary in fundamental ways from those in other lakes. The use of species-level phytoplankton data to assess 'ecosystem health' will require the development of an objective, quantifiable index specific to the Great Lakes.

Given the current lack of comparable, long-term data, the difficulties involved in interpretation of such complex data mentioned above, as well as the limited temporal window afforded by a biannual monitoring program, it is important to identify alternate sources of appropriate data to help monitor trends in phytoplankton. In this context, the use of remote sensing technologies has great potential to enhance our ability to detect trends in chlorophyll concentrations in the Great Lakes. While there is currently not universal agreement as to the applicability of standard chlorophyll algorithms to the Great Lakes, particularly in cases in which absolute concentrations are of interest, satellite imagery has shown promise in the detection of chlorophyll trends in the Great Lakes (e.g., Kerfoot et al., 2010; Barbiero et al., 2011).

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X	X			
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data			X			
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report				X		

Clarifying Notes: Information has been drawn from a number of sources, including the peer-reviewed scientific literature and unpublished SeaWiFS satellite data. The validity of SeaWiFS imagery for quantifying chlorophyll concentrations in the Great Lakes has not been fully worked out as of yet, and therefore any conclusions based on this data should be approached with some caution. Quantification of data quality is typically not treated in detail in the scientific literature.

Acknowledgments

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Last Updated

State of the Great Lakes 2011

Preyfish Populations

Overall Assessment
Status: Undetermined
Trend: Deteriorating
Rationale: In all five Laurentian Great Lakes, preyfish biomass has decreased since 1988. This decrease in preyfish biomass may be partly attributable to predation by piscivorous fish populations. However, other factors likely contributed to the decrease in preyfish biomass, including variation and gaps in recruitment of ciscoes, shifts of fish populations to waters deeper than those sampled by bottom trawl surveys, declines in offshore primary productivity and phosphorous levels, and negative effects induced by dreissenid mussel and *Bythotrephes* invasions. Expansion of non-native gobies in demersal habitats of the lower lakes is symptomatic of a change in the food web. Assessing and quantifying bottom-up effects on preyfish biomass will require additional years of surveillance, across-lake comparisons, and food-web analyses. Because Lake Superior has not been successfully invaded by dreissenid mussels, Lake Superior can serve as a control lake when attempting to assess the effects of dreissenid mussels on food webs and preyfish populations.

Lake-by-Lake Assessment
Lake Superior
Status: Undetermined
Trend: Improving
Rationale: Abundance of preyfish populations, dominated by native coregonids, continues to fluctuate with a downward trend that sharply steepened in 2009. The decline in preyfish populations since the early 1990s is attributed to recruitment variation and predation by recovered lake trout populations. Non-native rainbow smelt remains as a principal component of preyfish assemblage. Round gobies are present though rare in western Lake Superior and Eurasian ruffe, though uncommon, continues to colonize inshore waters and embayments. The Lake Superior preyfish community is considered improving because of an increase in the proportion of native species comprising the assemblage and the prey base's ability to support the recovery of the wild lake trout population.

Lake Michigan
Status: Undetermined
Trend: Deteriorating
Rationale: Several preyfish populations (i.e., alewife, bloater, rainbow smelt, deepwater sculpin) are near historic lows, while densities of non-native round goby are increasing. The decline in *Diporeia* and expansion of dreissenids, particularly quagga mussels, to deeper waters signal a shift in food web toward greater biomass in the benthic food web relative to the pelagic one; further community change is expected.

Lake Huron
Status: Undetermined
Trend: Deteriorating
Rationale: Non-native preyfish populations are at historic lows and native bloater has become the dominant prey species. The decline in *Diporeia* and colonization of dreissenids signals a shift in food web toward a benthic organization and further community change.

Lake Erie
Status: Undetermined
Trend: Deteriorating
Rationale: Preyfish (spiny-rayed and softfin fish species) populations have increased since the early1990s but have

fluctuated considerably. Biomass of clupeids has declined since 2001. Non-native round goby populations expanded rapidly after 1994, peaked in 2007, and afterwards declined by 90%. The colonization of dreissenid mussels has resulted in major changes in the food web.

Lake Ontario
Status: Undetermined
Trend: Deteriorating
Rationale: Non-native preyfish populations have fluctuated about historic lows and non-native alewife remains the dominant prey species. Abundance of non-native round goby has declined sharply since 2008. Colonization of offshore waters by dreissenids has increased energy flow from the pelagia to the lake bottom. Catches of native deepwater sculpin, a population thought to be extirpated from Lake Ontario, have increased steadily in catches taken at depths > 70 m since 2005. Native deepwater ciscoes have not been reported in the lake since 1983; however, initial restoration efforts have begun. A new invasive invertebrate, *Hemimysis anomala,* was discovered in 2006 and has become widely established in nearshore waters. Thus far, its impacts on the lake ecosystem appear to be minimal.

Purpose

- To assess the abundance and diversity of preyfish populations
- To infer the stability of predator species necessary to maintain the biological integrity of each lake
- The Preyfish Populations indicator is used in the Great Lakes indicator suite as an indicator in the Aquatic-dependent Life top level reporting category.

Ecosystem Objective
The importance of preyfish populations to support healthy, productive populations of predator fishes is recognized in the Fish Community Goals and Objectives (FCGOs) for each lake. For example, the Fish Community Objectives (FCOs) for Lake Michigan specify that in order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. This indicator also relates to the 1997 Strategic Great Lakes Fisheries Management Plan Common Goal Statement for Great Lakes fisheries agencies.

Ecological Condition
Background
The preyfish assemblage forms important trophic links in the aquatic ecosystem and constitutes the majority of the fish production in the Great Lakes. Preyfish populations in each of the lakes are currently monitored on an annual basis in order to quantify the population dynamics of these important fish stocks and to provide a better understanding of the processes that shape the fish community. Populations of lake trout, Pacifique salmon, and other salmonids have been established as part of intensive stocking programs designed to rehabilitate or develop new sport fish populations and commercial fisheries. These economically valuable predator species sustain increasingly demanding and highly valued fisheries, and information on their status is crucial. In turn, these apex predators are sustained by preyfish populations. In addition, some preyfishes, such as the bloater and the cisco, which are native species, and the rainbow smelt, which is non-native, are also directly important to the commercial fishing industry. Therefore, it is very important that the current status and estimated carrying capacity of the preyfish populations be fully understood in order to fully address (1) lake trout restoration goals, (2) stocking projections, (3) present levels of salmonid abundance, and (4) commercial fishing interests.

The component of the Great Lakes fish communities that we classify as preyfish comprises species – including pelagic, benthopelagic and benthic species – that prey on invertebrates for their entire life history. As adults, most preyfish depend on diets of crustacean zooplankton and macroinvertebrates *Diporeia* and *Mysis*. Round gobies, which have invaded in the past ~15 years, also make use of dreissenid mussels as a primary diet component. This convention also supports the recognition of particle-size distribution theory and size-dependent ecological processes. Based on size-spectra theory, body size is an indicator of trophic level, and the smaller, short-lived fish that constitute the planktivorous fish assemblage discussed here are a discernable trophic group of the food web. At present, bloaters (*Coregonus hoyi*), cisco (*Coregonus artedi*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and deepwater sculpins (*Myoxocephalus thompsonii*) constitute the bulk of the preyfish communities across the five lakes (Figure 1). In Superior, juvenile lake whitefish (*Coregonus clupeaformis*) is a principal prey species. Other species contributing a lesser extent to the preyfish assemblages include pygmy whitefish (*Prosopium coulteri*), ninespine stickleback (*Pungitius pungitius*), round goby (*Apollonia melanostoma*), trout-perch (*Percopsis omiscomaycus*), and slimy sculpin (*Cottus cognatus*). In Lake Erie, the preyfish community is unique among the Great Lakes in that it is characterized by relatively high species diversity. The preyfish community comprises primarily gizzard shad (*Dorosoma cepedianum*) and alewife (grouped as clupeids); emerald (*Notropis atherinoides*) and spottail (*N. hudsonius*) shiners; silver chub (*Hybopsis storeriana*); trout-perch (*Percopsis omiscomaycus*); round goby and rainbow smelt (grouped as soft-rayed); age-0 yellow perch (*Perca flavescens*) and white perch (*Morone americana*), and white bass (*M. chrysops*) (grouped as spiny-rayed).

The successful colonization of lakes Michigan, Huron, Erie, and Ontario by zebra mussel (*Dreissena polymorpha*) in the early 1990s and more recently the quagga mussel (*Dreissena bugensis*), has had a significant impact on the trophic structure of those lakes by sequestering energy and nutrients in the benthos and increasing water clarity of open waters. Only a handful of fish species (round gobies, lake whitefish, freshwater drum, lake sturgeon) consume dreissenid mussels. As a result, managers are concerned that expansion of dreissenids will reduce production of important pelagic preyfish species, because they can potentially reduce energy transfer from benthic to pelagic regions. As a result of profound ongoing changes in trophic structure in the lower Great Lakes, their ecosystems will continue to change, likely in unpredictable ways.

State of Preyfish Populations

Lake Superior: Undetermined, improving

Since 1994, biomass of the Lake Superior preyfish has declined compared to the peak years in 1986, 1990, and 1994, a period when cisco was the dominant preyfish species and wild lake trout populations were starting to recover (Gorman et al. 2011a). Since the early 1980s, the dynamics of preyfish biomass have been driven largely by variation in recruitment of age-1 cisco. Strong year classes in 1984, 1988-1990, 1998, and most recently 2003 were largely responsible for peaks in cisco biomass in 1986, 1990-1994, 1999, and 2004-2006. Prior to 1984, the non-native rainbow smelt was the dominant preyfish, but fluctuating population levels and recovery of native coregonids after 1984 resulted in reduced smelt biomass. Biomass of bloater and lake whitefish has increased since the early 1980s, and has been less variable than that of cisco. Since 2006, cisco and bloater abundance has declined sharply. During 2002 to 2004 and 2009-2010 rainbow smelt biomass declined to the lowest levels in the time series. There is strong evidence that declines in cisco, bloater, and rainbow smelt biomass are tied to increased predation by recovered lake trout populations. Other preyfish species, notably sculpins, burbot, and ninespine stickleback have declined in abundance since the recovery of wild lake trout populations in the mid-1980s. Thus, the current state of the Lake Superior preyfish community appears to be largely the result of recruitment variation in prey species, increased predation by recovered wild lake trout stocks, and to a lesser degree, the resumption of human harvest of lake trout, cisco, and lake whitefish.

Lake Huron: Undetermined, deteriorating.

In the 1970-mid-1980s the Lake Huron preyfish community was dominated by exotic alewife and rainbow smelt. Following this early period, strong recruitment of native bloater stocks contributed as much 47% to preyfish biomass. After 1994 preyfish biomass trended downward and accelerated after 2002 when alewife stocks abruptly collapsed. The collapse of alewife stocks appears due to heavy salmonid predation by increased Chinook salmon abundance which was augmented by wild reproduction. Further decline of rainbow smelt and recruitment of bloater resulted in a preyfish community dominated by boater. From 2004 to 2010, U.S. Geological Survey (USGS) surveys captured increasing numbers of wild juvenile lake trout, signaling natural reproduction from recovering lake trout stocks. Meanwhile, salmon catch rates by anglers declined, as did average size and condition of those fish. Accompanying the decline in fish biomass and shift toward native fishes was a decline in lower trophic level productivity; the deepwater amphipod *Diporeia* has declined throughout Lake Huron's main basin, and the zooplankton community has changed so that it resembles the assemblage found in Lake Superior. The reasons triggering the shift toward a more oligotrophic state are not known, but a widely held hypothesis is that zebra and quagga mussels are shunting energy and nutrients into a benthic pathway and are no longer available to *Diporeia* and pelagic zooplankton and fish.

Lake Michigan: Undetermined, deteriorating
Bloater abundance in Lake Michigan fluctuated greatly from 1973 to 2010, showing a strong expansion during the 1980s, and a rapid decline in the late 1990s (Madenjian et al. 2010). Bloater populations may have a cyclic pattern in year-class strength, with a period of about 30 years. The substantial decline in alewife abundance during the 1970s and early 1980s has been attributed to increased predation by salmon and trout. The Lake Michigan deepwater sculpin population exhibited a strong recovery during the 1970s and early 1980s, and this recovery has been attributed to the decline in alewife abundance. Alewives have been suspected of interfering with reproduction of deepwater sculpins by feeding upon deepwater sculpin fry. Slimy sculpin abundance appeared to be primarily regulated by predation from juvenile lake trout as it is a favored prey of juvenile lake trout. Temporal trends in abundance of rainbow smelt are difficult to interpret. Yellow perch may be showing early signs of a recovery in the main basin of Lake Michigan. The first catch of round gobies in the annual lakewide survey occurred in 2003, and round goby abundance in the main basin of the lake has increased during 2003-2010. Total preyfish biomass in Lake Michigan during 2007-2010 was at record low levels. Although this low abundance has been tied to the dreissenid mussel invasions, other explanations (including increased predation by Chinook salmon on alewives, shift of deepwater sculpin to deeper water, and a long-term cyclic pattern in bloater year-class strength) may to be more plausible. Assessing and quantifying the bottom-up effects on preyfish biomass will likely require additional years of surveillance, across-lake comparisons, and food-web analyses.

Lake Erie: Undetermined, deteriorating
The preyfish community of Lake Erie has shown mixed trends in composition and abundance since 1987. In the mid-1990s, spiny-rayed and clupeid preyfishes declined in abundance while softfin preyfish increased. Abundance of spiny-rayed preyfish abundance increased after 1998 while abundance of clupeids declined after 2000. Abundance of softfin preyfish remained relatively stable from 1997 through 2010. These patterns have not been consistent across the three basins of Lake Erie. In the eastern basin, abundance of rainbow smelt (part of the soft-rayed group) declined since the late 1980s, however, this trend may have reversed after 2000 as abundance of smelt increased though with high inter-annual variation. Preyfish abundance in the central and western basins also declined since the late 1980s, the result of declines in abundance of age-0 white perch and rainbow smelt, although abundances of white perch and rainbow smelt increased after 2006. In 2004, 2008 and 2010, the clupeid preyfish component of the central and western basins declined to the lowest levels in the time series. Overlying trends in principal preyfishes was the proliferation of invasive, non-native species. By 1989 dreissenids had successfully colonized all three basins (Barbiero and Tuchman, 2004). Following the invasion of round goby in 1994 and their proliferation throughout the lake by the late-1990s, abundance declined sharply after 2007 (Gorman and Bunnell, 2011). The establishment of dreissenids in Lake Erie has affected nutrient and energy cycling (Culver and Conroy 2007) and changes in the preyfish community after 1989 may be at least partly attributable to their proliferation.

Lake Ontario: Undetermined, deteriorating
The non-native alewife continues to dominate the preyfish community, but their populations remain at levels well below that of the early 1980s. The rainbow smelt population continues to decrease and has an abbreviated size structure suggestive of heavy predation pressure. Abundance of the non-native round goby appears to have stabilized at a biomass level similar to that of rainbow smelt. Frequent observations of round goby in sport fish diets

suggest that it is an important link in moving energy from dreissenids to larger predators. Catches of deepwater sculpin, thought to be extirpated from the Lake, have steadily increased in depths greater than 70 meters since 2005. Current deepwater sculpin bottom trawl catches include a mix of age classes, suggesting conditions are favorable for recovery. Deepwater ciscoes, however, have not been reported in the lake since 1983 and the large area of the lake they once occupied may be devoid of fish for much of the year. Furthermore, dreissenid colonization in deeper waters is increasing the flow of energy from the open water to the lake bottom. Zooplankton density in surface waters remains low, likely a result of non-native *Bythotrephes* and *Cercopagis* predation. Dynamic changes in zooplankton density with water depth suggest that algal and zooplankton production around the thermocline may be important for supporting the native *Mysis diluviana* and preyfishes. The nearshore invasive shrimp, *Hemimysis anomala*, discovered in the lake in 2006, has spread throughout the lake and is often found associated with rocky bottom types. Diet and energy tracer studies suggest *Hemimysis* consume a mix of near shore zooplankton and algae.

Pressures

The influences of predation by salmon and lake trout on preyfish populations appear to be common across all lakes. Additional pressures from dreissenid mussels which are linked to the collapse of *Diporeia*, are strong in all the Great Lakes except Lake Superior. Recent declines in preyfish abundance observed in lakes Ontario, Huron, and Michigan, suggest that dynamics of preyfish populations in those lakes may be driven by a combination of pressures from predation (top down) and benthification by dreissenid mussel proliferation (bottom up). Which of these pressures will have precedence in future years is unclear. Moreover, non-native zooplankters, *Bythotrephes* and *Cercopagis*, could negatively influence preyfish populations by competing for cladoceran and copepod zooplankton, if they are indeed limiting. A new invasive invertebrate *Hemimysis anomala*, now present in Lake Ontario, has the potential to further disrupt Great Lakes foodwebs,

Management Challenges/Opportunities

Recognition of significant predation effects on preyfish populations, particularly alewife, has resulted in recent salmon stocking cutbacks in Lake Michigan and Lake Huron and only minor increases in Lake Ontario. However, alewife have exhibited the ability to produce strong year classes from small adult stocks when climatic conditions are favorable such that the continued judicious use of artificially propagated predators may be necessary to avoid domination by alewife. For example, the 2010 year-class of alewife in Lake Michigan was among the largest ever recorded in the 15-year history of the acoustic survey. On the other hand, the continued low abundance of alewife in Lake Huron since their collapse in 2003 suggests that the ability to produce strong year-classes from small stock sizes is not inevitable, however, it is unclear whether poor biotic and abiotic conditions for alewife larvae or strong predatory pressure on age-0 alewife are responsible for the absence of an alewife recovery in Lake Huron. Continued strong predation pressure on alewife in Lake Huron may be preventing adults from reaching a threshold population size needed to generate a large year class. Thus, alewife stocks in Lake Huron may be trapped in a "predator pit" (J. Bence, personal communication). Stocking of predators is not an option in Lake Superior where lake trout and salmon are almost entirely lake-produced. This scenario reinforces the need to avoid further introductions of non-native species into the Great Lakes ecosystems.

Comments from the author(s)

In order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. However, the current mix of native and naturalized prey and predator species, and the contributions of artificially propagated predator species into the system, confound any sense of balance in any lakes other than Lake Superior. The metrics of ecological balance as the consequence of fish community structure are best defined through food-web interactions. It is through understanding the exchanges of trophic supply and demand that the fish community can be described quantitatively and ecological attributes such as balance can be better defined and the limits inherent to the ecosystem be realized.

Currently, new efforts to develop food web models are underway in all the Great Lakes. Ecosystem models (Ecopath with Ecosim) have been developed in all of the Great Lakes in recent years, and this synthesis of data across trophic levels will provide new insights into the important ecological drivers within each lake as well as the key differences across the Great Lakes. Because full development of these models is hindered by a lack of data, USGS plans to intensively sample multiple trophic levels in each of the Great Lakes over 2010-2014. This work will be conducted in coordination with intensive monitoring of lower trophic level communities in each lake by USEPA and Environment Canada. This work is above and beyond the long-term annual monitoring of fish communities. In addition, over the past decade or so, fisheries scientists have begun to recognize the sampling limitations of traditional capture techniques (day bottom trawling), and have added complementary night bottom trawling, midwater trawling, and acoustic techniques to more accurately estimate abundance of preyfish in the Great Lakes (Stockwell et al. 2006, 2007; Yule et al. 2007, 2008). Though not an assessment panacea, hydroacoustics have provided additional insights and have demonstrated utility in yielding more accurate estimates of preyfish biomass.

Long-term preyfish assessment data for Lake Superior is presently restricted to the nearshore waters (15-80 m depth) which constitute only ~16% of the Lake surface area. Offshore waters (>80 m depth) constitute ~77% of the Lake surface area and remain poorly studied. Surveys of offshore waters conducted during 2001-2010 revealed a preyfish assemblage dominated by adult cisco, kiyi (*C. kiyi*) and deepwater sculpin and the dominant predator is siscowet lake trout (Gorman et al. 2011a). Given the large area of offshore habitat in Lake Superior, consideration of trends in the offshore fish assemblage should be addressed to assess the state of the lake-wide fish community. Research on the offshore fish community since 2005 has shown that the offshore food web is distinct from the nearshore foodweb (Stockwell et al. 2010a,b; Gamble et al. 2011a,b). Studies of diel movement of Lake Superior fishes demonstrate that approximately 80% of the fish community biomass undergoes diel vertical migration, effectively linking benthic and pelagic zones of the lake (Gorman et al. 2011b). Trophic transfers between nearshore and offshore waters may be facilitated by seasonal movement of fish, primarily cisco. These findings have spurred the development of a new annual assessment program which will incorporate sampling in both nearshore and offshore waters.

The native deepwater demersal preyfish community in Lake Huron was historically dominated by deepwater ciscoes, sculpins, and cisco, with ninespine sticklebacks and trout-perch also present. By the 1950s, the native community was disrupted by introductions of alewife and rainbow smelt and was dominated by non-native invasive species. More recently, introductions of dreissenid mussels, predatory zooplankters (*Bythotrephes* sp. and *Cercopagis* sp.), and round gobies have further affected this community, which was in a state of collapse by 2006 (Riley et al. 2008). The total estimated lakewide offshore demersal prey biomass in Lake Huron (from bottom trawling) has continued to decline, and was at the second-lowest level recorded in 2010 (29.1 Kt; Roseman et al. 2011), approximately 12 percent of the highest estimate (242.5 Kt) recorded in 1987. Invasive alewife populations collapsed in 2003 and estimated biomass of this species has remained very low, but there are indications that rainbow smelt and bloater abundance are beginning to rebound. In particular, bloater abundance appears to be approaching the levels observed in the 1980s and 1990s, but biomass remains lower due to a relative lack of larger fish. In recent years biomass estimates for sculpins, sticklebacks, and trout-perch were near the lowest levels observed in the time series, indicating that benthic offshore conditions in Lake Huron may have changed in a way that does not favor previous population levels (Roseman et al. 2011). Round gobies have declined to relatively low abundance (Roseman et al. 2011). Changes in habitat use and fish schooling suggest that large-scale changes may be occurring in the benthic environment (Dunlop et al. 2009; Riley and Adams 2010). Abundance of *Diporeia* has declined sharply to low densities throughout the lake (Nalepa et al. 2007), and recent work suggests that invasive *Bythotrephes* may consume large amounts of zooplankton (Bunnell et al. 2011). Recent changes in fish populations may stem from restructured food webs which in turn may be related to the effects of invasive species. Continuing low levels of preyfish abundance may have serious implications for the growth, condition, and survival of predatory fish in the lake.

Protecting or re-establishing rare or extirpated members of the once prominent native preyfish communities, most notably the various members of the whitefish family (*Coregonus* spp.), should be a priority in all the Great Lakes, but especially so in Lake Ontario where vast areas of the lake once occupied by extirpated deepwater ciscoes are devoid of fish for much of the year. Lake Superior, whose preyfish assemblage is dominated by indigenous species and retains a full complement of ciscoes, should be examined more closely to better understand the trophic ecology of its more natural system.

With the continuous nature of changes that seems to characterize the preyfish populations of the Great Lakes, and the lower trophic levels on which they depend, the appropriate frequency to review this indicator should be on a 3-year basis.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin				X		
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Figure 1. Preyfish trends based on annual bottom trawl surveys.

Data sources: U.S. Geological Survey - Great Lakes Science Center, Ohio Division of Wildlife, Ontario Ministry of Natural Resources, and New York State Department of Environmental Conservation.

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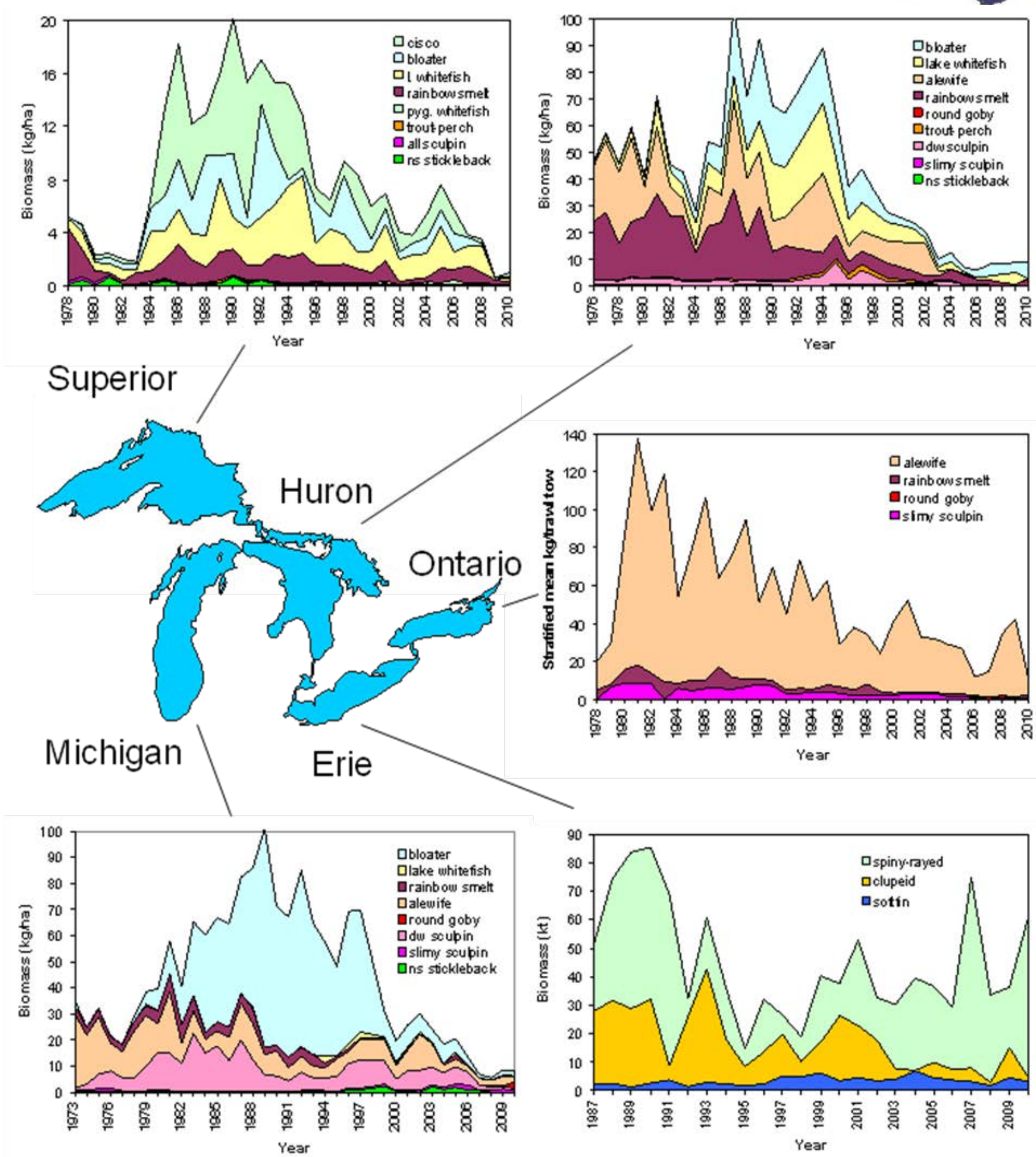

Figure 1. Preyfish trends based on annual bottom trawl surveys.
All day bottom trawl surveys were performed by USGS - Great Lakes Science Center, except for Lake Ontario, which was conducted jointly by USGS and the New York State Department of Environmental Conservation, and Lake Erie, which was conducted in the Western Basin by the USGS, Ohio Division of Wildlife, and the Ontario Ministry of Natural Resources (Lake Erie Forage Task Group). Trends shown for Lake Erie are from the Western Basin.
Data sources: U.S. Geological Survey - Great Lakes Science Center, Ohio Division of Wildlife, Ontario Ministry of Natural Resources, and New York State Department of Environmental Conservation.

Remediating Contaminated Sediment

Overall Assessment

Trend: **Increasing**

Rationale: Between 1997 and 2010, U.S. EPA and its partners have remediated approximately 7 million cubic yards of contaminated sediment in Great Lakes AOCs. As of 2010, over 200,000 cubic meters of contaminated sediment have been managed in the Canadian Great Lakes AOCs.

Purpose

- To measure the volume [cubic yards (U.S.) / cubic metres (Canada)] or area [square yards (U.S.) / square meters (Canada)] of contaminated sediment managed in Areas of Concern (AOCs).
- The Remediating Contaminated Sediment in AOCs indicator is used in the Great Lakes indicator suite as a Response indicator in the Restoration and Protection top level reporting category.

Ecosystem Objective

The ecosystem objective is to manage contaminated sediments in AOCs to reduce risks to the environment and to remove beneficial use impairments related to contaminated sediment.

Ecological Condition

Great Lakes AOCs are severely degraded geographic areas or "pollution hotspots" within the Great Lakes Basin. They are defined by the U.S.-Canada Great Lakes Water Quality Agreement (Annex 2 of the 1987 Protocol) as "geographic areas that fail to meet the general or specific objectives of the agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life." The U.S. and Canadian governments have identified 43 such areas; 26 in U.S. waters, 12 in Canadian waters, and five shared between U.S. and Canada on connecting river systems. Four of these AOCs have been delisted (Collingwood, Severn Sound, and Wheatley Harbour, in Ontario, and Oswego in New York State) and two have been declared to be in a "recovery stage" (Spanish Harbour in Ontario and Presque Isle Bay in Pennsylvania). Contaminated sediments are the main cause of beneficial use impairments (BUIs) in the majority of the AOCs.

- Contaminants of concern include PCBs, PAHs, pesticides, metals, and oil and grease, etc.
- Mention wood chips, pulp waste, enriched organic sediment
- Mass of contaminant managed?

Efforts to restore degraded conditions in the Great Lakes AOCs, including the remediation of the remaining estimated 40 million cubic yards of contaminated sediments, are underway using a variety of funding sources.

<u>United States</u>

GLNPO collects sediment remediation data from state and Federal project managers across the Great Lakes region. Several projects typically occur each year within the Great Lakes Basin to remediate contaminated sediments. Action has been taken at 20 of the remaining 30 U.S. and binational AOCs. While the annual volume can vary widely from year to year, the cumulative volume has been steadily increasing since 1997, when the U.S. first started tracking remediation information. As of 2010, approximately 7 million cubic yards of contaminated sediment have been remediated in U.S. AOCs.

<u>Canada</u>

The Great Lakes Sediment Remediation Program works with the Ontario Ministry of the Environment and local stakeholders to develop and implement sediment remediation plans for Great Lakes Ares of Concern. Action has taken place in 9 of the 17 Canadian AOCs. As of 2010 over 200,000 cubic meters of contaminated sediment have been managed in Great Lakes Areas of Concern. Over 1 million cubic metres of contaminated sediment are scheduled for management over the next 10 years in Canadian AOCs.

In Ontario, the *Canada-Ontario Decision-Making Framework for Assessment of Great Lakes Contaminated Sediment* provides step-by-step science based guidance for assessing risks posed by contaminated sediment. The framework is mainly concerned with risk to the environment but also considers human health concerns associated with biomagnifications of contaminants. As such, detailed risk assessment and/or human health risk assessment are conducted as appropriate. In addition, deeper sediments, and the risk of deeper sediments being exposed to biota, and associated risks are also assessed under the framework to assess the need for management action. In this assessment, sediment stability and sediment deposition rates are assessed. The framework identifies all possible sediment assessment outcomes based on four lines of evidence (sediment chemistry, toxicity, benthic community structure and the potential for biomagnifications), and provides specific direction on next steps in making sediment management decisions.

Linkages

The management of contaminated sediments in AOCs is expected to control a major source of sediment contamination to the Great Lakes, improve the water quality as measured by contamination in whole fish and waterbirds, and reduce restrictions on fish consumption.

Management Challenges/Opportunities

Secondary users of this information should be aware that there are several potential sources of error in the estimates. There are a number of different ways for contractors/project managers to determine the number of cubic yards/cubic metres remediated. U.S. Environmental Protection Agency and Environment Canada use best professional judgment in its oversight and review of the secondary data. To avoid introducing bias, the data are presented as reported by individual site Project Managers. While the information provided is quantitative, providing an estimate of error in the total volumes of contaminated sediments remediated is beyond the scale of this exercise. Thus, the numbers should not be viewed as exact totals. Data users are advised to take the process into account and recognize the unknown amount of error in these estimates. It is important to be realistic when applying these data quantitatively to scientific and policy questions.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			

Clarifying Notes: We are not able to quantify the uncertainty and variability in the data – see Management Challenges/Opportunities for more information.

Acknowledgments

Authors:

Mary Beth Giancarlo, U.S. Environmental Protection Agency GLNPO, Chicago, IL

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Source: U.S. EPA

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Source: U.S. Environmental Protection Agency

Figure 3. Canadian Great Lakes Areas of Concern Sediment Remediation Cumulative Volumes 1992-2010.
Source: Environment Canada

Figure 4. Canadian Great Lakes Areas of Concern Sediment Remediation Cumulative Volumes 1992-2010.
Source: Environment Canada

Figure 5. Canadian Great Lakes Areas of Concern Sediment Remediation Annual Volumes 1992-2010.

Source: Environment Canada

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U.S. Cumulative Sediment Remediation

Area of Concern	Cumulative Volume Sediments Remediated 1997 Through 2010 (cubic yards)	Disposition
Ashtabula River, OH - Great Lakes Legacy Act - Navigation Dredging	**629,490** 496,586 132,904	on-site TSCA[1] landfill
Buffalo River, NY - Buffalo Color - Area D - Navigation Dredging	**206,421** 45,000 161,421	encapsulated on-site CDF[2]
Detroit River, MI - Monguagon Creek - Black Lagoon - BASF Riverview	**166,500** 25,000 115,000 26,500	landfilled CDF encapsulated on site
Fox River, Green Bay, WI - Deposit 56/57 - Deposit N - Deposit O - OU 1 - Phase 1 - OU2, OU3, OU4	**2,227,600** 81,662 7,149 1,026 695,972 132,000 1,309,791	landfilled landfilled landfilled landfilled/capped landfilled landfilled/capped
Grand Calumet, IN - U.S. Steel/Gary Works - U.S.S. Lead - WBGCR Phase 1	**945,197** 840,200 25,370 79,627	on-site CAMU[3] CAMU & TSCA facility landfilled
Kalamazoo River, MI - Bryant Mill Pond - Allied Paper/Portage Creek	**274,000** 150,000 124,000	landfilled off-site TSCA/landfill
Manistique River, MI	161,162	landfilled
Maumee River, OH - Fraleigh Creek (Unnamed Tributary) - Ottawa River/Sibley Creek	**259,471** 8,000 251,471	landfilled
Menominee River, MI/WI - Ansul Eighth Street Slip	**13,000**	landfilled/awaiting further management
Milwaukee Harbor, WI - North Ave. Dam - Moss American - Kinnickinnic River	**196,960** 8,000 21,960 167,000	landfilled landfilled CDF
Muskegon Lake, MI - Ruddiman Creek	**90,000**	landfilled
Niagara River, NY - Scajaquada Creek - Gill Creek - Cherry Farm/River Road - Niagara Transformer	**77,850** 17,500 6,850 42,000 11,500	landfilled
River Raisin, MI - Ford Monroe Outfall - Csld. Packaging Corp.	**57,000** 27,000 30,000	on-site TSCA facility TSCA landfill/landfilled

Area of Concern	Cumulative Volume Sediments Remediated	Disposition
Rouge River, MI - Evan's Product Ditch - Newburgh Lake	**406,900** 6,900 400,000	off-site TSCA facility and landfilled
Saginaw River/Bay, MI - NRDA - Lake Linton - Wickes Park - Navigation Dredging	**510,213** 342,433 17,000 780 150,000	off-shore CDF landfilled landfilled CDF
Sheboygan River & Harbor, WI	**20,727**	off-site TSCA facility and landfilled
St. Lawrence River, NY - Reynolds Metals/Alcoa E. - Alcoa Grasse River ROPS	**112,000** 86,000 26,000	landfilled/capped landfilled
St. Louis River/Bay, MN/WI - Newton Creek/Hog Island Inlet - Interlake/Duluth Tar	**505,743** 52,143 453,600	landfilled capped/on-site CAD[4]
St. Marys River, MI - Cannelton - Tannery Bay - MGP	**49,412** 3,000 39,912 6,500	landfilled
White Lake, MI - Tannery Bay - Occidental Chemical Corp.	**105,500** 95,000 10,500	landfilled
TOTAL	**7,015,146**	

1 TSCA = Toxic Substances Control Act.
2 CDF = confined disposal facility
3 CAMU = corrective action management unit
4 CAD = confined aquatic disposal

Table 1. U.S. Cumulative Sediment Remediation Volume 1997 – 2010. Footnote: Information included in the matrix are quantitative estimates as reported by project managers. Data collection and reporting efforts are described in the "Great Lakes Sediment Remediation Project Summary Support" Quality Assurance Project Plan (GLNPO, June 2008). Detailed project information is available upon request from project managers.
Source: U.S. EPA

Canadian Sediment Remediation Volumes

Year	AOC	Volume Dredge (m3)	Volume Cap (m3)	Volume MNR[1] (m3)	Removal Technology	Disposition Post
1992/94	Collingwood	4,800			Hydraulic	CDF[2]
1994	Severn Sound	375			Mechanical	Landfill
1995	Niagara River - Welland River	11,000			Hybrid	Landfill/Reuse
1997/98	Thunder Bay - NOWPARC	11,000			Mechanical	Thermal Treatment
1998	Thunder Bay - NOWPARC		21,000			Containment
1998	Thunder Bay - NOWPARC			28,000		Monitoring
2004	St. Clair River Zone #1	13,690			Mechanical	Landfill/Bioremediation
2005	St. Lawrence River			130,000		Monitoring
2006	St. Marys River - Algoma Slip	2,630			Mechanical	Landfill
2007	Niagara River - Lyons Creek East	300			Mechanical	Landfill
2008	Detroit River - Turkey Creek	975			Mechanical	Landfill
	Subtotal Volume of remediated sediment :	44,770	21,000	158,000		
	Total volume of remediated sediment:			**223,770**		

1 MNR - Monitored Natural Recovery

2 CDF - Confined Disposal Facility;

Table 2. Canadian Sediment Remediation Volumes 1992 – 2010. Hybrid - Combination mechanical and hydraulic; Source: Environment Canada

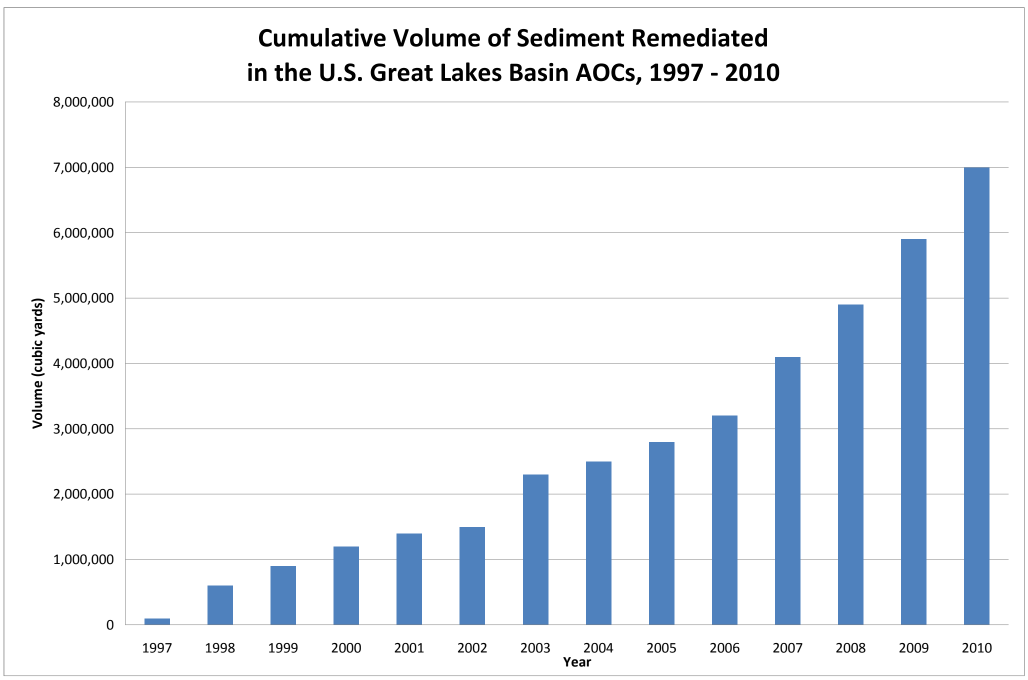

Figure 1. Cumulative Volume of Sediment Remediated in the U.S. Great Lakes Basin AOCs, 1997 – 2010. Source: U.S. Environmental Protection Agency

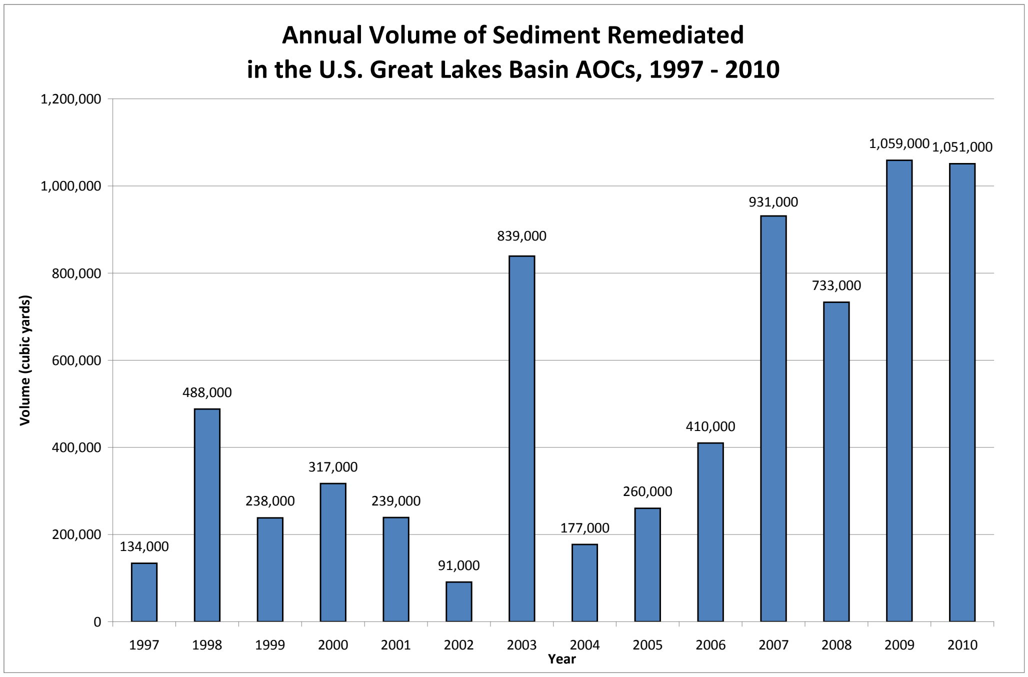

Figure 2. Annual Volume of Sediment Remediated in the U.S. Great Lakes Basin AOCs, 1997 – 2010. Source: U.S. Environmental Protection Agency

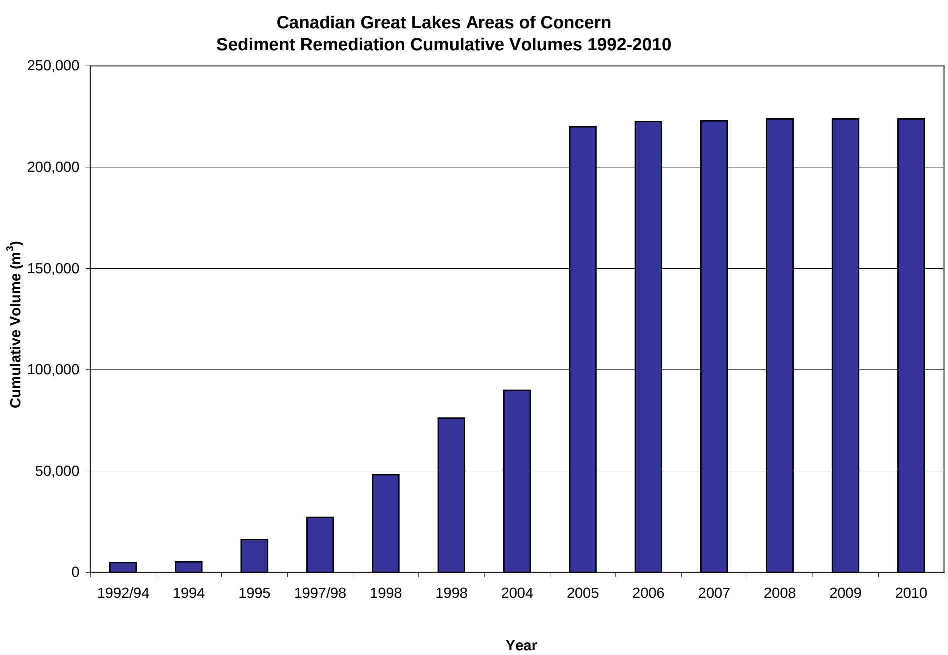

Figure 3. Canadian Great Lakes Areas of Concern Sediment Remediation Cumulative Volumes 1992-2010. Source: Environment Canada

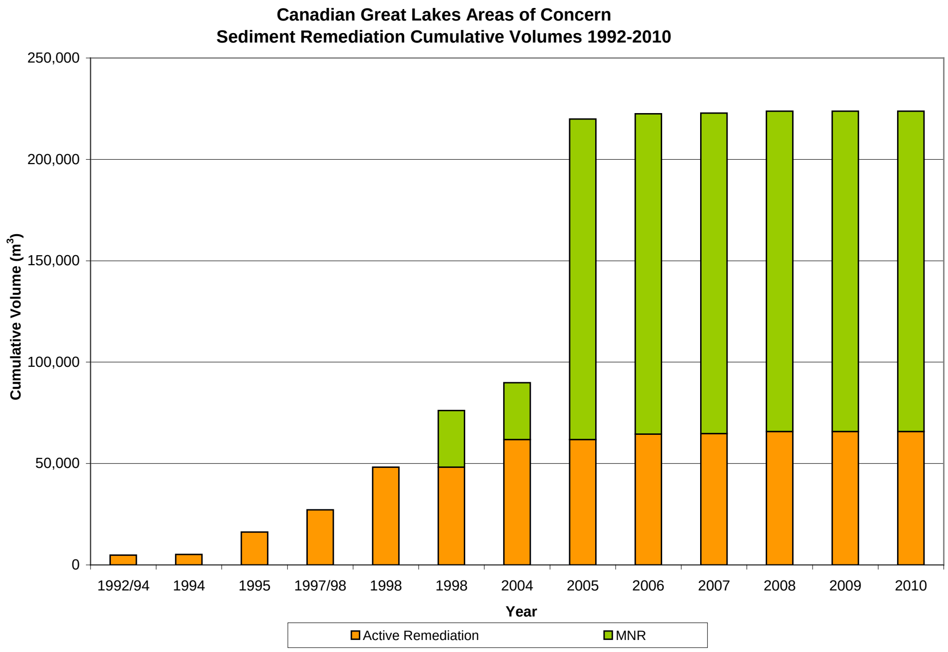

Figure 4. Canadian Great Lakes Areas of Concern Sediment Remediation Cumulative Volumes 1992-2010.
MNR - Monitored Natural Recovery.
Source: Environment Canada

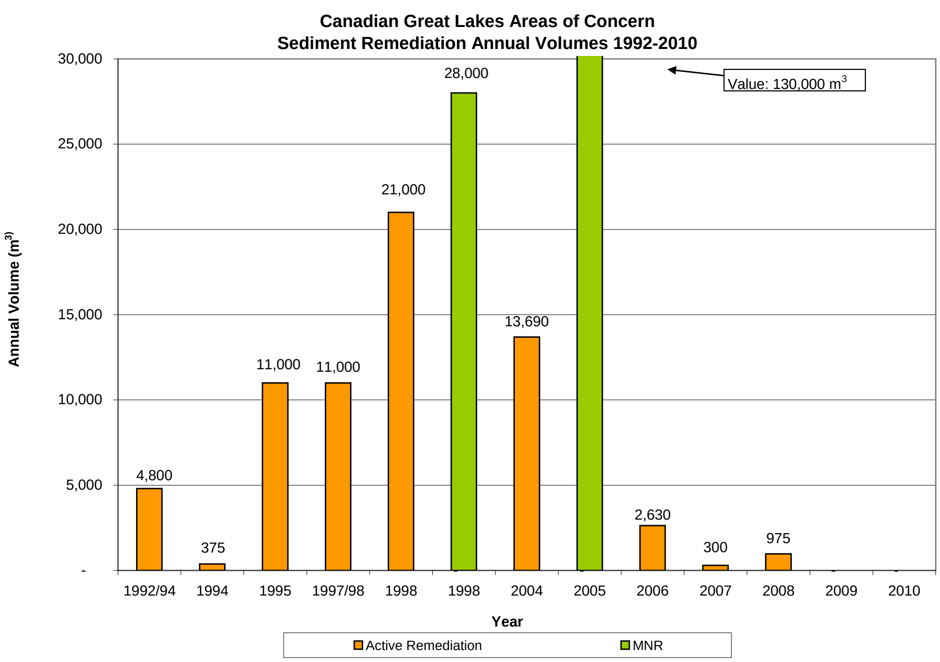

Figure 5. Canadian Great Lakes Areas of Concern Sediment Remediation Annual Volumes 1992-2010.
Source: Environment Canada

Sea Lamprey

Overall Assessment
Status: Fair
Trend: Unchanging
Rationale: Lake-wide spawning-phase sea lamprey abundances are above targets in all lakes except Superior and Ontario. Lake-wide sea lamprey wounding rates on lake trout are above targets in all lakes except Ontario. Lake trout relative abundances are variable.

Lake-by-Lake Assessment
Lake Superior
Status: Fair
Trend: Improving
Rationale: Sea lamprey abundance has declined since 2005, reaching the target range and holding there since 2009. The lake trout wounding rate is above target and has been increasing since 1999. Lake trout relative abundance has been increasing since 2003.

Lake Michigan
Status: Poor
Trend: Unchanging
Rationale: Sea lamprey abundance is above the target range after 2 years of decline to within the target range. The lake trout wounding rate is above target and has been increasing since 1995. Lake trout relative abundance has been variable, but unchanging.

Lake Huron
Status: Poor
Trend: Unchanging
Rationale: Sea lamprey abundance is above the target range and has not been within the target range since 1980. The lake trout wounding rate is above target and has been unchanging since 2002. Lake trout relative abundance has been increasing since 1995.

Lake Erie
Status: Poor
Trend: Deteriorating
Rationale: Sea lamprey abundance is nearly five times above the target range and remains at a pre-sea lamprey control level. The lake trout wounding rate is above the target and has been variable since 1997. Lake trout relative abundance has been variable.

Lake Ontario
Status: Good
Trend: Unchanging
Rationale: Sea lamprey abundance is within the target range and has been near or at the target for more than 25 years. The lake trout wounding rate is below the target and has been for 2 years. Lake trout relative abundance has been decreasing since 1995.

Purpose

- To estimate lake-wide spawning-phase sea lamprey abundances.
- To estimate the damage caused by the sea lamprey to the Great Lakes fish communities and ecosystem

through the calculation of lake-wide sea lamprey wounding rates on lake trout.
- To measure the success of sea lamprey control.
- The Sea Lamprey indicator is used in the Great Lakes indicators suite as a Pressure indicator in the Invasive Species top level reporting category.

Ecosystem Objective

Sea lamprey control supports the fish community objectives that were established by the Great Lakes Fishery Commission (commission) and fishery management agencies under *A Joint Strategic Plan for the Management of Great Lakes Fisheries*. Fish community objectives call for suppressing sea lamprey populations to levels that cause only insignificant mortality on fish to achieve objectives for lake trout and other members of the fish community (Horns *et al.* 2003, Eshenroder *et al*. 1995, DesJardin *et al.*1995, Ryan *et al.* 2003., Stewart *et al.* 1999). During 2004, the commission and fishery management agencies agreed upon target ranges for lake-wide spawning-phase sea lamprey abundances (Table 1) that will facilitate progress towards achieving fish community objectives in each lake. Suppressing sea lamprey abundances to the target ranges and minimizing sea lamprey damage to lake trout to five wounds or less per 100 fish in each lake (two wounds in Lake Ontario) should result in acceptable mortality on lake trout and other fish species and allow for rehabilitation of populations. In addition, sea lamprey control and the sea lamprey indicator support the Great Lakes Water Quality Agreement by implementing a program to control the invasive sea lamprey.

Ecological Condition

The sea lamprey is a non-native species and a lethal parasite of many fish species in the Great Lakes (e.g. Bergstedt and Schneider 1988; Kitchell 1990), and has caused ecologic and economic tragedy in terms of their impact on the Great Lakes fish communities (Smith and Tibbles 1980) and ecosystem. The first complete round of stream treatments with the lampricide TFM (as early as 1960 in Lake Superior) successfully suppressed sea lamprey populations to less than 10% of pre-control abundances in all of the Great Lakes, and subsequent lampricide treatments conducted on a regular basis across the Great Lakes have successfully maintained sea lamprey populations at this level in all lakes except Lake Erie. The sea lamprey, however, continues to be a significant source of mortality for many fish species (Bergstedt and Schneider 1988; Kitchell 1990) and the need for sea lamprey control continues to preserve, restore, and maintain the Great Lakes fish communities and ecosystem.

Lake-wide spawning-phase sea lamprey abundances relative to lake-specific target ranges are the primary performance indicators of the sea lamprey control program. Sea lamprey abundances are calculated by summing the population estimates generated using mark/recapture, trap catch data extrapolation, and the spawner-discharge model (Mullett et al. 2003) methods from sea lamprey-producing streams in a given lake. On all lakes except Huron, target ranges are the average sea lamprey abundance (+/- the 95% confidence interval) in each lake during times when lake-wide sea lamprey wounding rates on lake trout were tolerable, that is, causing less than 5% annual mortality (or when lake trout wounding rates were less than or equal to five wounds per 100 fish). For Lake Huron, the target range is set at 25% of the average sea lamprey abundance during the late 1980s. Sea lamprey abundances and target ranges for each lake are updated during the fall of each year as the newest data are incorporated into the population model.

In addition to setting sea lamprey abundance targets, lake trout wounding rates are used as another measure of sea lamprey abundance in relation to their prey and provide an indicator of damage caused to the fish community in each lake. Care must be taken, however, when interpreting lake trout wounding rates because they are also influenced by lake trout abundance (e.g. the lake trout wounding rate can increase while sea lamprey abundance remains static, if lake trout abundance is declining). Therefore, lake-wide relative abundance of lake trout is also estimated and reported with sea lamprey abundance and the lake trout wounding rate. Abundance and wounding data are collected during lake trout population assessment surveys conducted during spring (lakes Superior and

Michigan), late summer (Lake Erie), and fall (lakes Michigan and Ontario). For all lakes except Ontario, abundance data and sea lamprey wounds in stages 1-3 (of 4) of healing from lake trout greater than 533 mm are used to estimate the lake trout relative abundance and wounding rate. Fishery managers on Lake Ontario decided that abundance data and sea lamprey wounds in stage 1 of healing only from lake trout greater than 433 mm was more appropriate for estimating the lake trout relative abundance and wounding rate for Lake Ontario.

Status of Sea Lamprey

Annual lake-wide spawning-phase sea lamprey abundances with 95% confidence intervals and the lake-specific target ranges are presented in Figure 1. Annual lake-wide sea lamprey wounding rates on lake trout and lake-specific targets are presented in Figure 2. Annual lake-wide relative abundance estimates of lake trout are presented in Figure 3.

Lake Superior

During the past 20+ years, sea lamprey abundance has fluctuated, but remained at a level less than 10% of peak abundance (Heinrich et al. 2003). Sea lamprey abundance was within the target range during the late 1980s and mid-1990s and reached the lowest level of the time series in 1994. Sea lamprey abundance trended upward from 1994 to 2001, but has since been trending downward and has been within the target range since 2008.

The lake trout wounding rate has been increasing since 1997 and has not shown a corresponding decrease as seen recently in sea lamprey abundance, even with increasing lake trout relative abundance. The cause of this discrepancy is currently unknown, but is likely a result of uncertainty in the lake-wide lake trout wounding or abundance estimate. The lake trout wounding rate is above target and increasing with the most dramatic changes in the western portion of the lake, though there have been recent declines in Minnesota waters. Lake trout mortality estimates in Michigan waters indicate that sea lamprey-induced mortality exceeds fishery-induced mortality (commercial and recreational combined), but fishery-induced mortality is low in Michigan waters. Fishery objectives for lake trout continue to be met, but lake trout populations are still threatened by the sea lamprey as indicated by the above target lake trout wounding rate.

