State of the Great Lakes 2007 - Draft

DRAFT – JUNE 2007

Preface

The Governments of Canada and the United States are committed to providing public access to environmental information that is reported through the State of the Great Lakes reporting process. This commitment is integral to the mission to protect ecosystem health. To participate effectively in managing risks to ecosystem health, all Great Lakes stakeholders (e.g., federal, provincial, state and local governments; non-governmental organizations; industry; academia; private citizens, Tribes and First Nations) should have access to accurate information of appropriate quality and detail.

The information in this report, **State of the Great Lakes 2007**, has been assembled from various sources with the participation of many people throughout the Great Lakes basin. The data are based on indicator reports and presentations from the State of the Lakes Ecosystem Conference (SOLEC), held in Milwaukee, Wisconsin, November 1-3, 2006. The sources of information are acknowledged within each section.

Expanding upon previous State of the Great Lakes reporting systems, the 2007 information is presented in three different ways:

State of the Great Lakes 2007. This technical report contains the full indicator reports as prepared by the primary authors, the indicator category assessments, and management challenges. It also contains detailed references to data sources.

State of the Great Lakes 2007 Highlights. This report highlights key information presented in the main report.

State of the Great Lakes Technical Summaries Series. These summaries provide information from a variety of indicators such as: drinking water, swimming at the beaches, eating fish, air quality, aquatic invasive species, amphibians, birds, forests, coastal wetlands, the Great Lakes food web and special places such as islands, alvars and cobble beaches. In addition there is a technical summary for each of the lakes, plus the St. Clair-Detroit River ecosystem and the St. Lawrence River.

This approach of multiple reports addresses the needs of multiple audiences and also satisfies the U.S. *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies*, OMB, 2002, (67 FR 8452). The guidelines were developed in response to U.S. Public Law 106-554: H.R. 5658, Section 515(a) of the Treasury and General Government Appropriations Act for Fiscal Year 2001.

The State of the Lakes Ecosystem Conferences (SOLEC) and reports provide independent, 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 the Great Lakes stakeholders

The role of SOLEC is to provide clear, compiled information to the Great Lakes community to enable 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.

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.on.ec.gc.ca/solec.

1.0 Introduction

This **State of the Great Lakes 2007** report presents the compilation, scientific analysis and interpretation of data about the Great Lakes basin ecosystem. It represents the combined efforts of many scientists and managers in the Great Lakes community representing federal, Tribal/First Nations, state, provincial and municipal governments, non-government organizations, industry, academia and private citizens.

The seventh in a series of reports beginning in 1995, the **State of the Great Lakes 2007** provides an assessment of the Great Lakes basin ecosystem components using a suite of ecosystem health indicators. The Great Lakes indicator suite has been developed, and continues to be refined, by experts as part of the State of the Lakes Ecosystem Conference (SOLEC) process.

The SOLEC process was established by the governments of Canada and the U.S. in response to requirements of the Great Lakes Water Quality Agreement (GLWQA) for regular reporting on progress toward Agreement goals and objectives. Since the first conference in 1994, SOLEC has evolved into a two-year cycle of data collection, assessment