In response to above target sea lamprey abundance and the lake trout wounding rate, the number of lampricide treatments were increased beginning in 2001. In addition, large lentic populations along the north shore, which had been treated on a consistent basis until the late 1980's, but discontinued during the 1990's as a result of programmatic cuts, were once again treated at regular intervals beginning in 2005. Additionally, lampricide treatment crews adopted basin-wide tactics during 2006 that were tailored to increase treatment effectiveness by reducing the number of sea lamprey larvae that survive treatment. These tactics included increasing lampricide concentrations and the duration of treatment; applying lampricides to backwaters, springs, rivulets , and seepage areas that were not affected by the primary treatment that otherwise provided areas of escapement or refuge; and timing treatments to take advantage of seasonal susceptibility of larvae (Scholefield et al. 2008) and optimal flow regimes. Furthermore, greater effort was expended on assessing treatment efficacy basin-wide, such that significant residual populations could be addressed in a timely manner. The effects of increased treatment effort and the implementation of basin-wide tactics to increase treatment effectiveness likely have contributed to the downward trend in sea lamprey abundance to within the target range. Increased treatment efforts will continue and their impacts on sea lamprey abundance and the lake trout wounding rate will be observed in the future.

Lake Michigan

Sea lamprey abundance is at about 10% of peak levels, but has not been consistently within the target range since the mid-1990s and has been widely variable since 2003. After trending upward since 1980 (Lavis et al. 2003), sea lamprey abundance fell to within the target range during 2009, but was again above the target range during 2010.

The lake trout wounding rate has also shown an upward trend and has been above target since 1995. This upward trend is likely attributable in part to the declining abundance of larger lake trout in the northern part of the lake (lake trout relative abundance across the whole lake has been variable, but holding steady) as well as recent increases in sea lamprey abundance. Increased sea lamprey-induced mortality on lake trout in the northern waters has set lake trout restoration efforts back by a decade or more by removing a large portion of the spawning population. Furthermore, elevated sea lamprey-induced mortality is affecting the quota allocation of lake trout (caught as bycatch in the whitefish fishery) in that components of the lake trout management regimen in the consent decree between the tribes, the state, and the federal government are currently suspended. Achievement of lake trout rehabilitation and other fishery objectives will continue to be challenged if sea lamprey abundance and the lake trout wounding rate remain above targets.

Increases in sea lamprey abundance and the lake trout wounding rate during the 1990s were attributed to sea lamprey production from the St. Marys River, the large connecting channel between lakes Superior and Huron. In response, an integrated control approach using lampricides, sterile male release, and spawning-phase traps was initiated in the St. Marys River (Schleen et al. 2003) and has reduced the reproductive potential of sea lampreys in the river by about 90%. The continuing upward trend in sea lamprey abundance and the lake trout wounding rate during the late 1990s and early 2000s indicated there were other significant sources of sea lampreys. The number of lampricide treatments increased on Lake Michigan during 2001 and included the treatment of newly discovered populations in nearshore lentic areas and the Manistique River, a large system where the deterioration of a dam near the river mouth allowed sea lampreys access to hundreds of kilometers of habitat. During 2003, sea lamprey abundance and the lake trout wounding rate did not show decreases as a result of the increased treatments during 2001, however, the sharp decrease in sea lamprey abundance observed during 2005 was most likely associated with the 2003 treatment of the Manistique River. Increased lampricide treatment efforts during recent years, including implementation of the basin-wide tactics in 2006 to increase treatment effectiveness (see brief description above under *Lake Superior*) and additional treatments of the Manistique River have not consistently reduced sea lamprey abundance or the lake trout wounding rate. Other potential sources of sea lampreys are being assessed and increased treatment efforts will continue with the effects expected to be observed in future estimates of sea lamprey abundance and the lake trout wounding rate.

Lake Huron

During the past 20+ years, sea lamprey abundance has fluctuated, but remained at a level less than 10% of peak abundance (Morse et al. 2003). During the early 1980s, sea lamprey abundance increased from the target range, particularly in the northern portion of the lake, peaking during 1993 with a gradual decline since then. Despite this decline, sea lamprey abundance is currently above the target range and has been since 1981.

Through the 1990s, there were more sea lampreys in Lake Huron than all the other lakes combined and fishery objectives were not being achieved. Sea lamprey-induced mortality was so severe that during 1995, lake trout restoration efforts were suspended in the northern portion of the lake. There has been a significant reduction in the lake-wide sea lamprey wounding rate on lake trout since the implementation of the integrated control approach on the St. Marys River (see brief description above under *Lake Michigan* and Schleen et al. 2003), although they remain above target. Lake trout restoration efforts have resumed, showing positive signs such as increasing populations and significant natural reproduction. Nevertheless, achievement of lake trout restoration and other fishery objectives will continue to be challenged if sea lamprey abundance and the lake trout wounding rate remain above targets.

During the 1990s, the St. Marys River was identified as the major source of sea lampreys in Lake Huron, but the size of the river prohibited conventional treatment with the lampricide TFM. As part of the integrated control approach (see brief description above under *Lake Michigan* and Schleen et al. 2003), a new formulation of a bottom-release lampricide (granular Bayluscide) was used to treat roughly 800 ha of St. Marys River larval sea lamprey habitat during 1999. As predicted, the integrated approach significantly reduced the larval sea lamprey population in the river from 5.2 to 1.4 million, which was followed by dramatic declines in lake-wide spawning-phase sea lamprey abundance and the lake trout wounding rate. Nevertheless, sea lamprey abundance has been variable since 2001 (the year in which the effects of the 1999 integrated control approach were first observed). Granular Bayluscide spot treatments on the St. Marys River continued to target areas with high larval sea lamprey densities through 2009, with average annual treatment of around 100 ha. By 2009, however, the larval sea lamprey population had risen to 3.3 million, the highest since integrated control was implemented and not differing significantly from the pre-1999 estimate of 5.2 million. During 2010, 876 ha were treated as part of a large-scale strategy that included the treatment of 40 infested tributaries in the North Channel and northern Lake Huron. This effort will be repeated in 2011 with the effects to be seen beginning in 2012. In addition to the integrated control strategy on the St. Marys River, basin-wide tactics to increase treatment effectiveness were implemented during 2006 (see brief description above under *Lake Superior*), but did not reduce sea lamprey abundance and the lake trout wounding rate to targets.

Lake Erie

Following the completion of the first round of stream treatments in 1987, sea lamprey abundance plummeted (Sullivan et al. 2003) and remained within the target range during 1989 to 1997. Sea lamprey abundance increased briefly during 1998 to 2000, but with increased control effort, returned to within the target range during 2001 to 2004. Unexpectedly, sea lamprey abundance has rebounded, exceeding targets since 2005, and reaching a historic high in 2009.

After the initial stream treatments, and retreatment of most of the major producing tributaries, beginning in 1989, the lake trout wounding rate declined and lake trout survival increased to a level sufficient to meet the rehabilitation objectives in the eastern basin of the lake. During 1997 to 2002, the lake trout wounding rate increased to and remained at a level that threatened lake trout restoration. The lake trout wounding rate fell below the target during 2003, but has been variable since, has trended upward, and is currently above target. Reductions in lake trout stocking that occurred during the late 1990s and early 2000s may have affected lake trout abundance and hence, the lake trout wounding rate. Wounding rates on other fish species have also been increasing. Efforts to rehabilitate lake trout and achieve other fishery objectives will be impossible to achieve, and may be suspended, if high sea lamprey abundance and the lake trout wounding rate are not significantly reduced.

In response to recent increases in sea lamprey abundance, basin-wide tactics to increase treatment effectiveness were implemented during 2006, but failed to reduce sea lamprey abundance and the lake trout wounding rate to targets. Additionally, an aggressive and experimental whole-lake treatment strategy in which all sea lamprey-producing streams were treated at least twice in consecutive years was conducted during 2008 to 2010. Results from the whole-lake treatment strategy will not be fully known until 2011, but high sea lamprey abundance during 2010 and a high lake trout wounding rate during 2009 and 2010 are not promising signs.

Lake Ontario

Sea lamprey abundance was greatly reduced following the completion of important lampricide treatments during the 1980s (including the Black and Oswego river systems) and steadily declined from the mid-1980s to 2003 (Larson et al. 2003). Sea lamprey abundance has been slightly above or within the target range since the mid-1980s and is currently within the target range.

The lake trout wounding rate has also been holding steady at around or below the target since the mid-1980s, although high localized wounding has been noted in the nearshore areas adjacent to the Oswego and Niagara rivers in recent years, and the Ontario Ministry of Natural Resources has reported increased wounding on steelhead at the Ganaraska River fishway. Changing strain composition and reduced abundance of lake trout may be affecting wounding rates and host selection.

Lampricide treatments are continuing, including the basin-wide tactics to increase treatment effectiveness implemented during 2006 (see brief description above under *Lake Superior*), and sea lamprey abundance and the lake trout wounding rate are expected to remain close to targets during the future. Despite the relative success of control efforts in Lake Ontario, achievement of lake trout rehabilitation and other fishery objectives will continue to be challenged by the sea lamprey.

Linkages

Lake Trout; Walleye; Lake Sturgeon; Threatened Species; Top Predator Fish; Other Fish Species: Sea lampreys remain a significant source of mortality on many fish species of the Great Lakes including Atlantic, chinook, and coho salmon, burbot, ciscoes, lake sturgeon (threatened in some parts of the Great Lakes basin), lake trout, steelhead, walleye, whitefish, etc. Short lapses in sea lamprey control can result in rapid increases in sea lamprey abundance and the damage they inflict on fish. Continued stream and lentic area treatments are necessary to overcome the reproductive potential of the sea lamprey and to ensure the achievement of fishery objectives for many different species, and to preserve functioning ecosystems.

Aquatic Habitat Connectivity; Water Quality: The potential for sea lamprey to colonize new locations is increased with improved aquatic habitat connectivity through the removal of dams and improved water quality. The failure of the Manistique River dam to block sea lampreys and the subsequent sea lamprey production from the river is an example of the linkages between sea lamprey and aquatic habitat connectivity. Additionally, as water quality improves, streams and lentic areas once inhospitable to sea lampreys may become viable spawning and nursery habitats. As examples, during the mid 2000's, a significant larval population requiring regular lampricide treatment was established for the first time in the estuary of the Kaministiquia River (Lake Superior) after a local paper mill began tertiary treatment of its effluent. The establishment of larval populations in the St. Marys, St. Clair, and Lower Niagara rivers followed concerted efforts to improve water quality, and with observations of successful reproduction by lake sturgeon, whitefish, and brindled madtom, it is likely only a matter of time before sea lamprey reproduction is documented in the Detroit River. This could have dire consequences for efforts to control sea lampreys and rehabilitate native coldwater species in Lake Erie.

Climate Change: Rising temperatures in the Great Lakes have recently been associated with increasing size of adult sea lampreys (Jim Kitchell, personal communication). As temperatures rise, sea lampreys may grow larger increasing metabolism and becoming more fecund, which may increase the number of sea lampreys and the damage they cause to host fish.

Management Challenges/Opportunities

Sea lamprey control in the Great Lakes has successfully reduced spawning-phase sea lamprey abundance from peak levels by about 90%. Sea lampreys, however, still remain a significant source of mortality on many Great Lakes fish species and a road block to achieving critical fishery objectives. The commission and its agents have increased the number of stream and lentic lampricide treatments and made changes to improve the efficacy of lampricide applications in response to increasing sea lamprey abundances and lake trout wounding rates during recent years. To best guide lampricide application, computer models driven by empirical data are being used to help allocate lampricide control effort, and research is being conducted to better understand and manage the variability in sea lamprey populations and assess the impact of sea lamprey control. Securing increased funding to continue and expand lampricide treatments, improve treatment methodologies, and searching for new/unidentified sources of sea lampreys is critical to the maintenance and advancement of sea lamprey control.

The commission has a goal of increasing efforts to integrate other control techniques, such as the sterile-male-release technique, spawning-phase trapping, and the installation and maintenance of barriers to stop the upstream migration of spawning-phase sea lampreys. Expansion of the sterile-male-release technique will be challenged by the number of males available for sterilization, but current research on sea lamprey behavior may help to increase trapping efficiency (and thus provide more males to sterilize). Sea lamprey trapping is currently only a viable control technique when associated with sterile-male-releases, but again, recent research on sea lamprey behavior may help to increase trapping efficiency so that enough sea lampreys can be removed to affect recruitment in a stream. Environmental issues related to sea lamprey barriers and fish passage, and the deterioration of dams built for other purposes, but also provide a sea lamprey control function, will continue to challenge the sea lamprey control program in terms of dam rehabilitation and construction costs or increased parasitic-phase sea lamprey production and the associated sea lamprey control costs. The commission also continues to focus on research and development of new control strategies. For instance, pheromones that affect migration and mating have been discovered and offer exciting potential as new controls. Additionally, the sequencing of the sea lamprey genome has rapidly advanced basic sea lamprey research and may uncover new ways to control sea lampreys through avenues yet to be conceived.

As fish communities recover from the effects of sea lamprey predation, there is evidence that sea lamprey populations will benefit from increased prey availability. Facilitated through what are called “compensatory mechanisms”, more sea lampreys may survive to maturity due to the increase in prey availability, thus precipitating an increase in reproductive potential and recruitment (i.e. more sea lampreys may be available to prey on fish). To combat potential compensatory responses, significant additional control efforts, like the integrated control approach on the St. Marys River, the experimental whole-lake treatment strategy on Lake Erie and the large-scale treatment strategy in northern Lake Huron, and the implementation or development of other sea lamprey control strategies will be necessary to further suppress sea lamprey abundances and lake trout wounding rates to targets.

Comments from the author(s)

Increases in lampricide treatments have reduced lake-wide spawning-phase sea lamprey abundances to within target ranges in two of the five Great Lakes. The effects of increased lampricide treatments will be observed in sea lamprey abundances beginning two years after they occur and in lake-wide sea lamprey wounding rates on lake trout beginning within a year after they occur. Discrepancies among sea lamprey abundances and lake trout wounding rates need to be resolved beyond the influence of the number of lake trout in a lake. Efforts to identify new/unidentified sources of sea lampreys also need to continue. In addition, research to better understand sea lamprey/prey interactions, the population dynamics of sea lampreys that survive treatment, and refinement of and research into other control methods are all keys to achieving and maintaining sea lamprey abundances and lake trout wounding rates at targets.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Table 1. Sea lamprey abundance targets and 95% confidence interval ranges.
Source: Great Lakes Fishery Commission

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Figure 1. Yearly lake-wide adult sea lamprey abundances (blue diamonds) with 95% confidence intervals plotted on sea lamprey spawning year. Green horizontal and dashed lines represent the target abundances and ranges for each lake.
*Note: the smaller scale for Lake Erie.
Source: Great Lakes Fishery Commission

Figure 2. Yearly lake-wide sea lamprey wounding rates on lake trout (red circles) plotted on sea lamprey spawning year. Green horizontal lines represent the wounding rate targets for each lake.
*Note: Lakes Superior, Michigan, and Huron report A1-3 wounds on lake trout greater than 533 mm and have a target of five wounds per 100 fish. Lake Erie reports A1-3 wounds on age 5 or older lake trout from the east basin and uses a target of five wounds per 100 fish. Lake Ontario reports A1 wounds only (notice different scale) on lake trout greater than 433 mm and uses a target of two wound per 100 fish.
Source: Great Lakes Fishery Commission

Figure 3. Yearly lake-wide relative abundance of lake trout (gray squares) with 95% confidence intervals for each lake.
*Note: CPE = fish/km/net night of lean lake trout greater than 533 mm total length for lakes Superior, Michigan, and Huron; CPE = relative abundance of age 5 and older lake trout sampled in gill nets from the east basin; and CPE = arithmetic mean fish/0.1476 km/net night of lean lake trout greater than 433 mm total length.
Source: Great Lakes Fishery Commission

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Lake	Abundance Target	95% Confidence Interval
Superior	37,000	19,000
Michigan	57,000	13,000
Huron	73,000	20,000
Erie	3,000	1,000
Ontario	31,000	4,000

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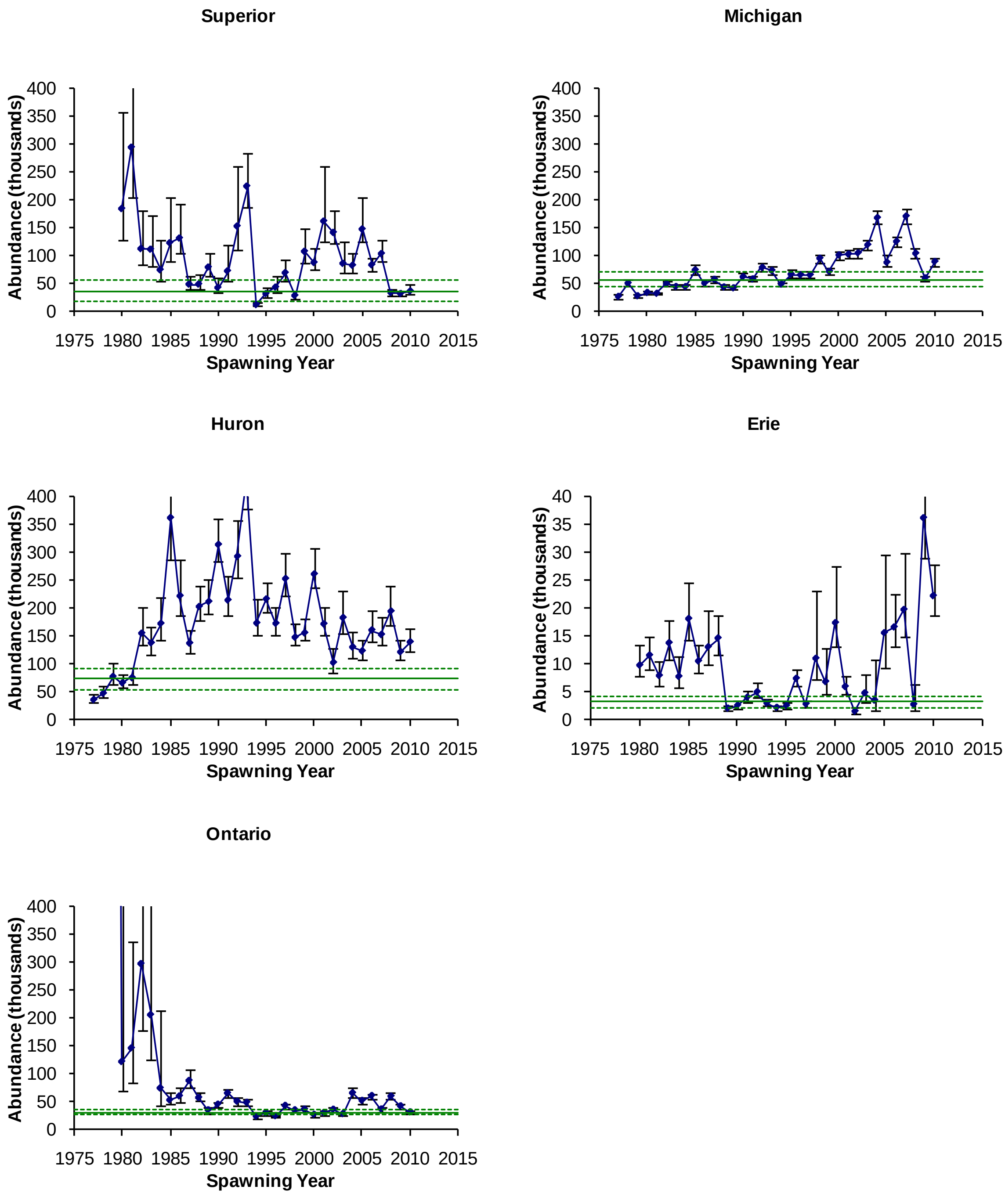
Source: Great Lakes Fishery Commission



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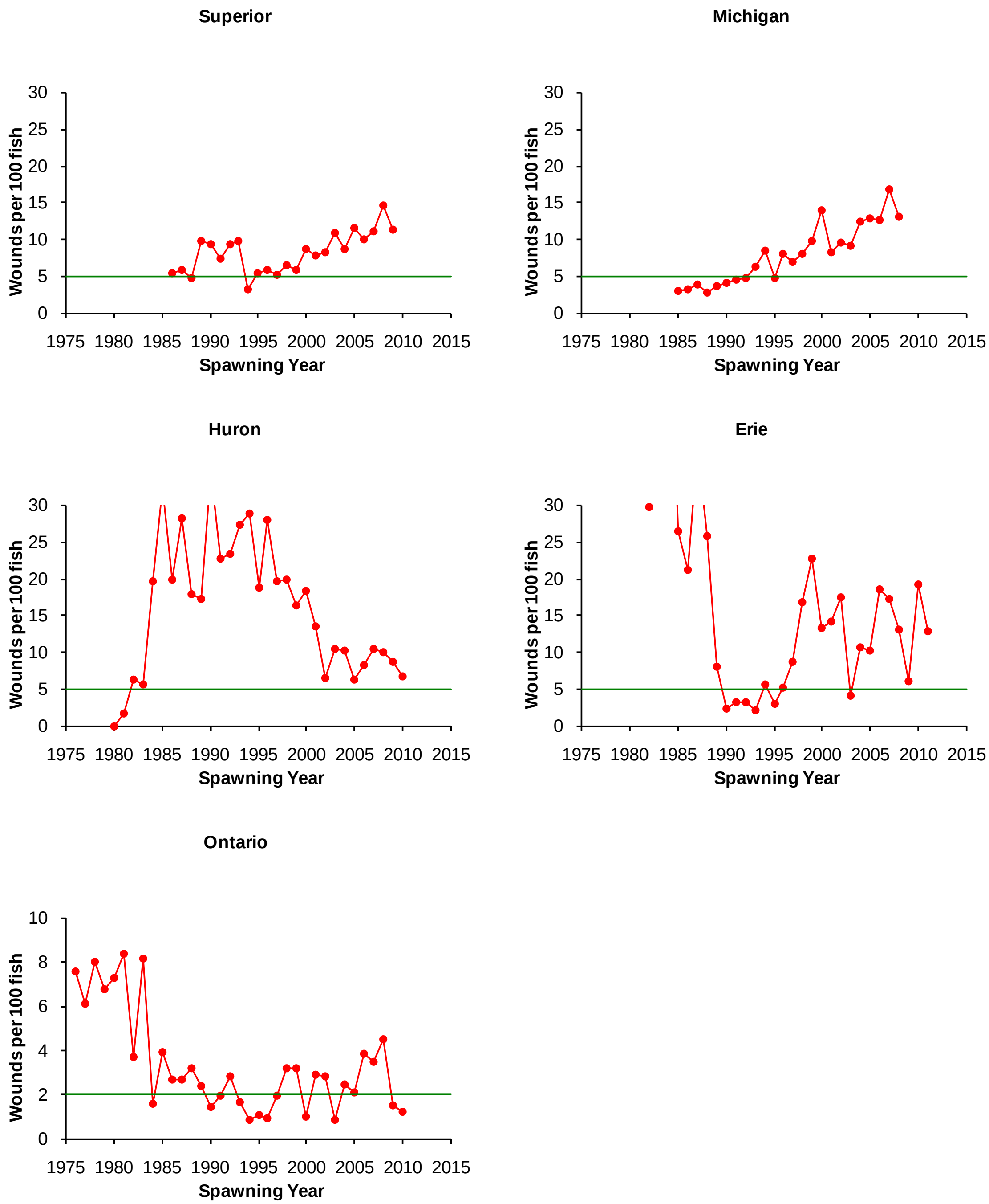

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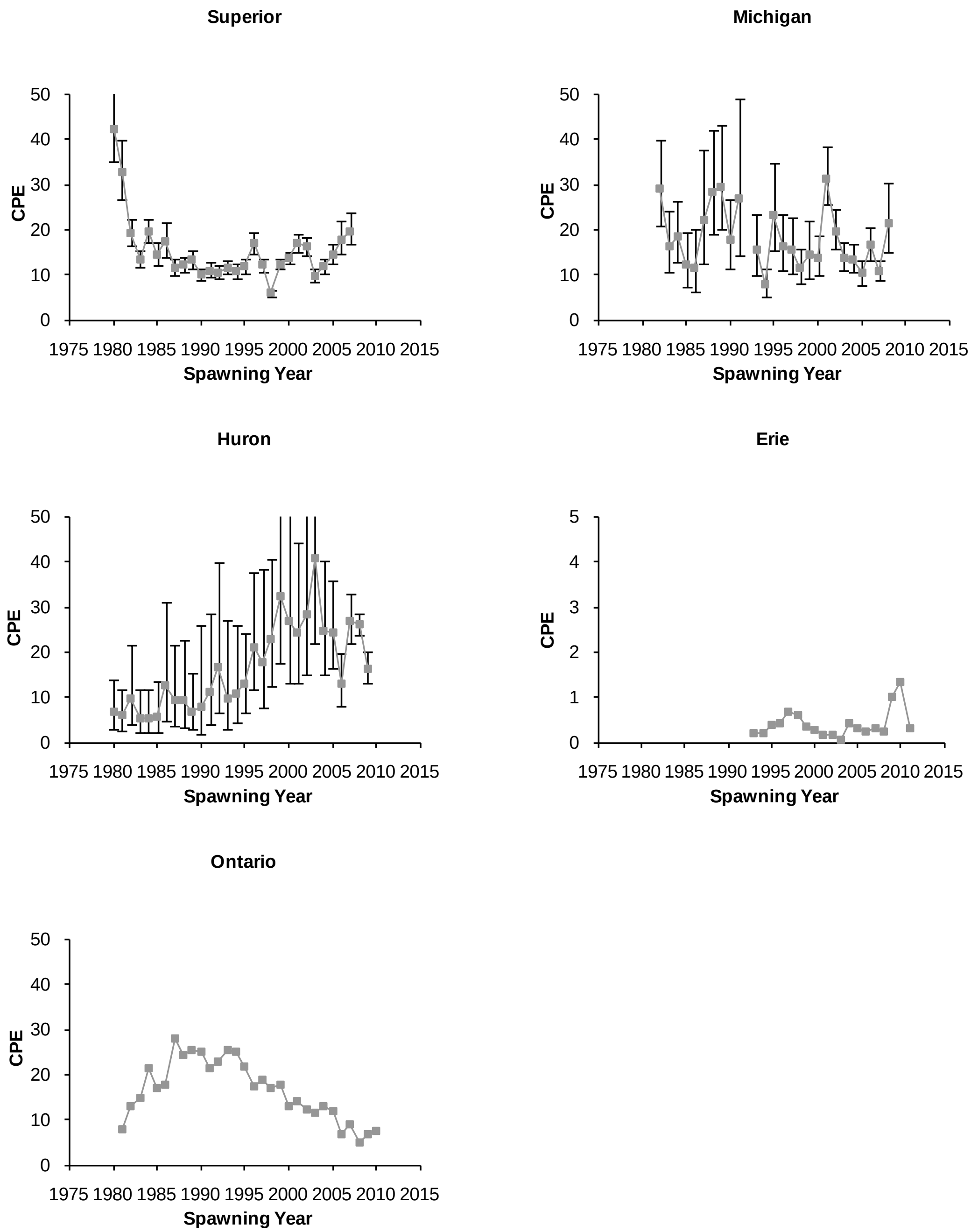

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Source: Great Lakes Fishery Commission

Surface Water Temperature

Overall Assessment, onset of summer stratification

Trend: **Based on the date of the onset of summer stratification, Lakes Superior, Michigan, and Huron are all stratifying earlier and are thus classified as increasing. Based on the same metric, Lakes Erie and Ontario are classified as undetermined due to data unavailability. Data from the National Oceanic and Atmospheric Administration's National Data Buoy Center (NOAA NDBC) were used in this report.**

Lake-by-Lake Assessment

Lake Superior

Trend: Increasing

Rationale: The date of the onset of summer stratification in Lake Superior is occurring earlier at a rate of roughly 0.5+/-0.3 days per year. This rate is consistent between three NOAA NDBC buoys.

Lake Michigan

Trend: Increasing

Rationale: The date of the onset of summer stratification in Lake Michigan is occurring earlier at a rate of roughly 0.8+/-0.3 days per year. This rate is consistent between two NOAA NDBC buoys.

Lake Huron

Trend: Increasing

Rationale: The date of the onset of summer stratification in Lake Huron is occurring earlier at a rate of roughly 0.6 +/- 0.3 days per year. This rate is consistent between two NOAA NDBC buoys.

Lake Erie

Trend: Undetermined;

Rationale: Due to its shallowness, the overturn in Lake Erie naturally occurs earlier in the year than the rest of the lakes. However, the NOAA NDBC buoys are typically not yet deployed and therefore data is not available for this report.

Lake Ontario

Trend: Undetermined.

Rationale: Data is only available since 2002.

Overall Assessment, Summer Water Temperature

Trend: **Based on open-lake surface water temperature measurements, summer (July-September) water temperatures are increasing at statistically significant rates in Lakes Superior, Huron, and Michigan. The rate of warming in Lake Erie was not statistically significant. Insufficient data exists to evaluate Lake Ontario.**

Lake-by-Lake Assessment

Lake Superior

Trend: Increasing

Rationale: The open-lake surface water temperature in Lake Superior is increasing at 0.1+/-0.04 degrees C per year. This rate is consistent between two NOAA NDBC buoys.

Lake Michigan

Trend: Increasing

Rationale: The open-lake surface water temperature in Lake Michigan is increasing at 0.06+/-0.03 degrees C per year. This rate is consistent between three NOAA NDBC buoys.

Lake Huron

Trend: Increasing

Rationale: The open-lake surface water temperature in Lake Huron is increasing at 0.07+/-0.03 degrees C per year. This rate is consistent between two NOAA NDBC buoys.

Lake Erie

Trend: Not significant;

Rationale: The estimated trend was not distinguishable from zero.

Lake Ontario

Trend: Undetermined.

Rationale: Data is only available since 2002.

Purpose

- To assess trends in surface water temperature and to infer the impact of climate change on the Great Lakes region.
- The Surface Water indicator is used in the Great Lakes indicator suite as a Pressure indicator in the Resource Use and Physical Stressors top level reporting category.

Ecosystem Objective

The Great Lakes Water Quality Agreement Act's General Objectives state, "these water should be free from materials and heat directly or indirectly entering the water as a result of human activity that...produces conditions that are toxic or harmful to human, animal, or aquatic life." Furthermore, this indicator relates to Annex 1 of the Great Lakes Water Quality Agreement which states, "there should be no change in temperature that would adversely affect any local or general use of the waters."

Ecological Condition

The development of the temperature structure of a lake is a direct reflection of its regional climate. Upward trends in surface temperatures have been documented for the Laurentian Great Lakes (Austin and Colman, 2007) as well as lakes around the world (Schneider and Hook 2010). However, surface temperatures by themselves do not necessarily reflect the volumetric average temperature of a lake, and surface temperatures are subject to daily fluctuations, largely tied to variability in the wind field. The heat content of a lake (equivalent to the depth averaged temperature) is a much more robust measure of a lake's thermal condition, varying on seasonal and inter-annual scales, and hence a more useful measure of long-term change in lakes.

Subsurface temperature data is not available on a long-term basis necessary for determining lake heat content or trends therein. However, due to an unusual thermodynamic property of fresh water, we can determine the heat content using just a surface temperature in one specific circumstance. Specifically, when the surface water temperature reaches its temperature of maximum density (3.98C) in the spring (or early summer) the entire water column must also be at the same temperature. Subsequent to this, lakes tend to form stratification in which a layer of warm water sits on top of cooler water below; hence, this date is often referred to as the onset of spring stratification. While this only gives us a glimpse of the heat content, we can use the date at which this event happens as a proxy for inter-annual variability in heat content. In warm years, this event will occur early, and in cold years it will be delayed. In large, in partially ice covered lakes like Lake Superior, it has been shown that the timing of this event is strongly correlated to the average ice cover the previous winter (Austin and Colman 2007).

Data from NOAA NDBC buoys in the Laurentian Great Lakes from 1979-2010 (as available) was used to examine trends in the timing of the onset of positive stratification and hence trends in heat content. Lakes Superior, Michigan, Huron, and Erie all show trends towards earlier onset of spring stratification, from 0.5 to 0.8 days earlier per year. In addition to this trend there is a great deal of natural inter-annual variability. Inter-annual variability between the lakes is roughly correlated, suggesting that the variability observed is a reflection of climate over the entire upper portion of the lakes. On top of the trend towards earlier overturn, a significant portion of the remaining inter-annual variability is correlated with the ENSO index. Summer average (July-September) water temperatures show a corresponding increase in Superior, Michigan, and Huron.

Linkages

As the date of the onset of spring stratification becomes earlier, both average and maximum summer water temperatures tend to increase. A statistically significant link between these was demonstrated by Austin and Colman (GRL, 2007). Separate research (Austin and Colman, L&O 2008) has shown that the length of the stratified season has increased from approximately 145 days to 170 days, an increase in the length of this season of about 18%.

In response to an increase in stratification period, and warmer bottom temperatures, oxygen depletion in the deep waters of the Great Lakes will likely decrease. Lower oxygen levels, in accordance with higher water temperatures will also support greater nutrient and contaminant release from bottom sediments. Specially, phosphorous release would be enhanced, mercury releases and uptake by biota would likely increase, and the release of some heavy metals would also increase (Kling at. al., 2003). As such, this report relates to the indicators of “Water Quality as Measured by Contaminants in Whole Fish,” “Water Quality as Measured by Contaminants in Waterbirds,” “Water Quality as Measured by Contaminants in Bald Eagles,” and “Harmful Algal Blooms.” This indicator is also related to the climate indicators of “Air Temperature,” “Water Levels,” and “Ice Duration.”

Management Challenges/Opportunities

Response options that could be used to address climate change are classified into two categories, the first of which is adaptation, or “initiatives and measures designed to reduce the vulnerability of natural and human systems against actual or expected climate change effects.” The other way in which climate change can be addressed is through mitigation, or technological change and substitution that reduce resource inputs and emissions per unit of output (Koslow, 2010).

Comments from the author(s)

Note on trends: the stated rates of change are average rates over the period 1979-2010; there is significant inter-annual variability on top of these trends.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validate or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respectable generator of data	X					
4. geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada						X

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Figure 1. Trends in the timing of the onset of positive stratification and hence trends in heat content for lakes Superior, Michigan and Huron from 1979-2010.
Source: NOAA

Figure 2. Average summer (July-September) surface water temperature from Lakes Superior, Michigan, Huron, and Erie, 1979-2010. Individual lines represent different buoys in each lake.
Source: NOAA

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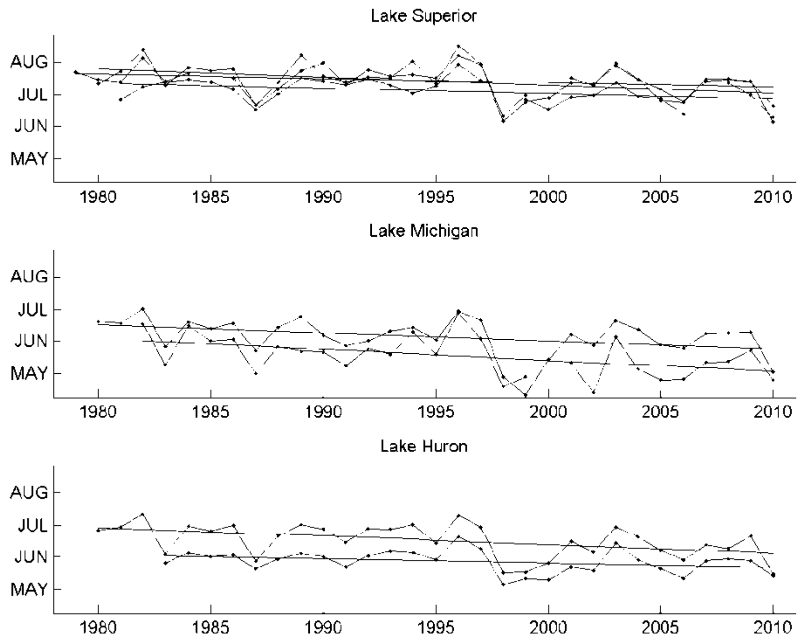

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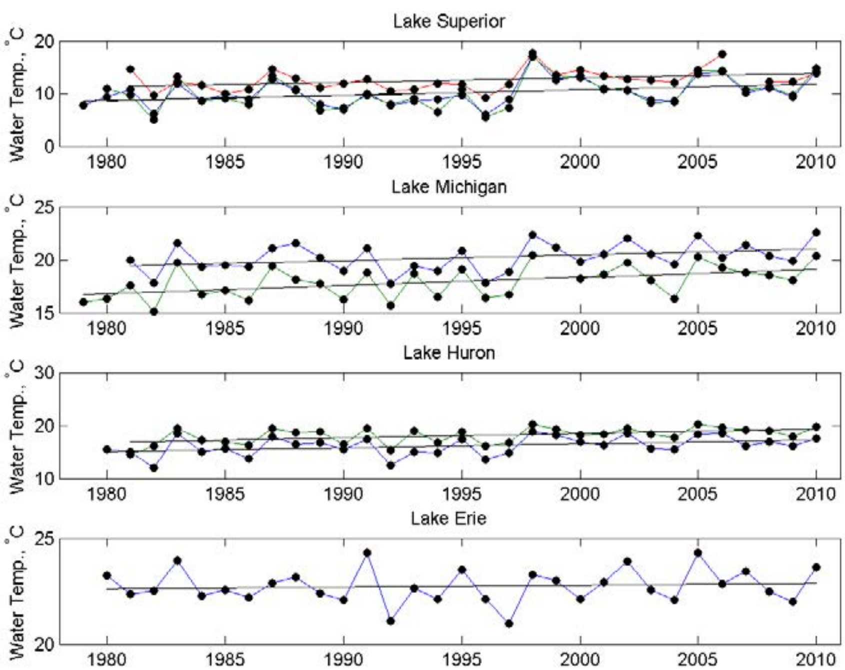

Figure 2. Average summer (July-September) surface water temperature from lakes Superior, Michigan, Huron, and Erie, 1979-2010. Individual lines represent different buoys in each lake. Source: NOAA

Terrestrial Non-Native Species

Overall Assessment
Status: Undetermined
Trend: Undetermined
Rationale: At this time, there is no comprehensive measure of terrestrial non-native species. Terrestrial non-native species (NIS) are ubiquitous in the Great Lakes basin. Although, not all introductions have an adverse affect on native habitats, those that do, pose a considerable ecological, social, and economic burden. Historically, the Great Lakes basin has been vulnerable to NIS. Post-industrialization, fragmentation of the natural landscape and the volume of transboundary movement of goods and people are the conditions which promote the invasion of terrestrial non-native species.

Lake-by-Lake Assessment
Standards are being developed within and across states and provinces. However, assessments of individual lake basins are unavailable due to lack of monitoring data. Inferences into lake-by-lake non-native species can be made from the geography of landscape fragmentation and development; as such landscapes tend to harbor a greater number of terrestrial non-native species.

Purpose

- To assess the presence, number, and distribution of harmful terrestrial non-native species in the Laurentian Great Lakes basin, and to understand the means by which these species are introduced and persist.
- To aid in the assessment of the status of terrestrial biotic communities, as non-native species can alter both the structure and function of ecosystems and compromise the biological integrity of the lakes.
- The Terrestrial Non-native Species indicator is used in the Great Lakes indicator suite as a Pressure indicator in the Invasive Species top level reporting category.

Ecosystem Objective
The objective is to assist in the limitation or prevention of unauthorized terrestrial non-indigenous species introductions, and to minimize the adverse affects of harmful non-native species in the Great Lakes basin. This report seeks to facilitate in the realization of the U.S. and Canada Great Lakes Water Quality Agreement objective to restore and maintain the biological integrity of the waters of the Great Lakes ecosystem (United States and Canada 1987).

Ecological Condition
Globalization, i.e. the movement of people and goods, has led to a dramatic increase in the number of terrestrial non-native species that are transported between countries and across oceans. As a consequence of high population density and high-volume transportation of goods, the Great Lakes basin receives a high number of non-native species. Every time a new species is brought into the basin there is a chance that it will invade into the landscape. Figure 1 depicts a steady increase in the number of terrestrial NIS introduced into the Great Lakes basin from 1900 to 2004. Once a new species arrives in the basin, the status of the landscape (ie. degradation, fragmentation, and loss of native ecosystems) potentiates non-native species to invade terrestrial habitats and become established invasive species (OMNR 2011). Invasive species are non-native species that are prolific and cause social, economic, or ecological harm. Terrestrial invasive species lower biodiversity through changing the ecology of a place (Klionsky et al 2011, Farrer and Goldberg 2009, Heneghan et al 2004). Although only a relatively few non-native species become established as invasive, the introduction of invasive species is recognized as one of the greatest threats to the biodiversity and natural resources of this region, second only to habitat destruction (Great Lakes Regional Collaboration Strategy 2005; Canadian Food Inspection Agency 2005).

There is an overabundance of terrestrial NIS and the number continues to grow. The most common category of non-native species introductions is the plant. Basin-wide data provided in 2003 by the World Wildlife Fund of Canada (Haber 2003) indicates that there were 157 non-native terrestrial species located within the Ontario Great Lakes watershed, including: 95 vascular plants, 11 insects, 6 plant diseases, 4 mammals, 2 birds, 2 animal diseases, 1 reptile, and 1 amphibian (Figure 1). The Invasive Plant Association of Wisconsin (2003) identified 66 non-native plants within the state, while over 100 terrestrial plants have been introduced into the Chicago region alone (Chicago Botanic Garden 2011). While estimates vary, the magnitude of data listed above does not compare to the over 900 non-native plants that have been identified within the state of Michigan (Michigan Invasive Plant Council 2005) and the 1138 species of non-native plants reported in the province of Ontario (Canadian Endangered Species Conservation Council 2010).

Monitoring of terrestrial NIS is primarily locally based, as a region-wide standard has yet to be established. The majority of non-native species monitoring occurs on geographic scales smaller than states and provinces. There is a growing number of invasive species monitoring programs at regional scale, ie. the Chicago Region. While programs are in development, a comprehensive basin-wide standard for invasive species monitoring has yet to be established. Monitoring data come from a variety of agencies and organizations throughout the region, and are difficult combine for a useful assessment of the overall presence and impact invasive species are having on the region.

Lake-by-lake and regional monitoring efforts are underway in Great Lakes basin mapping efforts for select species. For example, the United States coastal distribution of monotypic *Phragmites australis* stands have been documented (see Figure 2, Lake Erie). The maps represent potential stands of Phragmites with a minimum mapping unit of 0.5 acres, and have been produced using a combination of synthetic aperture radar and field documentation (Bourgeau-Chavez et al 2011). *Phragmites* is a highly productive plant, spreading quickly by horizontal runners, exhibiting a strong tendency to form monotypic stands, exclude native species, and change native plant communities. This invasive species is taking advantage of rapid water level fluctuations and increasing ambient temperatures to invade the coastal wetlands of the Great Lakes (Wilcox et al. 2003). Once established, Phragmites is difficult and costly to control. A pilot project by the Ontario Ministry of Natural Resources (OMNR) estimates control costs to range from $865-$1,112 per hectare (Gilbert et al 2009a, Gilbert et al 2009b).

There are a multitude of terrestrial NIS and the number of documented invasions continues to grow. There are many examples of terrestrial NIS, the impact of which can vary greatly, ranging from little or no affect to dramatically altering the native ecological communities and processes. Degraded and fragmented natural landscapes create safe harbor for the propagation and establishment of high impact NIS or invasive species (OMNR 2011).

Linkages

The NIS issue is a complex one. There are numerous policies, laws, and regulation within the Great Lakes basin that address NIS. Similar to monitoring data, such legislation originates across multiple scales and thus the efficacy of legislation encounters similar obstacles as do monitoring programs.

The growing transboundary movement of goods and people has heightened the need to prevent and manage terrestrial invasive non-native species. Most invasive species introductions can be linked to intended or unintended consequences of economic activities (Perrings et al. 2002). For this reason, the Great Lakes basin has been, and will continue to be, a hot bed of introductions unless strict preventive measures are enforced. Prevention alone is not a silver bullet. The expansion of population, recreation, and tourism all contribute to the number of non-native species in the region, while factors such as the ecological consequences of previous species introductions and a long-term forecast of increased extreme weather events elevate the level of vulnerability to NIS invasion. Because this issue has social, ecological, and economic dimensions, it can be assumed that the pressure of invasive non-native species will persist unless managed across the multiple dimensions. It is the opinion of the author that civic engagement for the restoration and management of the landscape for biodiversity and ecological resilience is the next step in combating the NIS.

Management Challenges/Opportunities

"Invasive non-native species are a significant stressor on ecosystem functions, processes, and structure in terrestrial, freshwater, and marine environments. This impact is increasing as numbers of invasive non-native species continue to rise and their distributions continue to expand" (Canadian Biodiversity: Ecosystem Status and Trends 2010).

Since the early 1800s, biological invasions continue to compromise the ecological integrity of the Great Lakes basin. Despite an elevated awareness of the issue and efforts to prevent and manage non-native species in the Great Lakes, the region remains highly vulnerable to new introduction both intentional and non-intentional. Political and social motivation to address this issue must not only be driven by the cumulative economic impact of invaders, i.e. threats to food supplies and human health, but the ecological effects on the structure and function of regional ecosystem goods and services.

Managers of terrestrial non-native species in the Great Lakes basin recognize that successful strategies must involve a collaborative effort across federal, provincial and state governments, and into local non-governmental organizations. Furthermore, improved integration, coordination and development of inventories, mapping, and mitigation of terrestrial invasive species will improve future strategies and enable the examination of trends in terrestrial non-native species at a basin-wide scale.

International cooperation in the management of terrestrial NIS is taking place in the North American Invasive Species Network (NAISN). Since 2011, the Commission for Environmental Cooperation (CEC) has been funding the NAISN and the Global Invasive Species Information Network (GISIN) for, amongst others, enhancing NAISN/GISIN for web-based information sharing.

The United States and Canada deploy similar strategies for terrestrial NIS and invasive species management. The precedent has been set to focus on the prevention of species introductions and the subsequent establishment of populations. Early detection and rapid response follow prevention to eliminate new NIS invaders. Using ranking systems to pre-screen potential invaders, the four elements provide the fundamental set of policies guiding NIS (NISC 2001, Environment Canada 2004). The functionality of these programs depend upon communication and agreement between all levels of organization whether local, state/provincial, or federal.

Innovational ideas and methods begin at smaller scales of organization before they are adapted regionally. An example of this is found at the provincial level, where Ontario's Invasive Species Plant Council is the organizing center for non-native species prevention and management. The latest articulation of progressive non-native species philosophy and management is found in the Ontario's Invasive Species Strategic Plan for 2011 (OISSP 2011). The Strategy continues emphasis on prevention, early detection, rapid response, and effective management, but includes nuanced views for the inclusion of ecosystem resilience, biodiversity, climate change, and adaptive management as relates to invasive species. The strategy acknowledges that invasive species are best able to invade degraded environments, and forwards the view that managing for healthy, resilient ecosystems, is a prerequisite strategy to preventing the spread and naturalization of non-native species. "Ensuring ecosystems are healthy and resilient will increase their capacity to cope with disturbances, such as invasive species. Efforts by the Ontario Government and our partners to protect healthy ecosystems and rehabilitate degraded ecosystems will help prevent invasive species from establishing" (Ontario Invasive Species Strategic Plan 2011).

Examples of ongoing Canadian multi-level responses include the Ontario Federation of Anglers and Hunters' and Ontario Ministry of Natural Resources' *Invading Species Awareness Program*, which contributes an invasive species reporting hotline to a restoration ecology program; and the State of the St. Lawrence program, which utilizes community-based monitoring to track temporal and spatial trends in invasive plant species.

Although the current landscape of policy/monitoring programs in the basin is fragmented, collaborative efforts are being developed to determine future monitoring priorities. This information will be applied to risk analysis, predictive science, modeling, improved technology for prevention and management of NIS, legislation and regulations, education and outreach and international co-operation.

Comments from the author(s)

Terrestrial invasive non-native species degrade the biological integrity of the whole Great Lakes ecosystem through the erosion of ecological services that the watershed provides. The health of the Great Lakes cannot be mantained through management of the waters alone.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						X
2. Data are traceable to original sources						X
3. The source of the data is a known, reliable and respected generator of data						X
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin						X
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report						X

Clarifying Notes: No data is utilized in the non-assessment of terrestrial non-native species status and trend.

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2011

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Figure 1. A timeline of terrestrial introduction in the Great Lakes basin by taxonomic group.
Source: World Wildlife Fund-Canada's Exotic Species Database, and the Canadian Food Inspection Agency
Figure 2. Lake Erie Potential Phragmites locations, 2011.
Source: Laura Bourgeau-Chavez, Michigan Tech Research Institute

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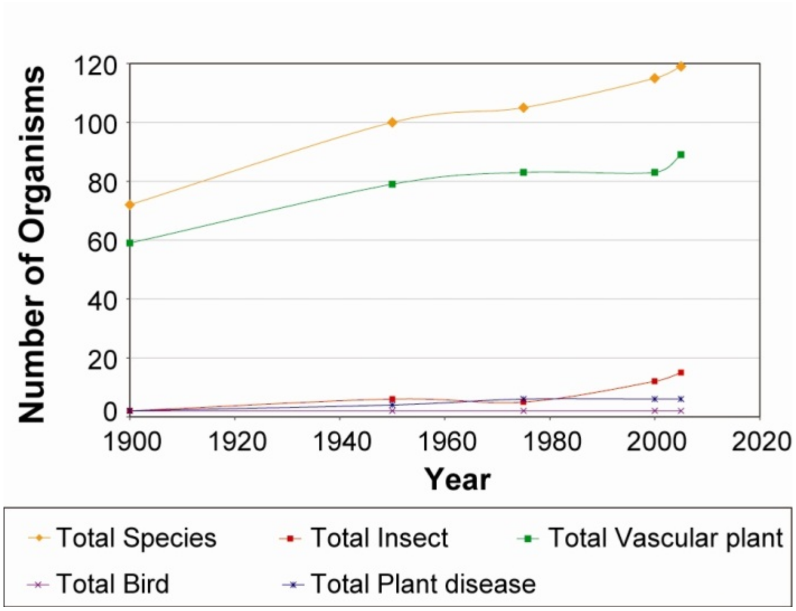

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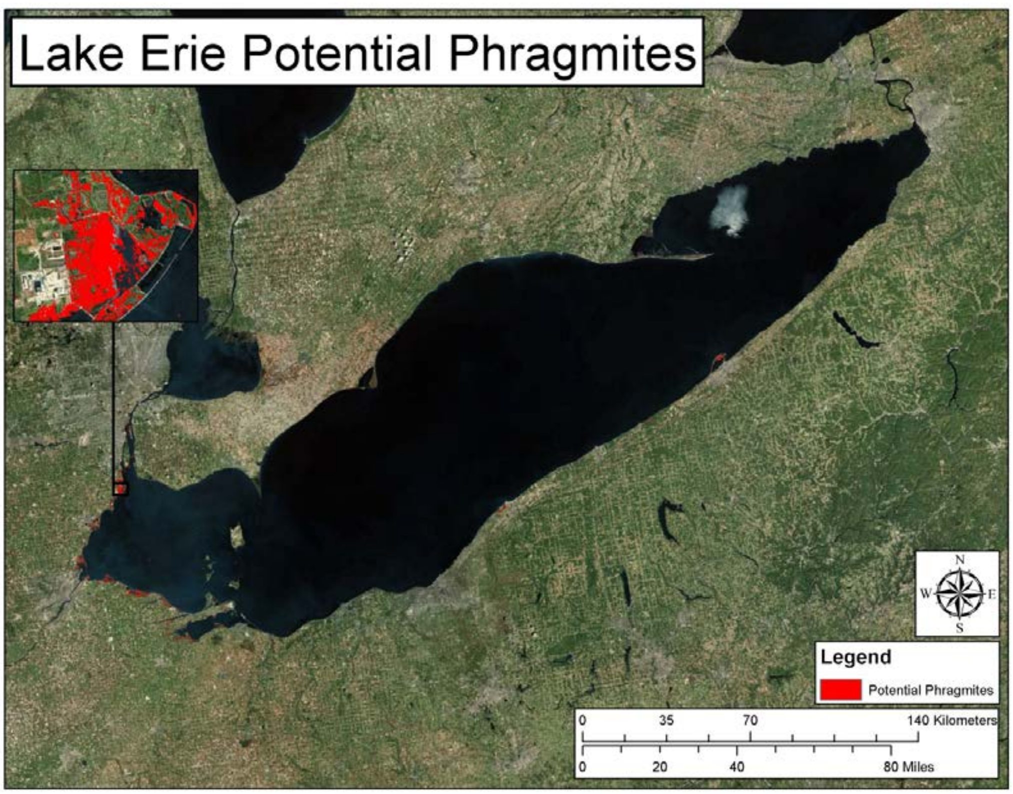

Figure 2. Lake Erie Potential Phragmites locations, 2011.
Source: Laura Bourgeau-Chavez, Michigan Tech Research Institute

Toxic Chemicals in Offshore Waters

Overall Assessment

Status: Fair

Trend: Undetermined

Rationale: Concentrations of many compounds are still detectable, although they are at very low concentrations. The trends are mixed (and therefore "undetermined"). The majority of trends are favourable (declining concentrations) for the organochlorine compounds. For PAHs, the trends are mixed, and the trends for in-use pesticides indicate increasing concentrations or no change.

Lake-by-Lake Assessment

Lake Superior

Status: Fair

Trend: Undetermined

Rationale: Concentrations of some compounds are lowest in Lake Superior, but several persistent compounds that are delivered to Lake Superior by atmospheric deposition are found at higher concentrations compared to the other Great Lakes. The temporal changes are subtle but mixed, resulting in an overall assessment of "undetermined".

Lake Michigan

Status: Fair

Trend: Undetermined

Rationale: More limited information is available for Lake Michigan from the Great Lakes Surveillance Program. Temporal trends cannot be determined. Concentrations of most compounds are low, but some relatively elevated concentrations were observed at the most southern sampling station in 2006 compared to the rest of the lake.

Lake Huron

Status: Good

Trend: Undetermined

Rationale: The water quality in Lake Huron tends to reflect the inflows from Lake Michigan and Lake Superior. Higher concentrations of atmospherically-deposited substances that are observed in Lake Superior are not as apparent in Lake Huron, resulting in lower concentrations of these substances here. Long-term trends are subtle, but the pattern is mixed.

Lake Erie

Status: Fair

Trend: Undetermined

Rationale: The highest concentrations of some parameters, such as mercury, are observed here. Within Lake Erie, higher concentrations are observed in the western basin. Data are variable and do not indicate significant change over time for most parameters with the exception of some currently used pesticides which are increasing.

Lake Ontario

Status: Fair

Trend: Undetermined

Rationale: The highest concentrations of some parameters, such as total PCBs and certain in-use pesticides, are observed in Lake Ontario. With some exceptions, such as declining trends of certain organochlorines and increasing trends for some in-use pesticides, most trends are subtle, indicating little change over time.

Purpose

- To assess the concentration of priority toxic chemicals in offshore waters
- To infer the potential for impacts on the health of the Great Lakes aquatic ecosystem by comparison to criteria for the protection of aquatic life and human health
- To infer progress toward virtual elimination of toxic substances from the Great Lakes basin
- The Toxic Chemicals in Offshore Waters indicator is used in the Great Lakes indicator suite as a State indicator in the Water Quality top level reporting category.

Ecosystem Objective

The GLWQA and the Binational Strategy both state the virtual elimination of toxic substances to Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human, animal, or aquatic life. This indicator supports Annexes 1, 11 and 12 of the GLWQA.

Ecological Condition

This indicator tracks whether concentrations of the IJC priority toxic chemicals are, as a group, decreasing, staying the same, or increasing in open waters over time. The chemicals of interest include, but are not limited to, PCBs, dieldrin, chlordane, DDT and metabolites, hexachlorobenzene and mercury. Monitoring for this indicator occurs during the three year periods between SOLEC. Sampling is conducted during spring, isothermal conditions, as maximum concentrations of many priority toxics have been reported during this time.

Endpoint

When concentrations of toxic chemicals associated with existing water quality criteria in the offshore waters of the Great Lakes are no longer measurable above naturally-occurring levels by current technology, or are below existing water quality criteria and show a declining trend. The endpoint will be achieved when 95-100% of the available data indicate concentration levels below criteria. Progress will be determined based on whether trends of the IJC priority toxic chemicals are positive (i.e., increasing pollutant concentrations) or negative (decreasing pollutant concentrations) and by the number of chemicals which reach the endpoint.

Background

Water quality samples for the analysis of toxics have been collected from the Great Lakes since the mid 1980s as part of Environment Canada's Great Lakes Surveillance Program. Ship-based monitoring cruises are conducted to measure water quality in each of the lakes upon which Canada borders. Measuring organic contaminants in water is challenging, and it requires special equipment, techniques and knowledge. In the first years of monitoring for organic contaminants, whole water samples were collected. Special studies, conducted between 1992 and 1995, recommended collecting surface, dissolved phase samples during the spring only (Williams et al., 2001). With the exception of some in-use pesticides, maximum concentrations were observed during the spring, and therefore represent the worst-case situation and can be used to determine compliance with water quality objectives.

Prior to 2004, samples for organic contaminants were centrifuged to separate the dissolved and particulate fractions, and the dissolved fraction was prepared for analysis immediately after collection, on board the ship, using a Goulden large volume extractor (Goulden and Anthony, 1985). Extracts were stored and returned to Environment Canada laboratory facilities in Burlington, Ontario, for analysis using gas chromatography/mass spectrometry. Since 2004, we have improved the technique and the 16 – 24 L samples are now stabilized in the field, and brought back to a specially constructed clean laboratory at Environment Canada for extraction. There appears to be less interference from extraneous contamination (presumably from ship-derived pollutants). Improvements in laboratory methods have resulted in much better (i.e., lower) detection limits for many compounds including PAHs and some organochlorines. For some parameters, the improvements mean that we have greater confidence in the more recent data compared to those obtained before 2004, but this also means that longer-term trends are difficult to determine. For example, detection limits for many polycyclic aromatic hydrocarbons (PAHs) have greatly improved. Measurable concentrations of some PAHs are now reported in Great Lakes waters for the first time; this does not necessarily mean that they were previously absent, but rather our ability to detect them has improved.

The Canadian Council of Ministers of the Environment (CCME, 1999) has withdrawn the water quality guidelines for several of the organochlorine compounds (aldrin, chlordane, dieldrin, endrin, heptachlor and PCBs) and a water quality guideline is no longer recommended. Exposure to these compounds for aquatic organisms is primarily via sediment, soil and/or tissue, therefore assessment of environmental quality relative to sediment and fish tissue guidelines is instead recommended. Indeed, these compounds are relatively hydrophobic and are difficult to measure in surface waters. Because of those difficulties, and because of the short time period of higher quality data that is available for assessing trends, it may be more useful to assess longer term trends using sediments or fish as environmental quality indicators for these compounds.

Status

Lake Superior

Concentrations of most organic compounds are lowest in Lake Superior. This is likely because historic sources of most compounds were predominantly located in more industrial and agricultural regions. However, several compounds that are more susceptible to atmospheric transport and deposition are found at higher concentrations in the upper Great Lakes compared with the lower lakes. Compounds that are found at higher concentrations in Lake Superior include a-HCH, lindane, g-chlordane, a-endosulfan, endrin, and b-endosulfan (b-endosulfan was only found in trace quantities in Lake Superior). An example of the spatial distribution of one of these compounds, a-HCH, is shown using the most recent quality-assured data in Figure 1. No exceedences of Canadian federal water quality guidelines are observed for any parameter in Lake Superior.

Concentrations of most organochlorine compounds are below detection limits or declining, although data are insufficient in most cases to quantify the rate of decline. Concentrations of a few organochlorines appear to be unchanging, such as HCB, heptachlor epoxide and dieldrin, although the latter shows some indication of a more recent decline (2005-2008). Increases are observed for the in-use pesticides atrazine and possibly metolachlor. The overall temporal trend for toxics is therefore mixed.

The ecosystem objective has not been achieved in Lake Superior because detectable concentrations of many parameters are observed and some compounds are showing increasing trends.

Lake Michigan

Only limited information is available for Lake Michigan. Environment Canada does not conduct monitoring in Lake Michigan as it is located entirely within the United States. In 2006, however, as part of the Cooperative Monitoring and Science Initiative, some limited sampling for toxics in water was conducted. Data are also available from the USEPA for Lake Michigan from 1994 to 1997 and from the mid-2000s, and these are used for comparison purposes. Samples were collected from six stations in Lake Michigan in 2006. Similar to Lakes Superior and Huron, concentrations of most compounds were low. However, certain compounds showed higher concentrations compared to the other Great Lakes, including dieldrin, heptachlor epoxide and a-chlordane. Although the Canadian water quality guidelines are not applicable to United States' waters, comparison with the benchmark CCME water quality guideline indicated no exceedences. Within Lake Michigan, higher values of certain compounds (some PAHs, g-chlordane, a-endosulfan) were found at sites in the southern basin compared to more offshore locations.

Information about contaminants in the waters of Lake Michigan is available from the USEPA from sampling conducted during the 1990s and 2000s. These data can be used to help determine changes over time, although inter-laboratory differences make trend determinations more difficult. A comparison of total PCBs obtained by the two agencies, and a comparison of values obtained by Environment Canada in the other Great Lakes, indicates that our values determined from 2006 samples in Lake Michigan may be too low. Total PCBs determined by EPA in the 1990s and again from 2003 – 2005 indicate values are typically in the 110 to 170 pg/L range, which are higher than Environment Canada's measured whole-lake average of only 49 pg/L in 2006. Additional samples were collected by Environment Canada from Lake Michigan in 2010. Values of total PCBs appeared to be higher than in 2006, but blank values are currently being analyzed to assess the blank-corrected concentrations for comparison with the other lakes.

Lake Huron

With inflows from both Lake Superior and Lake Michigan, the water quality of Lake Huron tends to reflect these other two Great Lakes. North Channel waters tend to reflect the outflow from Lake Superior, with very low values of many compounds (such as PAHs and organochlorines such as dieldrin), but higher concentrations of compounds that are deposited from atmospheric sources in Lake Superior, such as a-HCH. The waters of Georgian Bay are similar to the main body of Lake Huron with respect to toxic chemicals (i.e., low concentrations). Slightly higher concentrations of some parameters (for example, HCB) have been observed in and near Saginaw Bay and the inflow from Lake Michigan, compared to the remainder of the lake.

The overall status for most toxic compounds is better in Lake Huron compared to the other Great Lakes. Temporal trends indicate little change over time. The ecosystem objective has not been achieved in Lake Huron because toxics are still measurable and because temporal trends are not demonstrating significant declines.

Lake Erie

The waters of Lake Erie have some of the highest concentrations of chemicals that are still in commercial use or that had historical sources in its basin or upstream in the St. Clair and Detroit Rivers. Within Lake Erie, water quality tends to be poorest in the western basin, and improves towards the east. For example, the highest concentrations of mercury in Great Lakes surface waters are observed in the western basin of Lake Erie. Although the maximum concentration of mercury (18.2 ng/L in 2009) approaches the CCME (1999) water quality guideline for inorganic mercury for the protection of freshwater aquatic life (26 ng/L), there have been no observed exceedances of the guideline to date.

a-endosulfan is only consistently detectable in the western and central basins of Lake Erie; a-chlordane is only detected in the western basin of Lake Erie, in Lake Michigan and in Toronto harbour. The current use pesticides are found at highest concentrations in Lake Erie; contrary to most other parameters, concentrations tend to be higher in the central and eastern basins compared to the west. DDT and its metabolites are routinely detected only in the lower Great Lakes (lakes Erie and Ontario), likely due to historic usage in agriculture. The majority of the PAH compounds monitored are also found at highest concentrations in Lake Erie compared with the other lakes.

Concentrations of a-HCH have decreased over time, although the rate of decline appears to have slowed and recent measurements indicate higher concentrations in the western basin compared to other locations within Lake Erie. Similarly, concentrations of Lindane (g-HCH) appear to be lower since about 2000, with higher values found in the western basin compared to other sites. Other compounds, such as d-HCH, indicate no spatial or temporal trends. The trends for PAH compounds are mixed. For example, phenanthrene concentrations indicate a possible decline since about 2000, but most others indicate no clear temporal trend. The current use pesticides atrazine and metolachlor both showed maximum values in 1998, but no clear trend over time.

The ecosystem objective has not been achieved in Lake Erie because many compounds are detectable and show higher concentrations compared to the other Great Lakes, and because declining trends are not generally observed.

Lake Ontario

Many compounds, particularly those resulting from historical use in industry and agriculture, are found at highest levels in the lower Great Lakes (Ontario and Erie). These compounds include hexachlorobenzene (HCB), lindane, dieldrin, DDT and its metabolites and some PAHs. The spatial distribution of HCB is shown in Figure 2. Higher values of total PCBs are observed in Lake Ontario and along the southern shore and western basin of Lake Erie compared to the upper Great Lakes. The monitored current-use pesticides (atrazine and metolachlor) are observed in higher concentrations in Lake Ontario. However, no CCME water quality exceedences are observed.

Because the highest concentrations of some compounds are observed here, and because the temporal trends are mixed, the ecosystem objective has not been achieved for Lake Ontario.

Total PCBs

Polychlorinated biphenyls (PCBs) are monitored as congeners and are summed to give total PCB concentrations. Field and laboratory methodologies have improved since we began measuring PCBs in Great Lakes waters, and the detection limits have lowered from 0.8 ng/L to 0.044 ng/L. Field and laboratory blanks have improved as well, but background, extraneous PCB contamination remains problematic. Total PCBs are detected in all Great Lakes waters, but concentrations are significantly higher in sample water than in field blanks only in Lake Ontario and in the western basin of Lake Erie.

Temporal trends are difficult to discern because of improved detection limits and extraneous contamination as measured by laboratory and field blanks. The best record exists for Lake Ontario, where toxics were measured on five occasions between 2004 and 2010. The data indicate values in the offshore have been relatively constant over this time period (~190 pg /L). Studies conducted by the USEPA in spring 1993 indicated similar values (range 110 – 190 pg /L), indicating no change over the past 15 years.

Despite the problems with determining the absolute values of total PCBs in lake water, the relative values indicate a spatial distribution of PCBs with higher levels in the lower Great Lakes compared with the upper Great Lakes, and higher values in the nearshore environment compared to the open lake. The most recent (2004-2008) quality-assured data indicate total (laboratory blank-corrected) PCBs in the open waters of Lake Ontario are approximately 190 pg/L. Concentrations at nearshore stations (where water depth is less than 50 m) have remained relatively constant at about 287 pg/L, and values in Toronto Harbour (395 pg /L) and Hamilton Harbour (2565 pg /L) are greater. In Lake Erie, concentrations are highest in the western basin (average 547 pg /L) and decline as the waters flow through the central basin (144 pg /L) to the east (116 pg /L). Values in the upper Great Lakes (Huron, Georgian Bay, Michigan and Superior) are lower, and range from 50 pg /L to about 124 pg/L.

Dieldrin

Dieldrin is detected throughout the Great Lakes. Lakewide average concentrations are highest in Lake Michigan (184 pg/L) and lowest in Lake Huron and Georgian Bay (63 to 85 ng/L). Concentrations in most lakes are declining. In Lake Ontario, the rate is about 6.6 pg/L·yr ($p<0.001$), resulting in a half-fold time of approximately 16 years (starting from 1992). In Lake Erie the rate is about 8.9 pg/L·yr ($p=0.04$) and in Lake Superior the rate is about 3.3 pg/L·yr ($p=0.078$). In Lake Huron, dieldrin appears to be increasing at a rate of 5.9 pg/L·yr ($p=0.056$) but the data are relatively sparse and the trend in Lake Michigan is unknown.

Lindane

Lindane (g-HCH) is detected in all of the Great Lakes. Concentrations are highest in Lake Superior and lowest in

Lake Huron, Georgian Bay and Lake Michigan. The temporal trend (Figure 3) shows that lindane is declining in all the lakes (no temporal information is available for Lake Michigan). The use of lindane in the US and Canada started to be restricted in the 1970s and in 2007 its major uses were banned entirely with the exemption of its use for the treatment of head scabies and lice. The marked decline in the lakes reflects the success of usage restrictions. The high concentrations found in Lake Superior are likely due to atmospheric deposition and slower volatilization and breakdown at lower water temperatures.

Mercury

Mercury is a metal found in trace concentrations in the Great Lakes, but due to the processes of bioconcentration (accumulation within organisms) and bioaccumulation (accumulation within the food chain), even low water concentrations accumulate and adversely affect higher organisms. Mercury is responsible for the majority of the fish consumption advisories in the Great Lakes (Health Professionals Task Force, 2004). Total mercury has been measured in the Great Lakes using novel, ultra-clean techniques since 2003 (Dove et al., 2011). The record of total mercury on suspended sediments extends back to 1986 in the Niagara River. The modern data provides us with a spatial overview of surface water mercury concentrations (Figure 4) and the longer-term record provides a trend over time (Figure 5).

Currently, mercury concentrations tend to be highest in the western basin of Lake Erie, where higher turbidity levels and proximity to urban areas and probable historical sources likely contribute to elevated mercury levels. With the notable exception of Lake Erie, the nearshore areas of Lake Ontario also show higher concentrations of total mercury than the nearshore of the other lakes. Offshore concentrations throughout most of the Great Lakes are within a relatively narrow range from about 0.24 to 0.54 ng/L. Within this narrow range, the lowest concentrations are observed in Lake Huron and Georgian Bay (mean 0.24 and 0.3 ng/L, respectively), intermediate concentrations are observed in Lake Superior and Lake Ontario (mean ~0.35 ng/L), and higher concentrations are observed in Lake Michigan (0.49 ng/L) and the eastern basin (most representative of the offshore) of Lake Erie (0.54 ng/L) (Figure 4). The average concentration of total mercury in waters from the western basin of Lake Erie was 12.4 ng/L in 2009 (Dove et al., 2011).

Long-term concentrations of mercury appear to be declining. Figure 5 shows the concentration of total mercury in Niagara River waters, calculated from the concentration of mercury on suspended sediment, and the concentration of suspended sediment in the water. The equivalent water concentrations show considerable variability but the long-term trends are declining. Upstream at Fort Erie, the rate of decline has been 0.0061 ng/L·yr and downstream at Niagara-on-the-Lake the rate has been 0.015 ng/L·yr. For the time period 1986 to 2005, these rates translate to an approximate 18% decline at FE and a 30% decline at NOTL. The faster rate of decline downstream indicates that sources of mercury to the river are decreasing.

Currently-Used Pesticides

In-use pesticides are monitored only at selected stations and on selected cruises, mainly during the summer to reflect post-application concentrations. The monitored parameters include a suite of acid and neutral herbicides as well as organophosphorus pesticides. In-use pesticides are not as persistent nor as bioaccumulative as the other compounds monitored here, and Canadian federal water quality guidelines instead reflect their potential for direct toxicity to aquatic organisms.

Most organophosphorus pesticides are not detected or only rarely detected at low concentrations in Great Lakes waters. However, several compounds are detected almost ubiquitously, including the herbicides atrazine and metolachlor. Despite their relatively low persistence, concentrations of these in-use pesticides are increasing or remaining stable in the lakes due to their continued use in agriculture and on urban lawns and gardens. The temporal trend of atrazine is shown in Figure 6, and indicates that concentrations are highest in lakes Ontario and

Erie, where usage is greatest, and lowest in Lake Superior. An increasing trend is detected for each lake, ranging from a rate of 0.4 ng/L·yr in Lake Superior to 4.74 ng/L·yr in Lake Ontario. All concentrations are below the Canadian federal water quality guideline of 1800 ng/L; current open lake concentrations range from 6.3 ng/L in Lake Superior to 83.6 ng/L in Lake Ontario.

Chemicals Management Plan

The Canadian federal Chemicals Management Plan incorporates environmental monitoring into the assessment and management of compounds in commercial use in Canada. Surveillance has been conducted in selected lakes for compounds in commercial use that are more likely to be found in waters, such as perfluorinated compounds and some pharmaceuticals. The available data are currently being analyzed. In addition, work has been initiated in 2011 to screen for additional compounds in Great Lakes waters. This initiative will permit the qualitative and quantitative assessment of compounds that are not included in the targeted analytical suite currently monitored in the Great Lakes.

Linkages

Some pressure indicators such as industrial loadings, contamination in sediment, pesticides in tributaries, and the inland water quality index are also linked to this indicator since they assess the toxic chemicals which enter our waterways and can contribute to increased contamination levels in the Great Lakes. The reader is referred to the Contaminants in Whole Fish indicator to compare the available information.

Management Challenges/Opportunities

For over 40 years, the Great Lakes Surveillance Program has monitored water quality in the Great Lakes, and since approximately 1986, toxic contaminants have comprised an important component of that program. Knowledge of the concentration of toxics dissolved in Great Lakes waters is important for comparison with other measurements in water (e.g., tributaries and precipitation), for the assessment of bioaccumulation and bioconcentration behaviours and rates, and for the calculation of water-atmosphere fluxes in order to assess atmospheric deposition and volatilization of contaminants. The long-range atmospheric transport of contaminants remains an important concern, particularly to more northern Great Lakes.

Continued refinements of field and laboratory methods have both improved the quality of the sample results and reduced the resources required to conduct the program. Despite these improvements, measuring toxic contaminants in Great Lakes surface waters remains a challenging task. Concentrations of many substances are extremely low; in the part per quadrillion (1×10^{-15}) to part per trillion (1×10^{-12}) range. Routine monitoring for determining trends might be better accomplished, for some parameters, using sediment and fish samples. Contaminants in sediment can be used to indicate long-term changes in contaminant concentrations, as the settling of sediments represents a long-term sink for contaminants as they are gradually buried over time. Contaminants in fish are better indicative of the exposure of aquatic organisms to toxics in lake water and through their food chain. Because many of the legacy toxics are bioaccumulative and hydrophobic, higher concentrations can be measured in sediment and fish and these media are more appropriate for assessing ecosystem health. It remains important, however, to continue periodic monitoring of Great Lakes waters to verify concentrations and trends. Monitoring water concentrations is important for assessing compounds that are soluble in water such as certain in-use pesticides, selected legacy toxics as well as many of the compounds of emerging concern.

Environment Canada is currently reviewing its programs and refinements are being considered. One proposal is to primarily use fish tissue measurements for tracking contaminant trends, supplemented with the periodic review of water column concentrations at selected offshore stations. Contaminants that are not bioaccumulative or that are of greater concern due to direct toxicity, such as some of the currently-used pesticides, are more appropriate for continued monitoring in Great Lakes waters.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	×					
2. Data are traceable to original sources	×					
3. The source of the data is a known, reliable and respected generator of data	×					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	×					
5. Data obtained from sources within the U.S. are comparable to those from Canada						×
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			×			

Clarifying Notes: The comparability of organic contaminant data with other available information is currently being conducted. A full report on toxic contaminants in Great Lakes waters is in preparation. For some parameters, the comparison with other data sources and the quality assurance information indicates the data are robust. For other parameters, laboratory and field blank interference remain problematic and some uncertainty about absolute values remains.

Acknowledgments

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Information Sources

All data from Great Lakes Surveillance Program, Water Quality Monitoring and Surveillance, Environment Canada, Burlington, Ontario. GLSP-PSGL@ec.gc.ca

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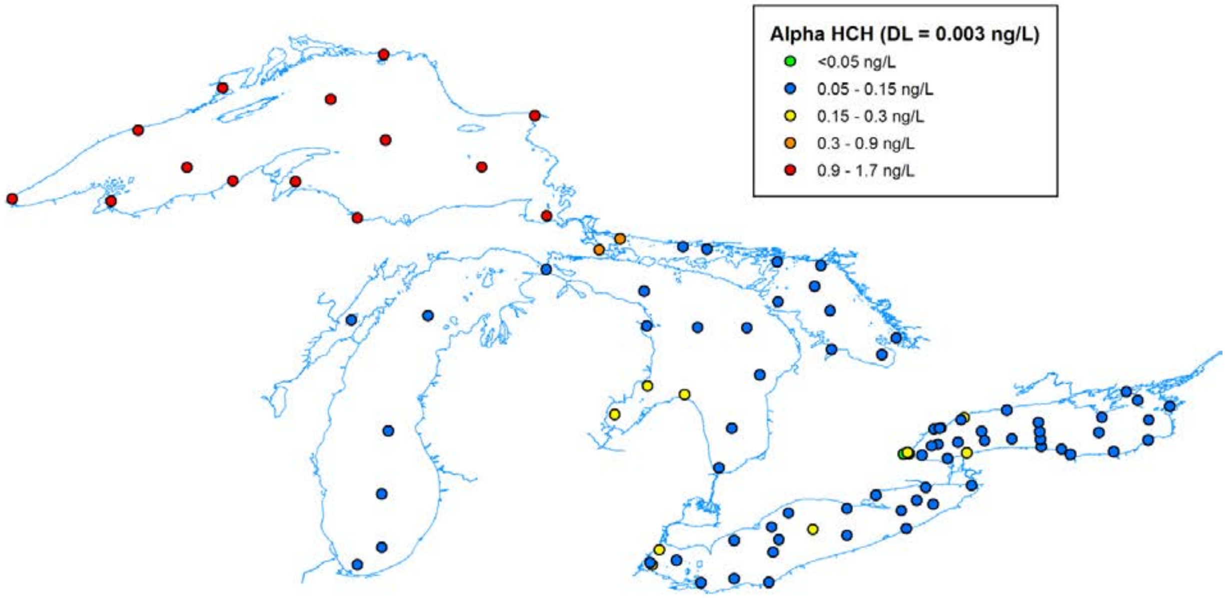

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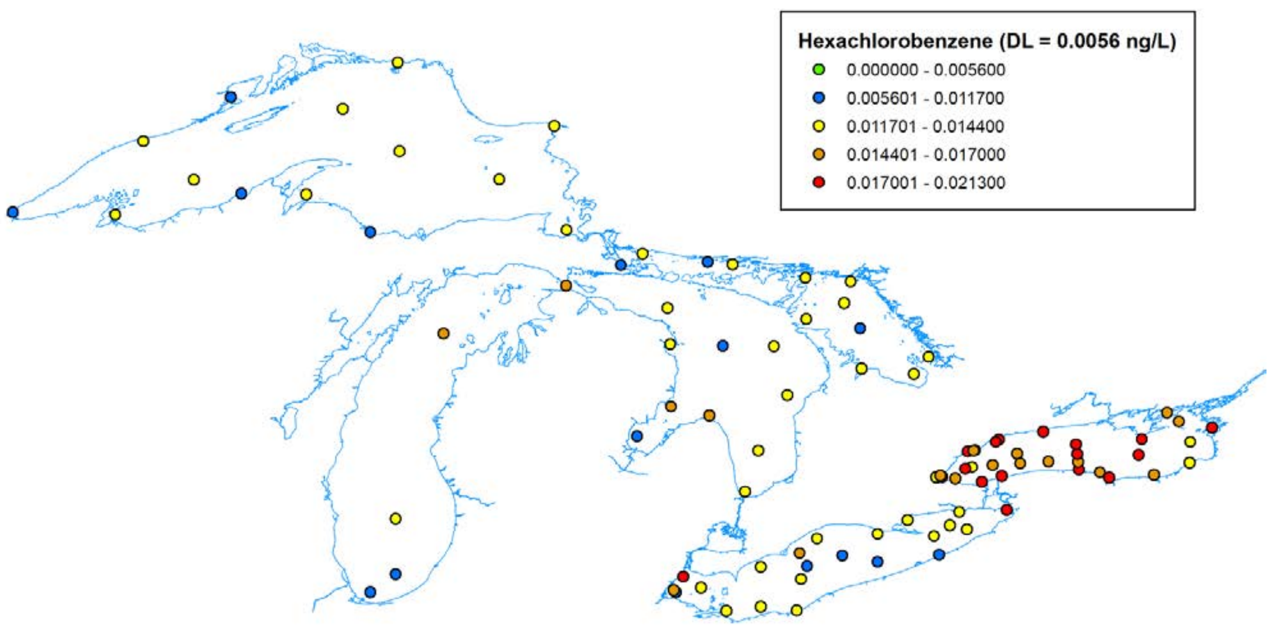

Figure 2. Spatial distribution of dissolved hexachlorobenzene in Great Lakes surface waters
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Source: Environment Canada's Great Lakes Surveillance Program

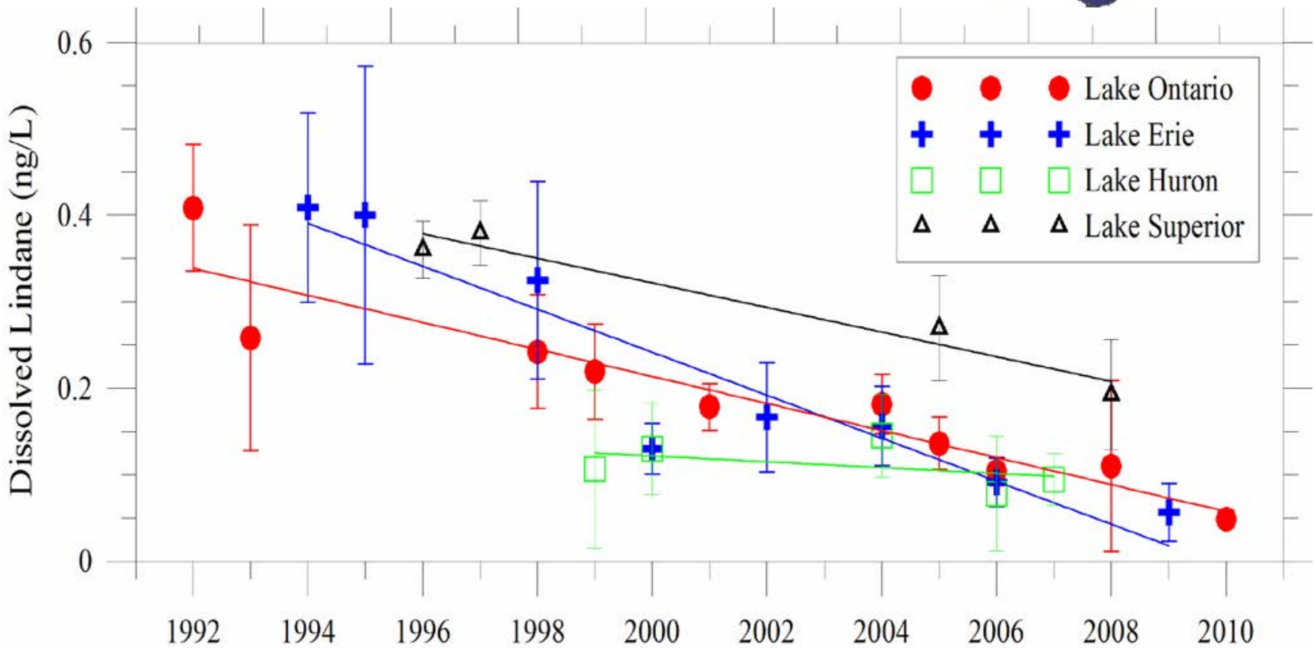

Figure 3. Temporal trend of dissolved lindane in Great Lakes surface waters
Data are spring, surface, open lake mean values ± standard deviation.
Source: Environment Canada's Great Lakes Surveillance Program

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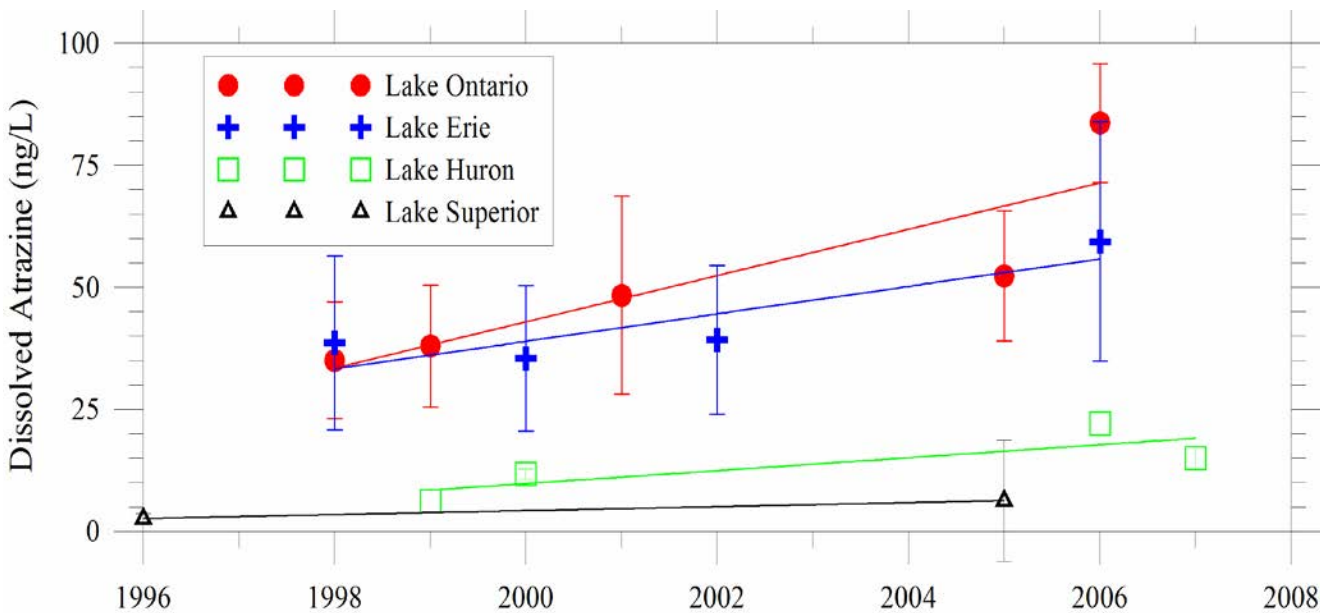
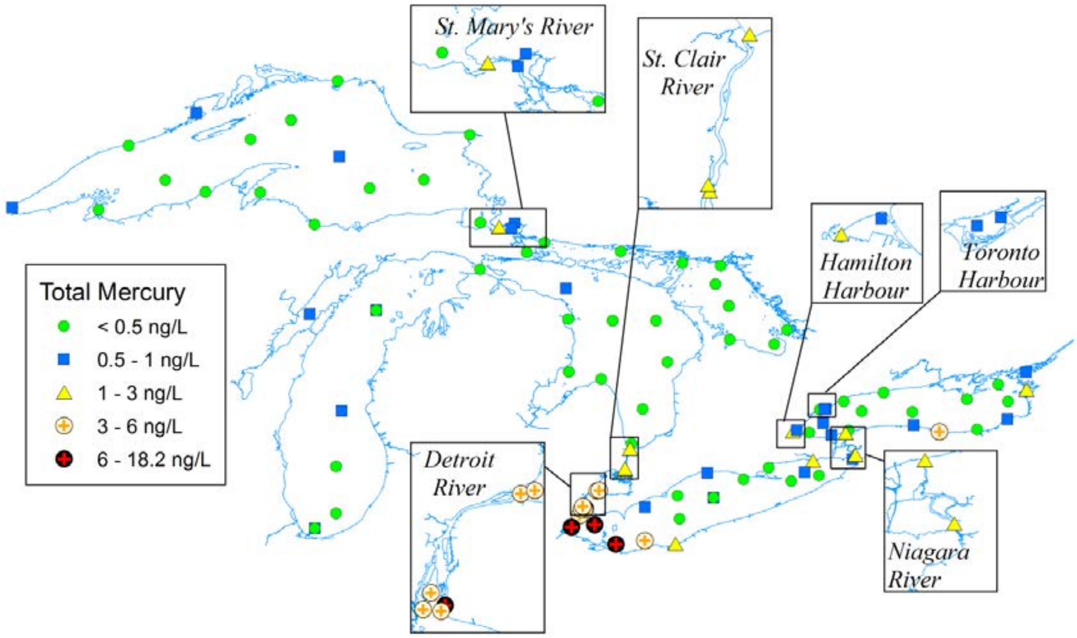


Figure 4. Temporal trend of dissolved atrazine in Great Lakes surface waters
Data are spring, surface, open lake mean values ± standard deviation.
Source: Environment Canada's Great Lakes Surveillance Program



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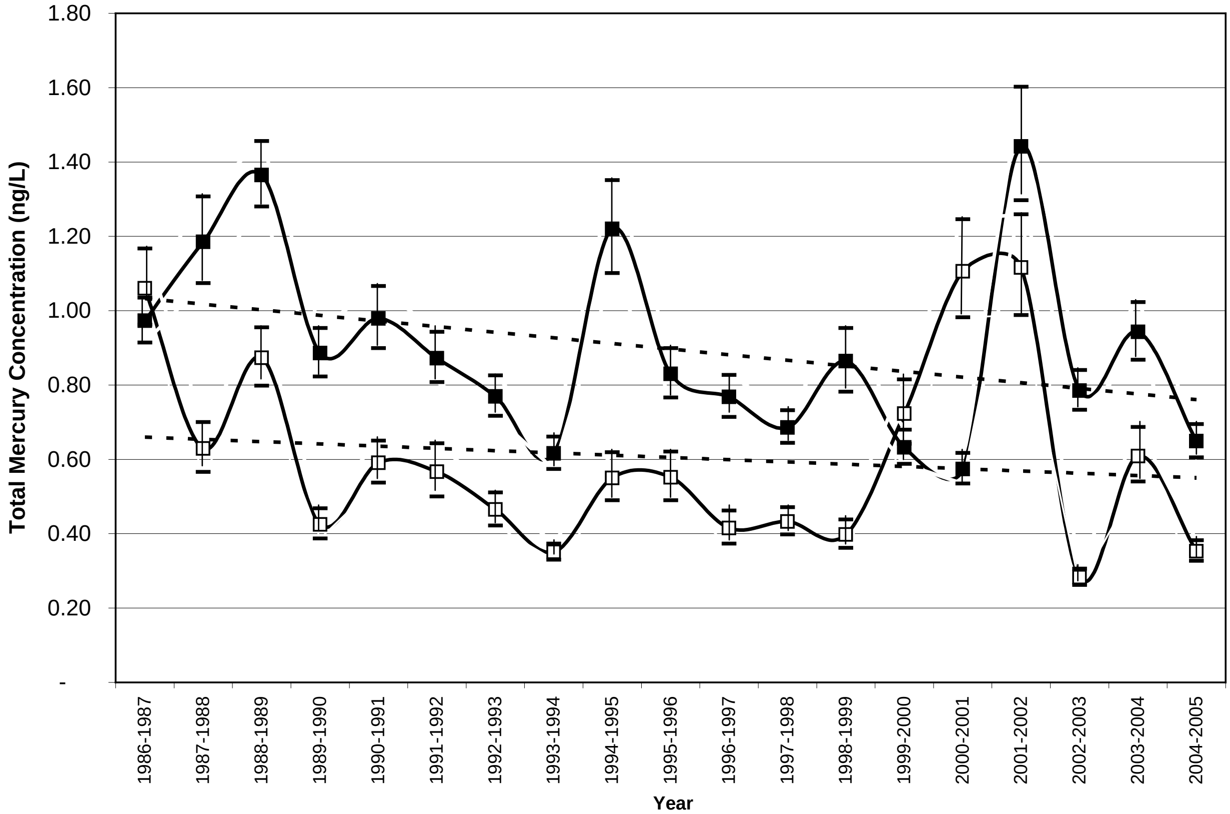

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Source: Environment Canada's Great Lakes Surveillance Program

Treating Wastewater

Overall Assessment

Trend: **Increasing**

Rationale: **In the Canadian portion of the basin, the percent of the population served secondary wastewater treatment or higher increased from 90% in 2004 to 95% in 2006 and 99% in 2009.**

Lake-by-Lake Assessment

Lake Superior

Trend: Increasing

Rationale: In the Canadian portion of the Lake Superior basin, the percent of the population served secondary wastewater treatment or higher increased from 4% in 2004 to 98% in 2006 and 99% in 2009.

Lake Michigan

Trend: Unavailable

Rationale: Unavailable

Lake Huron

Trend: Undetermined

Rationale: In the Canadian portion of the Lake Huron basin, the percent of the population served secondary wastewater treatment or higher increased from 93% in 2004 and in 2006 to 97% in 2009

Lake Erie

Trend: Increasing

Rationale: In the Canadian portion of the Lake Erie basin, the percent of the population served secondary wastewater treatment or higher increased from 75% in 2004 to 85% in 2006 and 99% in 2009

Lake Ontario

Trend: Increasing

Rationale: In the Canadian portion of the Lake Ontario basin, the percent of the population served secondary wastewater treatment or higher increased from 94% in 2004 to 98% in 2006 to almost 100% (99.8%) in 2009

Purpose

To measure the proportion of the Great Lakes basin population served by municipal sewage treatment facilities by treatment level which is reflective of the quality of water discharged

To measure the percent of collected wastewater that is treated (proportion flow bypass)

To measure the level of municipal treatment provided with respect to current treatment standards

The Treating Municipal Wastewater indicator is used in the Great Lakes indicators suite as a Response indicator in the Restoration and Protection top level reporting category.

Ecosystem Objective

To reduce the pressures induced on the ecosystem by insufficient wastewater treatment networks and procedures and further progression towards sustainable development.

Measures

1. Percentage of the Great Lakes population served by municipal sewage treatment facilities by treatment levels

2. Percentage of collected wastewater that is released to waters of the Great Lakes basin without treatment (proportion flow bypass)
3. Percentage of wastewater systems achieving provincial/state Great Lakes effluent water quality standards

Only measure 1 will be reported in 2011.

Ecological Condition

Background

Wastewater refers to the contents of sewage systems drawing liquid wastes from a variety of sources, including municipalities, institutions, industry and stormwater discharges. After treatment, wastewater is released as effluent into receiving waters such as lakes, ponds, rivers, streams and estuaries.

Wastewater contains a large number of potentially harmful pollutants, both biological and chemical. Wastewater systems are designed to collect and remove many of the pollutants using various levels of treatment, ranging from simple to very sophisticated. Effluents released from wastewater systems can still contain pollutants of concern, since even advanced treatment systems do not necessarily remove all pathogens and chemicals.

The following constituents, although not necessarily routinely monitored, are mostly associated with human waste and are present in all sewage effluent to some degree:

- biodegradable oxygen-consuming organic matter (measured as BOD)
- suspended solids (measured as total suspended solids (TSS)
- nutrients, such as phosphorus (usually measured as total phosphorus) and nitrogen-based compounds (nitrate, nitrite, ammonia, and ammonium, which are measured either separately or in combination as total nitrogen)
- microorganisms (which are usually measured in terms of the quantity of representative groups of bacteria, such as fecal coliforms or fecal streptococci, found in human wastes)
- sulphides
- assorted heavy metals
- trace amounts of other toxins and chemicals of emerging concern that have yet to be consistently monitored for in wastewater effluents

Municipal wastewater effluent is one of the largest sources of pollution, by volume, discharged to surface water bodies in Canada (CCME 2006). Reducing the discharge of pollution through wastewater effluent requires a number of interventions ranging from source control to end of pipe measures.

The concentration and type of effluent released into a receiving body of water depend heavily on the type of sewage treatment used. As a result, information regarding the level of wastewater treatment is integral in assessments of potential impacts on water quality. In both the United States and Canada, the main levels of wastewater treatment used include primary, secondary, and advanced or tertiary.

In the United States, *pretreatment* of industrial wastewater may be required to reduce levels of contaminants and to remove large debris before the waters are released to municipal treatment systems for regular treatment. U.S. federal regulations require that Publicly Owned Treatment Works (POTW) pretreatment programs include the development of local pretreatment limits for industrial pollutants that could potentially interfere with municipal treatment facility operations or contaminate sewage sludge. The U.S. Environmental Protection Agency (U.S. EPA) can authorize the states to implement their own pretreatment programs as well. Of the eight states that are part of the Great Lakes basin, Michigan, Minnesota, Ohio and Wisconsin currently hold an approved State Pretreatment Program (U.S. EPA 2006a).

In *primary* wastewater treatment, solids are removed from raw sewage primarily through processes involving sedimentation. This process typically removes about 25% to 35% of solids and related organic matter (U.S. EPA 2000).

Secondary wastewater treatment includes an additional biological component in which oxygen-demanding organic materials are removed through bacterial synthesis enhanced with oxygen injections. About 85% of organic matter in sewage is removed through this process, after which the excess bacteria are removed (U.S. EPA 1998). Effluent can then be disinfected with chlorine prior to discharge to kill potentially harmful bacteria. Subsequent dechlorination is also often required to remove excess chlorine that may be harmful to aquatic life.

Advanced, or *tertiary*, levels of treatment often are used as well and are capable of producing high-quality water. Tertiary treatment can include the removal of nutrients, such as phosphorus and nitrogen, and essentially all suspended and organic matter from wastewater through combinations of physical and chemical processes. Additional pollutants can also be removed when processes are tailored to those purposes.

Levels of Treatment in the United States and Canada

United States

In the United States, secondary treatment effluent standards are established by the U.S. EPA and have technology-based requirements for all direct discharging facilities. These standards are expressed as a minimum level of effluent quality in terms of biochemical oxygen demand measurements over a five-day interval (BOD5), TSS and pH. Secondary treatment of municipal wastewater is the minimum acceptable level of treatment according to U.S. federal law unless special considerations dictate otherwise (U.S. EPA 2000).

Data on the level of treatment utilized in the United States are available from the Clean Water Needs Survey (CWNS). This cooperative effort between the U.S. EPA and the states resulted in the creation and maintenance of a database with technical and cost information on the 16,000 POTWs in the nation. According to the results of the 2000 CWNS, the total population served by POTWs in U.S. counties fully or partially within the Great Lakes basin was 17,400,897. Of this number, 0.7% received treatment from facilities that do not discharge directly into Great Lakes waterways and dispose of wastes by other means, 14.1% received secondary treatment, and 85.3% received treatment that was greater than secondary, making advanced treatment the type used most extensively (Fig. 4). These values do not include a possible additional 12,730 people who were reportedly served by facilities in New York for which watershed locations are unknown within the CWNS database.

Canada

In Canada, the Great Lakes drainage basins are all located in the province of Ontario. Wastewater Treatment Plants (WWTPs) in Ontario also use primary, secondary, and tertiary treatment types. Most of the municipal wastewater produced in the Great Lakes basin portion of Ontario is treated at a secondary level or higher. Figure 1 shows the distribution of population served according to level of treatment. Figure 2 shows the distribution of population served according to level of treatment for each of the Great Lakes basins.

Secondary-mechanical treatment is the most common type of sewage treatment across the Great Lakes basin, as inferred from the distribution data in both Figures 1 and 2. Tertiary treatment is the second most widespread treatment type. This indicates the potential for good to high effluent water quality, but this can only be verified through analysis of regulatory and monitoring programs.

The proportion of the population served secondary treatment or higher has increased in the Great Lakes basin, from 90% in 2004 to 99% in 2009. The data show an increase in the proportion of the population served secondary treatment or higher in each of the Great Lake basins. The large jump in population served secondary treatment or higher in the Lake Superior basin between 2004 and 2006 is due to upgrades to secondary level treatment in Thunder Bay and Sault Ste. Marie.

Condition of Wastewater Effluent in Canada and the United States: Regulation, Monitoring, and Reporting

Canada

The regulatory framework for wastewater treatment in Canada is currently undergoing significant changes. New federal Wastewater Systems Effluent Regulations have been proposed to set national baseline effluent quality standards achievable through secondary treatment or equivalent. The regulations would also take a first step toward managing sewage overflows from combined sewers. The federal government published the proposed Wastewater Systems Effluent Regulations in the Canada Gazette, Part I, on March 20, 2010. The target for Final Regulations to be published in Canada Gazette, Part II, is December 2011. The Regulations deliver on the federal government's commitment under the Canadian Council of Ministers of the Environment (CCME) Canada-wide Strategy for the Management of Municipal Wastewater Effluent (CCME Strategy) endorsed by all jurisdictions, except Quebec, Nunavut and Newfoundland and Labrador, in February 2009.

In Canada, wastewater treatment levels are tracked through the Municipal Water and Wastewater Survey (MWWS) administered by Environment Canada. The survey collects data on wastewater treatment levels directly from a large sample of municipalities across Canada, with the resulting data stored in a publically-accessible database.

United States

The United States regulates and monitors wastewater treatment systems and effluents through a variety of national programs. The U.S. EPA's Office of Wastewater Management promotes compliance with the Clean Water Act through the National Pollutant Discharge Elimination System (NPDES) permit program. These permits regulate wastewater discharges from POTWs by setting effluent limits, monitoring, and reporting requirements, and they can lead to enforcement actions when excessive violations occur. The U.S. EPA can authorize the states to implement all or part of the NPDES program, and all U.S. states in the Great Lakes region are currently approved to do so, provided they meet minimum federal requirements (U.S. EPA 2006a). This distribution of implementation power can create difficulties, however, when specific assessments are attempted across regions spanning several states.

Large-scale, national assessments of wastewater treatment have been completed in the past using BOD and dissolved oxygen (DO) levels as indicators of water quality. Since DO levels are proven to be related to BOD output from wastewater discharges (increased BOD loadings lead to greater depletion of oxygen and therefore lower DO levels in the water) historical DO records can be a useful indicator of water quality responses to wastewater loadings. According to a national assessment of wastewater treatment completed in 2000, the U.S. Great Lakes basin had a statistically significant improvement in worst-case DO levels after implementation of the Clean Water Act (U.S. EPA 2000). The study's design estimates also showed that the national discharge of BOD5 in POTW effluent decreased by about 45%, despite a significant increase of 35% in the population served and the influent loadings. This improving general trend supported assumptions made in the 1996 CWNS Report to Congress that the efficiency of BOD removal would increase due to the growing proportion of POTWs using advanced treatment processes across the nation.

Unfortunately, comprehensive studies such as the examples listed above have not been conducted for pollutants other than BODs, and none have been completed to an in-depth level for the Great Lakes region. However, an extensive investigation of the Permit Compliance System (PCS) database is one way an evaluation of wastewater treatment could be accomplished. This national information management system tracks NPDES data, including permit issuance, limits, self-monitoring, and compliance. The PCS database can provide the information necessary to calculate the loadings of specific chemicals present in wastewater effluent from POTWs in the U.S. portion of the Great Lakes basin, providing the relevant permits exist.

Management Challenges/Opportunities

There are numerous challenges to providing adequate levels of wastewater treatment in the Great Lakes basin. These include: facility aging, disrepair and outdatedness; population growth that stresses the capabilities of existing plants and requires the need for more facilities; new and emerging contaminants that are more complex and prolific than in the past; and new development that is located away from urban areas and served by decentralized systems (such as septic systems) that are much harder to regulate and monitor. The escalating costs associated with addressing these challenges continue to be a problem for both U.S. and Canadian municipalities (U.S. EPA 2004, Government of Canada 2002).

Despite demonstrated significant progress in wastewater treatment across the basin, nutrient enrichment, sediment contamination, heavy metals, and toxic organic chemicals still pose threats to the environment and human health. To maintain progress on these issues, and to ensure that current achievements in water pollution control are not overwhelmed by the demands of future urban population growth, governments should continually invest in wastewater treatment infrastructure improvements. In addition, investments are needed to control or mitigate polluted urban runoff and untreated municipal stormwater, which have emerged as prime contributors to local water quality problems throughout the basin (Environment Canada 2004).

WWTPs are challenged to keep up with demands created by urban development. The governments of Canada and Ontario and municipal authorities, working under the auspices of the Canada-Ontario Agreement (COA) Respecting the Great Lakes Basin Ecosystem, have been developing and evaluating new stormwater control technologies and sewage treatment techniques to resolve water quality problems (Environment Canada 2004). Under COA, Canada and Ontario will continue to build on this work, implementing efficient and cost effective projects to reduce the environmental damage of a rapidly expanding urban population (Environment Canada 2004).

The presence of chemicals of emerging concern in wastewater effluent is another developing issue. Current U.S. and Ontario permit requirements are based on state or provincial water quality laws that are developed according to pollutants anticipated to exist in the community. This means the existence of new potentially toxic substances can be overlooked. For example, even in areas with a high degree of municipal wastewater treatment, pollutants such as endocrine-disrupting substances can inadvertently pass through wastewater treatment systems and into the environment. These substances are known to mimic naturally occurring hormones and may have an impact on the growth, reproduction, and development of many species of wildlife. Additional monitoring for these pollutants and corresponding protection and regulation measures are advised.

Comments from the author(s)

A number of challenges and barriers to the full implementation of this indicator report were encountered during its preparation. Included were:

Population estimates

The actual proportion of the entire population receiving municipal wastewater treatment is difficult to calculate. In Canada, data from the MWWS is used. The MWWS has a high but not complete response rate; the 2009 MWWS collected wastewater treatment levels for an estimated 82% of the population connected to a municipal sewer. In the United States population estimates were compiled by county, and therefore represent a skewed total for the population that actually resides within the boundaries of the Great Lakes watershed. GIS analysis of census data needs to be completed in order to obtain a more accurate estimate of the Great Lakes population.

Data availability

In Canada, three years of data from the Environment Canada MWWS was used. For Canada overall, the 2009 MWWS collected wastewater treatment levels for an estimated 82% of the population connected to a municipal sewer. Prior to 1999, the survey was called Municipal Water Use and Pricing Surveys (MUD/MUP). In 2001, the survey format was changed and the name updated to the Municipal Water and Wastewater Survey (MWWS). The most recent data set for MWWS is for 2009, with the most recent water use report released in 2007. New data from the 2011 MWWS will be available in 2012.

Loadings calculations

Several problems exist in the calculation of effluent loadings. For example, actual effluent flow is not consistently monitored in the United States. Although influent levels are obtainable for every facility, effluent levels might not be comparable, since a substantial volume may be removed during treatment processes. Because effluent flow data are necessary to calculate loadings from concentration values of pollutants, precise estimates of total loadings to Great Lakes waters may be next to impossible to obtain on a large scale without actual effluent flow data.

Consistency in implementation of analysis

Consistent guidelines and practices for the analysis of wastewater treatment in both the United States and Canada would be helpful. In the United States, data were compiled from several different databases, with population information derived from a separate source than effluent monitoring reports. In Canada, data on both population and wastewater treatment is taken from the Environment Canada MWWS. The MWWS data is geocoded, so it can be analyzed at the level of the Great Lakes basin and each individual Great Lake basin.

Consistency in monitoring and reporting

To successfully correlate wastewater treatment quality with the environmental status of the Great Lakes basin, a more organized monitoring program must be implemented. Although wastewater treatment plants provide useful monitoring information, they only report the quality of the effluent at that specific municipality, rather than the overall quality of the Great Lakes. Additionally, differences in monitoring requirements between Canada and the United States make assessments of the quality of wastewater treatment difficult on a basin-wide scale. Implementation of a more standardized, updated approach to monitoring contaminants in effluent and a standardized reporting format and inclusive database, accessible to all municipalities, researchers, and the general public, should be established for binational use. The proposed federal Wastewater Systems Effluent Regulations are expected to improve the collection and monitoring of wastewater effluent quality data in Canada.

Automated data processing

Considering all the difficulties encountered while attempting to adequately summarize the vast amount of U.S. effluent monitoring data contained in the PCS database, a logical solution would be an application that could automate accurate calculations. Such an application previously existed that was capable of producing effluent data mass loadings reports from the PCS database, and annual NPDES Great Lakes Enforcement reports were once compiled. However, the application used to calculate loadings was discontinued due to the modernization of the PCS system that is currently underway, and resources have not yet been available to extend the overhaul to this tool. Incorporating this component into the current modernization could take years due to various logistical problems, including the inherent quality assurance issues (James Coleman, personal communication). Despite these problems, the reinstatement of such a tool would solve the data summarization needs presented in this indicator report and could lead to an effective, comprehensive, and time-efficient analysis of pollutant loadings to the Great Lakes from U.S. wastewater treatment plants.

Further development of this indicator

The ultimate development of this progress report into a reportable Great Lakes indicator is necessary and would be possible in the near future if:

- Increased manpower and time could be dedicated to indicator development,
- Revisions were made to the proposed indicator that included a decreased scope, more realistic reporting metrics, and a less-strenuous reporting frequency,
- The data retrieval process were streamlined with appropriate quality controls, and
  A workgroup was created of members that held specific expertise regarding wastewater systems, treatment plant analytical methods, municipal infrastructure, permitting, and who had knowledge of and access to the relevant databases.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						
2. Data are traceable to original sources						
3. The source of the data is a known, reliable and respected generator of data						
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin						
5. Data obtained from sources within the U.S. are comparable to those from Canada						
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report						

Acknowledgments

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Pamela Finlayson, Environment Canada, Toronto ON (Canadian revisions 2009)

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Figure 3. Percent of population served secondary treatment or higher, 2004 to 2009.
Source: Municipal Water and Wastewater Survey, Environment Canada

Figure 4. Population Served by Publicly Owned Treatment Works (POTWs) by treatment level in the U.S. Great Lakes basin. (a) = “No discharge” facilities do not discharge treated wastewater to the Nation’s waterways. These facilities dispose of wastewater via methods such as industrial re-use, irrigation, or evaporation.
*Lake St. Clair and Detroit River watersheds are considered part of the Lake Erie basin.
** MI unknown refers to the population served by facilities in the state of Michigan for which exact watershed locations are unknown, so the data could not be grouped with a specific lake basin. Population could potentially be distributed between Lakes Michigan, Huron or Erie.
Source: 2000 Clean Watershed Needs Survey

Last Updated

Canadian information updated for *State of the Great Lakes 2011*.
US data last updated for *State of the Great Lakes 2007*.

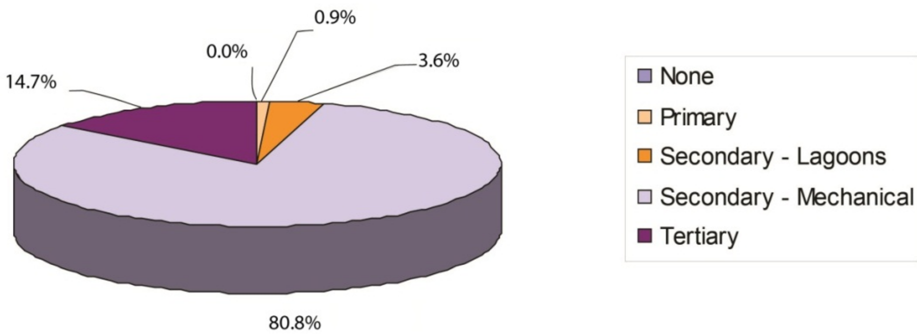


Figure 1. Percent of Canadian population in the Great Lakes basin served by wastewater treatment type in 2009. Source: Municipal Water and Wastewater Survey, Environment Canada

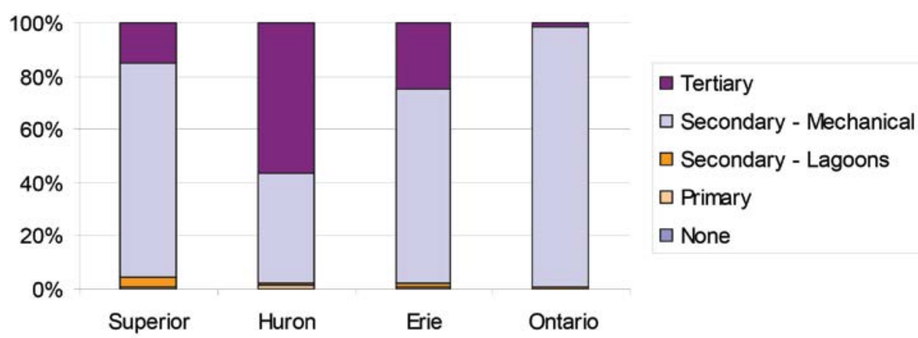


Figure 2. Percent of Canadian population in each Great Lake basin served by wastewater treatment type in 2009. Source: Municipal Water and Wastewater Survey, Environment Canada

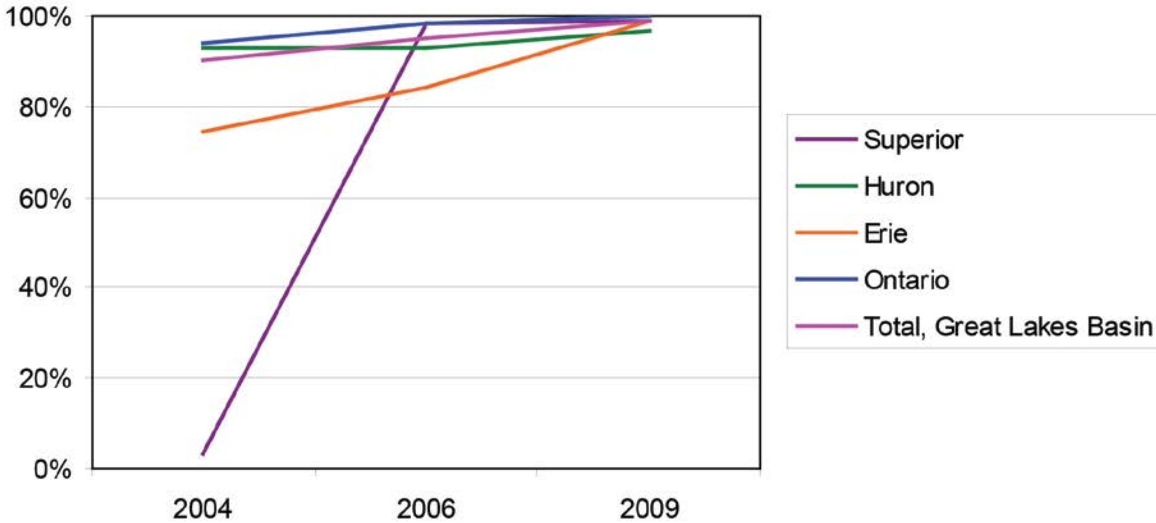
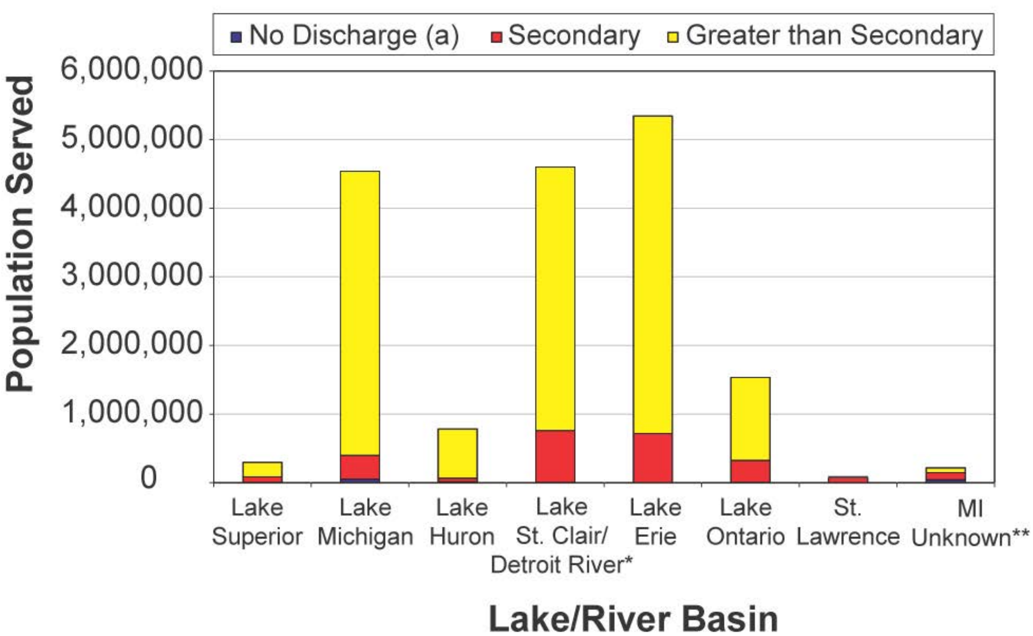


Figure 3. Percent of population served by secondary treatment or higher, 2004 – 2009.
Source: Municipal Water and Wastewater Survey, Environment Canada



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*Lake St. Clair and Detroit River watersheds are considered part of the Lake Erie basin.
** MI unknown refers to the population served by facilities in the state of Michigan for which exact watershed locations are unknown, so the data could not be grouped with a specific lake basin. Population could potentially be distributed between Lakes Michigan, Huron or Erie.
Source: 2000 Clean Watershed Needs Survey

Tributary Flashiness

Overall Assessment
Status: **Fair**
Trend: **Improving**
Rationale: **Tributary flashiness is a measure that reflects the frequency of short-term changes in streamflow; the flow of a flashy stream increases and decreases dramatically in hours or a few days in response to rainfall. On average, tributary flashiness has significantly decreased in six out of 11 selected tributaries over a ten-year period, meaning flow conditions are becoming more stable. However, flashiness in four of these tributaries has increased and one tributary did not exhibit significant trends in flashiness over this same time period. Periodic changes in flow rates are natural in streams and rivers and organisms that live in these systems adapt to them. However, changes in hydrologic regimes, either reductions or increases in flashiness, can lead to displacement of native biotic communities. Status and trends in tributary flashiness have not been analyzed for each lake basin.**

Lake-by-Lake Assessment
Each lake was categorized with a not assessed status and an undetermined trend, indicating that assessments were not made on an individual lake basis.

Other Spatial Scales:
River-by-River Assessment – U.S. Rivers
Genesee River in the Lake Ontario Basin
Status: Good
Trend: Unchanging
Rationale: Long-term trend is toward lower R-B Index ($p<0.0001$), but the last two decades have same average index to 3 decimal places.

Maumee River in the Lake Erie Basin
Status: Poor
Trend: Improving
Rationale: Long-term trend is toward higher R-B Index ($p<0.0001$), but the average for the most recent ten-year period is lower than that for the previous period.

Saginaw River in the Lake Huron Basin
Status: Good
Trend: Improving
Rationale: Only 14 years of continuous flow data are available, preventing comparison of two 10-year periods. However, the 14-year trend is downward ($p=0.039$). The most recent 10 year average is lower than the average of the first four years, and the most recent 7 year average is lower than the average of the first 7 years.

Muskegon River in the Lake Michigan Basin
Status: Good
Trend: Deteriorating
Rationale: Long-term trend is toward lower R-B Index ($p<0.0001$), but the average for the most recent ten year period is higher than that for the previous period.

St. Joseph River in Lake Michigan Basin
Status: Good
Trend: Improving
Rationale: Long-term trend is toward lower R-B Index (p<0.0001). The average for the most recent ten-year period is lower than that for the previous period.

Fox River in the Lake Michigan Basin
Status: Fair
Trend: Deteriorating
Rationale: Long-term trend is very slightly toward lower R-B Index and not statistically significant. The average for the most recent ten-year period is higher than that for the previous period, and the index has increased each of the past 7 years.

St. Louis River in the Lake Superior Basin
Status: Good
Trend: Improving
Rationale: Long-term trend is toward lower R-B Index (p=0.0153). The average for the most recent ten-year period is lower than that for the previous period.

River by River Assessment – Canadian Rivers
Humber River in the Lake Ontario Basin
Status: Fair
Trend: Improving
Rationale: Long-term trend is upward but not significant. The average for the most recent ten-year period is lower than that for the previous period.

Thames River in the Lake Erie Basin
Status: Fair
Trend: Deteriorating
Rationale: Long-term trend is upward but not significant. The average for the most recent ten-year period is higher than that for the previous period.

Saugeen River in the Lake Huron Basin
Status: Fair
Trend: Improving
Rationale: Long-term trend is nearly flat. The average for the most recent ten-year period is lower than that for the previous period.

Pic River in the Lake Superior Basin
Status: Fair
Trend: Deteriorating
Rationale: Long-term trend is downward but not significant. The average for the most recent ten-year period is higher than that for the previous period.

Purpose

- This indicator quantifies the nebulous concept of flashiness, which is an important aspect of the hydrologic regime to which the aquatic ecosystem must be adapted. Increases or decreases in flashiness usually lead to ecosystem stress.
- Tributary Flashiness indicator is used in the Great Lakes indicator suite as a State indicator in the

Landscapes and Natural Processes category.

Ecosystem Objective

The ecosystem objective is to avoid hydrologic alteration. Periodic changes in flow rate are characteristic of streams and rivers, and the organisms that live in them are adapted to those changes. Spring floods may be important in opening up spawning areas or nurseries. Higher energies associated with storm runoff flush finer sediment from gravel beds, improving them as habitats for invertebrates and as spawning sites for salmonids. But changes in the hydrologic regime, either by reduced flashiness such as occurs when a dam is constructed, or by increased flashiness such as occurs with urbanization, require adaptation by the resident organisms; if the changes are great enough, they can lead to the displacement of the native community and its replacement by another, often less desirable community.

Ecological Condition

Tributary flashiness is a measure that reflects the frequency and magnitude of short-term changes in streamflow; the flow of a flashy stream increases and decreases dramatically in hours or a few days in response to rainfall.

Measure

The measure is the flashiness of hydrological response of a stream or river to rainfall/snowmelt events. The Richards-Baker Flashiness Index (R-B Index for short) is calculated from mean daily flows from the U.S. Geological Survey or Environment Canada, usually on an annual basis, and is the sum of the absolute values of the changes in flow from one day to the next, divided by the total discharge for the year.

$$R - B\ Index = \frac{\sum_{n=1}^{365} |q_n - q_{n-1}|}{\sum_{n=1}^{365} q_n}$$

The rivers used for this indicator are listed in Table 1. Most of these rivers have long flow records and are part of a proposed national monitoring network (http://acwi.gov/monitoring/network/design/; http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1). They cover a range of flashiness and land use, but are in the same broad size range (HUC6 or HUC8), although the Canadian rivers are generally smaller.

Endpoint/Target Range

There is no universal scale for the R-B Index, so it is not possible to say that a particular index value is good or bad. Small streams tend to be flashier than large rivers, and this is reflected in the R-B Index values. Streams with steep gradients and/or impervious watersheds will have high index values, even if they are totally unimpacted by human activities (e.g. rock basin mountain streams).

Desirable outcomes are lack of trend in flashiness, or in most cases of altered ecosystems, reductions in flashiness. Urbanizing watersheds typically show increases in flashiness over time that parallel increases in imperviousness.

Status Justification

Good = statistically significant decreasing long-term trend in flashiness in the Great Lakes basin or in a specific river,
Fair = no long-term trend in flashiness in the Great Lakes basin or in a specific river,
Poor = statistically significant increasing long-term trend in flashiness in the Great Lakes basin or in a specific river.

Trend will be evaluated by comparing the average index of the most recent 10 years with the average for the preceding 10 years.

The overall status determination is based on the average, across all rivers, of the ratio of the more recent flashiness index to the one for the previous period. This tends to decrease the influence of the more-variable flashier rivers, in comparison with averaging the flashiness values across all rivers for each 10-year period, and then taking the ratio.

Linkages
Fish habitat, land cover, land conversion, and extreme precipitation events.

Management Challenges/Opportunities
This index offers an integrated perspective on changing hydrology in selected, and hopefully representative, major Great Lakes tributaries. It can be used to track the effects of, and guide decisions about, land use changes as they affect hydrology and its impact on riverine ecosystems. It utilizes basic flow data from the U.S. Geological Survey, which are more likely to be available at times of financial duress and lack of support for environmental monitoring than other environmental monitoring data. However, this indicator cannot substitute for these other kinds of data, and management systems that fail to recognize this are vulnerable to unpleasant surprises.

Comments from the Author
The R-B Index is easy to calculate from widely available data, and has come into widespread use. Possible range of values is from 0 to 2. Typical values are from 0.05 (very stable) to about 1.2 (very flashy). The Index integrates all flow data, rather than picking a given percentile. It is believed to be the only flashiness index or index of hydrologic alteration which incorporates the temporal sequence of flows, a very important part of the concept of flashiness. The Index is relatively stable from year to year (i.e. insensitive to weather effects), consequently it is relatively sensitive to longer-term trends.

For small streams, the hydrologic response is too rapid to be adequately resolved by daily flow data. For such systems, a version of the R-B Index based on hourly flow data can be used. However, index values derived from hourly data cannot be directly compared with those derived from daily data. Since the best use of the R-B Index is to track the hydrologic response of a stream through time, the index based on daily data is still useful for small streams, even if it under-represents the true flashiness. The watersheds selected for this indicator are large, and flows change relatively slowly, so daily data are adequate for calculating the R-B Index.

More information about the R-B Index, and some applications in the Midwestern United States, can be found in the paper cited below.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Information Sources
Literature Citation:
Baker, D.B., R.P. Richards, T.T. Loftus, and J.K. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. Journal of the American Water Resources Association 40(2): 503-522.

Data Sources:
Genesee: nwis.waterdata.usgs.gov/ny/nwis/dv/?site_no=04231600
Maumee: nwis.waterdata.usgs.gov/oh/nwis/dv?site_no=04193500
Saginaw: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04157000 (Incomplete series until WY1991)
Muskegon: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04122000 (1950-1993) Newaygo
Muskegon: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04121970 (No data prior to WY1995) Croton
St. Joseph: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04101500
Fox: nwis.waterdata.usgs.gov/wi/nwis/dv/?site_no=04084500
St. Louis: nwis.waterdata.usgs.gov/mn/nwis/dv/?site_no=04024000
Canadian Rivers: Water Survey of Canada, Environment Canada http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1

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Source: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04122000 (1950-1993)
nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04121970 (No data prior to WY1995)
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Source: nwis.waterdata.usgs.gov/mn/nwis/dv/?site_no=04024000
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Source: Water Survey of Canada, Environment Canada

http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1
Figure 9. R-B flashiness index for the Thames River at Thamesville, Ontario, 1950-2010
Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1
Figure 10. R-B flashiness index for the Saugeen River at Port Elgin, Ontario, 1950-2010
Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1
Figure 11. R-B flashiness index for the Pic River near Marathon, Ontario, 1950-2010
Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1

Last Updated
State of the Great Lakes 2011

Rivers used for the Tributary Flashiness Indicator

River	Town	County	State/Province	Latitude	Longitude	HUC	Drainage Area
Genesee	Rochester	Monroe	NY	43°08’30.2”	77°36’58.7”	04130003	2474 mi^2
Maumee	Waterville	Lucas	OH	41°30’00”	83°42’46”	04100009	6330 mi^2
Saginaw	Saginaw	Saginaw	MI	43°24’46”	83°57’47”	040802	6060 mi^2
Muskegon	Croton	Newaygo	MI	43°26’05”	85°39’55”	04060102	2313 mi^2
Muskegon	Newaygo	Newaygo	MI	43°25’20”	85°48’07”	04060102	2350 mi^2
St. Joseph	Niles	Berrien	MI	41°49’45”	86°15’35”	04050001	3666 mi^2
Fox	Wrightstown	Brown	WI	44°26’58”	88°03’52”	040302	6110 mi^2
St. Louis	Scanlon	Carlton	MN	46°42’12”	92°25’07”	040102	3430 mi^2
Humber	Elder Mills		ON	43°48'40"	79°37'39"		117 mi^2
Thames	Thamesville		ON	42°32'41"	81°58'2"		1660 mi^2
Saugeen	Port Elgin		ON	44°27'23"	81°19'35"		1529 mi^2
Pic	Marathon		ON	48°46'26"	86°17'47"		1649 mi^2

Table 1. Rivers used for the Tributary Flashiness Indicator. When a stream includes several HUC8s but does not comprise a complete HUC6, the HUC8 is listed that includes the gaging station from which the flow data are derived.

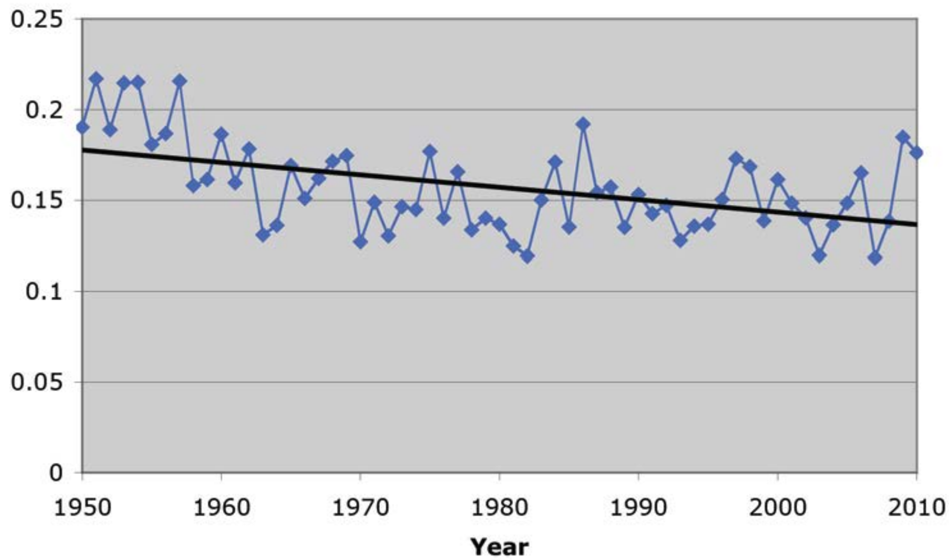

Figure 1. R-B flashiness index for the Genesee River at Rochester, New York, 1950-2010
Source: nwis.waterdata.usgs.gov/ny/nwis/dv/?site_no=04231600

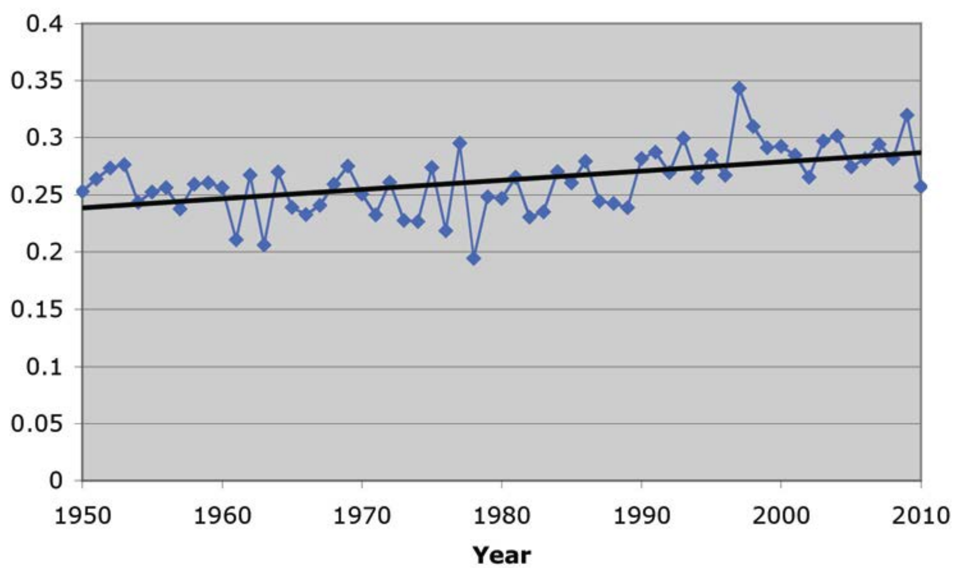

Figure 2. R-B flashiness index for the Maumee River at Waterville, 1950-2010
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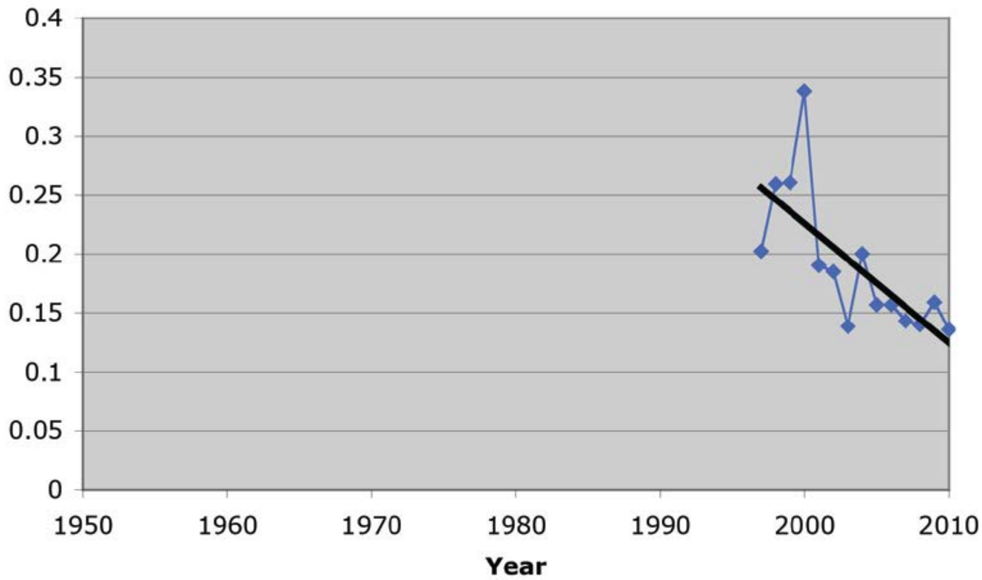

Figure 3. R-B flashiness index for the Saginaw River at Saginaw, Michigan, 1950-2010.
Source: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04157000

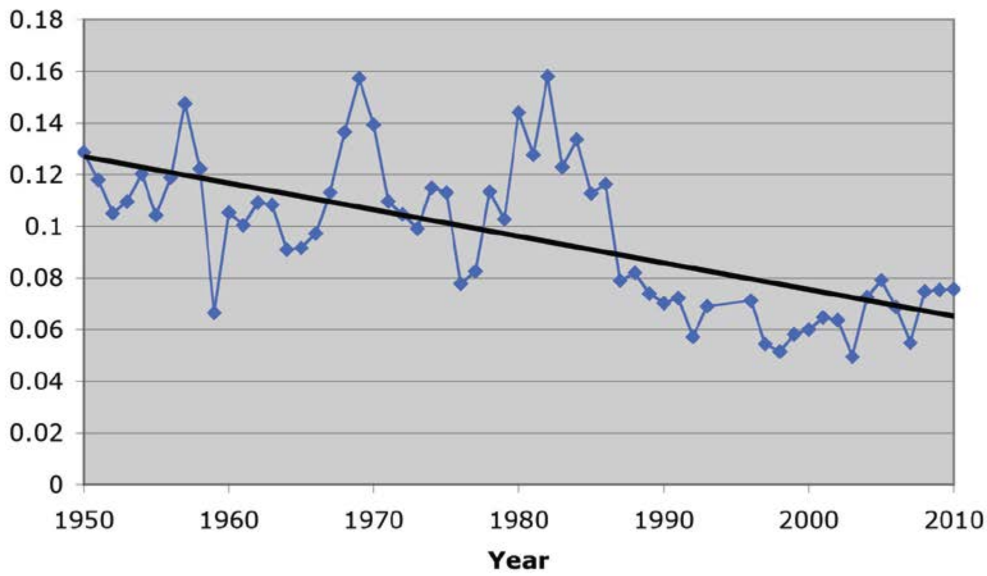

Figure 4. R-B flashiness index for the Muskegon River at Newaygo from 1950-1993 and Croton, Michigan, 1996-2010.
Source: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04122000 (1950-1993)
nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04121970 (No data prior to WY1995)

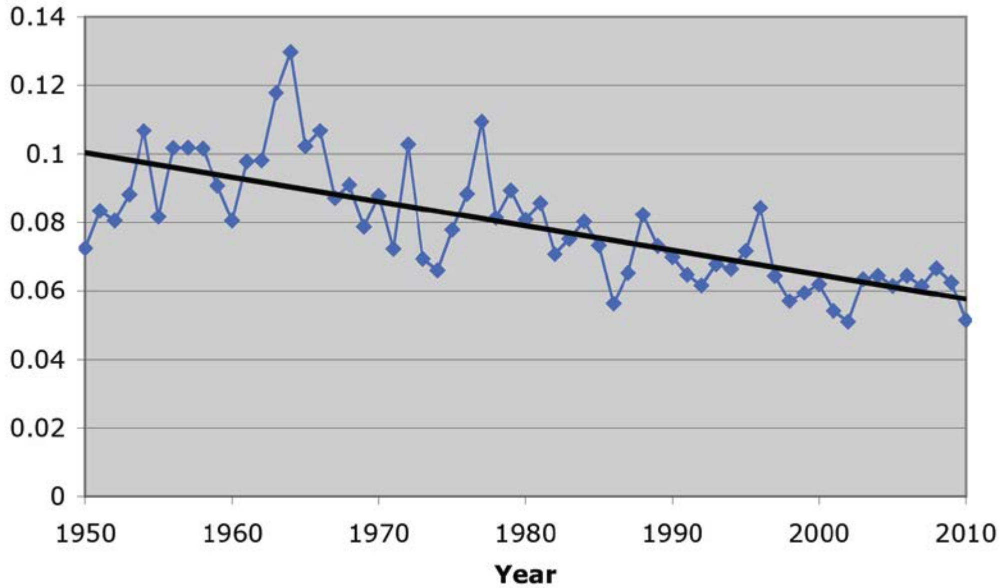

Figure 5. R-B flashiness index for the St. Joseph River at Niles, Michigan, 1950-2010.
Source: nwis.waterdata.usgs.gov/mi/nwis/dv/?site_no=04101500

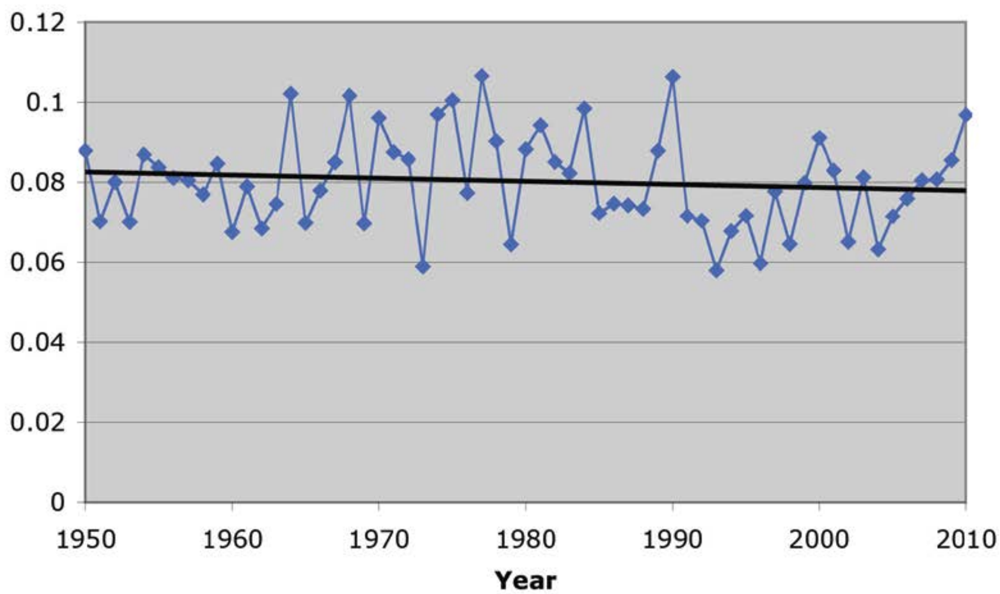

Figure 6. R-B flashiness index for the Fox River at Wrightstown, Wisconsin, 1950-2010.
Source: nwis.waterdata.usgs.gov/wi/nwis/dv/?site_no=04084500

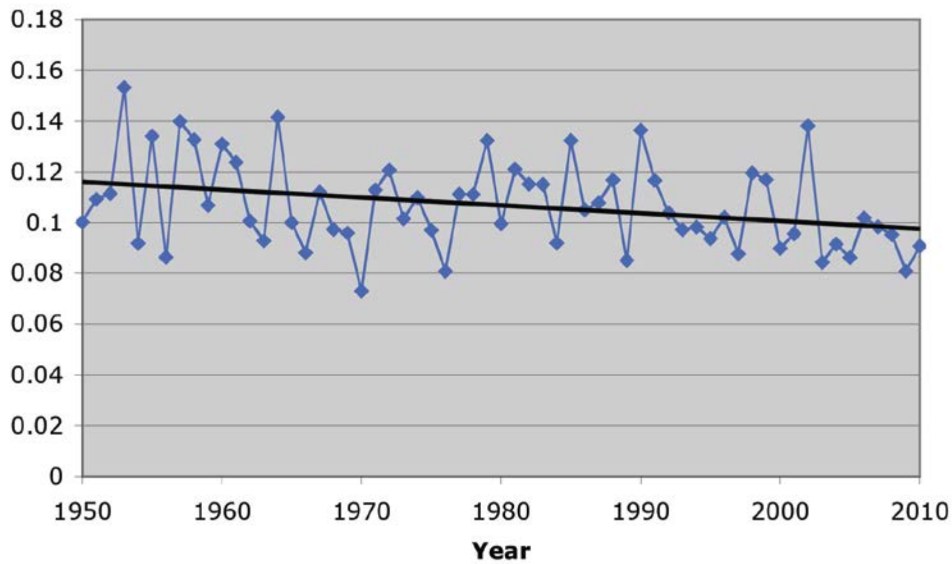

Figure 7. R-B flashiness index for the St. Louis River at Scanlon, Minnesota, 1950-2010.
Source: nwis.waterdata.usgs.gov/mn/nwis/dv/?site_no=04024000

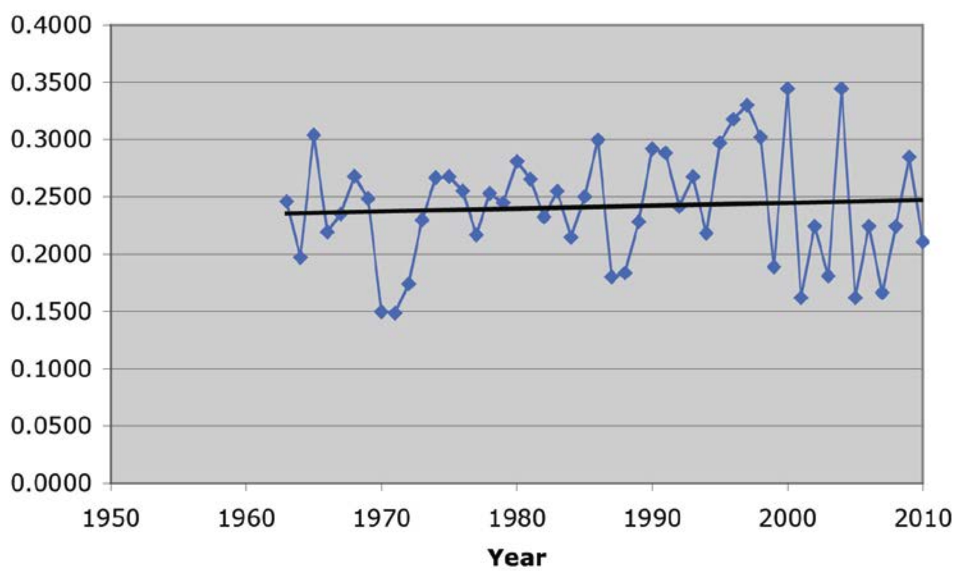

Figure 8. R-B flashiness index for the Humber River at Elder Mills, Ontario, 1950-2010.
Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1

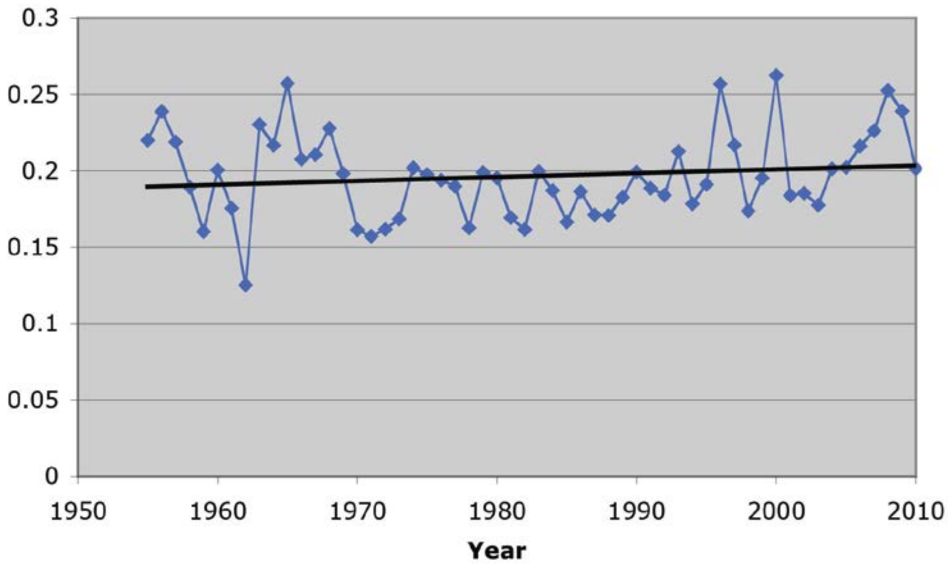

Figure 9. R-B flashiness index for the Thames River at Thamesville, Ontario, 1950-2010.
Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1

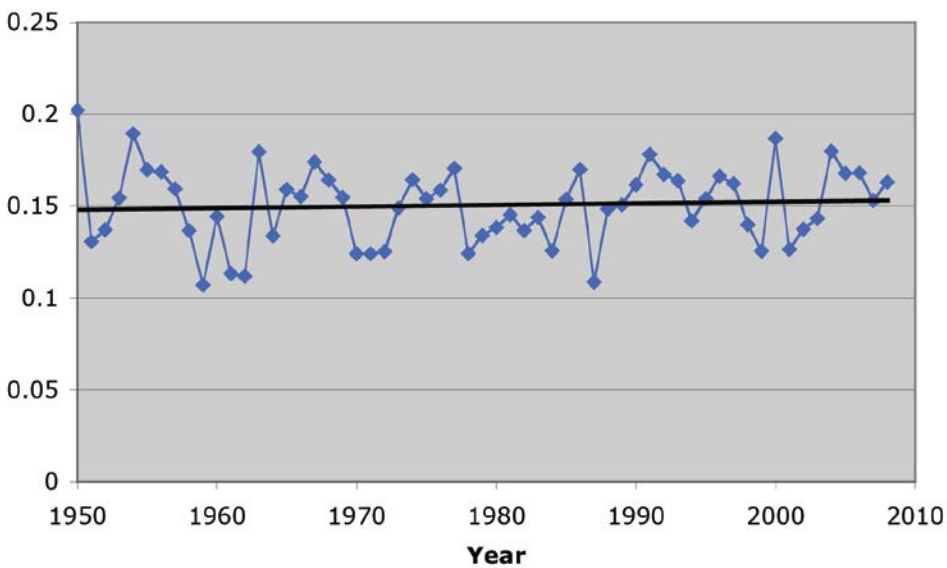

Figure 10. R-B flashiness index for the Saugeen River at Port Elgin, Ontario, 1950-2010.
Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1

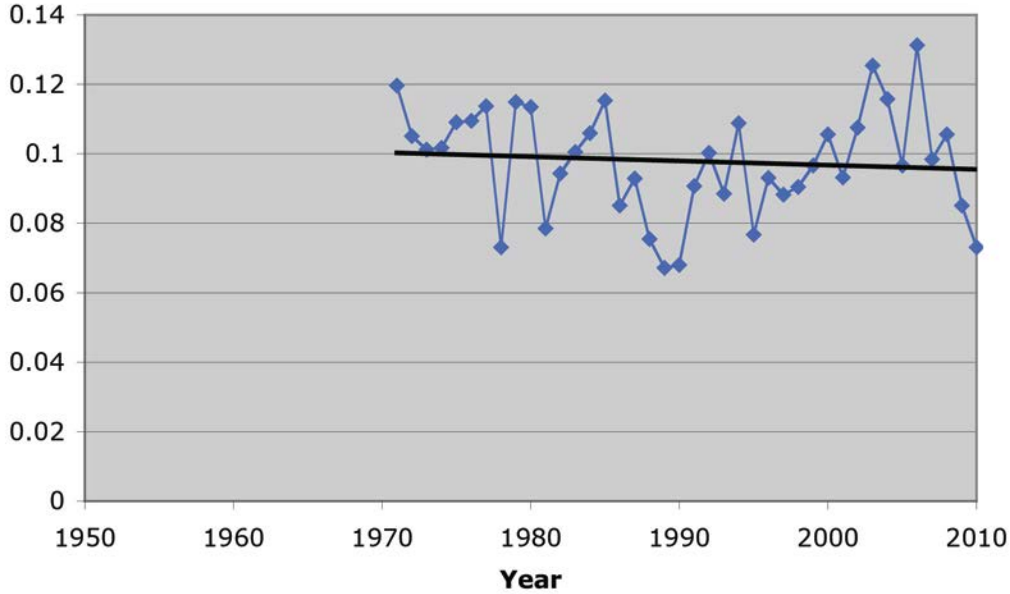

Figure 11. R-B flashiness index for the Pic River near Marathon, Ontario, 1950-2010.
Source: Source: Water Survey of Canada, Environment Canada
http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1

Walleye

Overall Assessment
Status: Fair
Trend: Undetermined
Rationale: The health of native walleye populations in the Great Lakes is quite variable. In lakes where exotic species have been on the decline (including alewife) and increases in productivity have been beneficial, there have been some rebounds in the walleye populations. Where productivity increases or other factors have been deleterious to ecosystem health, walleye populations have struggled to maintain the robust levels recently attained. Recruitment trends in each Great Lake or in each localized (embayment) sub-population continue to play a large part in the overall health of walleye. Consistent years of good recruitment in a given time series has helped fortify specific Great Lakes walleye populations, while poor overall recruitment trends in spite of one or two banner years of recruitment has eroded some Great Lakes walleye populations.

Lake-by-Lake Assessment
Lake Superior
Status: Fair
Trend: Undetermined
Rationale: Walleye abundance in all areas of Lake Superior, with the possible exception of the St. Louis River, is still below historical levels. Walleye in the St. Louis River (MN, WI) area and the Kaministiquia River (Thunder Bay, Ontario) contain the only healthy, self-sustaining walleye populations in Lake Superior, while other walleye populations in Black, Nipigon, Chequamegon Bay and Bad River (WI), have low populations due to habitat loss and predation issues. Rehabilitation efforts of the walleye population in Black Bay, Ontario, are ongoing, but competing fish community objectives for walleye and sea lamprey (*Petromyzon marinus*) in the Black Sturgeon River, a Black Bay tributary, complicates rehabilitation plans. Fish Community Objectives for walleye abundance and harvest are only being met in the St. Louis River. Rehabilitation strategies are developing with agencies and tribes addressing habitat loss, periodic stocking programs, and harvest control with highly-managed fisheries. Impediments to walleye rehabilitation in Lake Superior remain including: slow walleye growth, highly variable recruitment, habitat loss, variable stocking success, continued need for basin-wide long-term assessment, and predation on juvenile and adult walleye.

Lake Michigan
Status: Good
Trend: Improving
Rationale: Walleye are continuing to gain interest within the nearshore fishery. On a lake-wide basis, harvest levels have reached the target sustainable levels of 200,000 to 400,000 pounds, as outlined in the Fish Community Objectives (FCOs) for Lake Michigan, three of the last four years. The average walleye harvest (biomass) was 260,770 pounds during 2007-2010, with a high of 311,350 pounds in 2009. This includes a 25,000 pound average commercial harvest by the Tribal commercial fishers for the time period, as well as the sport-caught walleye from the four state jurisdictions. Michigan and Wisconsin sport anglers are the two main user groups contributing to the sport harvest, primarily in the northern end of the lake, Green Bay, and the Big and Little Bay De Noc areas. Most of the walleye harvested in Wisconsin were in Green Bay, where strong spawning runs occur in the Fox, Oconto, Peshtigo and Menominee rivers that have resulted in strong year classes in 2003, 2008, 2009 and 2010. For data available from 1985-2007, FCOs for Lake Michigan walleye biomass harvested

were only reached in 1994 to 1996, so recent FCO attainment in three of the last four years represents a substantial improvement.

Lake Huron

Status: Good

Trend: Improving

Rationale: Walleye production in Lake Huron declined in 2010 from the previous year, but continues to show strong trends across most fisheries. The increased walleye production is credited to greatly improved reproductive success since the collapse of alewives in Lake Huron. Gains have been most notable in the recreational fishery of Saginaw Bay, the single largest source for walleye in the lake. The Michigan DNR maintains several recovery criteria for walleye in Saginaw Bay, all of which were met or exceeded in recent years. While yield is not a sole objective, it is noted that historical levels of annual walleye harvest averaged 453.6 metric tonnes. In 2010, a study conducted by Michigan State University documented that the commercial by-catch mortality of walleye in Saginaw Bay was substantial – estimated at approximately 104 metric tonnes that year. If that value is typical of recent years, then the total yield for walleye in the bay for 2009 was 460 metric tonnes, thereby achieving the historical average yield.

Five of the last eight year classes of walleye produced in Saginaw Bay were very strong compared to those produced before the alewife collapse. The turning point was in 2003, but recent data indicates that the 2008 walleye year class is a record when measured as abundance of yearling walleye in 2009. As the walleye stock rises in Saginaw Bay, density dependent stock/recruitment mechanisms are likely now regulating the recruitment magnitude. Since 2007, year class strength appears more variable, typical of a walleye population at carrying capacity.

In Ontario waters, the commercial yield of walleye in the main basin of Lake Huron increased in 2009 and again in 2010. Yield in the main basin is the highest it has been in 15 years and is currently equal to the 30-year average. Recent increases have resulted from improved recruitment, particularly from the relatively strong 2003 and 2005 year classes. Commercial harvests have been more variable, with modest increases in the North Channel and no definite trends in Georgian Bay. Limited targeted effort for this species in these regions does not necessarily reflect the current abundance of walleye.

Recreational surveys for walleye in Ontario waters have not been conducted in recent years. Restrictive regulations governing the recreational harvest of walleye from Georgian Bay and the North Channel were instituted in 2003 primarily to aid in the recovery of depressed populations.

Independent assessment of walleye populations in all three basins of Lake Huron suggest that walleye abundance has increased in recent years. Relative abundance criteria established from standardized surveys have been above average in several locations in recent years.

Lake Erie

Status: Fair

Trend: Unchanging

Rationale: The walleye population and associated fisheries in Lake Erie are managed individually by four United States state agencies and one Canadian provincial agency. Under the auspices of the Great Lakes Fishery Commission's Lake Erie Committee, a Walleye Management Plan was implemented in 2005 and is undergoing a review process. Annual Total Allowable Catches, fishery quotas set for the west and central basins of Lake Erie, steadily declined since the recent peak in 2006, with the exception of a slight increase in 2011. The Walleye Management Plan called for the adjustment fishing rates downward as the population in the west and central basins declined. Fishery harvests, in numbers of walleye, steadily declined for sport and commercial fisheries in the west and central basins in the years that followed full recruitment of the exceptional 2003 year class (Walleye Task Group 2011). Annual sport fishing effort and catch rates for the west and central basins are generally lower compared to highs seen in the 1990s and early 2000s. A slight increase in the sport fishery catches and effort has been observed in the eastern basin. The Lake Erie Committee does not set an international annual quota in the eastern basin of the lake, but agencies' fisheries regulations have maintained relatively smaller fisheries.

Commercial effort and number of walleye harvested declined in the past five years across all basins, yet catch rates improved substantially in 2010. Lake Erie walleye fisheries have been largely dependent on the strong 2003 cohort, and more recently a moderate 2007 cohort. Mean age of walleye in the sport harvest has risen for the past three years, while the trend for mean age declined for the commercial fishery for the same time period.

Walleye biological characteristics in Lake Erie remain good, with the exception of variable recruitment in the west and central basins. Biomass of mature walleye, particularly females, is still well above the long-term mean, with a very high relative number of older females primarily from the 2003 cohort. Growth for the last several years has been good, with annual median lengths and weights for walleye ages 2-5 in assessment surveys meeting or exceeding long-term median values (Walleye Task Group, experimental sample data). The 2010 cohort was assessed to be moderate in strength as young-of-the-year and yearlings; however, other cohorts, with the exception of 2003 and 2007, are weak and have contributed little to the fishery. The high growth rate and the 2010 cohort abundance will stem the declines of walleye in the Lake Erie western and central basins in the short-term, but more consistent recruitment of stronger cohorts is needed to rebuild the walleye populations in the long-term to preferred maintenance levels. Some recovery and expansion is apparent in eastern basin walleye stocks with increased recruitment in a few of the recent years, but it is difficult to quantify because of the highly migratory nature of stocks of walleye from the western and central basins of Lake Erie.

Lake Ontario
Status: Fair
Trend: Unchanging
Rationale: The largest walleye population, fishery, and assessment focus revolves around the Bay of Quinte walleye population. This population spawns in the four major rivers and along the shoreline of the Bay of Quinte. Young walleye (less than 4 or 5 years of age) remain in the bay year-round while the mature portion of the population migrates to eastern Lake Ontario for the summer months. Annual summer gillnetting in both the Bay of Quinte and eastern Lake Ontario (Ontario and New York waters) provides excellent long-term abundance trends for juvenile and adult walleye. Catches in eastern Lake Ontario are likely comprised of both migrating Bay of Quinte adult fish as well as walleye produced in eastern Lake Ontario proper. Annual bottom trawling during August in the Bay of Quinte provides a long-term index of juvenile walleye abundance that is highly correlated with gillnet catches at older ages.

Following declines in juvenile and adult walleye abundance in the 1990s, associated with reduced production in the mid-1990s, the walleye population appears to have stabilized or increased slightly in the Bay of Quinte and in NY and Ontario waters of the eastern basin. Walleye performance targets, identified in the Bay of Quinte Fisheries Management Plan (2010) and based on a post-dreissenid time-period (2002-2006), are currently being met or exceeded. Recent hatches should keep the population at current or somewhat improved levels of abundance for the next several years. Smaller, local walleye populations exist in other areas of Lake Ontario, both open-coastal and embayments. Some areas support small but healthy and self-sustaining populations (e.g., Wellers Bay, West Lake) while other areas with degraded habitat require rehabilitation efforts (e.g., Hamilton Harbour); however, these areas receive much less walleye population assessment.

Other Spatial Scales

Huron-Erie Corridor (St. Clair River-Lake St. Clair-Detroit River)

Status: Fair

Trend: Unchanging

Rationale: Walleye harvest in Lake St. Clair is down from the early 2000s and the 1980s. Catch rates for walleye anglers in Lake St. Clair have also decreased. Angler catch rates for walleye in 2009 were the lowest on record in Lake St. Clair (0.151 walleye per rod hour, from 2009 creel survey in the Ontario waters of Lake St. Clair); however, catch rates in the Detroit River remained high. Walleye harvest in the Detroit River is similar to the early 2000s and early 1990s, and catch rates in this area remain good. Over time, angler effort in Lake St. Clair has shifted away from walleye towards other Huron-Erie Corridor species (i.e., muskie and smallmouth bass); however, walleye remains an important part of the recreational fishery. This fishery has been evaluated on an inconsistent basis and no continuous fishery data are available to incorporate estimates into our metric ton yield figure. There exists the potential for sizable harvest in the Huron-Erie Corridor. This harvest cannot be overlooked in the scale of Great Lakes walleye fisheries and production, and should be included in the indicator description.

The mean weight of walleye harvested from Lake St. Clair is 1.4 kg (from 2009 creel survey in the Ontario waters of Lake St. Clair). Growth rate of walleye in the Ontario fall trap net survey has increased each decade since the survey began. The highest growth rate of walleye occurred from 2007-2009 (this time period also had very low catch rates). Recent recruitment of walleye in Lake St. Clair has been poor. The last year-class of even moderate strength that was produced in Lake St. Clair was in 1986. Since then, very few age-1 walleye have been caught in the Ontario fall trap net survey.

Purpose

- To show the status and trends in walleye populations in various Great Lakes habitats.
- To infer the status of cool water predator communities.
- To infer ecosystem health, particularly in moderately-productive (mesotrophic) areas of the Great Lakes.
- The Walleye Indicator is used in the Great Lakes Indicators Suite as a state indicator in the Aquatic-dependent Life top-level reporting category.

Ecosystem Objective

Protection, enhancement and restoration of historically important, mesotrophic habitats that support natural stocks of walleye as the top fish predator. These habitats are necessary for stable, balanced, and productive elements in the Great Lakes ecosystem.

Ecological Condition

See information above under the Lake-by-Lake Assessment section of this report.

Linkages

The walleye indicator is linked to the following Great Lakes (SOLEC) indicators: toxic chemicals in offshore waters, nutrients in lakes, aquatic non-native species, and fish habitat.

Management Challenges/Opportunities

To improve the health of Great Lakes walleye populations, managers must enhance walleye reproduction, growth and survival rates, while making good management decisions about safe, sustainable harvest levels. Most walleye populations are dependent on natural reproduction, which is largely driven by uncontrollable environmental events (i.e., winter and spring weather patterns, water clarity, and alewife abundance). However, a lack of suitable spawning and nursery habitat is limiting walleye reproduction in some areas due to human activities and can be remedied through such actions as dam removal, substrate enhancement or improvements to watersheds to reduce siltation and restore natural flow conditions.

Growth rates are dependent on weather (i.e., water temperatures), quality of the prey base, and walleye density - most of which are not directly manageable. Survival rates can be altered through fishery harvest strategies, which are generally conservative across all of the Great Lakes. Continued interactions between land managers and fisheries managers to protect and restore natural habitat conditions in mesotrophic areas of the Great Lakes and in spawning and juvenile walleye habitats are essential for the long term health of walleye populations. Elimination of additional introductions of new non-native invasive species and control of existing non-native nuisance species, where possible, is also critical to future health of the walleye population and other native species.

Fisheries management and public expectations will need to respond to continuing ecosystem changes. Minnesota Department of Natural Resources personnel have developed a Fisheries Management Plan for their waters of Lake Superior. They have identified key areas in the St. Louis River estuary and the Pigeon River system that are important to Lake Superior watershed walleye populations. Most, if not all, agencies have developed or are revising strategic plans for the long-term health of the walleye populations. The Great Lakes Fishery Commission's Lake Erie Committee is in the process of revising their Walleye Management Plan with the assistance of stakeholders and academia at the Michigan State University Quantitative Fishery Center. This process allows managers and stakeholders to determine desired fishery objectives and a specific harvest policy with thresholds and an appropriate harvest rate based on population abundance. Improving long-term data collection and management scenarios will be important to allow managers to understand changes to the walleye populations and fisheries in the Great Lakes.

Comments from the Author

The historical dominance of walleye in mesotrophic habitats in the Great Lakes provides a good basis for a basin-wide evaluation of ecosystem health. Maintaining or re-establishing historical levels of relative abundance, biomass, or production of self-sustaining walleye populations throughout their native range in the Great Lakes basin will help ensure dominance of this species in the ecosystem and the maintenance of a desirable and balanced aquatic community in cool water, mesotrophic habitats. Historical data can be used to develop status and trend information on walleye populations. Commercial catch records for walleye in the Great Lakes extend back to the late 1800s; recreational catch data and assessment fishing data supplement these commercial catch records in some areas in recent decades and sport fishing data are especially useful in areas where the commercial fishery for the species has been closed.

Fishery yields are appropriate indicators of walleye health but only in a general sense. Fishery assessments are lacking for some fisheries (recreational, commercial, or tribal) in some years for all of the studied areas. Moreover, measurement units are not standardized among fishery types (i.e., commercial fisheries are measured by mass while recreational fisheries are typically measured in numbers of fish), which means additional conversions are necessary which reduce accuracy. Also, "zero" values need to be differentiated from "missing" data in any figures. Therefore, trends in fishery yields across time (blocks of years) are probably better indicators than absolute values within any year, assuming that any introduced bias is relatively constant over time. Given the above, a 10-year reporting cycle on this indicator is recommended. Many agencies have developed, or are developing, population estimates for many Great Lakes fishes. Walleye population estimates for selected areas (i.e., Lake Erie's western and central basins, Saginaw Bay, Green Bay, and Bay of Quinte) would probably be a better assessment of walleye population health in the Great Lakes than harvest estimates across all lakes, and switching to them as they become available in all areas is recommended.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		LE, LH, LM, LO, HEC	LS			
2. Data are traceable to original sources	LE	LH, LM, LO, HEC	LS			
3. The source of the data is a known, reliable and respected generator of data	LE	LM, LO, HEC	LH, LS			
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		LE, LM, LO	LH, LS, HEC			
5. Data obtained from sources within the U.S. are comparable to those from Canada		LE, LM, HEC	LO, LS	LH		
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	LE	LM, LO	LH, LS, HEC			

Clarifying Notes: There is room for improvement. Much of our data is not in yield form (pounds or kilos) and had to be converted. All elements of the harvest are not evaluated on a consistent basis. Knowledge of the population status is based on regular assessment surveys which may be more reliable or are associated with a greater degree of confidence by biologists and managers.

Acknowledgments
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Lake Ontario: Jana Lantry, New York Department of Environmental Conservation, jrlantry@gw.dec.state.ny.us
Lake Superior/Michigan/Huron: Karen Wright, Chippewa Ottawa Resource Authority, kwright@sault.com

Information Sources
Fishery harvest data and management information were obtained from the following sources:
Lake Superior: Ken Cullis, Ontario Ministry of Natural Resources (OMNR), ken.cullis@ontario.ca

Lake Superior/Michigan/Huron: Karen Wright, Chippewa Ottawa Resource Authority, kwright@sault.com
Lake Michigan: David Rowe, Wisconsin Department of Natural Resources, david.rowe@wisconsin.gov
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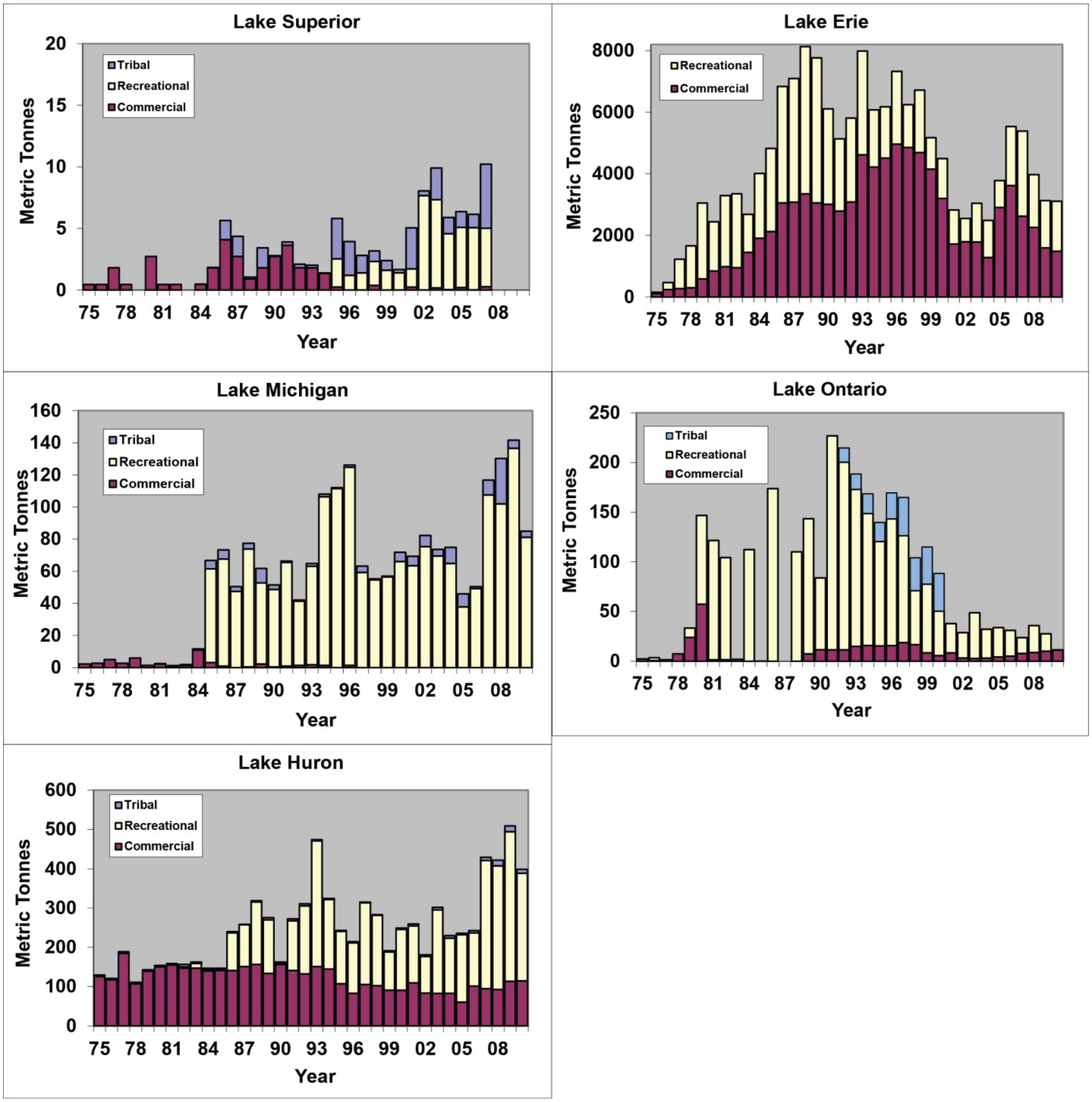
Lake Ontario: Jim Hoyle, OMNR, jim.hoyle@ontario.ca
Lake Ontario: Jana Lantry, New York Department of Environmental Conservation, jrlantry@gw.dec.state.ny.us

List of Figures

Figure 1. Walleye harvest, reported in metric tonnes, split into contributions from tribal, recreational and commercial fisheries in the five Great Lakes, 1975 – 2010. Fish Community Goals and Objectives are: Lake Michigan, 100-200 metric tonnes; Lake Huron, 700 metric tonnes; Lake Erie, sustainable harvest in all basins; Lake Ontario, maintain early 1990s populations and expand populations into favorable habitats.
Source: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, Minnesota Department of Natural Resources. New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources, Pennsylvania Fish and Boat Commission, Wisconsin Department of Natural Resources.

Last Updated

State of the Great Lakes 2011



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Source: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, Minnesota Department of Natural Resources. New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources, Pennsylvania Fish and Boat Commission, Wisconsin Department of Natural Resources.

Water Chemistry

Overall Assessment
Trend: Not Assessed/Undetermined
Rationale: Impractical to assess these parameters basin wide. The composition of each lake is unique to that lake.

Lake-by-Lake Assessment
Lake Superior
Specific Conductance
Trend: Increasing
Rationale: Spring lake-wide median values from 1992 through 2008 exhibited a statistically significant ($P<0.05$, $\rho=0.57$) positive Spearman's Rank Correlation. The median rate of change was 0.10 µmhos·cm^{-1}·yr^{-1}.

Total Chloride
Trend: No Change
Rationale: Spring lake-wide median values from 1992 through 2008 did not exhibit a statistically significant ($P>0.05$, $\rho=-0.10$) negative Spearman's Rank Correlation.

pH
Trend: No Change
Rationale: Spring lake-wide median values from 1992 through 2008 did not exhibit a statistically significant ($P>0.05$, $\rho=0.13$) positive Spearman's Rank Correlation.

Total Alkalinity
Trend: No Change
Rationale: Spring lake-wide median values from 1992 through 2008 did not exhibit a statistically significant ($P>0.05$, $\rho=0.43$) positive Spearman's Rank Correlation.

Turbidity
Trend: Increasing
Rationale: Spring lake-wide median values from 1992 through 2008 exhibited a statistically significant ($P<0.001$, $\rho=0.76$) positive Spearman's Rank Correlation. The median rate of change was 0.013 NTU·yr^{-1}.

Lake Michigan
Specific Conductance
Trend: Increasing
Rationale: Spring lake-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.0001$, $\rho=0.85$) positive Spearman's Rank Correlation. The median rate of change was of 0.67 µmhos·$cm^{-1}yr^{-1}$

Total Chloride
Trend: Increasing
Rationale: Spring lake-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.0001$, $\rho=0.99$) positive Spearman's Rank Correlation. The median rate of change was 0.14 mg Cl·yr^{-1}.

pH
Trend: No Change
Rationale: Spring lake-wide median values from 1983 through 2008 did not exhibit a statistically significant

(P>0.05, ρ =0.02) positive Spearman's Rank Correlation.

Total Alkalinity
Trend: Decreasing
Rationale: Spring lake-wide median values from 1983 through 2008 exhibited a statistically significant (P<0.01, ρ =-0.46) negative Spearman's Rank Correlation. The median rate of change was -0.065 mg $CaCO_3 \cdot yr^{-1}$.

Turbidity
Trend: No Change
Rationale: Spring lake-wide median values from 1983 through 2008 did not exhibit a statistically significant (P>0.05, ρ =-0.27) negative Spearman's Rank Correlation.

Lake Huron
Specific Conductance
Trend: Increasing
Rationale: Spring lake-wide median values from 1983 through 2008 exhibited a statistically significant (P<0.001, ρ =0.66) positive Spearman's Rank Correlation. The median rate of change was 0.28 $\mu mhos \cdot cm^{-1} \cdot yr^{-1}$.

Total Chloride
Trend: Increasing
Rationale: Spring lake-wide median values from 1983 through 2008 exhibited a statistically significant (P<0.0001, ρ =0.94) positive Spearman's Rank Correlation. The median rate of change was 0.064 mg $Cl \cdot yr^{-1}$.

pH
Trend: No Change
Rationale: Spring lake-wide median values from 1983 through 2008 did not exhibit a statistically significant (P>0.05, ρ =0.33) positive Spearman's Rank Correlation.

Total Alkalinity
Trend: No Change
Rationale: Spring lake-wide median values from 1983 through 2008 did not exhibit a statistically significant (P>0.05, ρ =-0.05) negative Spearman's Rank Correlation.

Turbidity
Trend: Decreasing at a median rate of -0.0088 $NTU \cdot yr^{-1}$.
Rationale: Spring lake-wide median values from 1983 through 2008 exhibited a statistically significant (P<0.001, ρ =-0.67) negative Spearman's Rank Correlation. The median rate of change was -0.0088 $NTU \cdot yr^{-1}$.

Lake Erie
Trend: Not Assessed
Rationale: Spring lake-wide median values from 1983 through 2008 are not assessed for Lake Erie as a whole lake, but rather by the three bathymetrically determined basins.

Lake Ontario
Specific Conductance
Trend: Decreasing at a median rate of -0.72 $\mu mhos \cdot cm^{-1} \cdot yr^{-1}$.
Rationale: Spring lake-wide median values from 1986 through 2008 exhibited a statistically significant (P<0.001, ρ =-0.68) negative Spearman's Rank Correlation. The median rate of change was -0.72 $\mu mhos \cdot cm^{-1} yr^{-1}$.

Total Chloride

Trend: No Change

Rationale: Spring lake-wide median values from 1986 through 2008 did not exhibit a statistically significant ($P>0.05$, ρ =-0.20) negative Spearman's Rank Correlation.

pH

Trend: No Change

Rationale: Spring lake-wide median values from 1986 through 2008 did not exhibit a statistically significant ($P>0.05$, ρ =0.27) positive Spearman's Rank Correlation.

Total Alkalinity

Trend: Decreasing

Rationale: Spring lake-wide median values from 1986 through 2008 exhibited a statistically significant ($P<0.001$, ρ =-0.83) negative Spearman's Rank Correlation. The median rate of change was -0.40 mg $CaCO_3 \cdot yr^{-1}$.

Turbidity

Trend: Decreasing

Rationale: Spring lake-wide median values from 1986 through 2008 exhibited a statistically significant ($P<0.05$, ρ =-0.51) negative Spearman's Rank Correlation. The median rate of change was -0.0075 $NTU \cdot yr^{-1}$.

Other Spatial Scales

Lake Erie Western Basin

Specific Conductance

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, ρ =0.30) positive Spearman's Rank Correlation.

Total Chloride

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, ρ =0.33) positive Spearman's Rank Correlation.

pH

Trend: Decreasing at a median rate of -0.0045 pH units $\cdot yr^{-1}$.

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.05$, ρ =-0.36) negative Spearman's Rank Correlation. The median rate of change was -0.0045 pH units $\cdot yr^{-1}$.

Total Alkilinity

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, ρ =-0.21) negative Spearman's Rank Correlation.

Turbidity

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, ρ =0.25) positive Spearman's Rank Correlation.

Lake Erie Central Basin

Spoecific Conductance

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, $\rho = 0.29$) positive Spearman's Rank Correlation.

Total Chloride

Trend: Increasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.0001$, $\rho = 0.72$) positive Spearman's Rank Correlation. The median rate of change was of 0.095 mg $Cl \cdot yr^{-1}$.

pH

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, $\rho = 0.24$) positive Spearman's Rank Correlation.

Total Alkilinity

Trend: Decreasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.05$, $\rho = -0.51$) negative Spearman's Rank Correlation. The median rate of change was -0.12 mg $CaCO_3 \cdot yr^{-1}$.

Turbidity

Trend: Increasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.01$, $\rho = 0.52$) positive Spearman's Rank Correlation. The median rate of change was 0.072 $NTU \cdot yr^{-1}$.

Lake Erie Eastern Basin

Specific Conductance

Trend: No Change

Rationale: Spring basin-wide median values from 1983 through 2008 did not exhibit a statistically significant ($P>0.05$, $\rho = 0.04$) positive Spearman's Rank Correlation.

Total Chloride

Trend: Increasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.0001$, $\rho = 0.71$) positive Spearman's Rank Correlation. The median rate of change was 0.12 mg $Cl \cdot yr^{-1}$.

pH

Trend: Increasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.05$, $\rho = 0.48$) positive Spearman's Rank Correlation. The median rate of change was 0.005 pH units $\cdot yr^{-1}$.

Total Alkilinity

Trend: Decreasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.01$, $\rho = -0.54$) negative Spearman's Rank Correlation. The median rate of change was -0.24 mg $CaCO_3 \cdot yr^{-1}$.

Turbidity

Trend: Decreasing

Rationale: Spring basin-wide median values from 1983 through 2008 exhibited a statistically significant ($P<0.001$, $\rho = -0.62$) negative Spearman's Rank Correlation. The median rate of change was 0.072 $NTU \cdot yr^{-1}$.

Purpose

- Monitor the water quality of the Great Lakes
- To assess water quality in the Great Lakes
- To support the evaluation of long term trends and changes in the water quality of the Great Lakes

Ecosystem Objective

The ecosystem objective is to monitor changes in the water quality of the Great Lakes.

Ecological Condition

Measure

To assess the long-term trends in water quality in the open waters of the Great Lakes, offshore Spring sampling stations are averaged over the entire depth of the water column.

Status

The water quality in the Great Lakes is monitored by the Canadian and United States federal governments. Both Environment Canada (EC) and the United States Environmental Protection Agency (USEPA) Great Lakes National Program Office (GLNPO) conduct ship-based cruises to collect water quality samples on the lakes. Methods for EC's Great Lakes Surveillance Program are described in Dove et al. (2009). Sampling and analytical procedures for GLNPO's Open Lake Water Quality Surveys is provided in GLNPO (2010). Briefly, EC conducts monitoring in each of the Great Lakes except Lake Michigan, which is located entirely within the United States. Each lake is generally monitored every second year, with several cruises conducted during that year. All regions (nearshore, offshore, and major embayments) are monitored for the EC program. USEPA conducts one spring and one summer cruise on all waters except Georgian Bay, with stations located more along the central axis of each lake. Here, we provide an update with respect to long-term trends in specific conductance, total chloride, pH, alkalinity and turbidity in each of the Great Lakes.

For the purpose of presenting long-term trends in this report only GLNPO data set were analyzed. The data are restricted to spring sampling periods at offshore locations when and where the water column is well mixed, with the exception of Lake Erie, which is relatively shallow and is therefore divided instead into three basins. The period analyzed for long-term trends was from 1983 through 2008 for Lake Michigan, Lake Huron and Lake Erie. Lake Ontario was monitored from 1986 through 2008 and Lake Superior began in 1992. The analyte values are averaged for each offshore location over the entire water column. The annual lake-wide and basin-wide median values were determined by calculating the median value of the station averages for each lake and basin over the period monitored.

The presentation of data is on a lake-by-lake basis, except Lake Erie, which is divided into three basins. The statistical analyses used to determine long-term trends in the data are, for the most part, non-parametric, or distribution-free statistical methods used to avoid transformations of the data, which would vary among lakes and parameters.

There are two non-parametric methods used to determine the existence, magnitude and significance of trends in the data by lake and by parameter. These are Spearman Rank Correlation (Siegel 1956) and the Sen (or Thiel-Sen) regression estimator (Sen 1968).

The ordering and ranking of the values allows the Spearman rank correlation coefficient to be equivalent to the Pearson product moment coefficient (Sen, 1968). It is not sensitive to the distribution of the data, or to very high or low values that bias the parametric alternative. The strength of the Spearman rank correlation determines the reported statistical significance of all long-term trends. The calculation of the Spearman rank correlation coefficients used the annual lake-wide and basin-wide medians to minimize Type I errors.

The Sen Regression estimator calculates the slopes of regression lines, where significant correlations exist. The Sen technique determines the median rate of change (slope) by choosing m to be the median among the n(n-1)/2 slopes of lines determined by pairs of data points. By using the Sen regression estimator (m) along with the median y (analyte) and x (year) values to determine b (y-intercept) the Kendall-Theil Robust Line (KTRLine) is determined (USGS, 2006). All slopes or rates of change reported in this report are Sen Slopes.

The results of offshore water quality values are shown in Figures 1-5 for the upper Great Lakes (lakes Superior, Huron and Michigan) and Figures 6-10 for the lower Great Lakes (lakes Erie and Ontario). The Graphical data presentation of the station averages are in the form of box plots. The box plots (also called box-and-whisker plots) are an easy way to summarize data and to assess and compare sample distributions. The top of the box is the third quartile (Q3), where 75% of the data values are less than or equal to this value. The line inside the box is the median (half of the observations are less than or equal to the median). The bottom of the box is the first quartile (Q1), where 25% of the data values are less than or equal to this value. The upper whisker extends to the highest data value within the upper limit, defined as Q3 + 1.5 (Q3–Q1). Similarly, the lower whisker extends to the lower limit of Q1 – 1.5 (Q3–Q1). Values that appear as asterisks on the plots are outside the upper or lower limits and considered outliers. The plotting of the KTRLine in the box plots occurs when a statistically significant correlation exists.

Lake Superior

The specific conductance in the open waters of Lake Superior has increased significantly ($P<0.05$, $\rho=0.57$) at a rate of 0.10 $\mu mhos \cdot cm^{-1} \cdot yr^{-1}$. The lowest lake-wide median of 97 $\mu mhos \cdot cm^{-1}$ occurred in 1992 with the highest lake-wide median of 100 $\mu mhos \cdot cm^{-1}$ occurred in 2002. However, a review of the quality assurance data for specific conductance indicates that the trend may be a result of systematic instrument error (LIMNO). The turbidity has increased significantly ($P<0.001$, $\rho=0.76$) at a rate of 0.013 $FTU \cdot yr^{-1}$. Turbidity values decreased from 1992 to 1996 followed by increases from 1997 to 2008 with minor inter-annual fluctuations. There were no significant trends in the total chloride, pH and alkalinity in the open waters of Lake Superior. The average annual lake-wide median chloride concentration, pH and alkalinity were 1.3 mg $Cl \cdot L^{-1}$, 7.81 and 41.6 mg $CaCO_3 \cdot L^{-1}$ respectively.

Lake Michigan

The specific conductance in the open waters of Lake Michigan has increased significantly ($P<0.0001$, $\rho=0.85$) at a rate of 0.67 $\mu mhos \cdot cm^{-1} \cdot yr^{-1}$. The lowest lake-wide median of 279 $\mu mhos \cdot cm^{-1}$ occurred in 1983 with the highest lake-wide median of 296 $\mu mhos \cdot cm^{-1}$ occurred in 2004. Specific conductance values increased consistently from 1983 to 2004 followed by a decrease from 2005 through 2008 with an increase overall. Total chloride has increased ($P<0.0001$, $\rho=0.99$) at a rate of 0.14 mg $Cl \cdot L^{-1} \cdot yr^{-1}$. The lowest lake-wide median of 8.7 mg $Cl \cdot L^{-1}$ occurred in 1983 with the highest lake-wide median of 11.8 mg $Cl \cdot L^{-1}$ occurred in 2007. Chloride concentrations were stable from 1983 to 1987 followed by a steady increase from 1998 to 2008. Total Alkalinity has decreased significantly ($P<0.01$, $\rho=-0.46$) at a rate of -0.065 mg $CaCO_3 \cdot L^{-1} \cdot yr^{-1}$. The lowest lake-wide median of 105 mg $CaCO_3 \cdot L^{-1}$ occurred in 1999 with the highest lake-wide median of 112 mg $Cl \cdot L^{-1}$ occurred in 1989. Alkalinity values fluctuated inter-annually over 2-3 year periods of increases and decreases with an overall decrease. There were no significant trends in the pH and turbidity in the open waters of Lake Michigan. The average annual lake-wide median pH and total alkalinity were 8.01 and 77.9 mg $CaCO_3 \cdot L^{-1}$ respectively.

Lake Huron

The specific conductance in the open waters of Lake Huron has increased significantly ($P<0.001$, $\rho=0.66$) at a rate of 0.28 $\mu mhos \cdot cm^{-1} \cdot yr^{-1}$. The lowest lake-wide median of 203 $\mu mhos \cdot cm^{-1}$ occurred in 1985 with the highest lake-wide median of 213 μmhos·cm^{-1} occurred in 2002. Specific conductance values increased from 1985 to 1993 and 1998 to 2002 followed by decreases from 2002 and inter-annual fluctuations through 2008. Total chloride has increased ($P<0.0001$, ρ =0.94) at a rate of 0.064 mg Cl·L^{-1}·yr^{-1}. The lowest lake-wide median of 5.4 mg Cl·L^{-1} occurred in 1985 with the highest lake-wide median of 7.0 mg Cl·L^{-1} occurred in 2007. Chloride concentrations, unlike specific conductance, continually increased from 1988 to 2008. Turbidity has decreased significantly ($P<0.001$, ρ =-0.67) at a rate of -0.0088 FTU·yr^{-1}. The lowest lake-wide median of 0.25 FTU occurred in 2005 with the highest lake-wide median of 0.62 FTU occurred in 1983. Turbidity values decreased overall with inter-annual fluctuations over 3-5 year periods from 1983 to 2005. After 2005, the turbidity values were relatively stable and low. There were no significant trends in the pH and total alkalinity in the open waters of Lake Huron. The average annual lake-wide median pH and turbidity were 8.12 and 0.4 FTU respectively.

Lake Ontario

The specific conductance in the open waters of Lake Ontario has decreased significantly ($P<0.001$, ρ =-0.68) at a rate of -0.72 μmhos·cm^{-1}·yr^{-1}. The lowest lake-wide median of 297 μmhos·cm^{-1} occurred in 2003 with the highest lake-wide median of 320 μmhos·cm^{-1} occurred in 1986. Specific conductance declined from 1986 to 1999, followed by increases from 1999 to 2005 and reached a plateau with an average of 308 μmhos·cm^{-1} for the remainder of the monitored period. Total alkalinity has decreased ($P<0.0001$, ρ =-0.83) at a rate of -0.40 mg $CaCO_3$·L^{-1}·yr^{-1}. The lowest lake-wide median of 88.2 mg $CaCO_3$·L^{-1} occurred in 2003 with the highest lake-wide median of 97.0 mg $CaCO_3$·L^{-1} occurred in 1990. Total alkalinity values were stable from 1986 to 1990 followed by a steady decline through 2002. From 2003 through 2007, the alkalinity increased followed by a decline in the median value in 2008. Turbidity has decreased significantly ($P<0.05$, ρ =-0.51) at a rate of -0.0075 FTU·yr^{-1}. The lowest lake-wide median of 0.09 FTU occurred in 2002 with the highest lake-wide median of 0.55 FTU occurred in 1990. Turbidity values increased from 1986 to 1990 followed by a decrease from 1990 to 1999. Turbidity increased in 2000 and 2001 followed by a stabilized period from 2003 to 2008 with a median of 0.25 FTU. There were no significant trends in the total chloride and pH in the open waters of Lake Ontario. The average annual lake-wide median total chloride and pH were 22 mg Cl·L^{-1} and 8.06 respectively.

Western Basin Lake Erie

The pH in the western basin of Lake Erie has decreased significantly ($P<0.05$, ρ =-0.36) at a rate of -0.005 pH units·yr^{-1}. The lowest basin-wide median of 7.75 occurred in 2007 with the highest basin-wide median of 8.25 occurred in 1986. Annual pH values fluctuated from year to year with an overall decrease. There were no significant trends in the specific conductance, total chloride, alkalinity and turbidity in the western basin of Lake Erie. The average annual basin-wide median specific conductance, total chloride, total alkalinity and turbidity were 260 μmhos·cm^{-1}, 14.2 mg Cl·L^{-1}, 86.6 mg $CaCO_3$·L^{-1} and 9.74 FTU respectively.

Central Basin Lake Erie

The total chloride in the central basin of Lake Erie has increased significantly ($P<0.0001$, ρ =0.72) at a rate of 0.095 mg Cl·L^{-1}·yr^{-1}. The lowest basin-wide median of 14.1 mg Cl·L^{-1} occurred in 1988 with the highest basin-wide median of 17.9 mg Cl·L^{-1} occurred in 2006. Chloride concentrations decreased from 1983 to 1988 followed by a plateau from 1989 to 1998 after which values increased from 1997 through 2006. Total alkalinity has decreased significantly ($P<0.01$, ρ =-0.51) at a rate of -0.12 mg $CaCO_3$·L^{-1}·yr^{-1}. The lowest basin-wide median of 85.7 mg $CaCO_3$·L^{-1} occurred in 1998 with the highest basin-wide median of 96.3 mg $CaCO_3$·L^{-1} occurred in 1986. There were two distinct periods of change in the alkalinity. The first was a period of decline from 1985 to 1996. The second was an increasing period from 1996 to 2008 with the last four years stabilizing at 91.2 mg $CaCO_3$·L^{-1}. The overall trend analysis masks the later increasing period occurring from 1996 to 2004. Turbidity has increased significantly ($P<0.01$, ρ =0.52) at a rate of 0.072 FTU·yr^{-1}. The lowest basin-wide median of 0.78 FTU occurred in 1986 with the highest basin-wide median of 7.82 FTU occurred in 2002. There were no observable patterns in the data; the turbidity of the central basin fluctuated from year to year with the highest annual variability observed in

2002, 2003 and 2007. There were no significant trends in the specific conductance and pH in the central basin of Lake Erie. The average annual basin-wide median specific conductance and turbidity were 276 μmhos·cm^{-1} and 2.08 FTU respectively.

Eastern Basin Lake Erie
The total chloride in the eastern basin of Lake Erie has increased significantly ($P<0.0001$, $\rho=0.71$) at a rate of 0.12 mg Cl·L^{-1}·yr^{-1}. The lowest basin-wide median of 14.5 mg Cl·L^{-1} occurred in 1988 with the highest basin-wide median of 18.4 mg Cl·L^{-1} occurred in 2006. Chloride concentrations were stable form 1984 to 1996. Concentrations steadily increased from 1996 to 2007, and then decreased in 2008. The pH has increased significantly ($P<0.05$,

$\rho=0.48$) at a rate of 0.005 pH units·yr^{-1}. The lowest basin-wide median of 7.91 occurred in 1988 with the highest lake-wide median of 8.35 occurred in 2000. The pH fluctuated over a 3-5 year cycle of increasing and decreasing values form 1983 to 2002. After 2002, pH values remained stable with minimal inter-annual variations. Total alkalinity has decreased significantly ($P<0.01$, $\rho=-0.54$) at a rate of -0.24 mg $CaCO_3$·L^{-1}·yr^{-1}. The lowest basin-wide median of 85.3 mg $CaCO_3$·L^{-1} occurred in 1996 with the highest basin-wide median of 97.0 mg $CaCO_3$·L^{-1} occurred in 1983 Alkalinity values were stable from 1983 to 1990, after which the values declined until 1996. Values gradually increased until 2003, after which values remained relatively stable through 2008. Turbidity has decreased significantly ($P<0.001$, $\rho=-0.62$) at a rate of -0.074 FTU·yr^{-1}. The lowest basin-wide median of 0.20 FTU occurred in 2000 with the highest basin-wide median of 3.29 FTU occurred in 1984. Turbidity steadily declined from 1983 to 2000 and exhibited inter-annual variability. After 2000, turbidity values increased slightly and remained stable through 20008, with 2007 exhibiting the greatest annual variation in values. There were no significant trends in the specific conductance in the eastern basin of Lake Erie. The average annual basin-wide median specific conductance was 279 μmhos·cm^{-1}.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada			X			
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

Clarifying Notes:
Only USEPA GLNPO Spring Water Quality Survey Data Was used in determining these trends.

Acknowledgments
Authors: Eric Osantowski, Chemist, Great Lakes National Program Office, USEPA.

Information Sources
United States data from Great Lakes National Program Office, United States Environmental Protection Agency, Chicago, Illinois.

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Last Updated

State of the Lakes Ecosystem Conference (SOLEC) 2011

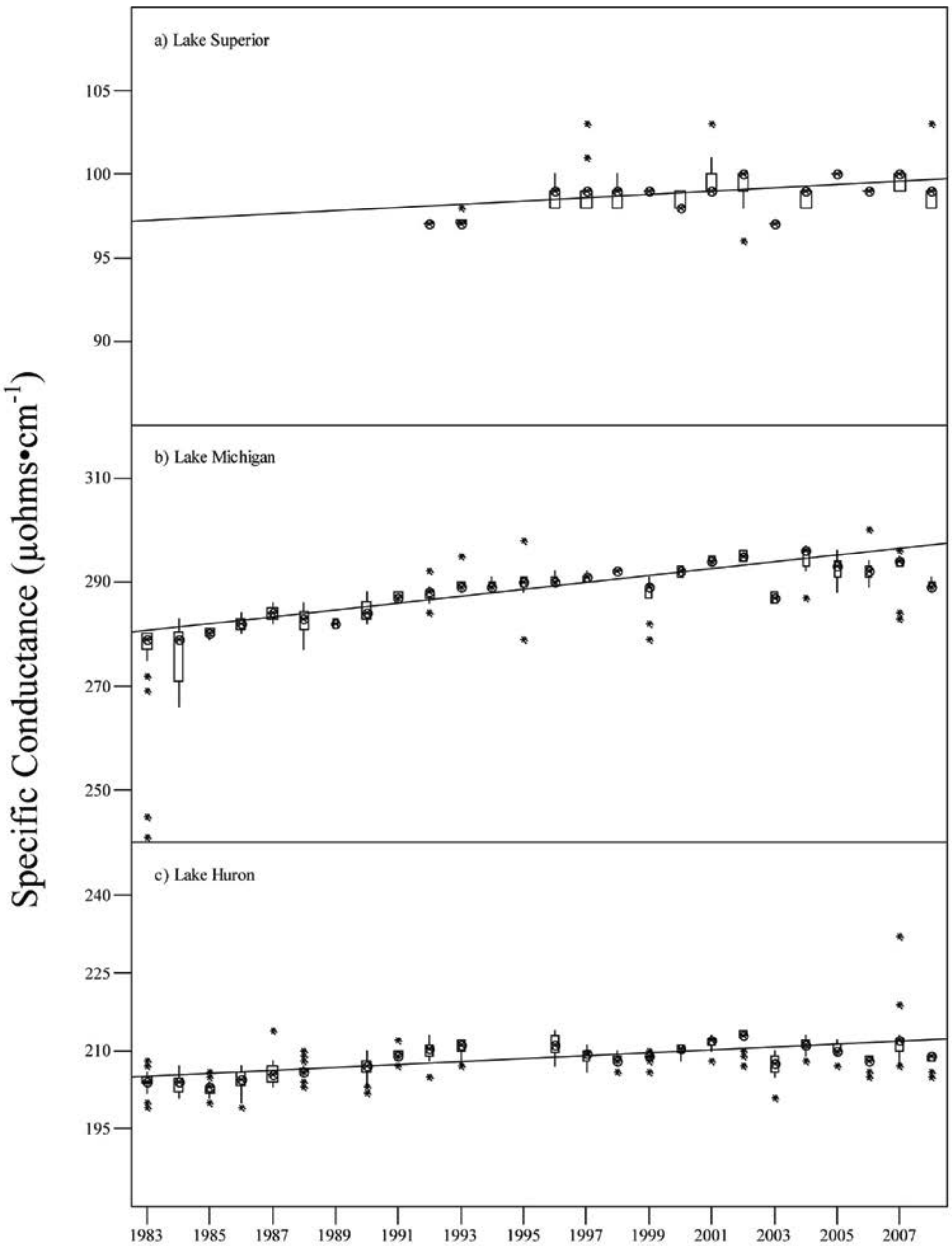

Figure 1. Long-term Trend of Specific Conductance in the Upper Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

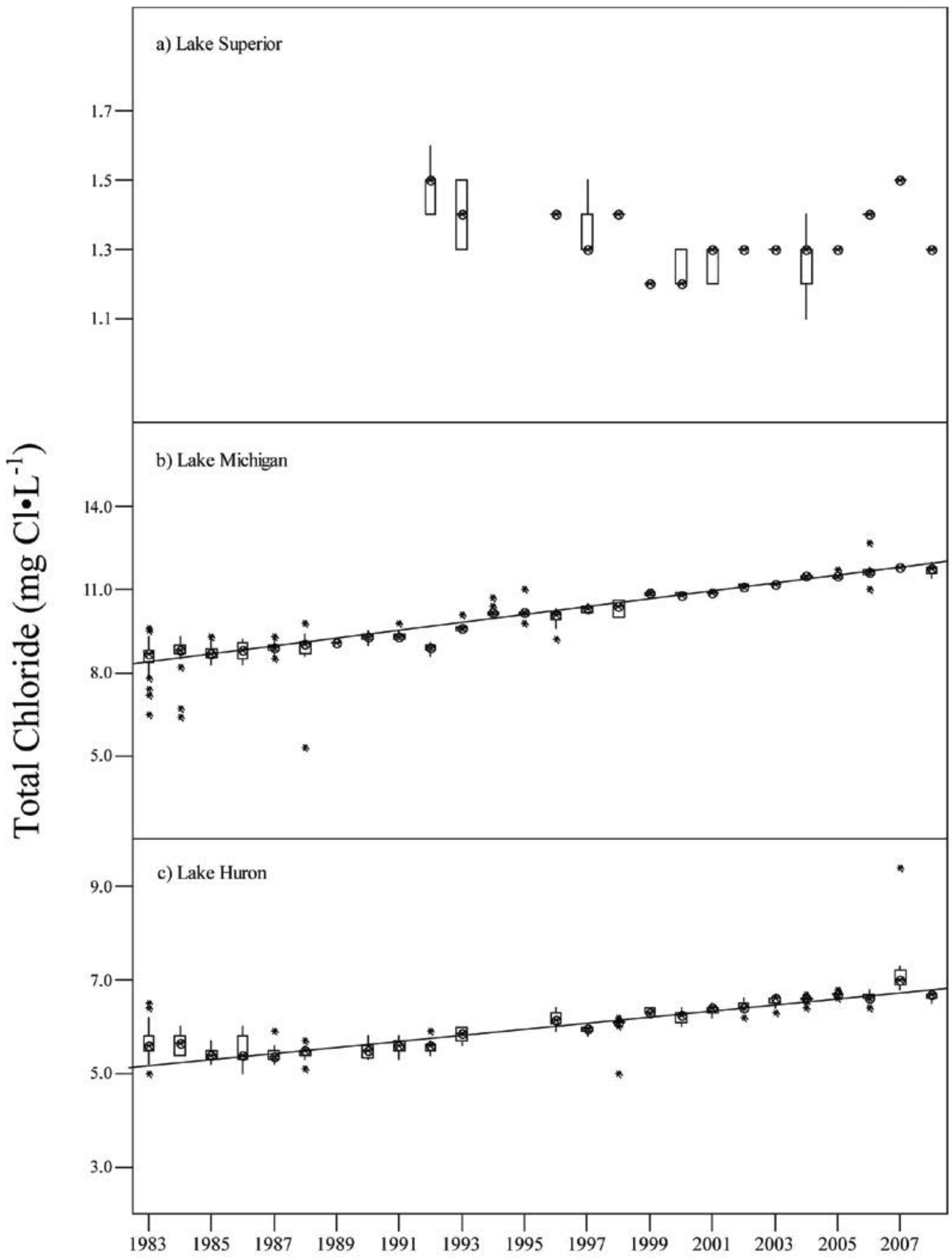

Figure 2. Long-term Trend of Total Chloride in the Upper Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

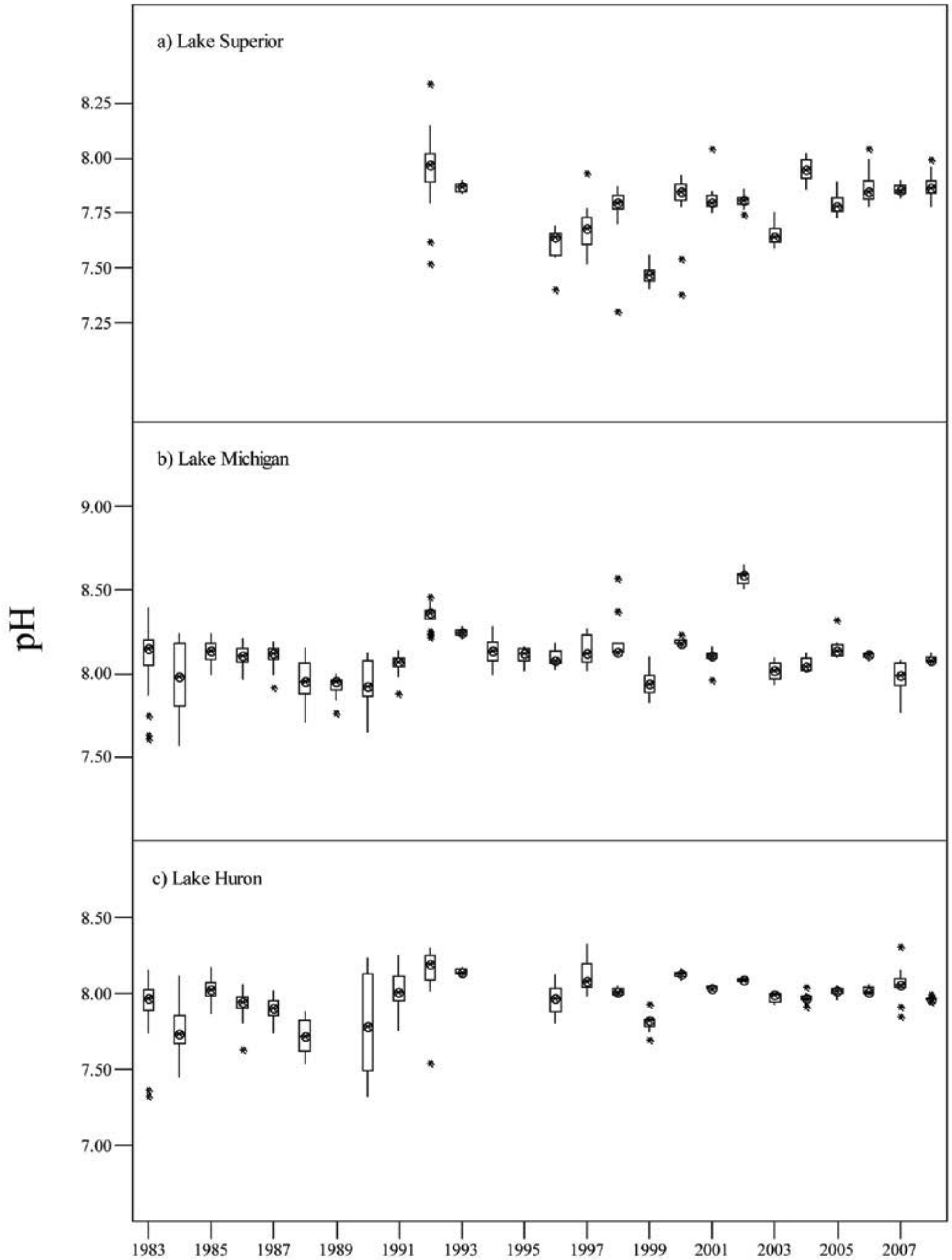

Figure 3. Long-term Trend of pH in the Upper Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

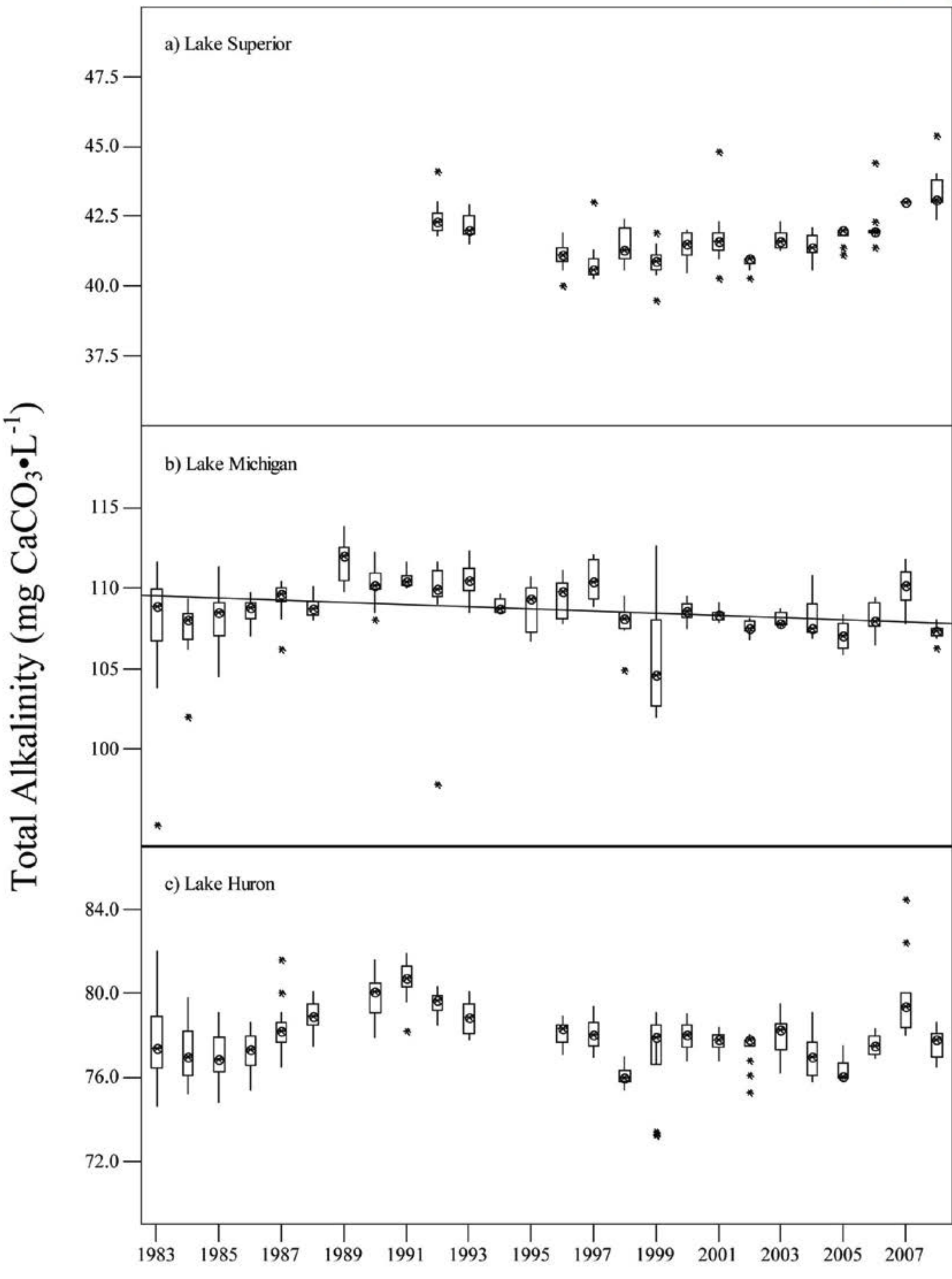

Figure 4. Long-term Trend of Total Alkalinity in the Upper Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

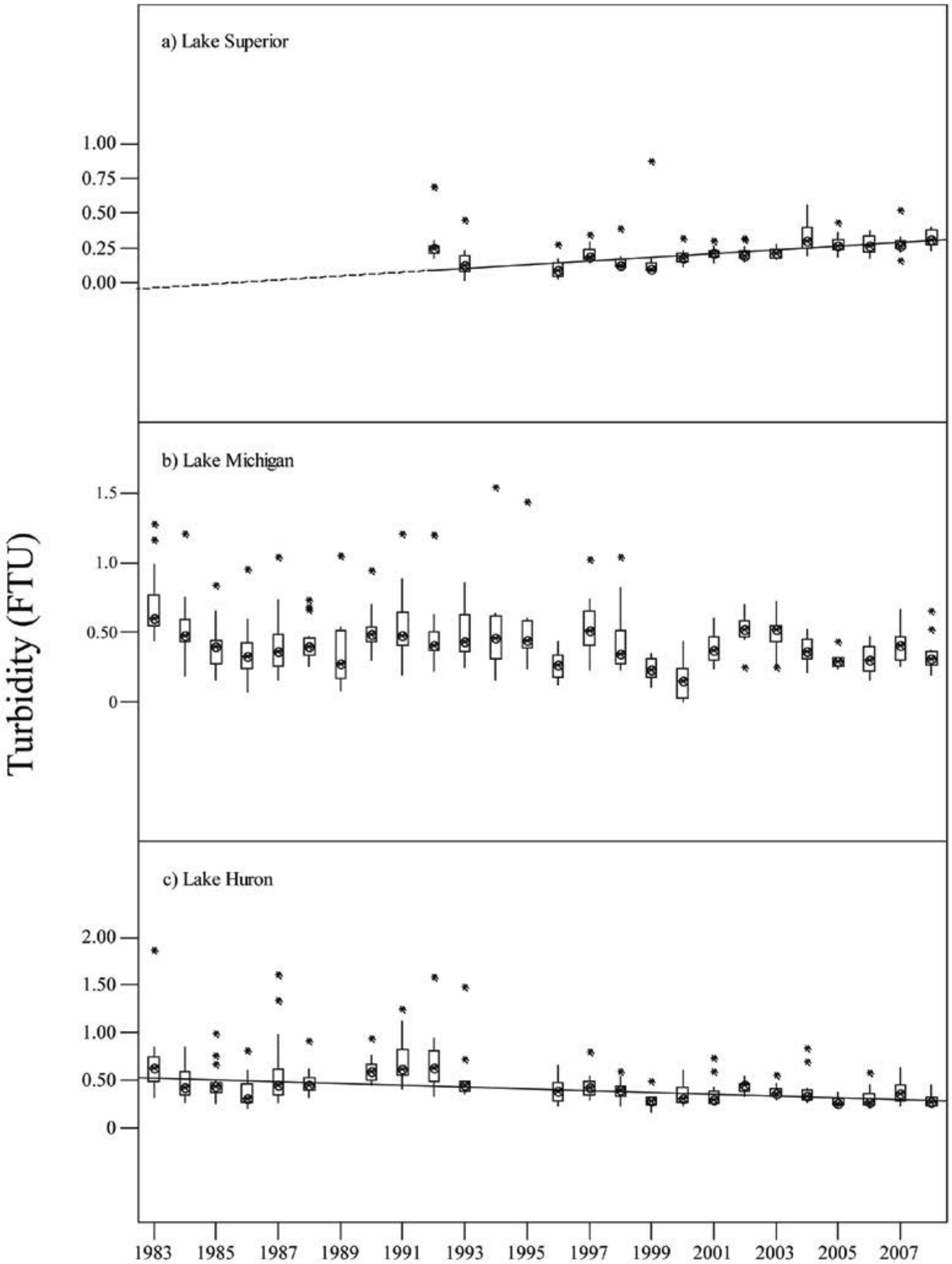

Figure 5. Long-term Trend of Turbidity in the Upper Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

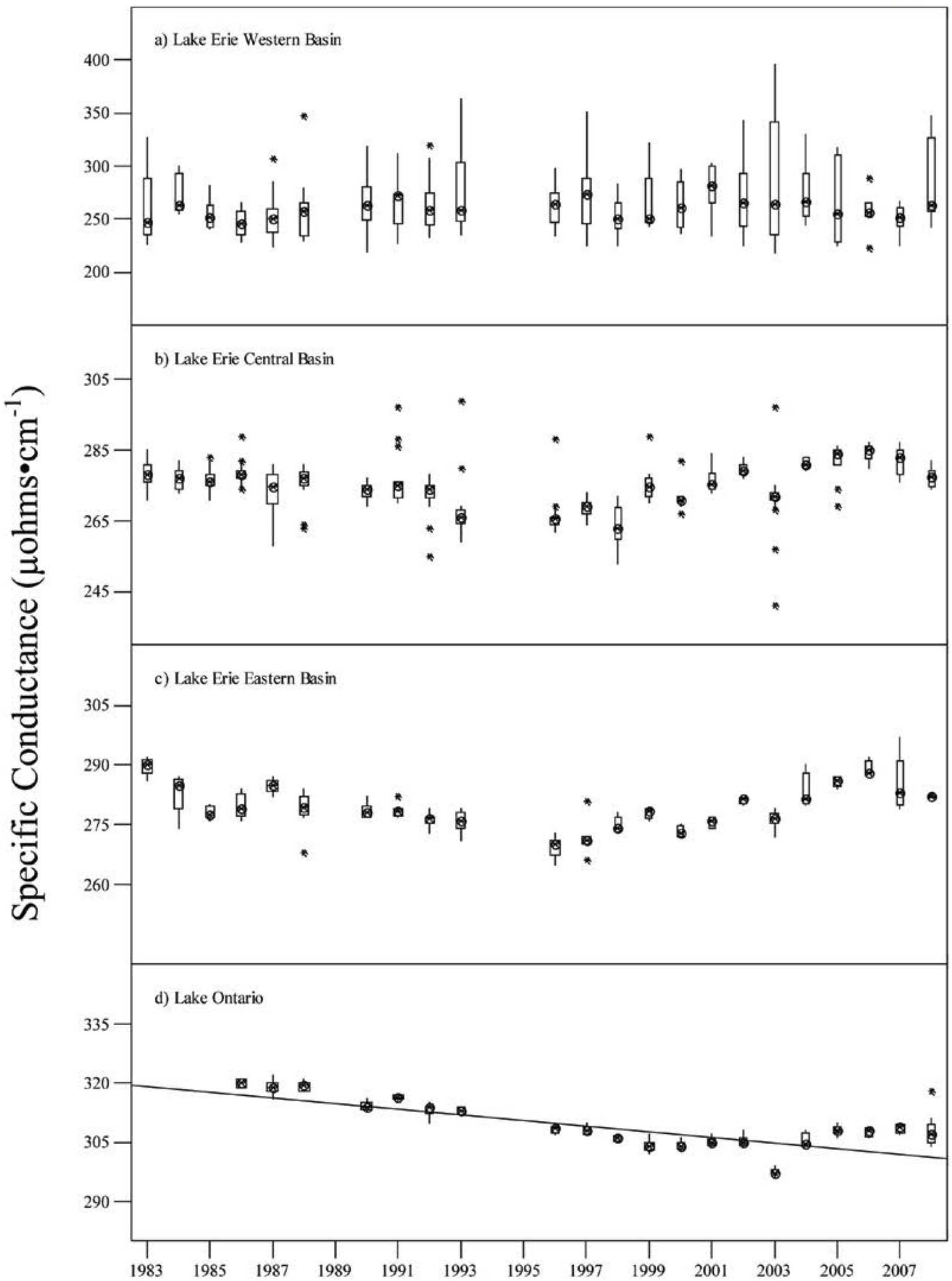

Figure 6. Long-term Trend of Specific Conductance in the Lower Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

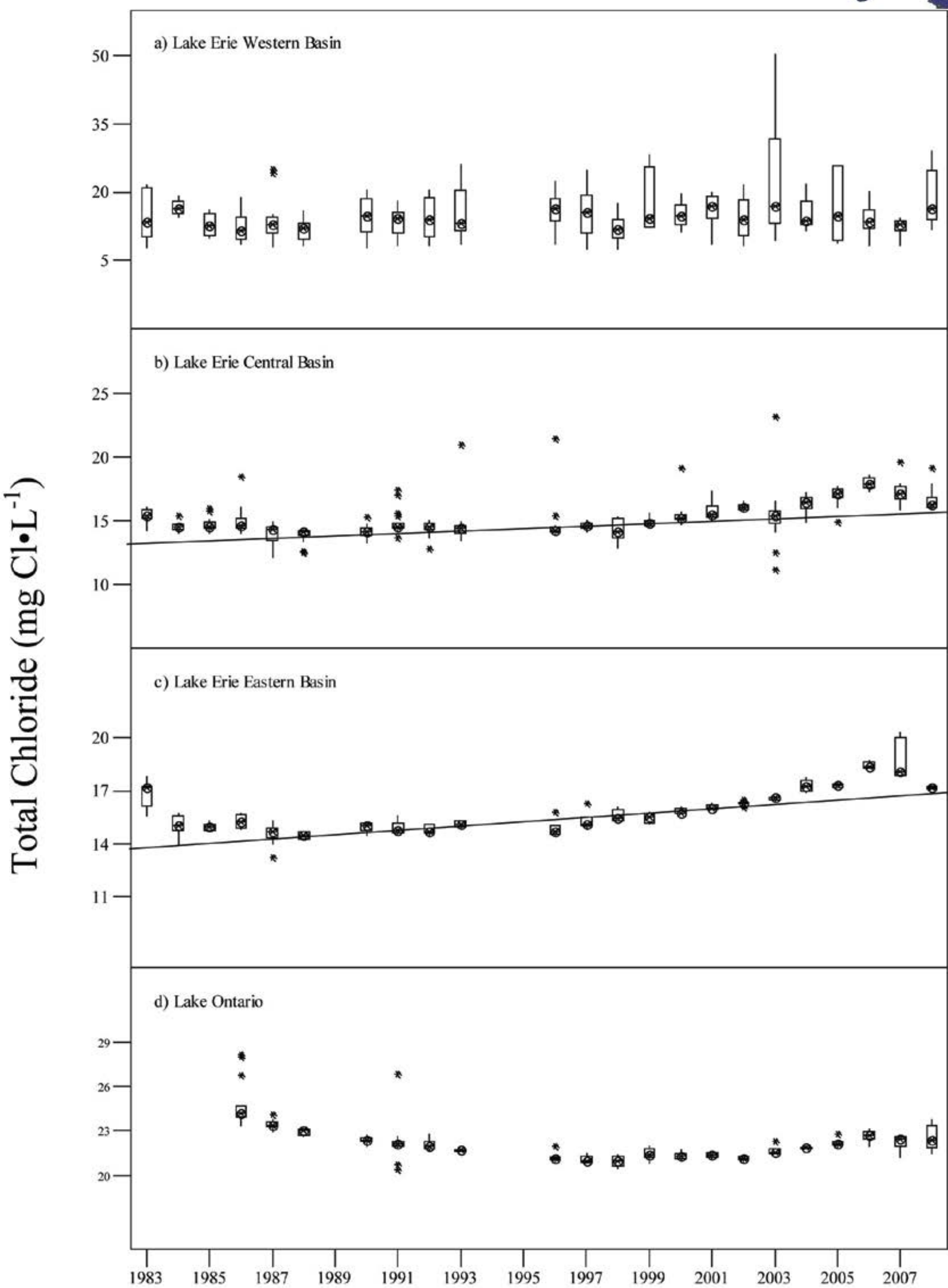

Figure 7. Long-term Trend of Total Chloride in the Lower Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

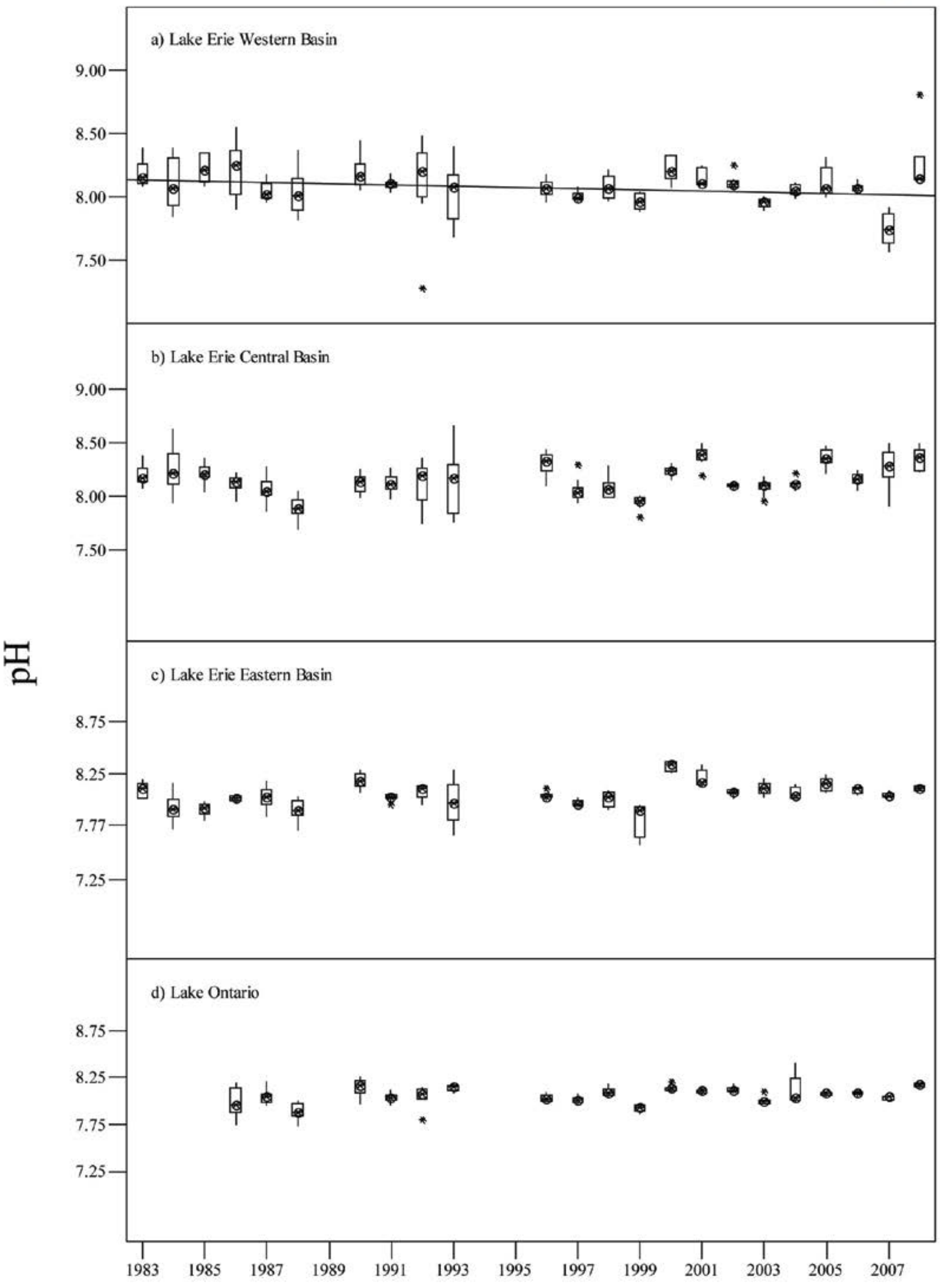

Figure 8. Long-term Trend of pH in the Lower Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

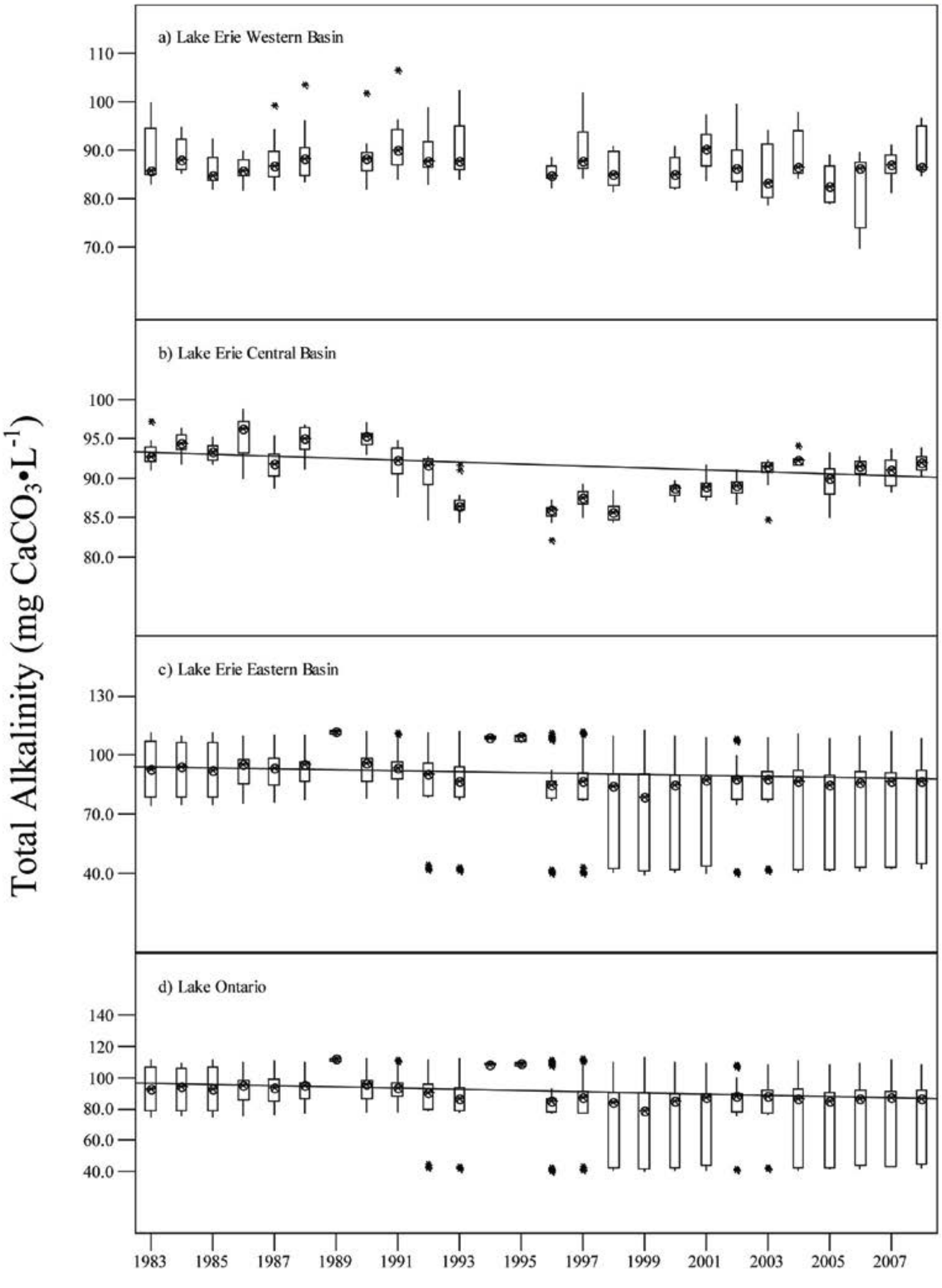

Figure 9. Long-term Trend of Total Alkalinity in the Lower Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

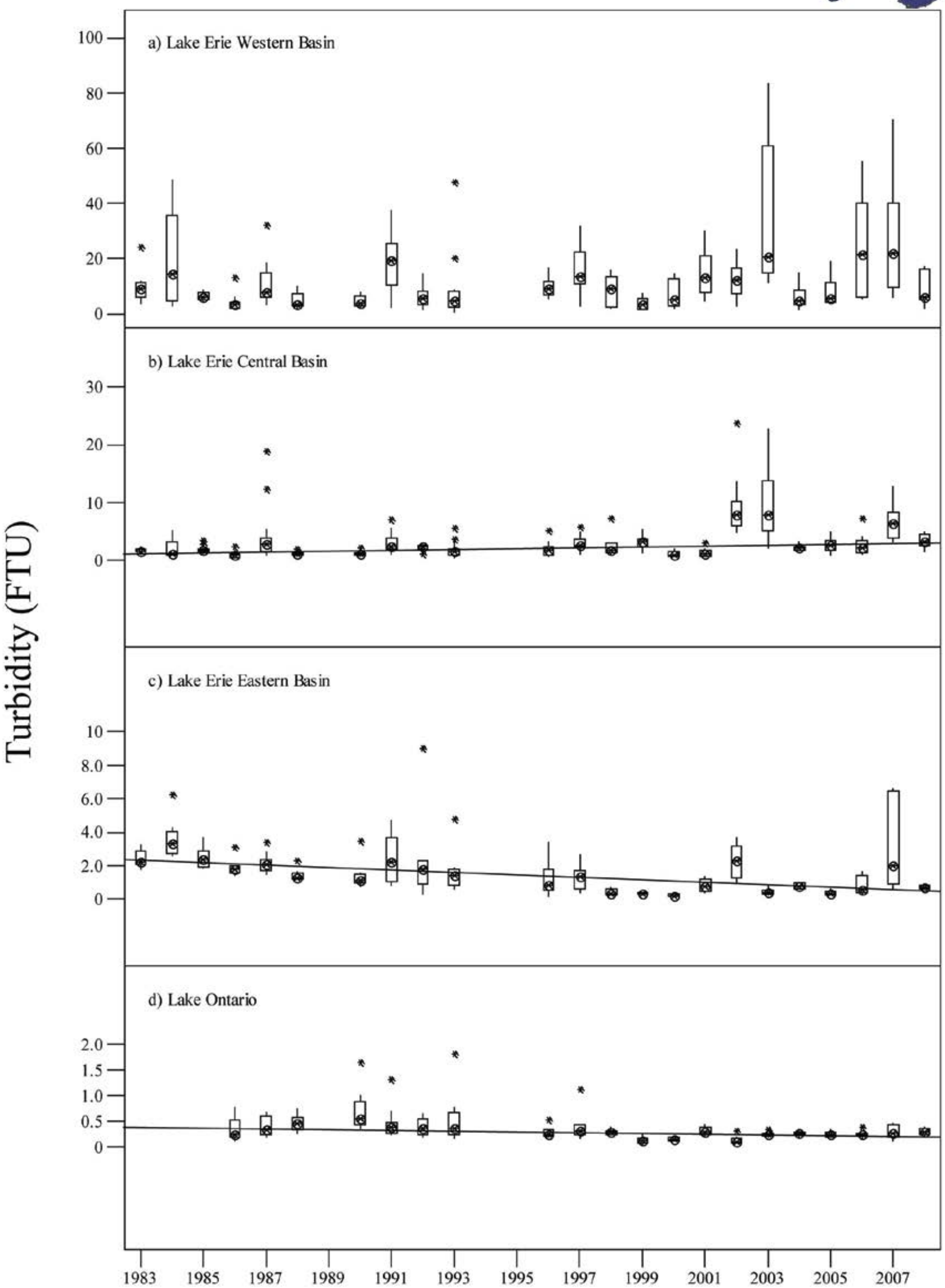

Figure 10. Long-term Trend of Turbidity in the Lower Great Lakes
Source: U.S. Environmental Protection Agency, GLNPO

Water Clarity

Overall Assessment

Status: Undetermined*

Trend: Mostly increasing, with the exception of Lake Erie and select nearshore locations

Rationale: There was an overall increase in water clarity for all of the Great Lakes between 1979-1986 and 1997-2005, with the exception of central and western Lake Erie, where it decreased significantly over these time periods. There have been some localized declines in clarity in regional nearshore locations in the other lakes.

Lake-by-Lake Assessment

Lake Superior

Status: Undetermined*

Trend: Increasing water clarity

Rationale: Unchanging to moderate increase in the clarity of offshore waters with some deterioration in near-shore zones such as Thunder Bay and Duluth.

Lake Michigan

Status: Undetermined*

Trend: Increasing water clarity

Rationale: Unchanging to moderate increase offshore with minor deterioration near-shore in Green Bay and southern shores near Chicago.

Lake Huron

Status: Undetermined*

Trend: Increasing water clarity

Rationale: Unchanging to minor increases in Georgian Bay, with broadly increasing water clarity offshore in Lake Huron. The overall trend in water clarity in Saginaw Bay is unclear.

Lake Erie

Status: Undetermined*

Trend: Decreasing water clarity in western and central basins, increasing clarity in eastern basin

Rationale: Lake Erie showed a deterioration in Secchi depth of up to 2 m in the central and western basins and in Lake St Clair between the observation periods 1979-1986 and 1997-2005, whereas the eastern basin showed an increase of up to 2 m.

Lake Ontario

Status: Undetermined*

Trend: Increasing water clarity

Rationale: Lake Ontario showed lake-wide increases in Secchi depth of up to 4 m between the observation periods 1979-1986 and 1997-2005. Isolated deterioration in water clarity is evident in some regional near-shore areas.

*Secchi Disk Depth is a complex combination of the effects of all particulate and dissolved materials on the transmission of light through the water column and as such could be detrimental (or advantageous) to different ecosystem components and indeed different water bodies at varying thresholds. For this reason a clear threshold upon which a water body can be judged “good” or “poor” with respect to its impact on aquatic ecosystems is not straightforward. A Secchi depth of 0.5 m attributable entirely to a pure mineral particulate concentration may not be as much of a concern to the ecosystem as a 0.5 m Secchi depth attributable to a harmful algal bloom. As such, it was deemed inappropriate to assign a status for this indicator at the present time.

Purpose

- To estimate historical conditions and recent trends in lake-wide water clarity over the Great Lakes from satellite-measured aquatic colour.
- To highlight regions of potential water clarity impairment.
- The Water Clarity indicator is used in the Great Lakes indicator suite as a State indicator in the Water Quality top level reporting category.

Ecosystem Objective

Water clarity is an important supporting element in assessing the ecological status of a water body through its direct linkages to ecosystem processes. These processes include, but are not limited to, defining the photic depth within which photosynthesis is possible, defining light availability to benthic communities, and monitoring the impacts of invasive species, climate change, and implemented management practices. While there is little specific reference to water clarity in the GLWQA aside from the direct effects of point-source pollution discharges on local light transmission (Annex 1, IIc), this indicator supports annex 11 (1c); surveillance and monitoring, through the evaluation of water quality trends in the Great Lakes.

Ecological Condition

<u>Background</u>

Water clarity is directly related to the particulate and dissolved materials contained within the water, which in combination determine the degree to which light is attenuated in the upper water column. Secchi Disk Depth (the depth in meters at which a white disk is no longer visible from the surface) is a commonly used, low cost descriptor of water transparency routinely performed in monitoring programs and offers the only multi-decadal historical measure of water clarity. Secchi Depth is often used as a surrogate estimate of phytoplankton biomass, as an indicator of eutrophication (Carlson, 1977). However, the optical properties of lakes are determined not just by phytoplankton, but also by suspended inorganic and organic particles and dissolved organic matter. Therefore, the indicator described here is treated as a broad measure of water clarity, although some causal links may be discussed based on prior knowledge of the lake system.

The introduction of non-native invasive species, point-source discharges, nutrient loading and resulting eutrophication and harmful algal blooms, as well as mandated programs to reduce phosphorus loadings, have all led to notable fluctuations in water clarity in the Great Lakes over the years (Environment Canada, 2001). Despite several detailed studies (Makarewicz et al., 1999; Barbiero & Tuchman, 2004, Howell et al., 1996), however, sparse spatial coverage and the discontinuous nature of ground-based monitoring often preclude reliable conclusions regarding long-term lake-wide changes in water clarity. Earth observation satellites offer regular, high resolution synoptic views of the lakes, which may provide more robust evidence of spatial and temporal trends in water clarity than point sampling alone.

Satellites measure the amount and spectral quality of light leaving the water's surface after interacting (through absorption and scattering) with dissolved and particulate materials. For this reason, satellite-measured aquatic colour signals can be interpreted in terms of coloured water quality parameters such as phytoplankton, mineral sediments and dissolved organic materials. A range of empirical through analytical bio-geo-optical modeling methods may be adopted to reach a quantitative measure of a specific water quality indicator. Imagery from the Coastal Zone Color Scanner (CZCS) has been used to produce monthly images of the Great Lakes for the period 1979-1985, offering an historical view of water clarity conditions. By merging this with imagery from the Sea-viewing Wide Field-of-view

Sensor (SeaWiFS) for the period of 1998-2006, it is possible to assess time-series evolution of water quality trends for the Great Lakes, documenting the extent to which the Great Lakes have changed over the last three decades. This time-series can be interpreted in terms of changes in water clarity, showing seasonal and inter-annual variability of bright-water episodes such as phytoplankton blooms, re-suspension of bottom sediments, and whiting events (whereby highly scattering calcium carbonate is precipitated out of solution under specific temperature and pH conditions) (Binding et al., 2007).

Measure

Satellite-derived water clarity is determined using a simple empirical relationship between Secchi Depth and the satellite-measured water-leaving radiance (nLw) at 555 nm, in the green portion of the visible spectrum, where the effects of mineral and algal particulate scattering on light penetration are broadly similar and can be treated in bulk. Particulate scattering enhances the apparent brightness of the water; therefore, the more turbid a waterbody is, the brighter the remote sensing signal. Methods for lake-wide water clarity analysis and some nearshore analysis are presented in full in Binding et al. (2007).

The near-shore water clarity analysis in this report is estimated with Landsat satellite imagery by utilizing the reflectance of water penetrating light in the visible portion of the electromagnetic spectrum. Water clarity is estimated by observing the depth at which light is no longer reflected from the bottom of the lake. This depth is derived by correcting imagery for water constituent reflectance, leaving only reflectance from the lake bottom (Lyzenga 1981, Lyzenga et al. 2006). Historical trends in near-shore water clarity were monitored over time using the Lyzenga technique with Landsat 5 and Landsat 2 satellite imagery for the following locations: Sleeping Bear Dunes National Lakeshore on Lake Michigan; Point Clark on Lake Huron; Port Maitland on Lake Erie; and Pickering on Lake Ontario. The satellite source (Landsat) and dates of analysis were chosen to reflect the least amount of interference from natural phenomena. Recent water clarity/optical depth maps for these four specific Great Lake locations as well as lake clarity field sampling results from two surveys in 2009 and 2010 offshore of Sleeping Bear Dunes National Lakeshore provide a Landsat analysis of water clarity in the near-shore zone.

Endpoint

Water clarity is determined by a whole suite of dissolved and particulate materials that may constitute a "poor" status under differing concentrations and may or may not have a detrimental effect on a range of ecosystem components. To the authors' best knowledge, there are currently no target water clarity levels for the Great Lakes. Therefore, there has been no assessment of the "status" of each lake. Instead, this report focuses on trends in water clarity over the last three decades relative to historical average conditions. The only reference to water clarity within the GLWQA is within Annex 1 IIC - PHYSICAL properties, where it describes variations in the Secchi depth by 10% in reference to substances attributable to municipal, industrial or other discharges and their effect on light transmission. There is no discussion of non-point source turbidity (natural sediment resuspension, algal blooms, etc.), which will constitute the vast majority of the remote sensing signal.

Trends in Water Clarity in the Great Lakes

While satellite imagery is available for the entire Great Lakes, methods using MODIS and MERIS to analyse water clarity on the entire lake have only been fully validated for Lakes Erie and Ontario. As such, it is possible to discuss trends for these two lakes in a quantitative manner with regard to a calibrated Secchi depth product. Results for the remaining lakes will be discussed in a qualitative manner from changes in water brightness (i.e. water-leaving radiance, nLw). Ongoing validation exercises will allow for a quantitative assessment of the remaining lakes for the next Great Lakes/SOLEC indicator report.

Lake Superior

Lake Superior exhibits by far the lowest overall levels of turbidity (i.e. lowest nLw) across the Great Lakes and has shown moderate further improvements in water clarity between the 1979-1985 and 1998-2005 observation periods, with little change in mid-lake conditions. Some near-shore regions show evidence of a moderate decrease in water clarity; in particular near Thunder Bay and Duluth. Intra-annual variability in water clarity has decreased between the two observation periods.

Lake Michigan
Lake Michigan water clarity broadly increased between the two observation periods, with notable increases in water clarity in the northern lake, no significant change in the southern offshore regions, and localized decreases in water clarity on the southern shores near Chicago and in Green Bay. Intra-annual variability in nLw decreased between the two periods and notably so in the years since 2002, suggesting a decrease in the intensity of brightness events (commonly whiting events or algal blooms in August/September each year).

A case study (in the next section) of the Landsat data analysis of near-shore water clarity at Sleeping Bear Dunes National Lakeshore describes the detailed improvements of water clarity along the north-eastern shore of Lake Michigan between 1974 and 2009.

Lake Huron
Lake Huron water clarity broadly increased between the two observation periods, with Georgian Bay showing only a modest increase. Saginaw Bay is highlighted in the lakewide analysis as the nearly the only region in the lake experiencing a reduction in water clarity. However, the Landsat analysis for Saginaw Bay clearly shows that more and deeper areas of bottom substrate are visible in more recent imagery (Figures 3 & 4), indicating at least localized areas of increased optical depth. Lake-wide, intra-annual variability has remained fairly consistent while the background water clarity conditions have improved.

There has also been an increase in the near-shore water clarity/optical depth from 1975 through 2011 (Figures 5 & 6). While some variability can be seen in the Landsat analysis, the general trend for the Point Clark area on the Bruce Peninsula has been an increase from 6.4 meters to 12.0 meters of optical depth over the 36 year observation period. The increase in water clarity/optical depth over this time is largely attributed to some key events in the Great Lakes areas. The invasion of the Zebra and Quagga mussels have played a key role as they found Lake Huron to be prime habitat and have exhibited their success as filter feeding organisms. In addition to the invasive species, the Great Lakes Water Quality Agreement in 1972 set the stage for decreases in nutrient discharge and the institution of best management practices with respect to waste water discharge into the Great Lakes.

Lake Erie
In contrast to all the other lakes, Lake Erie shows a marked increase in both the magnitude and variability in nLw levels between the two time periods (Fig. 7d). Figure 7 presents the derived Secchi depth for the two periods; during 1979-1985, lake-wide Secchi depths ranged from 2 to 4.5 m, whereas by 1998-2005, lake-wide Secchi depths ranged from 1.5 to > 6 m. The geographic distribution varied significantly between the two periods; Secchi depths of 4m or greater, while widespread during 1979-1985, were confined strictly to the eastern basin during 1998-2005. Figure 7c shows relative increases in Secchi depths in the eastern basin up to and exceeding 2 m. Additional analysis confirms a more than doubling of spring-time Secchi depths in the eastern basin between the two observation periods. In contrast, the central and western basins underwent a period of decreasing water clarity, with average reductions in Secchi depth of 1-2 m. Imagery confirms that Lake Erie has changed from fairly uniform lake-wide water clarity conditions to strong east-west water clarity gradients of up to 5 m. Despite historical reports of localised dramatic decreases in algal biomass in the years following the zebra mussel invasion (Barbiero & Tuchman, 2004), image analysis suggests this did not result in significant increases in water clarity in the western basin, suggesting that water clarity here is driven more by mineral resuspension signals.

In line with the water clarity changes described above for the eastern basin, the near-shore water clarity/optical depth in Lake Erie near Port Maitland has gradually increased from approximately 5 m to nearly 9 m between 1975 and the present based on the Landsat analysis (Figures 8 & 9).

Lake Ontario
Average Secchi depths over Lake Ontario as estimated from CZCS and SeaWiFS imagery for the periods 1979-1985 and 1998-2005 respectively are presented in Figure 10. Secchi depths are largely uniform across the lake at around 3-4 m for the 1979-1985 period and increase notably to 6-8 m by the 1998-2005 period. Figure 10c confirms that the entire lake appears to have undergone significant improvements in water clarity, with lake-wide increases in Secchi depth of between 2 and >4 m.

The absence of large regions of bottom sediment re-suspension in Lake Ontario suggests these changes may be attributed to bio-chemical changes, either a reduction in biological productivity or a reduction in the intensity/frequency of whiting events. Further analysis identified the largest monthly change to be in April, with a more than doubling of Secchi depths, suggesting a decline in the extent of the spring bloom on the lake. Millard et al. (2003) observed a lake-wide decline in chlorophyll between 1990 and 1996, attributing it to the combined effects of nutrient loading controls and the mussel invasion. Further evidence suggests a reduction in the frequency/intensity of whiting events in agreement with the effect of calcium uptake by mussels on lake water clarity.

The remotely sensed satellite-derived information on near-shore water clarity indicates little change in optical depth in Pickering, Ontario, located on the north shore of Lake Ontario (Figure 11), up to the year 2000, at which point optical depth increased from approximately 5 m to 8 m over the course of 12 years.

<u>Nearshore Water Clarity: Special Case Study</u>
Water clarity in Sleeping Bear Dunes National Lakeshore has been of significant interest in the remote sensing program at Michigan Tech Research Institute (MTRI). Over the period between 1974 and 2009, significant improvements in water clarity were found (Figures 13 & 14). The increase in red colour (Figure 14) from 1974 to 2009 indicates dramatic increases in the aerial extent over which the lake bottom is visible over the 35 year period.

Upon further research and discussions with Lake Michigan ecologists, it is suggested that these changes in water clarity have been related to the increase in invasive species (especially Zebra and Quagga mussels), best management practices, and political agreements such as the Great Lakes Water Quality Agreement. In particular, the increase in water quality over the past 20 years (Figure 15) is very likely due to the large amount of water filtering due to the invasion of Zebra and Quagga mussels, leading to much greater habitat availability for benthic algae such as *Cladophora* (Auer 2010, Tomlinson 2010), leading to associated issues of *Cladophora* algae beach fouling and avian botulism outbreaks (VanSumeren and Breederland 2008).

An intensive field investigation was completed along the Sleeping Bear Dunes National Lakeshore in 2009 and again in 2010 as part of a GLRI-funded *Cladophora* mapping effort. In 2009 and 2010, MTRI joined with the University of Michigan Marine Hydrodynamic Laboratory (MHL) to investigate the growth of *Cladophora* algae in the Sleeping Bear Dunes National Lakeshore coastal area in Lake Michigan (Shuchman et al., in press).

In both 2009 and 2010, Secchi disc measurements were recorded in locations throughout the study area using standard Secchi disc transparency (SDT) methods (Figure 16). Additionally, *Cladophora* samples were collected by a diver along with a remotely controlled video camera that was towed by the research vessel through the water.

There is a noticeable difference in the Secchi measurements at Sleeping Bear Dunes National Lakeshore between August 27, 2009 and July 8, 2010 (Figures 16 & 17). The average depth in 2009 is 9.08 meters, whereas in 2010 the average Secchi depth is 7.25 meters. While the sample locations from 2009 to 2010 are not exactly the same, a few locations are within close proximity to one another. Specifically, site A4 in 2009 and site C8S in 2010 are the same location, but in 2009 the Secchi reading was 7.32 meters and in 2010 the measurement was 6.95 meters. Also, Site C2 in 2009 and site C1 in 2010 are the same location, but the measurements are different. Site C2 in 2009 had Secchi reading of 11.28 meters, and site C1 in 2010 was recorded at 6.28 meters. This analysis of direct Secchi depth measurements demonstrates how much variability can occur from one year to the next, most likely due to algal blooms in the water column.

Linkages

Water clarity is important as a broad indicator of lake water quality and ecosystem status that reflects a variety of ecosystem processes and is both impacted by and has impacts upon a wide range of other indicators.

Harmful algal blooms/Phytoplankton: Water clarity dictates the photic depth and the quantity of light available for primary productivity. In addition, light quantity and quality (that is the spectral characteristics of the light field) has been shown to be significant in driving selective species dominance (e.g. cyanobacteria, Bennet and Bogorad, 1973), therefore playing a key role in determining species assemblages within the lakes.

Benthic Communities/*Cladophora*: Water clarity will again determine the depth to which light penetrates and therefore dictate the areal extent of benthic vegetation, with increasing water clarity resulting in an abundance of benthic algal mats.

Mussels: Water Clarity has been used as a primary indicator in monitoring the impact of filter feeding on the water quality of the Great Lakes.

Nutrients: Water clarity combined with prior knowledge of the lake system can be used as an indicator of eutrophication provided the contribution to water clarity from mineral particulate turbidity is known or constant.

Fish habitats: Water clarity is known to be a factor in determining the location of feeding/spawning grounds and is therefore an important indicator for broader understanding of fish habitat and population dynamics.

Management Challenges/Opportunities

The broad nature of water clarity as a measure of Great Lakes water quality is valuable in that it encompasses a variety of in-water constituents (algal blooms, mineral resuspension, point-source loadings) and therefore responds to, and is thus an indicator of, a wide variety of processes. However, it is this broadness that makes it a complex indicator to which to assign thresholds in order to define the status of a waterbody as “good”, “fair” and “poor”. Water clarity can be both advantageous and detrimental to different components/processes within an ecosystem, which adds to the uncertainty in threshold definition.

Satellite remote sensing methods have been developed to distinguish algal from mineral turbidity, which may go some way to further understanding the complex nature of this indicator, although at present this data is not available over an extended time period to allow a reliable trend analysis. Freely available satellite imagery of the Great Lakes combined with effective modeling and image processing methods allows for cost-effective ongoing monitoring of the trends discussed in this report and potential elucidation of emerging responses of Great Lakes water clarity to both natural and anthropogenically induced change.

Comments from the author(s)

Although the Landsat-derived historical timelines of water clarity/optical depth were produced for near-shore areas in the Great Lakes, it is important to note that this near-shore dataset is limited. Each date reporting water clarity/optical depth is a singular representation for that specific moment in time. The data from a specific date reflects any meteorological, stream and river discharge, anthropogenic, and Lake current phenomena that may have occurred on or recently before the acquisition date. Documentation of the phenomena listed above needs to be generated for this data as well as future water clarity documentation.

These data limitations do not apply to the MODIS and MERIS lake-wide time series analysis due to the significantly improved temporal resolution of those sensors.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada						X
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report			X			

Clarifying Notes:
Satellite-derived Secchi Depths are predicted with an RMSE of <25% of the mean for Lakes Erie and Ontario. All other lakes are described in a qualitative manner only as the product uncertainty has not been fully assessed.

Acknowledgments

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Source: Environment Canada, Binding

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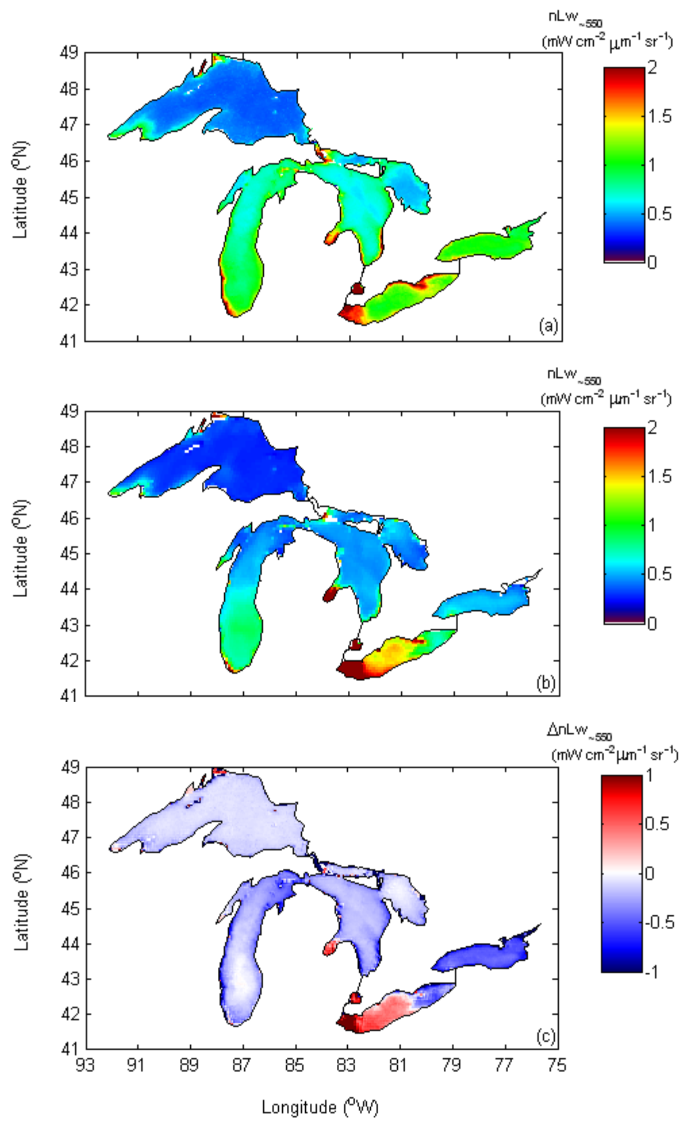

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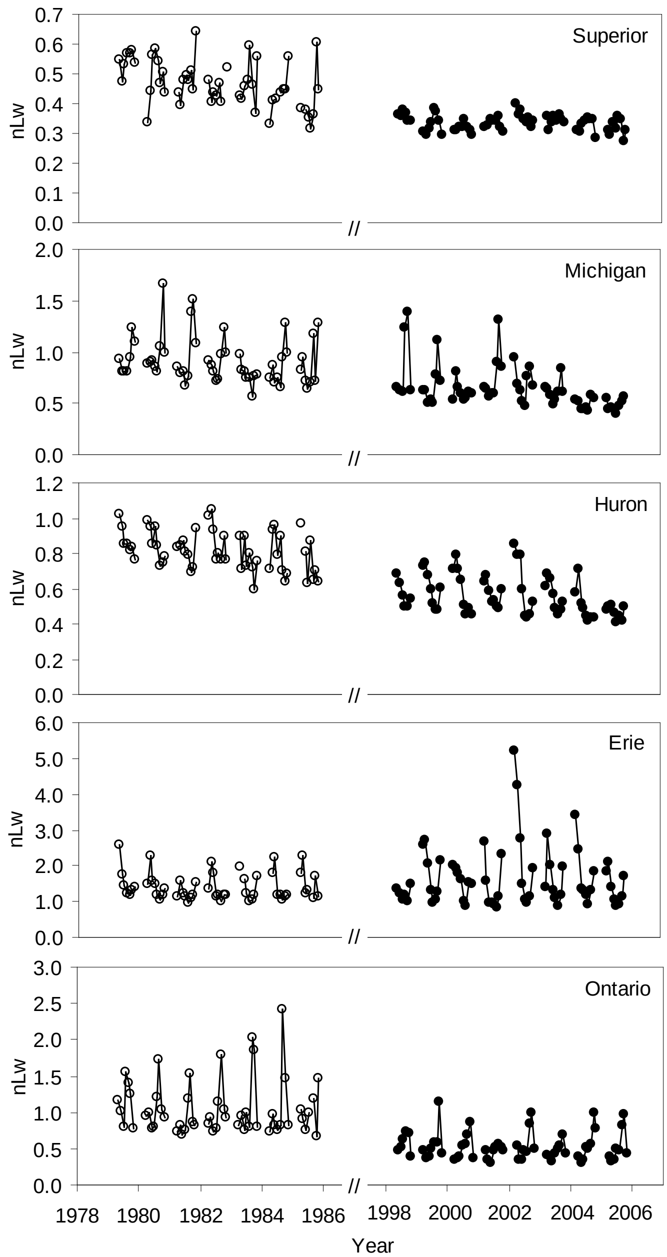

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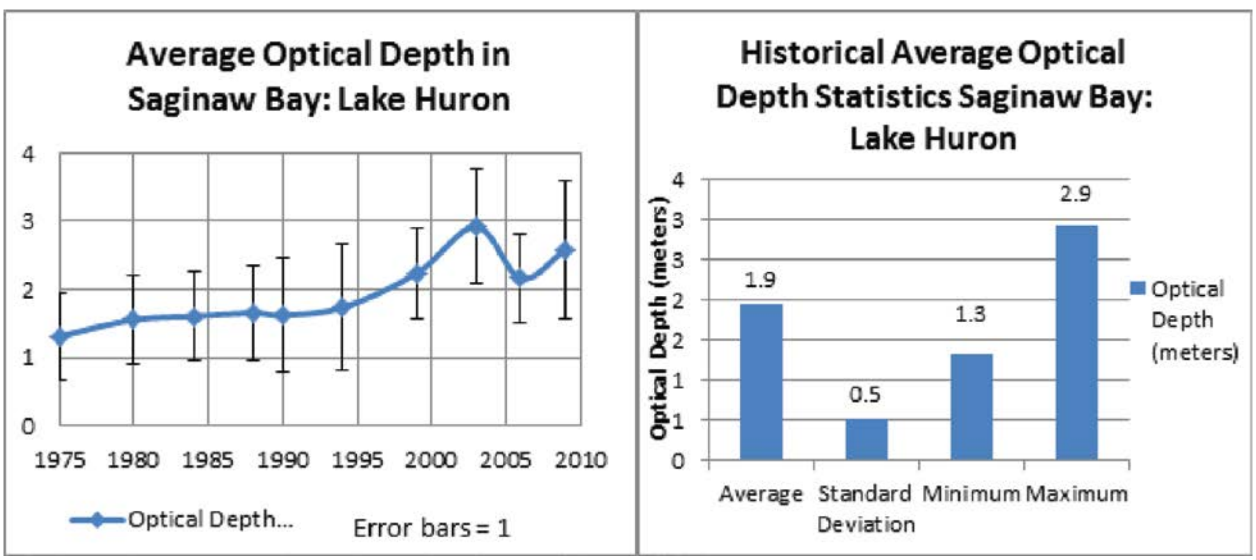

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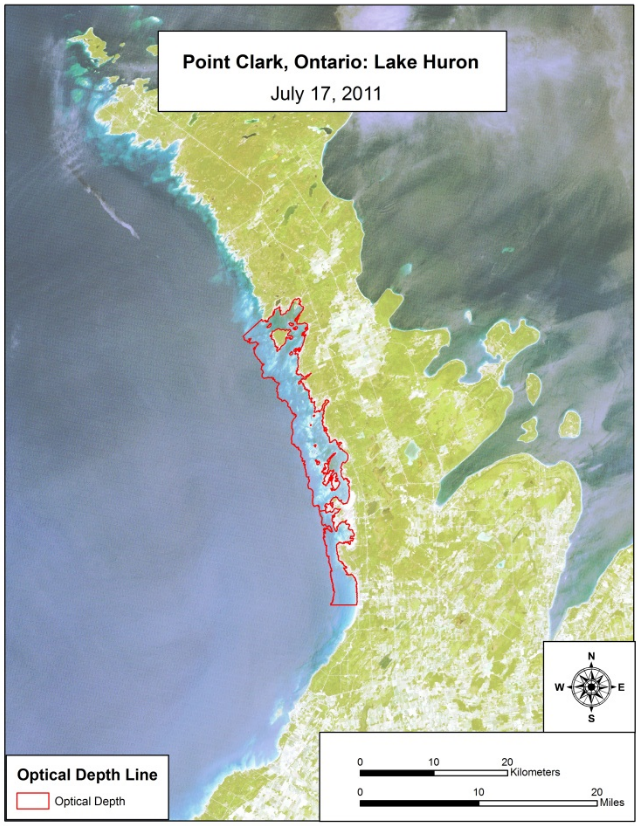

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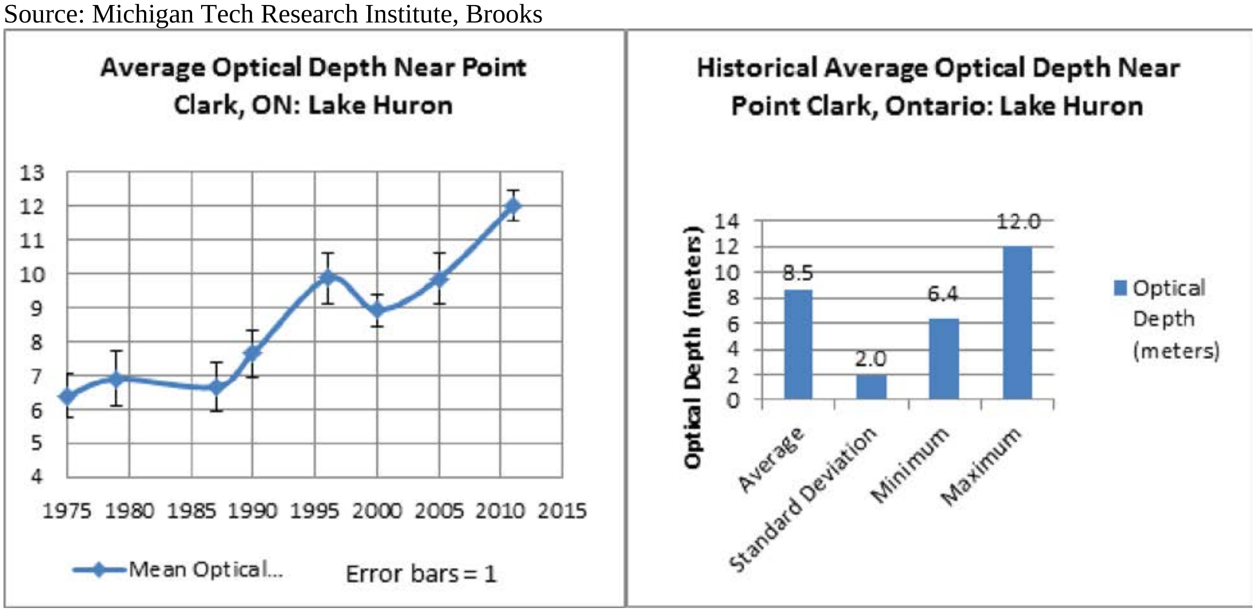
Source: Michigan Tech Research Institute, Brooks



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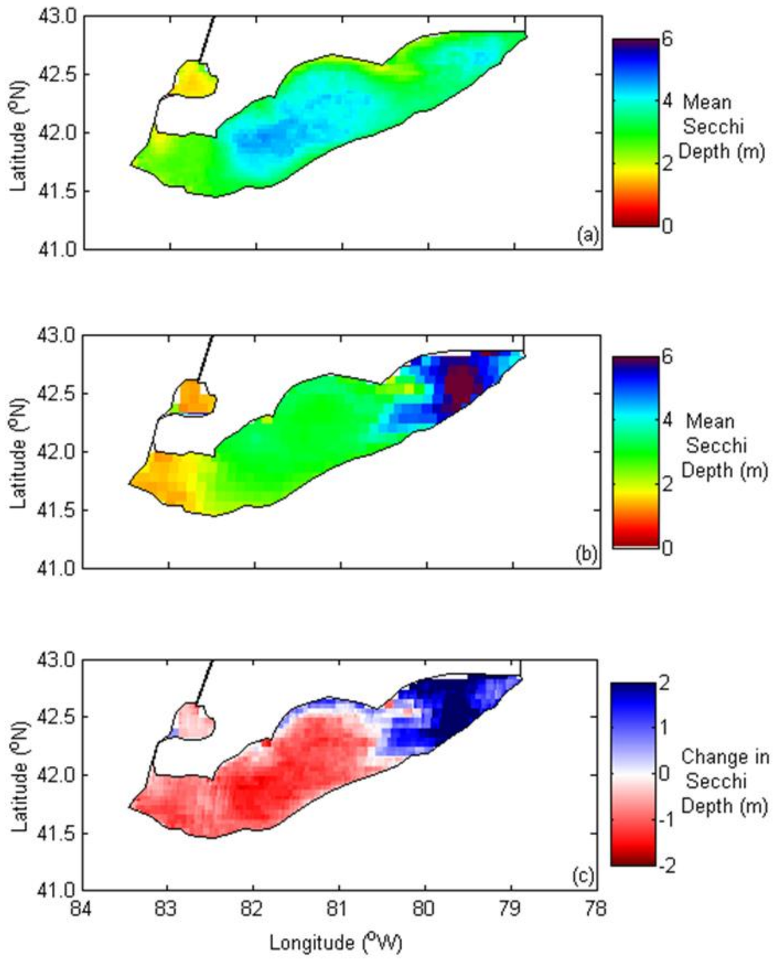

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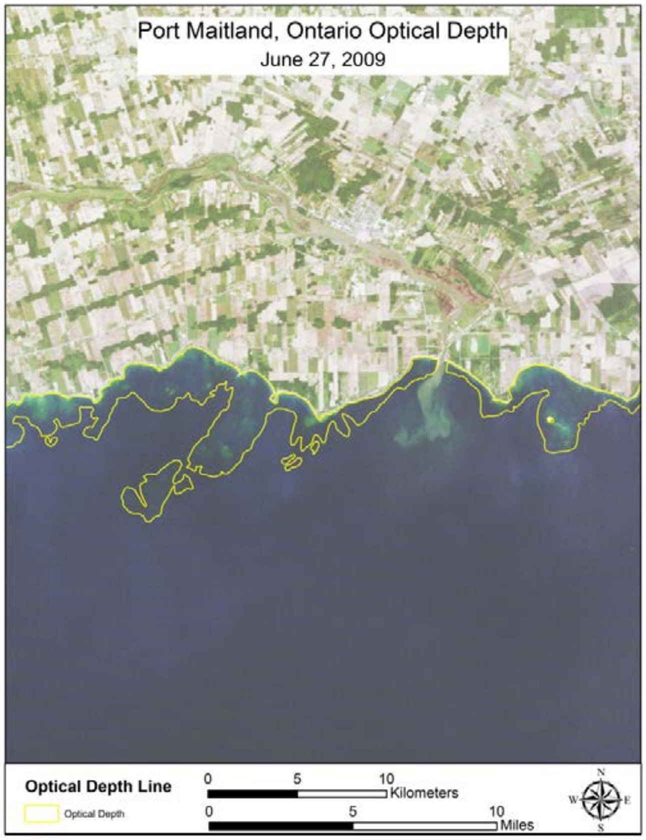

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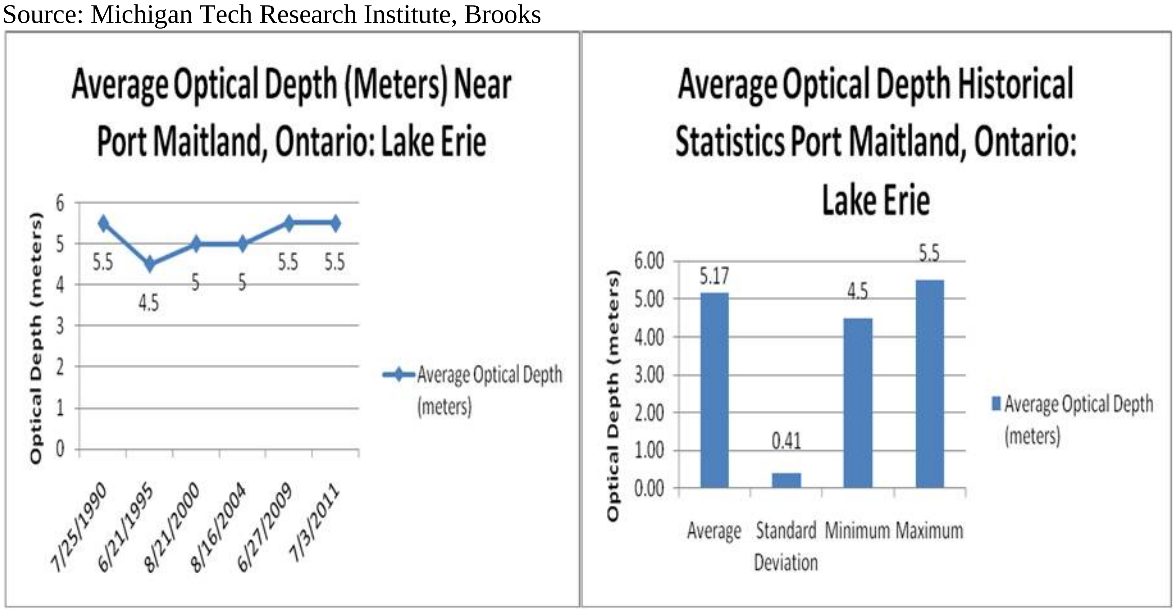

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Source: Michigan Tech Research Institute, Brooks

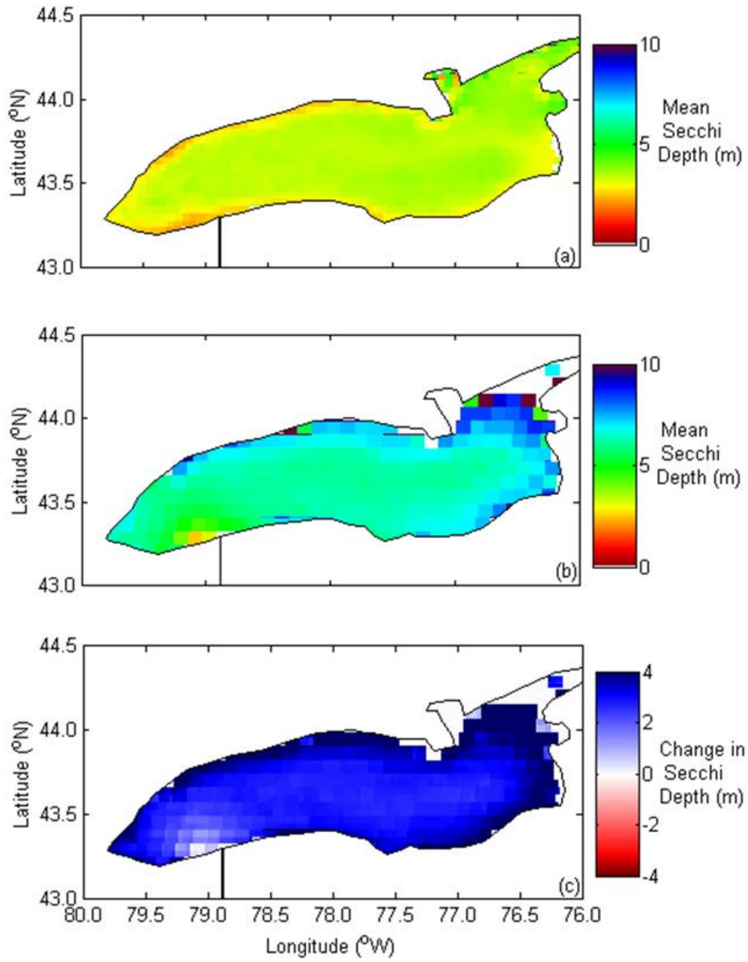

Figure 10. Satellite-derived Secchi Disk Depths for (a) CZCS, 1979-1986, (b) SeaWiFS, 1998-2005, and (c) the difference between the two, showing the change in Lake Ontario water clarity between the two observation periods. Source: Environment Canada, Binding

Figure 11. Current water clarity/optical depth extent derived from Landsat 5, near Pickering, Ontario Lake Ontario. August 4, 2011.
Source: Michigan Tech Research Institute, Brooks

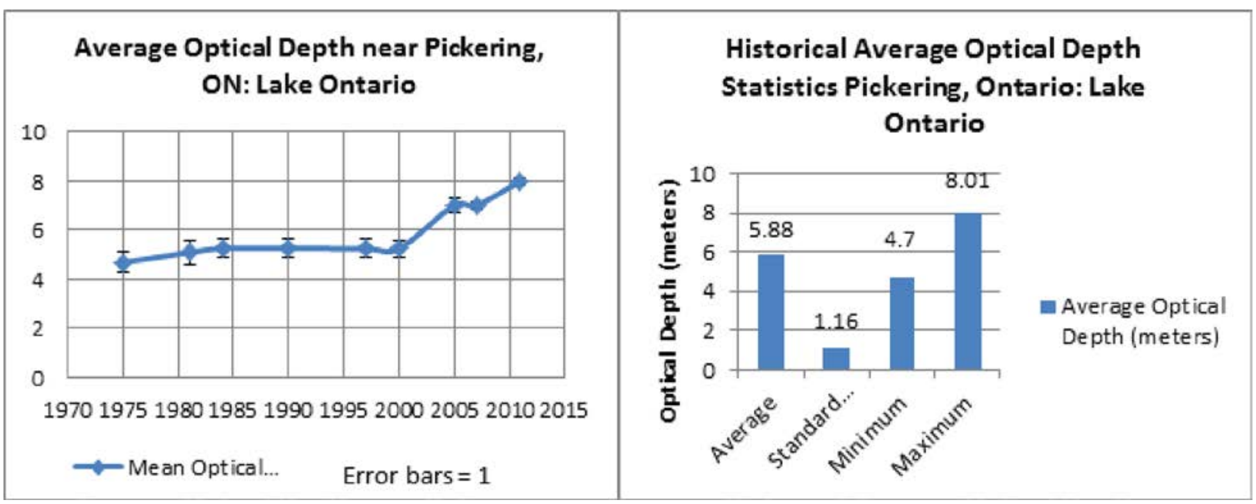

Figure 12. Average water clarity/optical depth a) derived from Landsat, over time near Pickering, Ontario between June 28, 1975 and August 4, 2011; b) Historical statistics of average water clarity/optical depth between 1975 and 2011.
Source: Michigan Tech Research Institute, Brooks

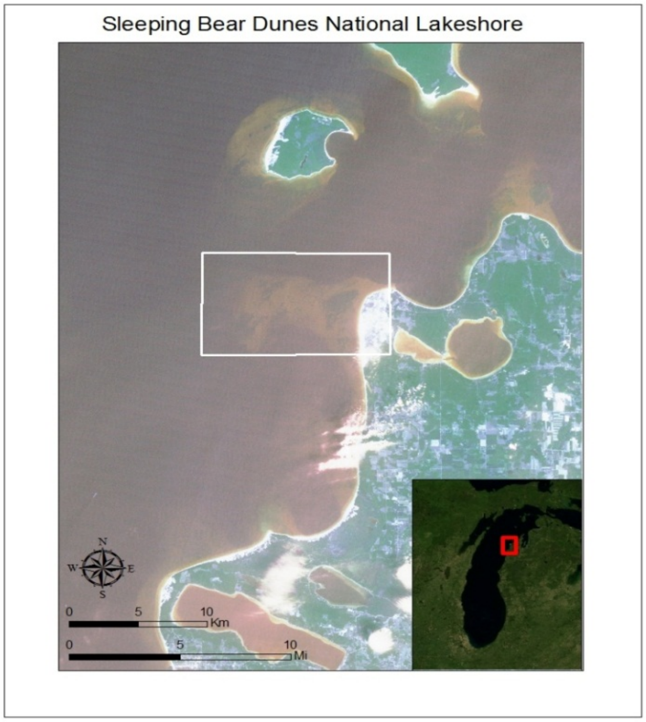

Figure 13. Reference map, from Landsat, showing 2009 and 2010 field data collection location study area, Sleeping Bear Dunes National Lakeshore.
Source: Michigan Tech Research Institute, Brooks

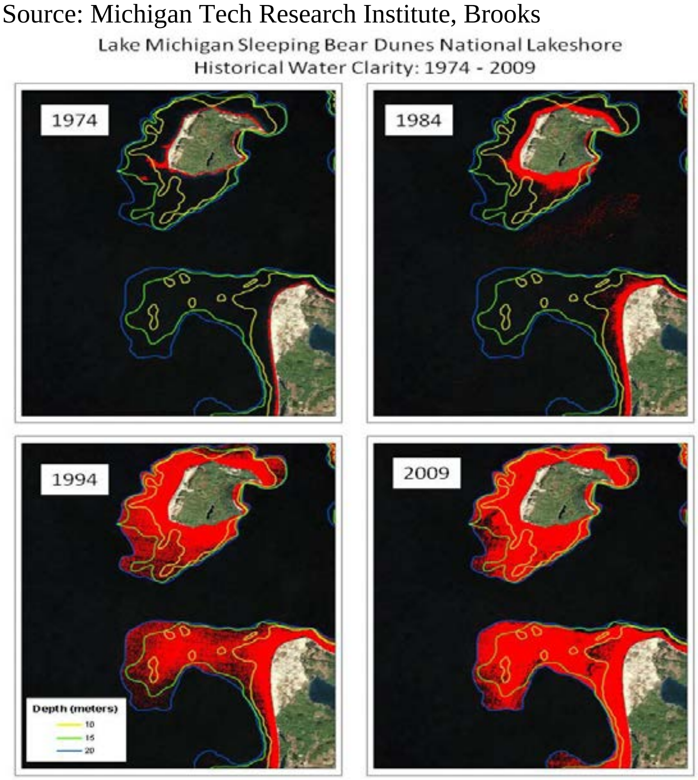

Figure 14. Historical water clarity/optical depth, derived from Landsat, at Sleeping Bear Dunes National Lakeshore from 1974 to 2009. Source: Michigan Tech Research Institute, Brooks

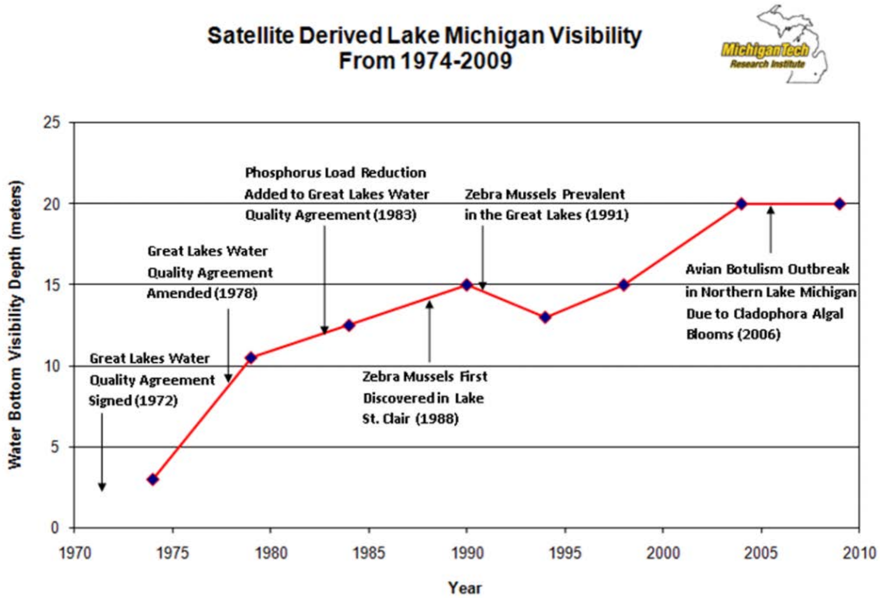

Figure 15. Water clarity plot derived from satellite imagery using the depth invariant index 1974-2009.
Source: Michigan Tech Research Institute, Sayers

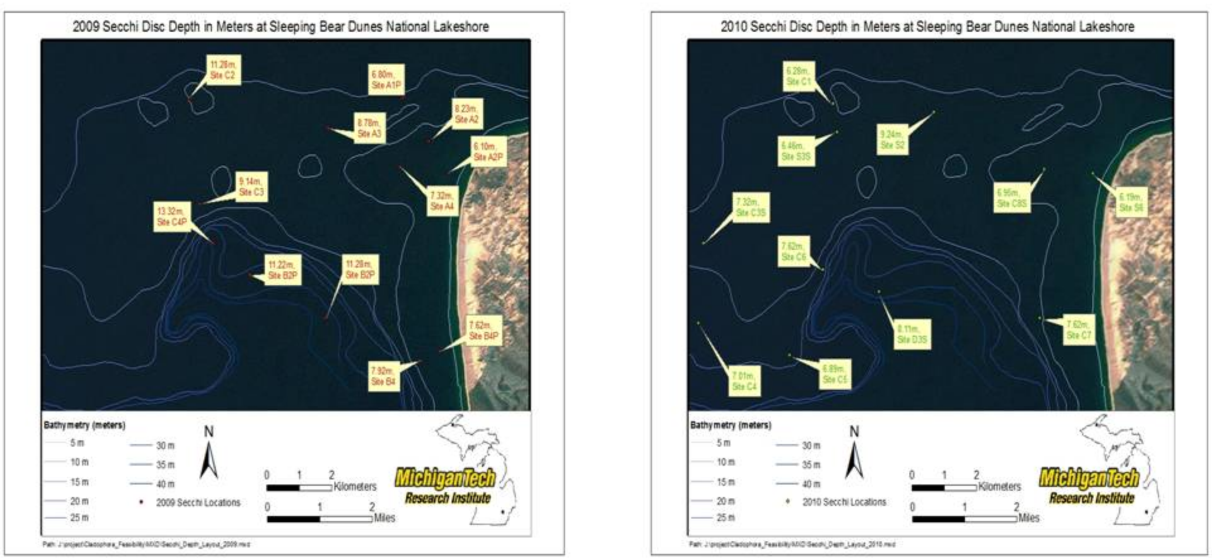

Figure 16. August 27, 2009 Secchi Disc Depth in Meters at Sleeping Bear Dunes National Lakeshore on a) August 27, 2009 and b) July 8, 2010.
Source: Michigan Tech Research Institute, Brooks

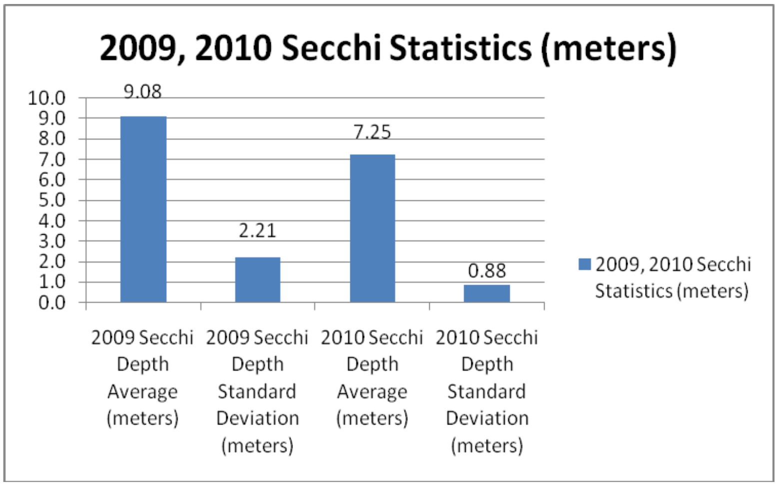

Figure 17. Secchi Disc Measurement Statistics from 2009 and 2010.
Source: Michigan Tech Research Institute, Brooks

Water Levels

Overall Assessment:

Status: **The annual water levels of Lakes Superior and Lake Michigan/Huron have been below average since 1998 while Lake Erie and Lake Ontario have fluctuated around their long term means.**

Trend: **There are no consistent trends in annual water levels across all of the Great Lakes.**

Rationale: **Water level regimes for all the Great Lakes are primarily the product of short- and long-term climate variability. Water levels of downstream lakes are impacted by the climate variability of all upstream lakes as well as their own variability. Other factors that affect individual lakes in a unique way are discussed below. In recent years the water levels of the upper Great Lakes have been consistently below average, while levels of the lower Great Lakes have fluctuated between above and below average. These levels are reflective of the climate conditions that have been experienced. Anthropogenic forcing of the climate system due to increasing concentrations of carbon dioxide and other greenhouse gases increases the probability that future conditions in the Great Lakes basin will be outside the envelope of conditions that have been historically observed (IPCC 2007). While some impacts of climate change are evident in the Great Lakes Basin (e.g. increased temperature, and wind speeds), there is uncertainty associated with regional projections of climate into the future, particularly with respect to precipitation patterns and how these changes will manifest themselves in terms of net basin water supplies, water levels and flows in all the Great Lakes. Evaporation from all of the Great Lakes has been increasing over the past six decades, probably due to a reduction in ice cover caused by warmer winter air temperatures, and this has been coincident with an increase in precipitation over all the lakes except Superior. The precipitation increase has somewhat offset the increase in evaporation (IUGLS, 2012). In the future, while low water extremes appear to be more likely, high water level extremes are also plausible and should not be dismissed (IUGLS, 2012). The International Joint Commission (IJC) is seeking public consultation in the winter/spring 2012 for a new approach to managing Lake Ontario outflows that is based on the desire to restore the region's wetlands which have suffered under the current plan. A new regulation plan was also proposed for Lake Superior by the International Upper Great Lakes Study (IUGLS) Board in March 2012. Future trends may be influenced by the implementation of these revised approaches to managing the outflows of Lakes Superior and Ontario.**

Lake-by-Lake Assessment:

Lake Superior

Status: The level of Lake Superior has been below average on an annual basis since 1998 and all but 3 months on a monthly basis since May 1998. It had a new period of record low for the months of August and September in 2007, but has remained within historical record since then.

Trend: There has been a low water period on Lake Superior for the past 12 years; however, this is not yet of sufficient duration to suggest a long-term trend or shift in climate. There is no certainty (and no method to determine) as to whether these low water levels will continue or wetter conditions may occur again and cause water levels to rise.

Rationale: Water level regimes are the product of short- and long-term climate variability and Lake Superior's water level is influenced by the regulation of its outflow. The water levels have remained within historical records since August and September 2007 when they did reach a period of record monthly low. Evaporation from the lake has been increasing, probably due to a reduction in ice cover, and it is likely that evaporation will continue to increase for the foreseeable future (IUGLS, 2012). Unlike the other Great Lakes, this increase in evaporation has not been offset by an increase in precipitation. A new regulation plan was proposed for Lake Superior by the International Upper Great Lakes Study

(IUGLS) Board in March 2012. Future trends are not expected to be influenced by the implementation of a revised regulation plan for the outflows of Lake Superior as regulation has significant limitations in addressing extremes. Glacial isostatic adjustment, or the gradual rebound of the land over time following the retreat of the glaciers, does have the effect of causing the water to gradually get shallower along the northeast shoreline and get deeper along the southwest shoreline over time.

Lake Michigan-Huron

Status: The level of Lake Michigan-Huron has been below average since 1999. The International Upper Great Lakes Study in 2009 concluded that erosion of the St. Clair River had occurred subsequent to the last navigation dredging project, resulting in an increase in the conveyance capacity of the St. Clair River and a lowering of Lake Michigan-Huron water levels by approximately 7 to 14 cm (2.8 to 5.5 in).

Trend: There have been low water conditions on Lake Michigan-Huron over the past 12 years. Paleo lake-level history suggests that low levels occur at approximately 30 year intervals (Baedke and Thompson, 2000), and analysis of recorded levels has found a similar cycle (Hanrahan et al., 2010). The IUGLS Study Board could not conclusively establish why or how the conveyance capacity of the St. Clair River increased since the 1960s, due to a lack of bathymetric and hydroclimate data. They did find that conveyance changes in the river do not appear to be ongoing. The permanent lowering of Lake Michigan-Huron water level has increased the plausibility of below average levels in the future but does not suggest the risk of high water levels can be ignored.

Rationale: The water level of Lake Michigan-Huron has been impacted by the dredging and erosion of the St. Clair River and, to a small extent, by the regulation of Lake Superior's outflow. Conveyance changes on the St. Clair River have resulted in a lowering of water levels on Lake Michigan-Huron, but possible future trends in conveyance changes are unknown. The permanent lowering of levels due to these conveyance changes has increased the plausibility of below average levels in the future due to climate variability. Glacial isostatic adjustment, or the gradual rebound of the land over time following the retreat of the glaciers, has the effect of causing the water to gradually get shallower on Georgian Bay and the North Channel and get deeper on the southeastern Lake Michigan shore.

Lake Erie

Status: The level of Lake Erie has fluctuated above and below average since 1998.

Trend: There are no apparent trends to Lake Erie water levels over the past ten years, but its level has been closer to average than over the previous thirty years.

Rationale: Conveyance changes on the St. Clair River have had no permanent impact on the water levels of Lake Erie. However, conveyance changes on the Niagara River as a result of infilling have caused an increase in Lake Erie's level. As well, the diversion of water out of Lake Erie through the Welland Canal has caused a decrease in the lake's level. Both of these changes occurred decades ago and are not causing new changes in water levels.

Lake Ontario

Status: The level of Lake Ontario has fluctuated above and below average since 1998.

Trend: High and low water levels on Lake Ontario have been compressed over the past 50 years since the implementation of the regulation of Lake Ontario outflows. The range over the past 15 years has been smaller than over the previous 35 years.

Rationale: The regulation of Lake Ontario outflows has a significant impact on its water level. The International Joint Commission (IJC) is seeking public consultation in spring 2012 for a new approach to managing Lake Ontario outflows that is based on the desire to help restore Lake Ontario's coastal wetlands, which have suffered under the current plan, while still balancing the basin's many needs and interests. The new regulation plan will have an influence on trends and if implemented will result in more natural flow and water level fluctuations in the Lake Ontario-St. Lawrence River system.

Other Spatial Scales:

Lake St. Clair

Status: The level of Lake St. Clair has fluctuated above and below average since 1998, with it being below average for the majority of the time.

Trend: There has been primarily a low water trend on Lake St. Clair over the past 13 years, but well above lows experienced since 1918.

Rationale: Lake St. Clair's water level is largely dependent on the magnitude of inflow from Lake Huron and the water level of Lake Erie. Ice jams in the St. Clair or Detroit Rivers can have a large short-term impact (days or weeks), as can intense rainfall/runoff events. Conveyance changes on the St. Clair River have had no permanent impact on the water levels of Lake St. Clair.

Purpose

- For this reporting period the purpose of the indicator is to highlight the current status of annual water levels and recent trends and the state of the science for projecting future water levels.
- The Great Lakes Water Levels indicator is used in the Great Lakes indicator suite as a State indicator in the Landscapes and Natural Processes top level reporting category.

For the future, the purpose will be to measure potential ecological vulnerability associated with changing water level regimes (deviation from pre-regulation levels and flows). Critical threshold criteria will be used to assess potential impacts of extreme water level events (anthropogenic and climate-change induced) to major components and features of the ecosystem.

Ecosystem Objective

For this reporting period, the indicator does not directly address ecosystem implications. In the future, the indicator will identify the range of water level regimes needed to support diverse biotic communities and natural ecosystem functions in the Great Lakes

Ecological Condition

Background on Great Lakes Water Level Fluctuations

Water level changes in the Great Lakes, including fluctuations that vary on timescales ranging from months to millennia, are the result of fluctuations of water supplies and storage in the Great Lakes basin. These are influenced by natural and anthropogenic factors, and long-term climate trends (Baedke and Thompson, 2000; Booth and Jackson, 2003). Fluctuating water levels and changing connecting channel flows on the Great Lakes pose significant risks to the economic, social, and environmental well-being of the Great Lakes region. High water levels can cause significant damage due to flooding, erosion, overtopping of shore protection structures, loss of beaches and recreational lands and their economic and social benefits, loss of wetlands, high channel flows can impede navigation, and there can be a greater susceptibility to storm damage from wind and waves. Low water can lead to increased dredging, encroachment of development in the nearshore, exposure of mudflats, undercutting of shore protection, loss of marina services and access to boat launch facilities, risks to water supply infrastructure, nearshore water quality issues, and ecosystem effects (e.g. isolating fish from their spawning habitats, or stranding wetlands). From an ecological perspective, short and long-term lake level fluctuations are critical to maintain healthy coastal habitats, especially coastal wetlands. However, dramatic or sustained long-term changes can degrade coastal habitats. The next SOLEC reporting period will provide a greater focus on the socio-economic and environmental implications of changing water levels particularly related to the ecosystem.

The summary below is an account of the overall factors affecting the Great Lakes water balance (Neff and Killian, 2003), and ultimately the water levels, and a limited discussion on water level history and variability.

The natural factors associated with long-term water level changes in the Great Lakes include environmental processes that contribute to inflow to, outflow from, and storage in the system. Within broad scales, water inflow and outflow are dictated by climatically-induced changes that affect the components of the hydrologic cycle. These components include over-lake precipitation, runoff, evaporation, and groundwater inflow-outflow. The 2007 SOLEC indicator report *Base Flow due to Groundwater Discharge* (Piggott *et al*., 2007) recognizes the contribution of groundwater discharge to runoff. The flow through the outlet and connecting channels are also elements of water inflow and outflow of the Great Lakes water balance (Neff and Killian, 2003; USGS, 2005; Wilcox *et al*., 2007), but over time the natural characteristics have been modified by anthropogenic changes.

An additional natural factor that affects water levels is glacial isostatic adjustment (GIA), which is the response of the earth's crust to removal of the weight of the last glacial ice sheets that crossed the area (Wilcox *et al*., 2007; IUGLS, 2009). Unlike hydrologic factors, GIA impacts on water levels vary from one location to another around a lake. At some locations, water levels appear to be rising as a result of GIA, while levels appear to be falling at other locations on the same lake. This has an implication for the analysis of historic water level data at a specific location.

While changes in land use/land cover have affected runoff, diversions into and out of the Great Lakes, dredging in connecting channels and construction of control structures on the outlets have had the largest anthropogenic impact on Great Lakes water levels (Wilcox *et al*., 2007). Infilling in connecting channels and consumptive uses have also had some impact.

Regulation of the outflows from Lake Superior and Lake Ontario seeks to lessen high and low levels (Wilcox *et al*., 2007). Lake Superior water levels have been regulated since 1916. In its 1914 Order of Approval, the International Joint Commission (IJC) established the International Lake Superior Board of Control and delegated to it responsibility for setting Lake Superior outflows. The Board of Control established a regulation plan that has undergone several revisions. The regulation plan currently in place incorporates the concept of balancing Lake Superior and Lake Michigan-Huron levels. The IUGLS examined whether a new regulation plan was warranted to address climate change and emerging issues. In their final report submitted in March 2012, the IUGLS Board has recommended a slightly revised regulation plan for the outflows of Lake Superior.

With the approval by the IJC of the hydropower project at Cornwall, Ontario and Massena, New York under the Order of Approval of 1952, Lake Ontario's outflow became subject to regulation. The first regulation plan became operational in 1960. Since the implementation of outflow regulation, water level fluctuations during the growing season have been reduced/compressed. For example, the standard deviation of June water levels has been reduced to 21 centimetres from a pre-regulation value of 40 centimetres. This reduction of the variability in water levels resulting from the regulation of Lake Ontario outflows has been shown to diminish wetland plant diversity and the habitats they support (LOSLR Study Board, 2006). A revised regulation plan that would allow for more natural patterns of water levels and flows was proposed by the IJC and is under consideration at the time of this writing.

One component of the recent International Upper Great Lakes Study (IUGLS) focused on the physical processes and possibility of ongoing (anthropogenic and/or natural) changes in the St. Clair River and the impacts on water levels of Lake Michigan-Huron (IUGLS, 2009). In that report, it was concluded that erosion of the St. Clair River had occurred subsequent to the last navigation dredging project, resulting in an increase in the conveyance capacity of the St. Clair River and a lowering of Lake Michigan-Huron water levels. While the IUGLS Board could not conclusively establish why the level of Lake Michigan-Huron is lower relative to that of Lake Erie since 1960, they did find that conveyance changes in the river do not appear to be ongoing. Recent IUGLS research verified that permanent lowering of Lake Michigan-Huron levels due to all human-induced and natural conveyance changes over the past century interacting with glacial isostatic adjustment exacerbated by climate variability and recent low water levels have threatened Georgian Bay wetlands and associated fish spawning habitat due to losses in hydraulic connectivity with the lake (IUGLS 2012). This is not a problem that can be addressed by regulation of Lake

Superior outflows because no regulation plan can permanently raise Lake Michigan-Huron levels.

Water levels are measured at several locations along the shore of the Great Lakes and their connecting channels by the National Oceanic and Atmospheric Administration (NOAA) in the United States and by the Canadian Hydrographic Service (CHS) in Canada (CHS, 2008). Several gauges in the current network of multiple gauges have been in operation only since 1918, while others have gauge records (some less reliable) extending back to the 1840s.

The recorded water level history is insufficient to capture a complete understanding of lake level variability. Rise and fall patterns showing a degree of periodicity in millennial timescale can be seen in reconstructed water level histories extended into the past, prior to the period of recorded water levels (USGS, 2005, Wilcox *et al*., 2007; Sellinger *et al*., 2007). Stochastic models can also be used to generate plausible alternative water supply sequences that reproduce key statistical characteristics of historical observations not seen in the brief historical record (Fagherazzi, 2011). These can be used in statistical analysis and regulation plan evaluation allowing a consideration of possible long-term wet and dry periods, beyond those experienced during the historic record.

<u>Status and Trends in Lake Level Fluctuations</u>

Hydrographs in Figures 1-5 of recorded lake levels show some similarities of interest (Wilcox *et al*., 2007). Generally, periods of higher levels occurred in the late 1920s, the mid-1950s, and from the early 1970s to mid-1990s. Pronounced low lake level periods occurred in the mid-1920s, the mid-1930s and the mid-1960s (Wilcox *et al*., 2007), and since levels declined again in 1998 (Sellinger *et al*., 2007). Though less well documented, low levels also occurred in the late 1890s, following a long period of high lake levels. Water levels on Lake Michigan-Huron have been consistently low since 1999, and Lake Superior levels hit new record lows (since 1918) for the months of August and September in 2007 (CHS, 2012; USACE, 2012). Some of those extreme levels were muted on Lakes Superior and Ontario after inception of regulation in 1916 and 1960, respectively (Wilcox *et al*., 2007). The range of fluctuations and the cyclic pattern of high and low levels on Lake Superior have not been altered as dramatically as on Lake Ontario. Since 1998, Lake Ontario has generally fluctuated around its long-term average level, but at a reduced range to what it would have without regulation.

Based on the historical record as shown in Figures 1-5, there appears to be a range within which the lake levels remain, but paleo records indicate a range that may have been greater (Brown *et al.*, 2012). Trends seen in the historical record are consistent with the quasi-periodic 160- and 30-33 year cycles identified in the paleo lake-level record (Baedke and Thompson, 2000). Recent observed impacts of climate change on lake ice cover, surface water temperature, evaporation, lake effect precipitation, and length of the stratification period have the potential to affect future Great Lakes water levels and quasi-periodic cycles. However, the interactions between these climate impacts are poorly understood and there is considerable uncertainty as to how these climate impacts will affect Great Lakes water levels. While there is clear evidence of temporal structure (e.g., years of high levels followed by years of low levels) scientists remain at a loss to explain or predict inter-annual and decadal cycles. Despite best efforts, forecasts of lake levels more than a month ahead do not yet have the skill required to effectively improve the regulation of outflows from Lake Superior or Ontario.

<u>Status and Trends of Lake Net Basin Supplies</u>

Through annual and monthly supply sequences it is possible to analyze the three important components of net basin water supply (NBS) terms and examine for trends. As noted by Fortin and Gronewold (2011) mean annual over-lake precipitation is generally higher than mean annual over-lake evaporation. More importantly mean annual runoff is higher than the mean annual net over-lake precipitation (P-E). Fortin and Gronewold (2011) point out that on an annual basis, the ratio of net over-lake precipitation to NBS is, on average, roughly 20% for Lake Superior and Michigan-Huron, roughly 1% for Lake Erie and roughly 10% for Lake Ontario. The contribution of net over-lake precipitation is much smaller than runoff hence, it is critical to accurately assess the runoff component. Figure 6 (derived from Fortin and Gronewold, 2011) shows annual mean net over-lake precipitation (P-E), runoff, and Component NBS for Lake Superior and Lake Michigan-Huron from 1948 to 2008, and indicates a general decrease in annual net over-lake precipitation (P-E) for Lake Michigan-Huron and Superior over the last several decades. On Lake Ontario (not shown), 2007 was the first year, for the period 1948-2008, with negative net over-lake precipitation.

Further attribution of the net precipitation (P-E) shows that over-lake precipitation is generally increasing largely in step with increasing lake evaporation, leading to a small year-over-year change to the net precipitation (P-E). However, this trend is not universal, as is easily demonstrated by contrasting Lake Superior and Lake Michigan-Huron, as shown in Figure 6, below. In the case of Lake Superior, annual precipitation appears relatively steady, while there appears to be increasing evaporation. Lake Michigan-Huron also shows an increasing evaporation trend since 1948 with what appears to be a corresponding trend towards increased over-lake precipitation. This evaporation trend has been documented on a number of occasions and is largely attributed to decreasing ice-cover as reported by Assel (2009) and in the phase I part of the IUGLS (2009).

Climate Change and Water Levels

The primary focus of the IUGLS was to evaluate options for regulation of Lake Superior outflows and water levels in a manner that benefits affected interests in the upper Great Lakes. Studies were undertaken to enhance the understanding of Great Lakes hydroclimatology and to better understand the implications of climate change and how this might impact the regulation decision. The Study included climate projections from ensembles of General Circulation Model (GCM) runs, regional climate models (RCMs), a variety of statistical modeling approaches, paleoclimate data analysis, observational data from two new eddy flux towers for open water evaporation measurement, and innovations in modeling of the Lake system responses to climate. The findings represent major steps forward in improving the understanding of the largest freshwater system in the world (Brown *et al.*, 2012; IUGLS, 2012).

There is considerable uncertainty in how climate change, particularly changes in precipitation may impact net basin water supplies and water levels and flows in the Great Lakes-St. Lawrence River region. The IUGLS Board undertook the development of a broad range of methods for developing plausible scenarios of climate change and variability. They developed a process for using the various sources of climate information to inform decision making. The focus of the approach was to first characterize the sensitivity of a decision to changes in climate conditions, and then evaluate the prospect of such changes based on a variety of climate information sources and their relative credibility as assessed by expert judgment (Brown *et al.*, 2012).

Analysis of the future sequences provided the context to determine plausible ranges of future net basin supply (NBS) sequences. The different future water supply scenario approaches used in the IUGLS included dynamic and statistical downscaling of global climate modeled scenarios (Angel and Kunkel, 2010; Lofgren and Hunter, 2010; MacKay and Seglenieks, 2010), stochastic generation of contemporary and climate change NBS sequences (Fagherazzi, 2011) and the use of paleo NBS sequences (Ghile *et al*., 2012) and were designed to provide an array of plausible future climate sequences for assessing the regulation plan. The stochastic sequences developed by Fagherazzi (2011) were found to encompass the full range of possible futures derived from the various methods. This series best reproduced the statistics of the historical NBS while introducing a range of variability in 30-year time windows well within the range of the various climate change projection methods (Brown *et al*., 2012). No attempt was made to assign a probability of occurrence to the sequences; they are considered to be plausible, and thus a potential future outcome.

The regional climate model (RCMs) results available to the IUGLS suggested that lake levels are unlikely to fall dramatically and may remain close to their contemporary mean over the next three decades (Lofgren *et al*., 2011;

MacKay and Seglenieks, 2010). New methods for RCM-type modeling that include and account for important atmospheric feedbacks were evaluated and found to be important. The RCMs in general appear to show systematic increases in both evaporation and overlake precipitation for most lake systems, consistent with observations since 1948. Climate change impacts may be increasing due to amplified seasonality of lake levels; loss of winter lake ice cover; loss of connecting channel ice cover; increased spring storminess; and increased wind speeds.

In the near term (i.e. next 10 – 20 years) the stochastic NBS series may be the most useful representation of future climate uncertainty impacting water levels (Brown *et al.*, 2012). Despite climate changes, at present there is no evidence that the statistics of the historical record are not valid (Brown *et al.*, 2012). The current record of Great Lakes NBS is marked by strong inter-annual and decadal variability, but showing no conclusive response that may be attributable with statistical certainty to climate change (Brown *et al.*, 2012). In the next 30 years, the IUGLS work suggests "natural variability" is likely to mask any forcing due to greenhouse gas emissions. Beyond that period of time, the GCM projections may hold more merit. However, due to limitations in the GCM projections for the Great Lakes region, it is clear that at present there is no satisfying representation of future climate change impacts on water levels on a near term time span. Nevertheless, based on all of the water supply sequences analyzed, there remains plausible risk of extreme water levels outside the historic range in the near- and/or long-term future. While the magnitude, duration and timing cannot be determined, the risk of wetter or dryer conditions and resulting extreme lake levels outside the historical range cannot be ignored. This is an important consideration when assessing the effectiveness of the regulation plans under altered conditions and determining when it may be appropriate to adjust the regulation plan as conditions change, and when considering alternative actions to managing risk.

Management Challenges/Opportunities

The IJC has proposed a revised regulation plan for the Lake Ontario-St. Lawrence River system for public comment in 2012. This revised plan encourages restoration of wetlands and habitats for key species through more natural flows while continuing to provide significant protection to other interests (IJC, 2012). The International Upper Great Lakes Study has identified an improved regulation plan for outflows of Lake Superior, but noted that the regulation of water flowing out through the existing structures on the St. Marys River has limited ability to reduce extremes, particularly downstream of Lake Superior. Regardless of the Lake Superior and Lake Ontario regulation plans adopted by the IJC, there will remain risk of water level extremes and ongoing monitoring and modelling efforts will be required to continue to assess risks and address uncertainties and changing conditions to inform management decisions.

While there is extensive knowledge of the broader impacts of climate change, there is considerable uncertainty in the quantification of these impacts on water levels and in the interaction of these impacts with other natural and anthropogenic factors that influence water levels.

While this uncertainty exists, there is strong evidence that water levels outside the historical range are plausible and should not be ignored, as they have clearly occurred in the past (Baedke and Thompson, 2000). As noted earlier in this document, fluctuating water levels can have significant implications across numerous economic sectors and across ecosystems.

In general, alternating periods of high and low levels are good for ecosystems as was demonstrated during both the LOSLR Study (2006) and the IUGLS (2012). However, there are complex relationships that can cause problems that are often a combination of water level range, time of the year, frequency and duration. The ecosystem risks include risks that can be managed to some degree by regulation, particularly for Lake Ontario and the upper St. Lawrence River (LOSL Study Board, 2006; IJC, 2012), and those that cannot. On the upper lakes, the risks that can be managed by changes to regulation plans are limited to impacts from low Lake Superior levels and impacts from low St. Marys River flows. St. Marys River impacts are more amenable to regulation remedies because solutions are

generally very short term and require less change in the water budget. All other ecosystem risks on the upper Great Lakes require other means of managing those risks (IUGLS, 2012).
Multi-lake regulation through the building of new dams in other connecting channels could help mitigate water level changes on lakes currently unregulated. However, it would not fully eliminate the risk of extreme lake levels, and could take decades to implement, cost billions of dollars and possibly come with significant ecological effects (IUGLS, 2012)

Efforts to coordinate approaches for managing risk and share successful approaches across jurisdictions have been limited with little focus to date placed on long-term implications of climate extremes and planning for an uncertain future (Donahue, 2010). Since the relatively short historical record of water levels may not be indicative of the future, and there are additional confounding issues such as glacial isostatic adjustment, storms, ice jams and human influences on the system, an adaptive management approach may provide the best alternative to addressing changing climate and the associated uncertainties (Brown *et al.*, 2012).

Adaptive management is a process of “learning while doing.” It provides a structured, iterative approach for improving actions through long-term monitoring, modeling and assessment, so that decisions can be reviewed, adjusted and revised as new information and knowledge becomes available and/or as conditions change. Adaptive management has an important role to play in addressing the risks of future changes in water levels in the Great Lakes. Many Great Lakes agencies have already begun developing or are undertaking an adaptive management planning framework. The IJC is proposing adaptive management as part of their proposed new approach to managing water levels and flows in the Lake Ontario-St. Lawrence River system, and the IUGLS Board proposed an adaptive management strategy as part of their report to the IJC in March 2012. Effective adaptive management will require binational coordination and agency support.

Comments from the authors

The purpose of this indicator as it is currently laid out in terms of reporting on current status of annual water levels and recent trends does not directly address ecosystem objectives or conditions. The authors propose therefore, that the next version of this indicator report place much more attention on the implications and related risk and vulnerabilities of changes in water levels rather than just reporting on the water levels themselves which in and of themselves does not really speak to the state of the ecosystem.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validate or quality-assured by a recognized agency or organization	X					
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respectable generator of data	X					
4. geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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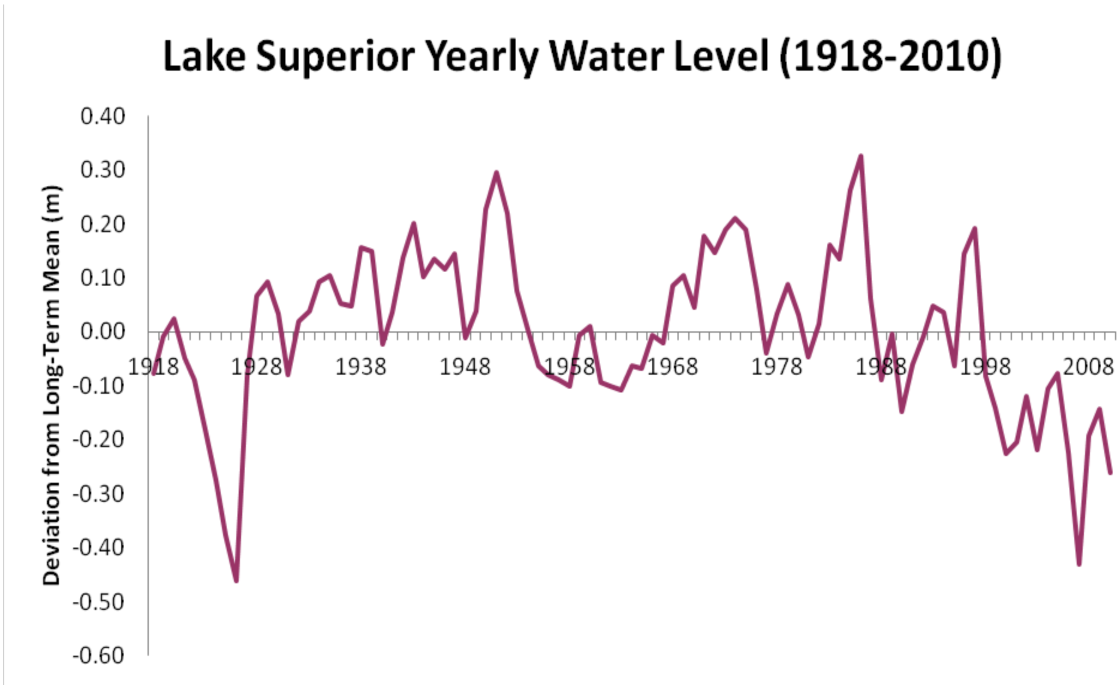
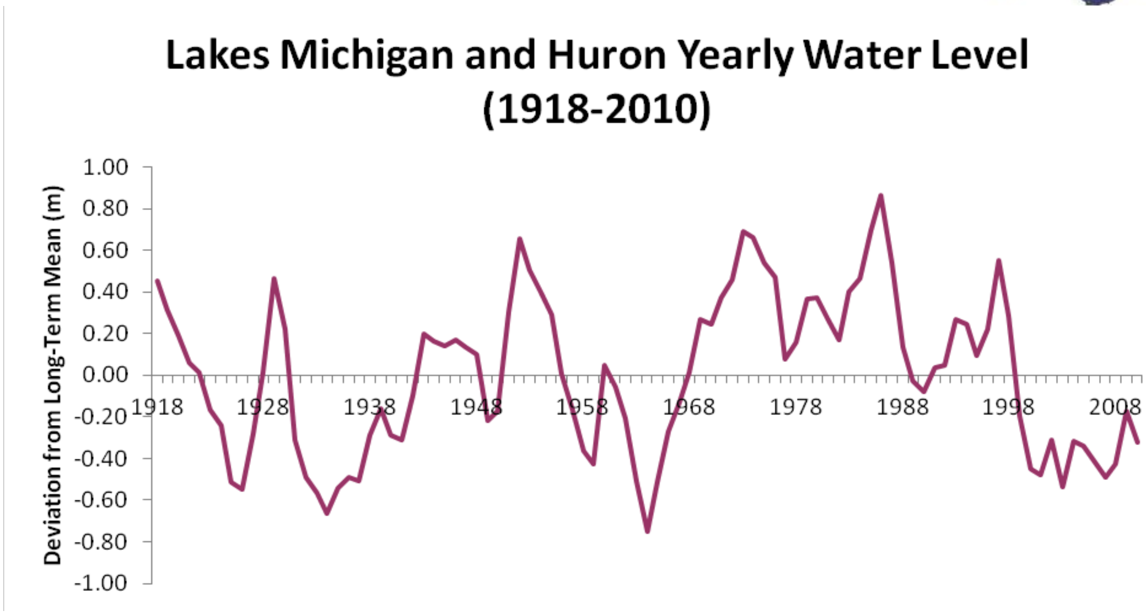


Figure 1. Lake Superior Deviations of Yearly Average Water Level from Long-Term Mean
Source: United States Army Corps of Engineers, Detroit District, Great Lakes Hydraulics and Hydrology



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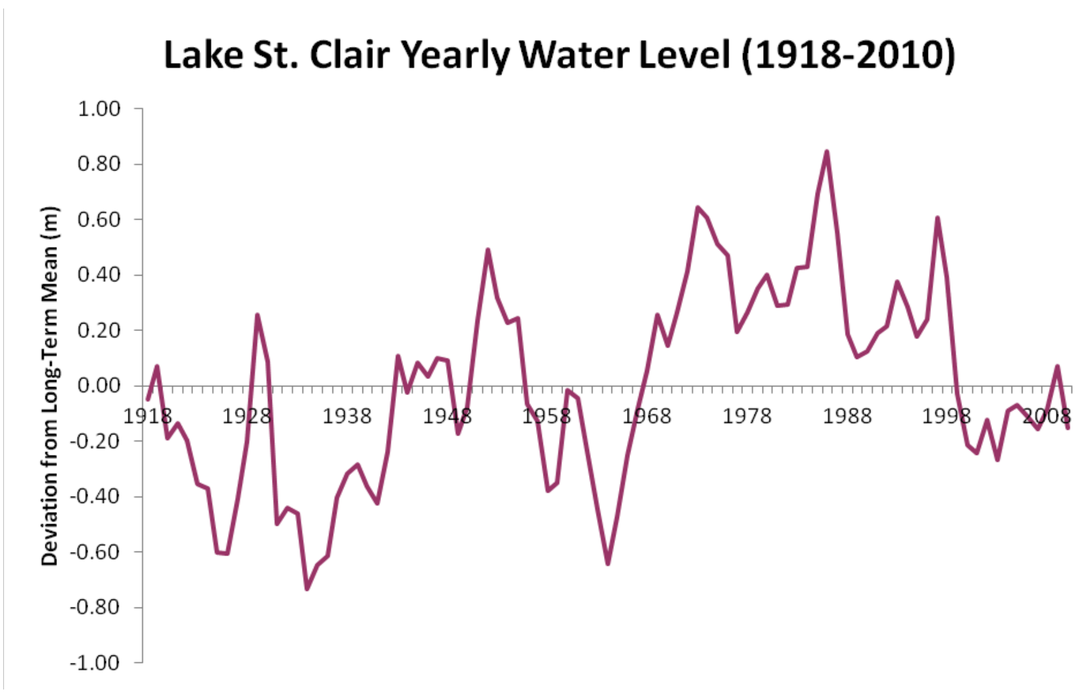

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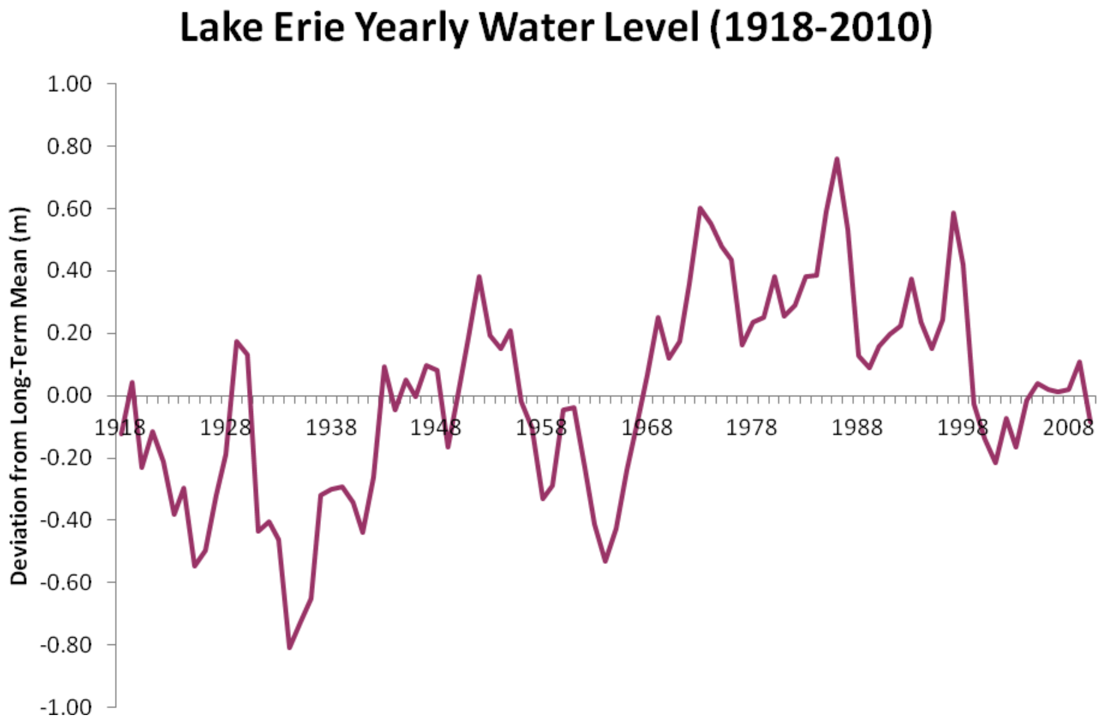

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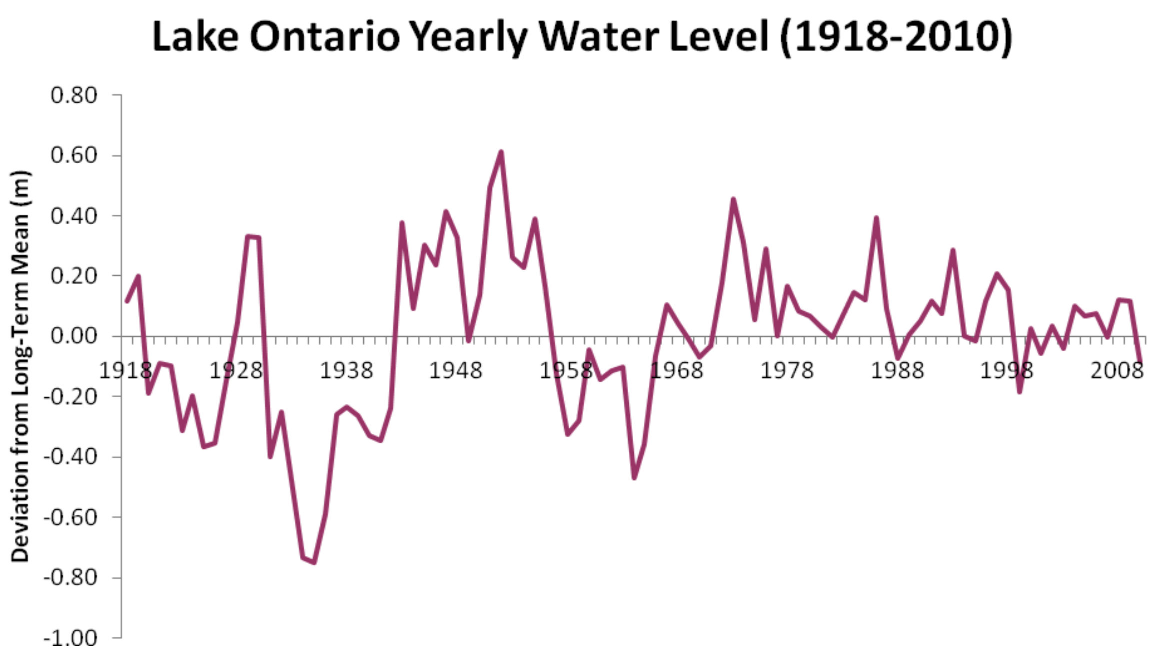

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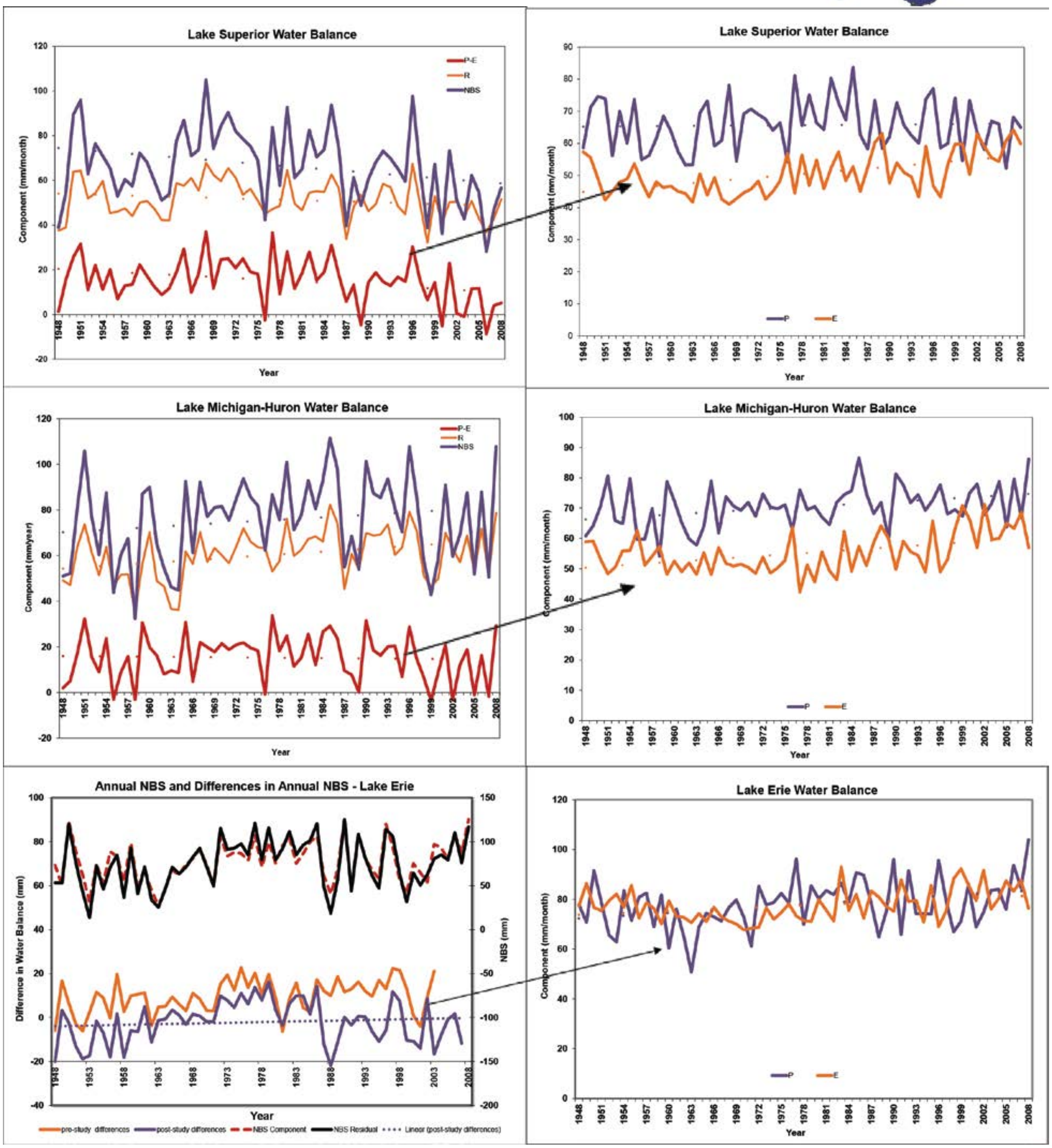

Figure 6. Water Balance of Lakes Superior, Michigan-Huron and Erie
Source: Fortin and Gronewold [2011]

Watershed Stressor Index (WSI)

Overall Assessment:

Status: **Because this is the first of report of a newly-derived indicator (the Watershed Stressor Index (WSI)) there is no existing frame of reference against which to assess status of the entire basin at this time. The basin is a globally unique entity subject to moderate or large amounts of development within its watershed. The spatial arrangement of watershed-based stress reflects the basin's geomorphology. Much of the southern part of the basin, which is underlain by rich soils and naturally supports deciduous forest, has been developed for agriculture or dwelling (Fig. 1), whereas the northern (Canadian Shield) part of the basin remains largely undeveloped (Fig. 1). When the combined stresses of population density, road density, agricultural development, conversion to non-natural land and point source pollution releases are considered, three of the five Great Lakes (Lakes Michigan, Erie and Ontario) are individually assessed as having a status of 'Poor', Lake Huron is assessed as 'Fair', and Lake Superior is assessed as 'Good'. Consequently, the status of the Great Lakes Basin overall is operationally defined as 'Fair'. The distribution of WSI scores among watersheds for the whole Great Lakes Basin is shown in Figure 2.**

Trend: Not assessed. This is the first report of the Watershed Stressor Index (WSI).

Lake-by-Lake Assessment:

Status: Table 1 summarizes the estimated degree of stress (risk of degradation) to which each Lake is subject according to 5 different watershed-based components and the Combined Watershed Stress Index score.

Lake Superior is minimally at risk of degradation due to human activities in the component watersheds (Fig. 3). Lake Superior had much more than 20% of its watersheds and total watershed area in the lowest stress quintile of every class of stressor. Consequently, its WSI scores were also in the lowest stress quintile and it is given an overall status of 'Good'.

Lakes Ontario and Erie fell at the opposite end of the WSI score scale (Fig. 4 and 5, respectively). Very few of the watersheds in these two lakes fell in the lowest quintiles, resulting in a classification of 'Poor' or 'Fair' for each component, and an overall status classification of 'Poor' (at greatest risk of degradation). Lake Erie watersheds were rated as 'Poor' (i.e. at greatest risk of degradation) because so many watersheds fell in the top quintile for agriculture-related stress (Fig. 6), proportions of developed land, and population density (Table 1). In contrast, although Lake Ontario was rated as 'Fair' for four of the five component stress categories (Table 1), its combined WSI score placed it in the 'Poor' category overall (Tables 2a and 2b; Fig. 4).

Lake Michigan had an underrepresentation of watersheds falling in the lowest quintile of agricultural stress from a basinwide perspective resulting in a rating of 'Poor' for this metric (Table 1). But Lake Michigan also was underrepresented in terms of watershed area supporting the highest population density. Other stressor conditions were classified as 'Fair' for Lake Michigan, leading to an overall status classification for Lake Michigan as 'Poor' (at high risk of degradation; Tables 2a and 2b). Fig. 7 shows the distribution of WSI across Lake Michigan.

Lake Huron was intermediate among the Great Lakes. It was classified as 'Good' (at lowest risk of degradation) for amount of developed land and road density, and 'Fair' in other stressor categories, leading to an overall classification of 'Fair' according to the WSI (Fig. 8).

Other Spatial Scales

The components of the WSI are tabulated and scored for the land bordering each Lake rather than for the Lakes themselves. However, there is strong evidence that the effects of land-based stress are manifested in the aquatic habitats most closely associated with each watershed. Niemi et al. (2007), Peterson et al. (2007) and Yurista and Kelly (2009) found that the correlation between land-based stress and waterborne nutrients was highest for tributary streams and coastal wetlands. Although the correlation becomes weaker with increasing distance from shore, the correlation remains statistically significant in water 10 m deep or more. The greater the stress, the greater the risks of degradation of biological features in the lakes themselves. These relationships have recently been qualitatively scored and shown in lakewide and basinwide maps as ‘threats’ (or risk of degradation) by Allan et al. (2013).

Purpose

The purpose of the Watershed Stressor Indicator is to assess the relative level of stress derived from the watersheds on the environmental quality of Great Lakes and to infer the potential (risk) of harm from manifestations of human activity in watersheds to Great Lakes water quality, aquatic-dependent life, and natural processes. The Watershed Stressor Index is used in the Great Lakes indicator suite as a Pressure indicator in the Resource Use & Physical Stressors category.

Ecosystem Objective

The combined effects of watershed stressors should not result in the impairment of the physical, biological or chemical integrity of the Great Lakes as reflected in Annex 2 and Annex 13 of the 1987 Great Lakes Water Quality Agreement – restoration and protection of beneficial uses and pollution from non-point sources.

Ecological Condition

The relative amount of stress imposed by 5 measures of human activity on the land within the 51,462,074 ha area of the Great Lakes basin was assessed for each of the 5,971 drainage basins surrounding the Great Lakes (as generated from an ArcHydro GIS analysis (Holllenhorst et al. 2007)).The measures compiled from various sources and evaluated were **Road Density**, **Population Density**, **Relative Amount of Agricultural Land**, **Relative Amount of Developed Land**, and **Number of Point Source Discharges**. The raw values of each variable were transformed to a standard ‘relative’ score for each watershed. Scores for each variable were scaled to range from zero (minimum value observed in the basin) to one (maximum value observed in the basin). The 5 standardized relative scores for each watershed were then added together to form a “SumRel” (sum of relative values) score. The combined “SumRel” value was itself then converted to a zero-to-one scale (zero = basin-wide minimum; one = basin-wide maximum). This combined measure of overall human activity in the watershed is the Watershed Stressor Index. The index was generated from data compiled from maps and surveys conducted between 2000 and 2007 (Ciborowski et al. 2011).

In the absence of biological data against which to calibrate the stressor scores, we have design-nated the 20th percentile of the distribution of stress scores for each variable and the WSI as the criterion for classifying a watershed as ‘Good’ vs. ‘Fair’. We have designated the 80th percentile the distribution as the boundary between ‘Fair’ and ‘Poor’. Watersheds classified as ‘Good’ pose minimal risk of degradation of the biological community in Great Lakes aquatic receiving habitats. Watersheds classified as ‘Poor’ are at greatest risk of having degraded Great Lakes communities. The raw values representing the minimum, maximum, 20th percentile and 80th percentiles for the Great Lakes components and WSI scores are listed in Table 3. Future status assessments will be made relative to these values.

Linkages

Many impairments of biological condition or ecosystem processes in the Great Lakes can be attributed to stresses imposed by human activity on the adjacent landscape. The WSI is a pressure indicator that quantifies the risk of impairment of the biological integrity of various aquatic habitats.

The quintile approach is used to classify the condition of each Great Lake’s shoreline according to the 5 stressor classes described above because there are presently no confirmatory data relating biological conditions to particular ranges of land-based stressor types. Although arbitrary, the approach of splitting data into quartiles or quintiles has traditionally been used to designate ‘nonreference’ conditions in the developing IBIs (Indices of Biotic Integrity) (US EPA 2000).

We designated the 20th percentile (Reference/Nonreference Condition or Good/Fair) and 80th percentile (Non-degraded/Degraded Condition or Fair/Poor) as boundaries for each basinwide stressor gradient by which to classify the watersheds in each Great Lake as either ‘Good’ (equivalent to reference; low risk of deterioration due to land-based stress), ‘Poor’ (equivalent to degraded; high risk of deterioration due to land-based stress), or ‘Fair’ (intermediate risk) as per SOLEC. These boundaries will be adjusted to reflect the amount of stress at which biological changes are observed first-hand in streams, wetlands, nearshore and offshore locations corresponding to the watershed for which the stressor scores are now known. Initiatives such as the GLRI-funded *“Testing and Refining Great Lakes Environmental Indicators”* [GLEI-2] (Johnson et al. 2010) and “*Implementing Great Lakes Coastal Wetland Monitoring”* (Uzarski et al. 2010) projects are generating the data that will allow the boundaries to be refined shortly.

Management Challenges/Opportunities

The components and total WSI score have been determined for every Great Lakes watershed based on data from 2000-2007. This permits managers to assess the risk of degradation due to the 5 component variables at any shoreline location. Once the Good/Fair and Fair/Poor boundaries have been refined through reference to changes in biological communities, the locations at greatest risk of significant biological loss (those approaching the boundaries) and those with greatest potential for restoration (sites with stress scores only slightly higher than the boundaries) can be identified. These are the locations where investment in protection or restoration should most likely to succeed.

Comments from the author(s)

The WSI scores have great value in helping with calibration of various SOLEC bioindicators-in-development, by providing independent measures of site-specific stress against which biological responses can be assessed. The major limitation is that the land-use information on which the indices are based was compiled 7-15 years ago. Thus, they may not reflect current conditions, especially in areas of rapid development that would benefit most from assessment.

Assessing Data Quality:

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization						X
2. Data are traceable to original sources	X					
3. The source of the data is a known, reliable and respected generator of data	X					
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin	X					
5. Data obtained from sources within the U.S. are comparable to those from Canada	X					
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report	X					

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Members of the Great Lakes Environmental Indicators project - Gerald L. Niemi (Senior PI; NRRI, University of Minnesota Duluth), Nicholas P. Danz (University of Wisconsin – Superior), and Thomas Hollenhorst (US EPA, Mid-Continent Ecology Division National Health and Environmental Effects Research Laboratory, Duluth, MN 55804) contributed to conceptual development of the approach used to derive the combined indicator. Scudder D. Mackey (Habitat Solutions NA) and Li Wang (University of Windsor) contributed to the cross-walking and amalgamation of Canadian and US-based information into a common dataset. Sandra E. George (Environment Canada, Burlington) and Mike Robertson (Ontario Ministry of Natural Resources, Peterborough, ON) were especially helpful in facilitating the licensing and acquisition of map data on which the combined stressor derivations were based. The SOLEC coordinators Rob Hyde, Nancy Stadler-Salt, Stacey Cherwaty-Pergentile (Environment Canada, Burlington, ON), and Paul Horvatin and Karen Rodriguez (US EPA GLNPO, Chicago, IL) provided the impetus for developing the concept paper on watershed stressors that led to the most recent iteration and calculations of the WSI.

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Table 1. Summary of the status (risk of biological degradation to adjacent waters) of 5 landscape-related stressor variables and combined Watershed Stress in each Great Lake assessed according to the relative proportion of watersheds and watershed areas representing the lowest and highest quintiles of each stressor class. Detailed Lake by Lake data and maps showing distribution of watersheds in 'Good' condition and 'Poor' condition are provided by Ciborowski et al. (2011).

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Figure 3. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Superior colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.

Figure 4. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Ontario colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.

Figure 5. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Erie colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.

Figure 6. Distribution of intensity of agriculture (Relative Amount of Land Area in Agriculture (percent)), across Lake Erie in 2002 (US) and 2006 (Canada) colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the agricultural intensity scale.
Figure 7. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Michigan colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.
Figure 8. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Huron colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.

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Stressor Class (Stress Risk)

Lake	Land In Agric.	Point Sources	Amount of Developed Land	Road Density	Population Density	Combined Watershed Stress
Ontario	Fair	Fair	Fair	Fair	Poor (Highest)	Poor (Highest)
Erie	Poor (Highest)	Fair	Poor (Highest)	Fair	Poor (Highest)	Poor (Highest)
Huron	Fair	Fair	Good (Lowest)	Good (Lowest)	Fair	Fair
Michigan	Poor (Highest)	Fair	Fair	Fair	Good (Lowest)	Poor (Highest)
Superior	Good (Lowest)	Good (Lowest)	Good (Lowest)	Good (Lowest)	Good (Lowest)	Good (Lowest)

Table 1. Summary of the status (risk of biological degradation to adjacent waters) of 5 landscape-related stressor variables and combined Watershed Stress in each Great Lake assessed according to the relative proportion of watersheds and watershed areas representing the lowest and highest quintiles of each stressor class. Detailed Lake by Lake data and maps showing distribution of watersheds in 'Good' condition and 'Poor' condition are provided by Ciborowski et al. (2011).

Combined Watershed Stress Score

Lake	Basinwide # Watersheds	Basinwide Total Area (ha)	No. watersheds in lowest quintile (basinwide)	Total area of these watersheds	No. watersheds in highest quintile (basinwide)	Total area of these watersheds
Ontario	816	6,492,391	20	1,341	340	3,305,851
Erie	1047	7,835,019	71	9,389	440	6,895,817
Huron	1496	12,880,829	370	1,290,473	138	2,887,869
Michigan	1081	11,711,965	49	14,570	238	7,378,519
Superior	1531	12,541,870	684	8,474,758	39	58,434
Total	5971	51,462,074	1194	9,790,531	1195	20,526,490

Table 2a. Number of watersheds and watershed area of each Great Lake in the quintiles with the lowest and highest Watershed Combined Stressor Score.
Source: Ciborowski et al. (2011)

Combined Watershed Stress Score

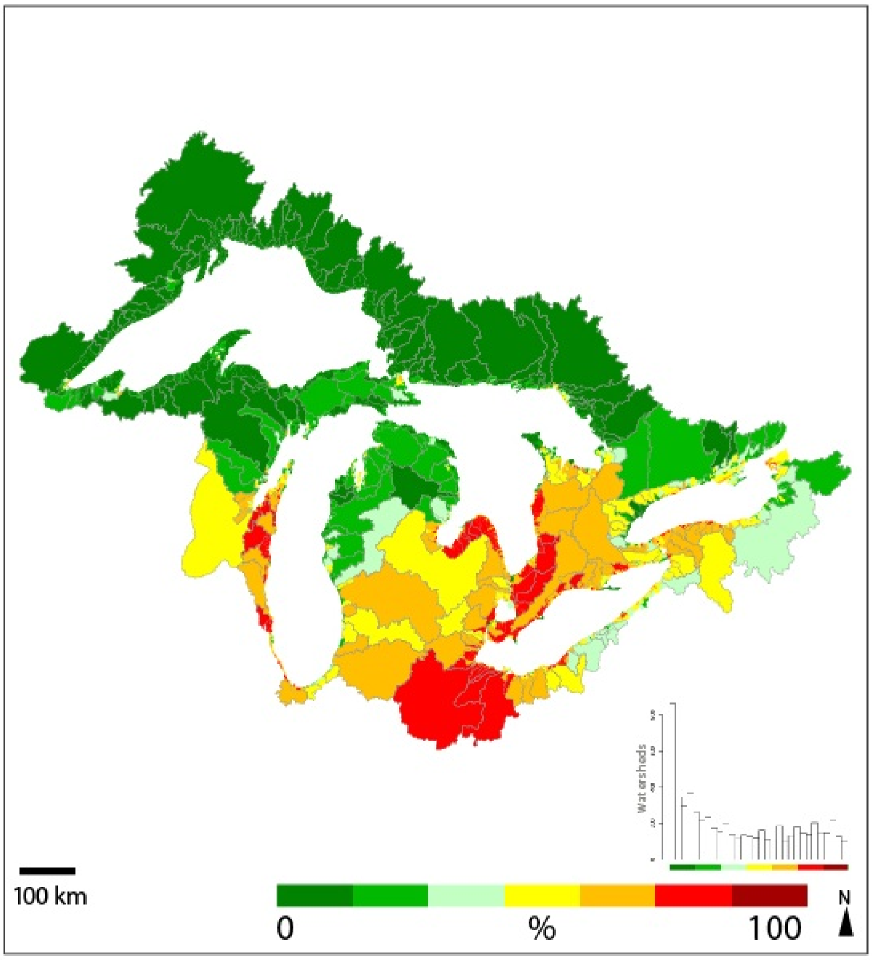
Lake	% of watersheds in lowest quintile	% of Area in lowest quintile	% of watersheds in highest quintile	% of Area in highest quintile	Provisional Assessment
Ontario	2.5	0.02	41.7	50.9	Poor
Erie	6.8	0.1	42.0	88.0	Poor
Huron	24.7	10.0	9.2	22.4	Fair
Michigan	4.5	0.1	22.0	63.0	Poor
Superior	44.7	67.6	2.5	0.5	Good
Total	20.0	19.0	20.0	39.9	

Table 2b. Proportion of watersheds and watershed area of each Great Lake in the quintiles with the lowest and highest Watershed Combined Stressor Score
Source: Ciborowski et al. (2011)

Raw values of 5 components of the combined Watershed Stressor Indicator

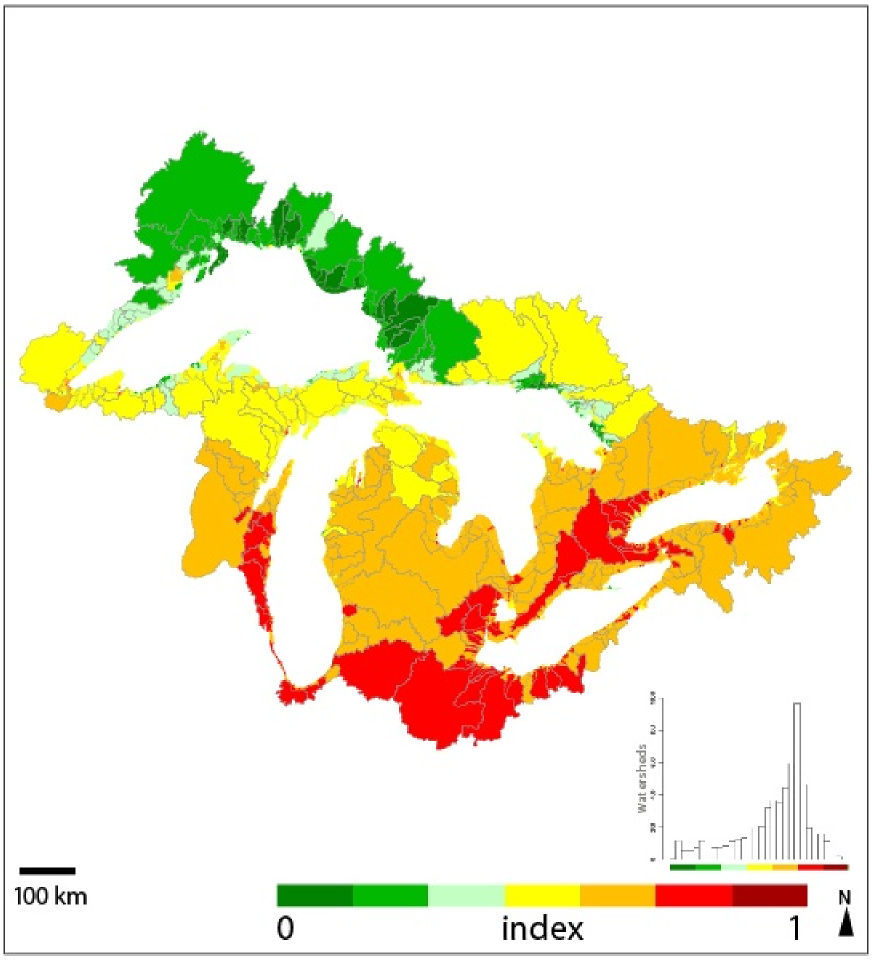
Variable	Minimum Risk	20th Percentile (Good/Fair)	80th Percentile (Fair/Poor)	Maximum Risk (99th percentile)
Road Density (km/km^2)	0	0.50	3.76	13.66
Population Density ($people/km^2$)	0	1.111	98.65	3.81×10^3
Point source discharges($points/km^2$)	0	0.00	0.00	0.77
Agricultural Land (percent)	0	0.00	54.94	100.00
Developed Land (percent)	0	1.35	29.29	100.00
Combined Stress Score	0	0.407	0.713	1.000

Table 3. Raw values of 5 components of the combined Watershed Stressor Indicator representing minimum and maximum risks (scale endpoints) and classification boundaries between reference/nonreference conditions (raw values at the 20th percentile of all watersheds in 2000) and non-degraded/degraded conditions (raw values at the 80th percentile of all watersheds in 2000) for Great Lakes catchments.
Source: Ciborowski et al. (2011)



Great Lakes Non-natural landcover

Figure 1. Distribution of intensity of developed land cover (Relative Amount of Land Area Developed (percent)) across the entire Great Lakes basin in 2000/2001 colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the developed land cover scale. Source: Ciborowski et al. (2011)



Great Lakes SumRel

Figure 2. Distribution of combined Watershed Stress Index (WSI) scores (SumRel – sum of the relative intensities of Relative Amount of Land Area in Agriculture (percent), Relative Amount of Land Area Developed (percent), Point Source Discharge Density, Population Density and Road Density by watershed across the entire Great Lakes basin colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.
Source: Ciborowski et al. (2011)

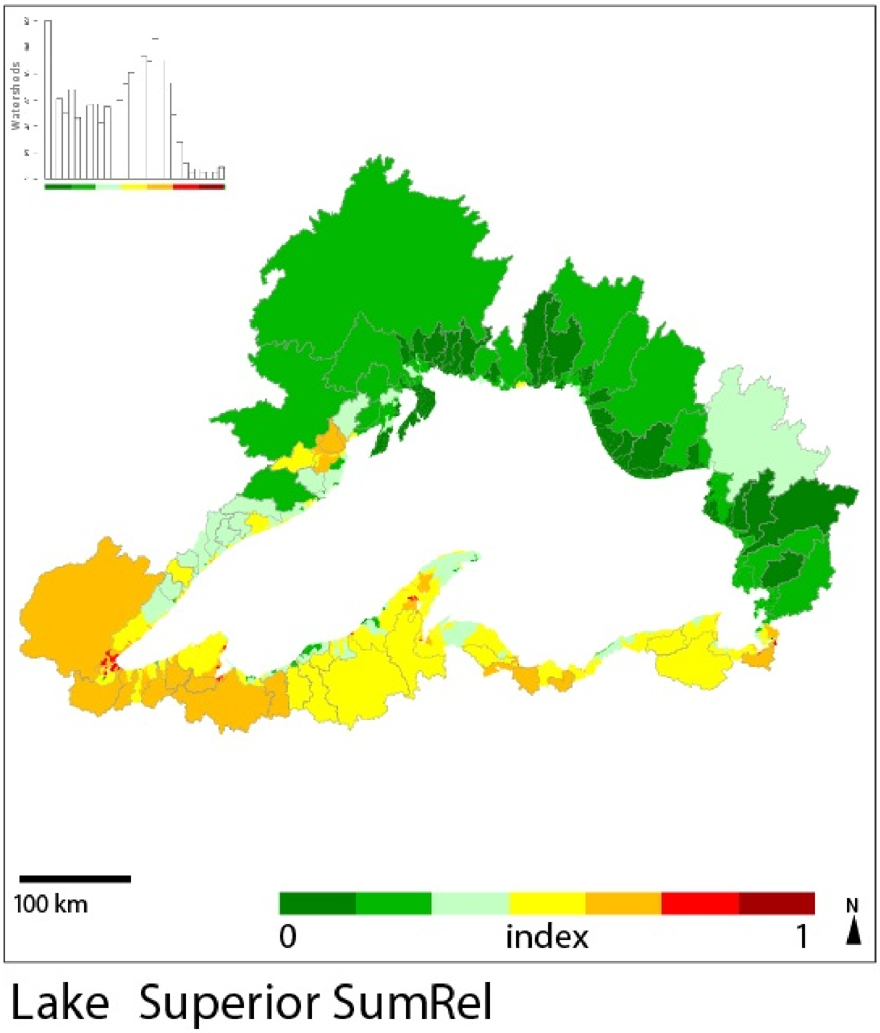
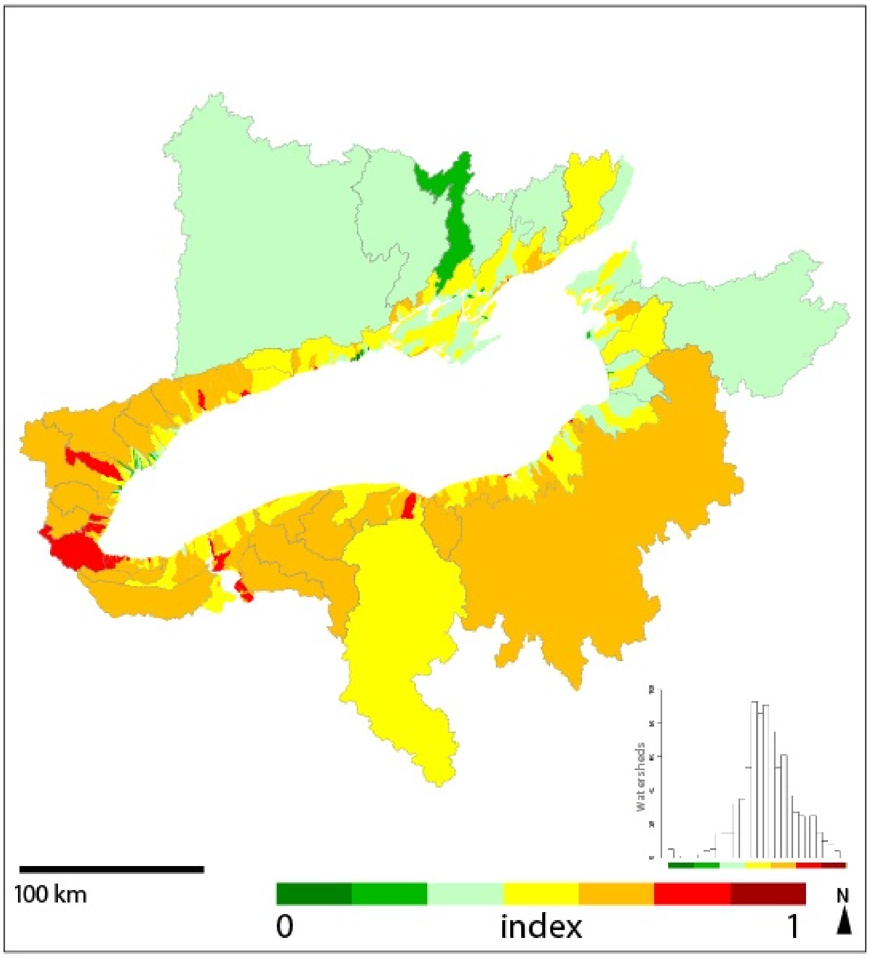


Figure 3. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Superior colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.
Source: Ciborowski et al. (2011)



Lake Ontario SumRel

Figure 4. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Ontario colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.
Source: Ciborowski et al. (2011)

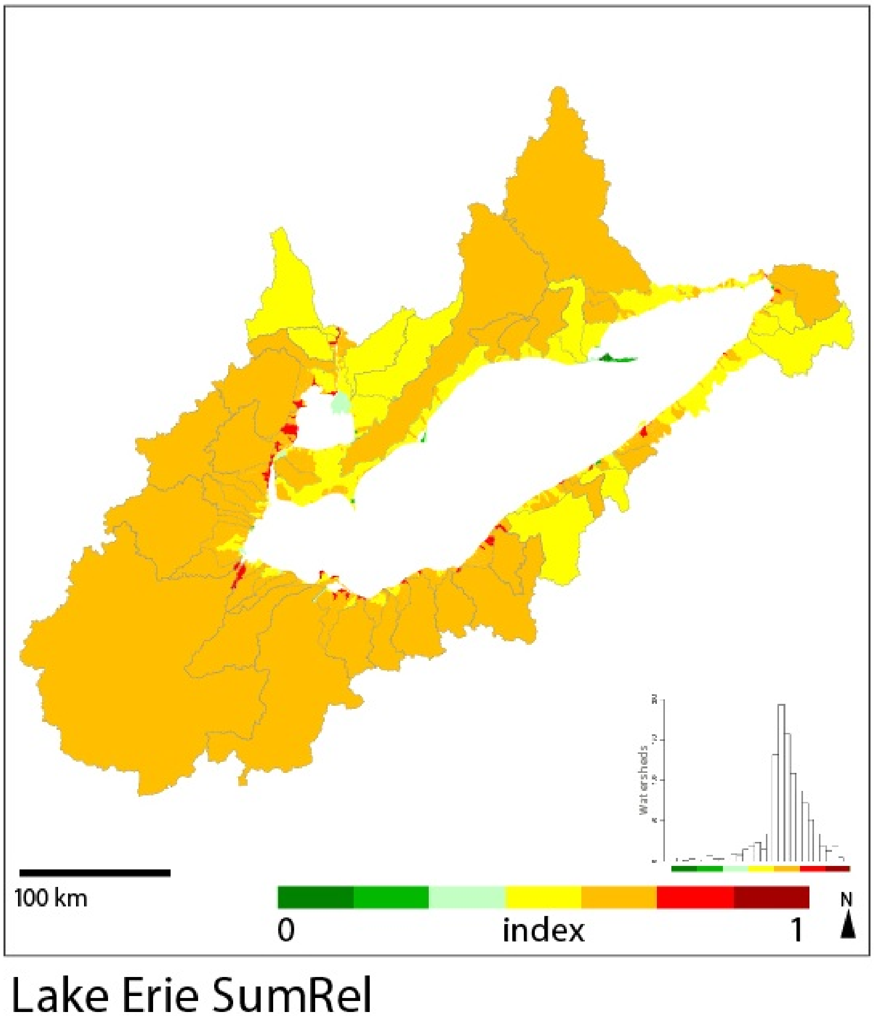
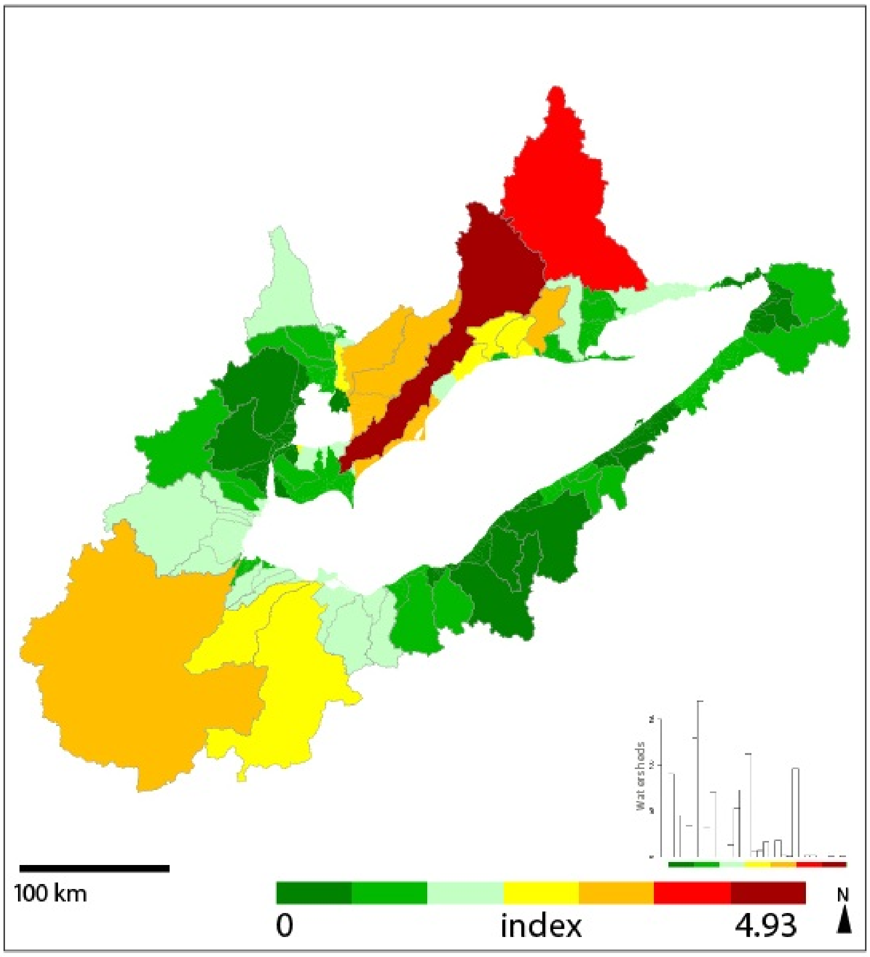
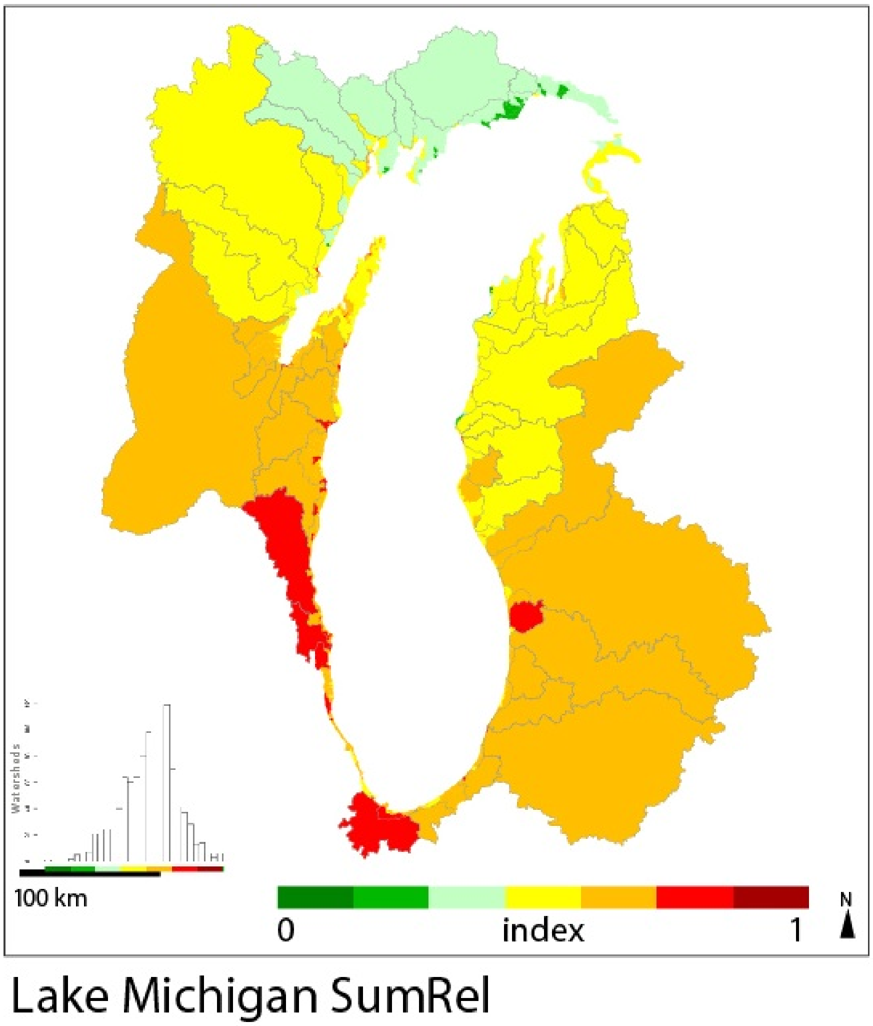


Figure 5. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Erie colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.
Source: Ciborowski et al. (2011)



Lake Erie Ag. census

Figure 6. Distribution of intensity of agriculture (Relative Amount of Land Area in Agriculture (percent)), across Lake Erie in 2002 (US) and 2006 (Canada) colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the agricultural intensity scale. Source: Ciborowski et al. (2011)



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Source: Ciborowski et al. (2011)

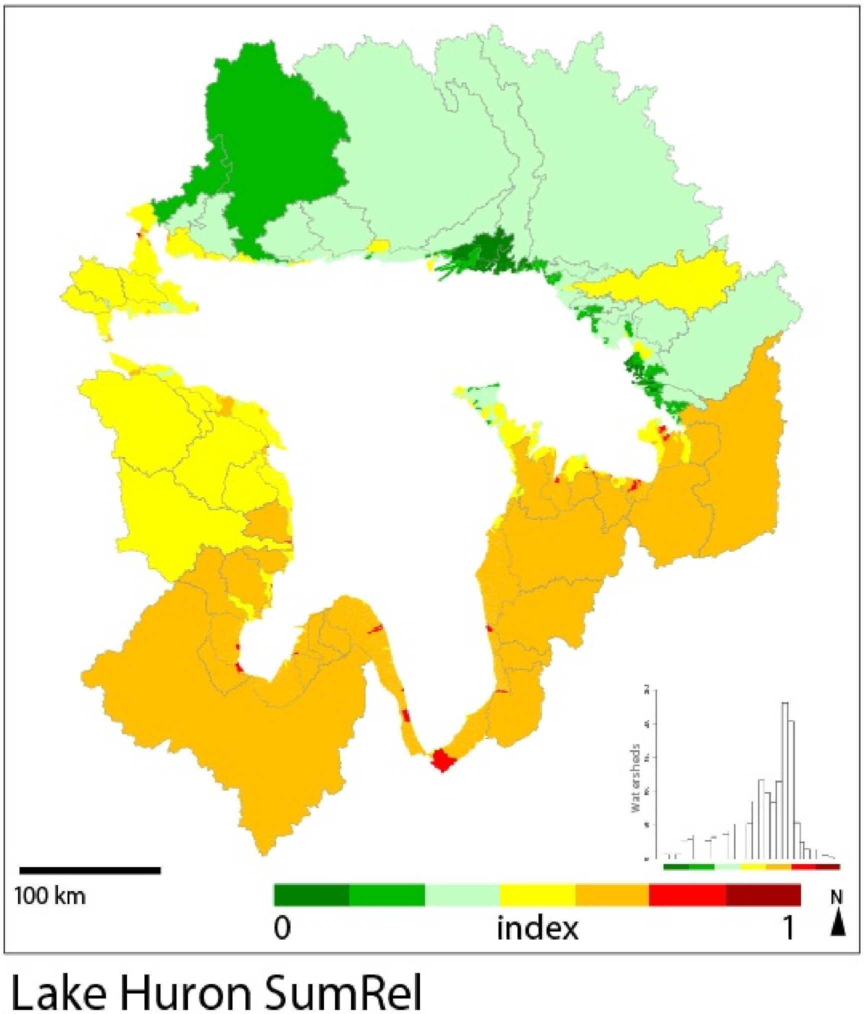

Figure 8. Distribution of Combined Stress (SumRel – sum of the relative intensities of Agricultural Activity, developed land cover, Point Source Discharge Density, Population Density and Road Density by watershed across Lake Huron colour-coded from least (dark green) through average (yellow) to most (maroon). Inset histogram shows the frequency distribution of watersheds across the SumRel scale.
Source: Ciborowski et al. (2011)

Zooplankton Biomass

Overall Assessment

Status: Undetermined

Trend: Undetermined (changing)

Rationale: Changes in community size and structure are occurring in Lake Michigan, Lake Huron, and Lake Ontario, with total biomass declining and shifts in community composition away from cladocerans and cyclopoid copepods towards calanaoid copepods, consistent with both oligotrophication and invasive species impacts. Consequences for fish communities are as yet unresolved.

Lake-by-Lake Assessment

Lake Superior

Status: Good

Trend: Unchanging

Rationale: Stable summer zooplankton community is dominated by large calanoid copepods.

Lake Michigan

Status: Undetermined

Trend: Undetermined (changing)

Rationale: Summer biomass of cladocerans has been declining since 2002. Summer mean size of zooplankton has increased due to increases in large calanoids. Current (2006) community is indicative of cold, unproductive system.

Lake Huron

Status: Undetermined

Trend: Undetermined (changing)

Rationale: Total summer biomass has declined dramatically since 2002 due to fewer *Daphnia*, bosminids, and cyclopoid copepods. Summer mean size of zooplankton is increasing. Current (2006) community is indicative of cold, unproductive system.

Lake Erie

Status: Undetermined

Trend: Undetermined

Rationale: Variable biomass and composition of summer crustacean zooplankton community in each basin. Most diverse zooplankton community in the Great Lakes. No trends apparent between 1998 and 2006.

Lake Ontario

Status: Undetermined

Trend: Undetermined (changing)

Rationale: Lowest percentage of calanoid copepods of all Great Lakes. Total summer biomass has declined since 2003 due to a decline in cyclopoid copepods. Invasive *Bythotrephes* might be influencing community size and spatial distribution.

Purpose

- The Zooplankton Populations indicator assesses characteristics of the zooplankton community over time and space, and will be used to infer changes over time in vertebrate or invertebrate predation, system productivity, energy transfer within the Great Lakes, or other food web dynamics.
- Measures used to characterize the zooplankton community are total crustacean biomass and composition,

average crustacean length, and ratio of calanoids to cladocerans + cyclopoids.

- The Zooplankton Populations indicator is used in the Great Lakes indicator suite as a State indicator in the Aquatic-dependent Life category.

Ecosystem Objective

Maintain the biological integrity of the Great Lakes and support a healthy and diverse fishery as outlined by the Goals and Objectives of the LaMPs and Great Lakes Fishery Commission. This indicator supports decision making about an Annex 2, beneficial use, specifically degradation of phytoplankton and zooplankton populations. The relationship between the measures tracked in this indicator and the above ecosystem objectives are not fully worked out. As such, precise quantitative goals for this indicator do not yet exist.

Gannon and Stemberger (1978) found that cladocerans and cyclopoid copepods are more abundant in nutrient enriched waters of the Great Lakes, while calanoid copepods dominate oligotrophic communities. They reported that areas of the Great Lakes where the density of calanoid copepods comprises over 50% of the summer crustacean zooplankton community (or the ratio of calanoids to (cyclopoids + cladocerans) is greater than 1) could be classified as oligotrophic. Clear objectives, though, have not presently been defined.

Planktivorous fish often feed size selectively, removing larger cladocerans and copepods. High densities of planktivores therefore can result in a reduction of the mean size of zooplankton in a community. Mills *et al.* (1987) have found that mean crustacean zooplankton size > 0.8 mm were associated with predator:panfish ratios > 0.2. Their work, however, was conducted in small, warm water lakes where cladocerans, rather than calanoid copepods, are likely to dominate. The universality of this relationship remains unclear at this time. In particular, there are questions regarding its applicability to systems with large numbers of calanoid copepods, systems impacted by predaceous cladocerans and dreissenids, and situations where the size structure of the crustacean zooplankton community is primarily a consequence of food type or availability rather than predation.

Ecological Condition

Currently EPA monitoring data for crustaceans are only available through 2006 due to delays in sample analysis. Details on methods for zooplankton sampling and analysis can be found in Barbiero et al. 2001. Summer biomass of crustacean zooplankton communities in the offshore waters of Lake Superior has remained at a relatively low but stable level since at least 1998 (Figure 1). The plankton community is dominated by large calanoid copepods (*Leptodiaptomus sicilis* and *Limnocalanus macrurus*) that are characteristic of oligotrophic, cold water ecosystems. Since 2003 the biomass of cladocerans and cyclopoid copepods in Lake Huron has declined dramatically, with total biomass very similar to that of Lake Superior as of 2006. Data from 2005 and 2006 suggest that a similar decline may now be occurring in Lake Michigan, although this has been offset somewhat by an increase in the biomass of *L. macrurus*. Summer communities in both lakes have become increasingly similar to that of Lake Superior, with both composition and magnitude characteristic of a cold oligotrophic system. Cyclopoid abundance has also begun to show evidence of decline in Lake Ontario. Mechanisms for these declines are not known at this time, although evidence has recently been presented for reductions in primary production as a driving factor in the changes in Lake Huron (Barbiero et al. 2011). Other possible causes include exotic species interactions or fish predation pressure.

The proportion of calanoid copepods in Lake Superior has remained fairly stable at 70%, indicating oligotrophic conditions (Figure 2). Summer zooplankton communities in Lake Michigan and Lake Huron have shown an increasing proportion of calanoid copepods in recent years, which suggest increased oligotrophication. Primary production, and in particular the spring phytoplankton bloom, has indeed declined notably in both lakes coincident with the changes in the zooplankton communities. In the case of Lake Michigan, the increased proportion of calanoids has been due both to an increase in *L. macrurus*, and a decline in cladoceran populations, while in Lake Huron it has been a result primarily of substantial declines in cladoceran and cyclopoid copepod populations. Lake Ontario has the lowest proportion of calanoids, followed closely by the nutrient enriched western basin of Lake Erie.

Values for the central and eastern basins of Lake Erie are at intermediate levels and exhibit considerable interannual variation.

Mean length of crustacean zooplankton in the offshore waters of the Great Lakes is generally greater in the spring than during the summer (Figure 3). In the spring, mean zooplankton size in all of the Great Lakes is near or above 0.8 mm. Mean length in Lake Superior declines during the summer due to the production of immature copepodids, but it is still above the criterion. Summer mean lengths in Lake Huron and Lake Michigan remain high and have begun to show increases in recent years, most likely due to the increased importance of *L. macrurus* noted above. In Lake Erie and Lake Ontario, the mean length of zooplankton declines considerably in the summer. Whether this decline is due to predation pressure or to the increased abundance of bosminids (0.4 mm mean length) and immature cyclopoids (0.65 mm mean length) is unknown.

Linkages

Zooplankton community size and structure can be influenced by a number of factors. As major food items of a number of fish species, shifts in both species composition and community size structure can result from changing planktivorous fish populations (e.g., Wells 1970), or alternatively, can potentially impact preyfish communities through bottom-up effects as noted below. Zooplankton communities can also be impacted by invasive species, both directly, e.g., through predation by the invasive predatory cladoceran *Bythotrephes longimanus* (Barbiero and Tuchman 2004), or indirectly, e.g., through alterations in nutrient cycling and transport caused by dreissenid mussels (Vanderploeg et al. 2012)

Management Challenges/Opportunities

Changes in the zooplankton communities of Lake Huron and Lake Michigan, and to a lesser extent Lake Ontario, are consistent with reductions in nutrient levels, which have been seen in all three lakes, and could represent a consequence of nutrient reduction activities, perhaps compounded by effects of dreissenid mussels. The reductions in cladocerans in the former two lakes, along with recent declines in populations of the benthic amphipod *Diporeia*, could represent a decreasing food base for forage fish and in turn require adjustments in fish stocking goals. However, exact mechanisms of these declines, and the relative strength of bottom-up versus top-down forcings, have yet to be fully determined.

An important threat to the zooplankton communities of the Great Lakes is posed by invasive species. The continued proliferation of dreissenid populations can be expected to impact zooplankton communities through the alteration of the structure and abundance of the phytoplankton community, upon which many zooplankton depend for food. Predation from the exotic cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi* may also have an impact on zooplankton abundance and community composition. Invasive predatory cladocerans have been shown to have had a major impact on zooplankton community structure in the Great Lakes (Barbiero and Tuchman 2004).

Comments from the author(s)

Currently the most critical need is for the development of quantitative, objective criteria that can be applied to the zooplankton indicator. The applicability of current metrics to the Great Lakes is largely unknown, as are the limits that would correspond to acceptable ecosystem health.

Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		x				
2. Data are traceable to original sources		x				
3. The source of the data is a known, reliable and respected generator of data		x				

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		x				
5. Data obtained from sources within the U.S. are comparable to those from Canada						x
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		x				

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Ora Johannsson, Department of Fisheries and Oceans Canada, Burlington, Ontario Canada

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List of Figures

Figure 1. Average composition of crustacean zooplankton biomass at Great Lakes offshore stations, 1998-2006, sampled in August of each year. Samples were collected with 153 µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

Figure 2. Average percentage of calanoid copepods (by abundance) in crustacean zooplankton communities from Great Lakes offshore stations sampled in August/September for 1998-2006 (excluding 2000). Samples were collected with 153 µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Line at 50% level is the suggested criterion for oligotrophic lakes.

Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

Figure 3. Average individual mean lengths of crustacean zooplankton in the Great Lakes in April/May and August/September for 1998-2006 (excluding 2000). Length estimates were generated from data collected with 153 µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Values are arithmetic averages of all sites sampled within each basin. Line at 0.8 mm was determined by Mills et al. (1987) to be associated with predator:panfish ratios > 0.2.

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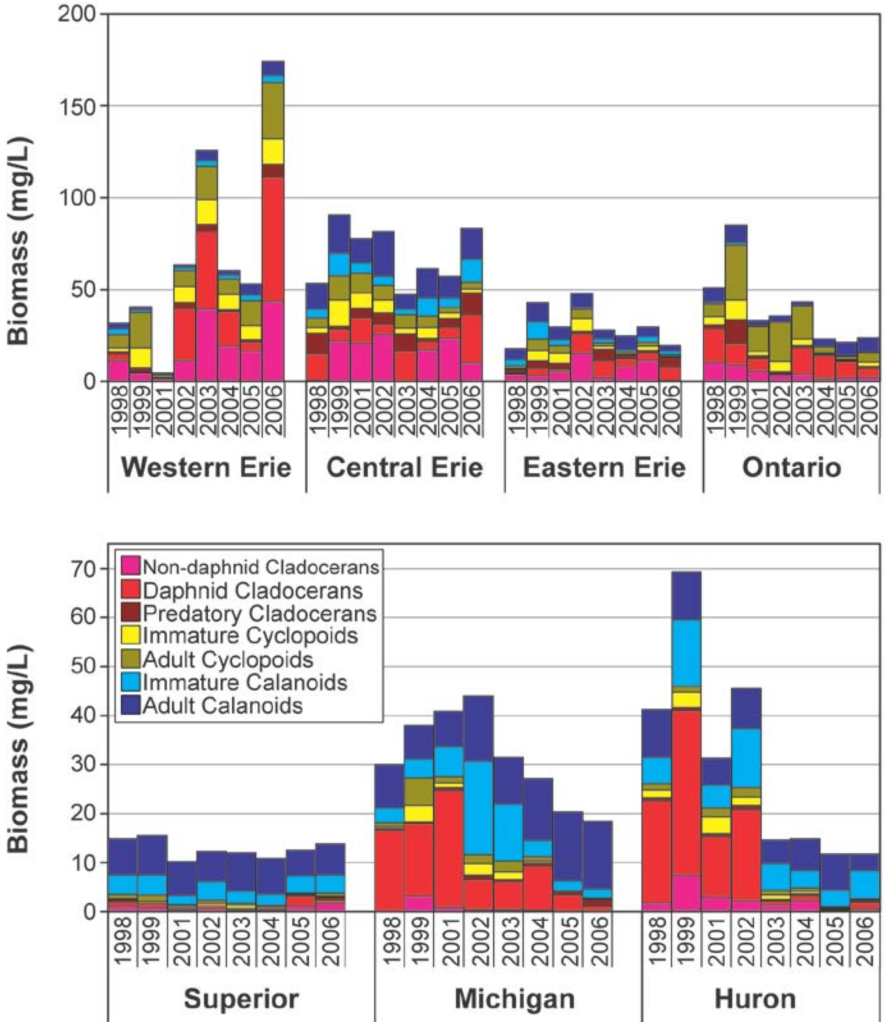
Last Updated

Full update completed in *State of the Great Lakes 2009*.

Some content updated for *State of the Great Lakes 2011*.



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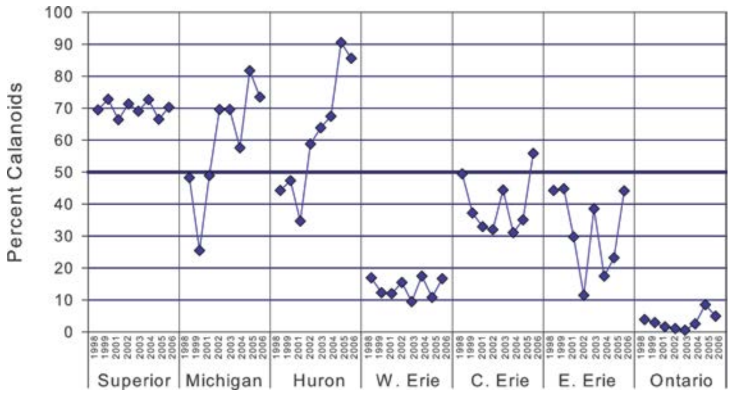

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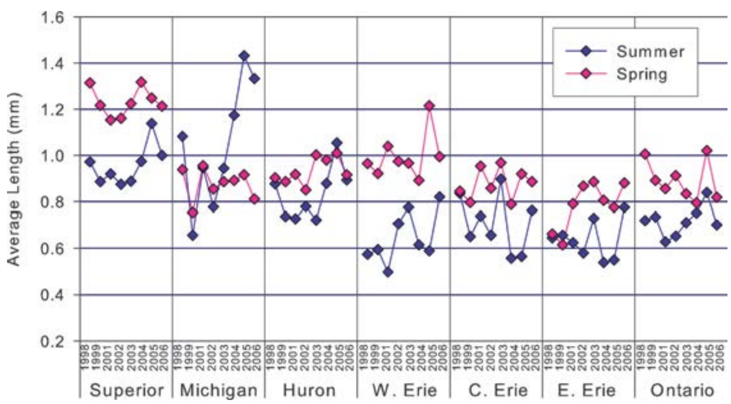

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Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

5. Acronyms and Abbreviations

Agencies and Organizations
ATSDR – Agency for Toxic Substances and Disease Registry
CAMNet – Canadian Atmospheric Mercury Network
CCME – Canadian Council of Ministers of the Environment
CDC – Center for Disease Control (U.S.)
CIS – Canadian Ice Service
CORA – Chippewa Ottawa Resource Authority
CWS – Canadian Wildlife Service
DFO – Department of Fisheries and Oceans Canada
EC – Environment Canada
ECO – Environmental Careers Organization
EERE – Office of Energy Efficiency and Renewable Energy (U.S. Department of Energy)
EIA – Energy Information Administration (U.S.)
EMAN – Ecological Monitoring and Assessment Network
FSC – Forest Stewardship Council
GERA – Gaia Economic Research Associates
GLBET – Great Lakes Basin Ecosystem Team (USFWS)
GLC – Great Lakes Commission
GLCWC – Great Lakes Coastal Wetlands Consortium
GLFC – Great Lakes Fishery Commission
GLNPO – Great Lakes National Program Office (U.S. EPA)
HPMS – Highway Performance Monitoring System (U.S.)
IJC – International Joint Commission
IUCN – International Union for the Conservation of Nature
MDEQ – Michigan Department of Environmental Quality
MDNR – Michigan Department of Natural Resources
NAPS – National Air Pollution Surveillance (EC)
NHEERL – National Health & Environmental Effects Research Laboratory (U.S. EPA)
NISC – National Invasive Species Council
NOAA – National Oceanic and Atmospheric Administration
NRCan – Natural Resources Canada
NRCS – Natural Resources Conservation Service (USDA)
NRRI – Natural Resources Research Institute (University of Minnesota – Duluth)
NYSDEC – New York State Department of Environmental Conservation
ODNR – Ohio Department of Natural Resources
ODW – Ohio Division of Wildlife
OFEC – Ontario Farm Environmental Coalition
OGS – Ontario Geological Survey
OIPIS – Ontario Invasive Plant Information System
OMAF – Ontario Ministry of Agriculture and Food (now OMAFRA, see below)
OMAFRA – Ontario Ministry of Agriculture, Food and Rural Affairs
OMOE – Ontario Ministry of Environment
OMNR – Ontario Ministry of Natural Resources
OSCIA – Ontario Soil and Crop Improvement Association
ORISE – Oak Ridge Institute for Science and Education
PDEP – Pennsylvania Department of Environmental Protection

REMAP – Regional Environmental Monitoring and Assessment Program (U.S.)
TNC – The Nature Conservancy
UKIH – United Kingdom Institute of Hydrology
USDA – U.S. Department of Agriculture
U.S. EPA – U.S. Environmental Protection Agency
USFDA – U.S. Food and Drug Administration
USFWS – U.S. Fish and Wildlife Service
USFS – U.S. Forest Service
USGS – U.S. Geological Survey
WBCSD – World Business Council for Sustainable Development
WDNR – Wisconsin Department of Natural Resources
WDO – Waste Diversion Organization (Ontario)
WiDPH – Wisconsin Department of Public Health
WWF – World Wildlife Fund (Canada)

Units of Measure
C – Celsius
Cm – centimeter, 10^{-2} meters
F – Fahrenheit
Fg – femptogram, 10^{-15} gram
ft – feet (British system)
ha – hectare, 10,000 square meters, 2.47 acres
lbs – pounds (British system)
kg – kilogram, 1000 grams, 2.2 pounds
km – kilometer, 0.62 miles
kt – British kiloton: $2x10^6$ pounds; metric kilotonne: 10^6 kg or $2.2x10^6$ pounds
kWh – kilowatt-hour
m – meter
mg – milligram, 10^{-3} gram
mg/kg – milligram per kilogram, part per million
mg/l – milligram per liter
ml – milliliter, 10^{-3} liter
mm – millimeter, 10^{-3} meter
MWh – megawatt-hour
ng – nanogram, 10^{-9} gram
ng/g – nanogram per gram, part per billion
ng/l – nanogram per liter
pg – picogram, 10^{-12} gram
pg/m^3 – picogram per cubic meter
pH – per Hydrogen (a unit of acidity)
ppb – part per billion
ppm – part per million
ton – British ton, 2000 lb
tonne – metric tonne, 1000 kg, 2200 lb
µg – microgram, 10^{-6} gram
µg/g – microgram per gram, part per million
µg/l – microgram per liter
$\mu g/m^3$ – microgram per cubic meter

µm – micrometer, micron, 10^{-6} meter

Chemicals
2,4-D – 2,4-dichlorophenoxyacetic acid
2,4,5-T – 2,4,5-trichlorophenoxyacetic acid
BaP – Benzo[α]pyrene
BDE – Brominated diphenyl ethers
BFR – Brominated flame retardants
CO – Carbon monoxide
DDT – 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane or dichlorodiphenyl-trichloroethane
DDD – 1,1-dichloro-2,2-bis(p-chlorophenyl) ethane
DDE – 1,1-dichloro-2,2-bis(chlorophenyl) ethylene or dichlorodiphenyl-dichloroethene
DOC – Dissolved organic carbon
HBCD – Hexabromocyclododecane
HCB – Hexachlorobenzene
α-HCH – Hexachlorocyclohexane
γ-HCH – Lindane
HE – Heptachlor epoxide
Hg – Mercury
MeHg – Methylmercury
NAPH – Naphthalene
NO_2 – Nitrogen dioxide
NO_X – Nitrogen oxides
O_3 – Ozone
OC – Organochlorine
OCS – Octachlorostyrene
PAH – Polynuclear aromatic hydrocarbons
PBDE – Polybrominated diphenyl ether
PCA – Polychlorinated alkanes
PCB – Polychlorinated biphenyls
PCDD – Polychlorinated dibenzo-*p*-dioxin
PCDF – Polychlorinated dibenzo furan
PCN – Polychlorinated naphthalenes
PFOA – Perfluorooctanoic acid
PFOS – Perfluorooctanyl sulfonate
PM10 – Atmospheric particulate matter of diameter 10 microns or smaller
PM2.5 – Atmospheric particulate matter of diameter 2.5 microns or smaller
SO_2 – Sulfur dioxide
SPCB – Suite of PCB congeners that include most of PCB mass in the environment
TCDD – Tetrachlorodibenzo-*p*-dioxin
TCE – Trichloroethylene
TDS – Total dissolved solids
TGM – Total gaseous mercury
TOC – Total organic carbon
TRS – Total reduced sulfur
VOC – Volatile organic compound

Other

AAQC – Ambient Air Quality Criterion (Ontario)
AFO – Animal Feeding Operation
ANS – Aquatic Nonindigenous Species
AOC – Area of Concern
AOU – Area of the Undertaking
APF – Agricultural Policy Framework (Canada)
AQI – Air Quality Index
ARET – Accelerated Reduction/Elimination of Toxics program (Canada)
ATFS – American Tree Farm System
BA – Abnormal Barbels
BEACH – Beaches Environmental Assessment and Coastal Health (U.S. Act of 2000)
BKD – Bacterial Kidney Disease
BMP – Best Management Practices
BOB – Ballast On Board (also Upbound Transoceanic Ballasted vessels)
BOD – Biochemical Oxygen Demand
BUI – Beneficial Use Impairments
CAFO – Concentrated Animal Feeding Operations
CAIR – Clean Air Interstate Rule
CBT – Caffeine Breath Test
C-CAP – Coastal Change and Analysis Program
CC/WQR – Consumer Confidence/Water Quality Report
CEPA – Canadian Environmental Protection Act, 1999
CFU – Colony Forming Units
CHT – Contaminants in Human Tissue program (part of EAGLE)
CMA – Census Metropolitan Area (Canada)
CNMP – Comprehensive Nutrient Management Plan (U.S.)
CSO – Combined Sewer Overflow
CUE – Catch per Unit of Effort
CUrLUS – Canadian Urban Land Use Survey
CWS – Canada-wide Standard (air quality)
DRP – Dissolved Reactive Phosphorus
DPSIR – Driving Forces – Pressures – State – Impacts – Responses Framework
DWS – Drinking Water System (Canada)
EAGLE – Effects on Aboriginals of the Great Lakes program (Canada)
DWSP – Drinking Water Surveillance Program (Canada)
EAPI – External Anomaly Prevalence Index
EFP – Environmental Farm Plan (Ontario)
EMS – Early Mortality Syndrome
EO – Element Occurrence
EPR – Extended Producer Responsibility
ESV – Early Successional Vegetation
FCGO – Fish Community Goals and Objectives
FCO – Fish Community Objectives
FD – Focal Discoloration
FIA – Forest Inventory and Analysis (USDA Forest Service)
FQI – Floristic Quality Index
FTU – Formazin Turbidity Unit

GAP – Gap Analysis Program (land cover assessment)
GHG – Greenhouse Gases
GIS – Geographic Information System
GLEI – Great Lakes Environmental Indicators
GLI – Great Lakes Initiative (U.S. EPA)
GLWQA – Great Lakes Water Quality Agreement
GMO – Genetically Modified Organisms
GW – Groundwater
HABs – Harmful Algal Blooms
HGEMP – Herring Gull Egg Monitoring Program
HUC – Hydrologic Unit Code
IACI – International Alvar Conservation Initiative
IADN – Integrated Atmospheric Deposition Network
IBI – Index of Biotic Integrity
IGLD – International Great Lakes Datum (water level)
IMAC – Interim Maximum Acceptable Concentration
IPM – Integrated Pest Management
ISA – Impervious Surface Area
LaMP – Lakewide Management Plan
LE – Lesion
LEL – Lowest Effect Level
LU/LC – Land use/Land cover
MAC – Maximum Acceptable Concentration
MACT – Maximum Available Control Technology
MCL – Maximum Contaminant Level
MEI – Modified Environmental Index
MGD – Million Gallons per Day (3785.4 m3 per day)
MLD – Million Liters per Day (1000 m3 per day)
MMP – Marsh Monitoring Program
MSA – Metropolitan Statistical Area (U.S.)
MSWG – Municipal Solid Waste Generation
NAFTA – North America Free Trade Agreement
NATTS – National Air Toxics Trend Site (U.S. network)
NATA – National Air Toxics Assessment (U.S.)
NEEAR – National Epidemiological and Environmental Assessment of Recreational [Water Study]
NEI – National Emissions Inventory (U.S.)
NHANES – National Health and Nutrition Examination Survey (CDC)
NM – Act Nutrient Management Act
NMAN – Nutrient Management Planning software (Ontario)
NIS – Terrestrial non-native species
NISA – National Invasive Species Act
NLCD – National Land Cover Data
NMP – Nutrient Management Plan (Ontario)
NOAEC – No Observable Adverse Effect Concentrations
NOAEL – No Observable Adverse Effect Level
NOBOB – No Ballast On Board (also Cargo Laden vessels)
NPDES – National Pollution Discharge Elimination System (U.S.)
NPRI – National Pollutant Release Inventory (Canada)

NRVIS – Natural Resources and Values Information System (OMNR)
NTU – Nephelometric Turbidity Units
ODWQS – Ontario Drinking Water Quality Standard
OPEP – Ontario Pesticides Education Program
PBT – Persistent Bioaccumulative Toxic (chemical)
PEL – Probable Effect Level
PICA – Priority Island Conservation Areas
PNP – Permit Nutrient Plans (U.S.)
PGMN – Provincial Groundwater-Monitoring Network (Ontario)
RAP – Remedial Action Plan
RfD – References Dose
RPA – Resource Planning Act
RG – Raised Growths
SDWIS – Safe Drinking Water Information System (U.S.)
SFI® – Sustainable Forestry Initiative
SIP – State Implementation Plan
SOLEC – State of the Lakes Ecosystem Conference
SOLRIS – Southern Ontario Land Resource Information System
SPP. or spp. – Species
SQI – Sediment Quality Index
SSO – Sanitary Sewer Overflow
SUV – Sport Utility Vehicle
SWMRS – Seasonal Water Monitoring and Reporting System (Canada)
TCC – Total Category Change
TCR – Total Coliform Rule
TDI – Tolerable Daily Intake
TEQ – Toxic Equivalent
TIGER – Topological Integrated Geographic Encoding and Reference (U.S. Census Bureau)
TM – Thematic Mapper
TRI – Toxics Release Inventory (U.S.)
UNECE – United Nations Economic Commission for Europe
VKT – Vehicle Kilometers Traveled
WIC – Women Infant and Child (Wisconsin health clinics)
WISCLAND – Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data
WQI – Water Quality Index
WTP – Water Treatment Plant
WWTP – Waster Water Treatment Plant
YOY – Young-of-year

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Federal

- Canadian Food Inspection Agency
  - Plant Pest Surveillance Unit
- Environment Canada
  - Canadian Wildlife Service
    - Ontario Region
    - Sustainable Water Management
  - Communications Branch
    - Program Advice and Support - Ontario
  - Environmental Stewardship Branch
    - Strategic Priorities
      - Air Emissions Priorities
      - Ecosystem and Biodiversity Priorities (formerly Biodiversity Convention Office)
    - Environmental Protection Operations Division – Ontario
      - Environmental Emergencies Section
      - Program Integration Section
  - Meteorological Service of Canada
  - Science and Technology Branch
    - Air Quality Research
      - Measurements & Analysis Research Section (formerly International Air Deposition Network)
      - Analysis and Air Quality Section (formerly National Air Pollution Surveillance Network)
    - Climate Research (formerly Climate and Atmospheric Research Directorate)
      - Climate Data and Analysis Section
    - Water Science and Technology (formerly National Water Research Institute)
      - Aquatic Ecosystem Impacts Research Division
      - Lake Management Research Division
      - Water Quality Monitoring and Surveillance (formerly Ecosystem Health Division)
    - Wildlife and Landscape Science
      - Landscape Science and Technology (formerly Ecological Monitoring and Assessment Network)
      - Wildlife Toxicology and Disease (formerly National Wildlife Research Centre)
    - Strategic Integration and Partnerships – Ontario
      - Great Lakes Environment Office
      - Great Lakes Management & Reporting Section (formerly Regional Science Advisor's Office)
      - Policy and Aboriginal Relations Section

Fisheries and Oceans Canada
- Great Lakes Laboratory for Fisheries and Aquatic Sciences

National Oceanic and Atmospheric Administration
- Great Lakes Environmental Research Laboratory
- Great Lakes Sea Grant Network
  - Illinois-Indiana Sea Grant
  - Michigan Sea Grant
  - New York Sea Grant
  - Pennsylvania Sea Grant

Natural Resources Canada
- Canada Centre for Remote Sensing
  - Geomatics Canada
- Central and Northern Branch
  - Geological Survey of Canada
- Canadian Forest Service

United States Army Corps of Engineers
- Detroit District
- Chicago District

United States Coast Guard
- Ninth Coast Guard District

United States Department of Agriculture
- Natural Resource Conservation Service
- United States Forest Service
  - Northern Research Station
    - Forest Inventory and Analysis
  - Northeastern Area State and Private Forestry

United States Department of Health and Human Services
- Center for Disease Control
  - Agency for Toxic Substances and Disease Registry
    - Research Implementation Branch
- Federal Occupational Health

United States Department of Interior
- National Park Service
  - Great Lakes Network Office
  - Sleeping Bear Dunes National Lakeshore

United States Environmental Protection Agency
- Great Lakes National Program Office
- Office of Research and Development
  - National Health and Environmental Effects Research Laboratory
    - Mid-Continent Ecology Division
- National Exposure Research Laboratory
  - Environmental Sciences Division
    - Landscape Ecology Branch
- Region 2
  - Watershed Management Branch
    - New York Watershed Management Section
- Region 5
  - Land and Chemicals Division
  - Office of Public Affairs
  - Water Division
  - Waste, Pesticides, and Toxics Division

United States Fish and Wildlife Service
- Alpena National Fish and Wildlife Conservation Office
- Ashland National Fish and Wildlife Conservation Office
- Green Bay National Fish and Wildlife Conservation Office
- La Crosse Fish Health Center
- Lower Great Lakes Fishery Resource Office

United States Geological Survey
- Biological Resources Division
- Great Lakes Science Center
  - Lake Erie Biological Station
  - Lake Ontario Biological Station
  - Lake Superior Biological Station
- National Wildlife Health Center
- Water Resources Division

Provincial and State

Illinois Department of Natural Resources

Illinois Environmental Protection Agency
- Division of Remediation Management

Indiana Department of Environmental Management
- Natural Resources Damage Program

Indiana Department of Natural Resources

Indiana Finance Authority
- Indiana Brownfields Program

Michigan Coastal Management Program

Michigan Department of Environmental Quality
- Office of the Great Lakes
- Remediation and Redevelopment

Michigan Department of Natural Resources

Minnesota Department of Natural Resources

Minnesota Pollution Control Agency
- Environmental Indicators Unit
- Voluntary Investigation and Cleanup Unit

New York Department of Environmental Conservation
- Cape Vincent Fisheries Research Station
- Great Lakes Programs

Ohio Department of Natural Resources

Ohio Division of Wildlife
- Sandusky Fish Research Unit

Ohio Environmental Protection Agency
- Lake Erie Program
- Voluntary Action Program

Ohio Lake Erie Office

Ontario Ministry of Agriculture Food and Rural Affairs

Ontario Ministry of Environment
- Environmental Monitoring and Reporting Branch
  - Air Monitoring and Reporting Section
  - Water Monitoring and Reporting Section
    - Great Lakes Unit
    - Sport Fish and Biomonitoring Unit (formerly Sport Fish Contaminant Monitoring Program)

Ontario Ministry of Natural Resources
    Forests Division
        Forests Management Branch
            Forest Evaluation and Standards Section
    Natural Resource Management Division
        Fish and Wildlife Branch
            Biodiversity Section
        Great Lakes Branch
            Lake Erie Management Unit
    Upper Great Lakes Management Unit
        Lands and Waters Branch
            Water Resources Section
    Ontario Natural Heritage Information Centre
Ontario Parks
Pennsylvania Department of Environmental Protection
    Great Lakes Office
    Land Recycling Program
Presque Isle State Park
Province of Quebec
Whitefish Dunes State Park
Wisconsin Department of Health and Family Services
Wisconsin Department of Natural Resources
    Division of Forestry
Wisconsin Division of Public Health
    Remediation and Redevelopment Program

Regional and Municipal
City of Barrie, Ontario, Canada
City of Cornwall, Ontario, Canada
City of Gary, Indiana, USA
    Environmental Affairs
City of Hamilton, Ontario, Canada
City of Kitchener, Ontario, Canada
City of Kingston, New York, USA
    Brownfields and Initiatives
City of London, Ontario, Canada
    Planning Division
City of Mississauga, Ontario, Canada
City of Thunder Bay, Ontario, Canada
    Planning Division
City of Toronto, Ontario, Canada
    Economic Development Corporation
Huron County Health Unit Ontario, Canada
Oswego County Soil and Water Conservation District

Aboriginal
Bad River Band of Lake Superior Tribe of Chippewa Indians
Chippewa/Ottawa Resource Authority
Haudenosaunee Environmental Task Force
Mohawk Council of Akwesasne

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Clemson University, South Carolina, United States
Cornell University, New York, United States
 Department of Natural Resources
  Cornell Biological Field Station
Grand Valley State University, Michigan, United States
 Annis Water Resources Institute
Indiana University, Indiana, United States
McGill University, Ontario, Canada
 Redpath Museum
Michigan State University, Michigan, United States
 Department of Zoology
 Department of Fisheries and Wildlife
 Michigan Natural Features Inventory
Michigan Technological University, Michigan, United States
 Center for Science and Environmental Outreach
Northern Michigan University, Michigan, United States
 Communication and Performance Studies
Oak Ridge Associated Universities, Tennessee, United States
 Oak Ridge Institute for Science and Education
Purdue University, Indiana, United States
 Human-Environment Modeling and Analysis Laboratory
State University of New York, New York, United States
 Great Lakes Consortium
State University of New York-Brockport, New York, United States
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 Large Lakes Observatory
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University of Toronto, Ontario, Canada
University of Windsor, Ontario, Canada
 Great Lakes Institute for Environmental Research
 Department of Biological Sciences
University of Wisconsin-Madison, Wisconsin, United States
 Department of Forest Ecology and Management
University of Wisconsin-Milwaukee, Wisconsin, United States
 Great Lakes WATER Institute
University of Wisconsin-Superior, Wisconsin, United States
 Lake Superior Research Institute

Partnerships
Ecological Monitoring and Assessment Network

Commissions
Great Lakes Commission
Great Lakes Coastal Wetland Consortium* no longer exists
Great Lakes Fishery Commission
Great Lakes Indian Fish & Wildlife Commission

International Joint Commission
    Great Lakes Regional Office

Environmental Non-Government Organizations
Bird Studies Canada
Grand River Conservation Authority
Great Lakes Forest Alliance
Great Lakes United
National Wildlife Federation
Nature Conservancy Canada
    Ontario Region
Northeast-Midwest Institute
    Great Lakes Cities Initiative
Northwest Michigan Council of Governments
Sustainable Forestry Initiative
The Nature Conservancy
    Great Lakes Program
World Wildlife Fund-Canada

Private Organizations
Bobolink Enterprises
Computer Sciences Corporation
Council of Great Lakes Industries
DynCorp
Environmental Affairs Consulting
Environmental Careers Organization* no longer exists
General Dynamics Advanced Information Systems
Habitat Solutions N.A.
LURA Consulting
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Private Citizens

Appendix A: Assessing Data Quality

Through both the triennial Conferences and the State of the Great Lakes reports (technical report, Highlights report), SOLEC organizers seek to disseminate the highest quality information available to a wide variety of environmental managers, policy officials, scientists and other interested public. The importance of the availability of reliable and useful data is implicit in the SOLEC process.

To ensure that data and information made available to the public by federal agencies adhere to a basic standard of objectivity, utility, and integrity, the U.S. Office of Management and Budget issued a set of Guidelines in 2002 (OMB 2002). Subsequently, other U.S. federal agencies have issued their own guidelines for implementing the OMB policies. According to the Guidelines issued by the U.S. Environmental Protection Agency (U.S. EPA 2002), information must be accurate, reliable, unbiased, useful and uncompromised though corruption or falsification.

Other assessment factors (U.S. EPA 2003) that are typically taken into account when evaluating the quality and relevance of scientific and technical information include:

- **Soundness** - the extent to which the scientific and technical procedures, measures, methods or models employed to generate the information are reasonable for, and consistent with, the intended application
- **Applicability and Utility** - the extent to which the information is relevant for the intended use
- **Clarity and Completeness** - the degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations and analyses employed to generate the information are documented
- **Uncertainty and Variability** - the extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods or models are evaluated and characterized
- **Evaluation and Review** - the extent of independent verification, validation and peer review of the information or of the procedures, measures, methods or models

Recognizing the need to more formally integrate concerns about data quality into the SOLEC process, SOLEC organizers developed a Quality Assurance Project Plan (QAPP) in 2004. The QAPP recognizes that SOLEC, as an entity, does not directly measure any environmental or socioeconomic parameters. Existing data are contributed by cooperating federal, state and provincial environmental and natural resource agencies, non-governmental environmental agencies or other organizations engaged in Great Lakes monitoring. Additional data sources may include local governments, planning agencies, and the published scientific literature. Therefore, SOLEC relies on the quality of datasets reported by others.

Characteristics of datasets that would be acceptable for indicator reporting include:

- Data are documented, validated, or quality-assured by a recognized agency or organization.
- Data are traceable to original sources.
- The source of the data is a known, reliable and respected generator of data.
- Geographic coverage and scale of data are appropriate to the Great Lakes basin.
- Data obtained from sources within the United States are comparable with those from Canada.

Additional considerations include:

- Gaps in data availability should be identified if datasets are unavailable for certain geographic regions and/or contain a level of detail insufficient to be useful in the evaluation of a particular indicator.

- Data should be evaluated for feasibility of being incorporated into indicator reports. Attention should be given to budgetary constraints in acquiring data, type and format of data, time required to convert data to usable form, and the collection frequency for particular types of data.

SOLEC relies on a distributed system of information in which the data reside with the original providers. Although data reported through SOLEC are not centralized, clear links for accessibility of the data and/or the indicator authors are provided. The authors hold the primary responsibility for ensuring that the data used are adequate for indicator reporting. *Users of the indicator information, however, are obliged to evaluate the usefulness and appropriateness of the data for their own application, and they are encouraged to contact the authors with any concerns or questions.*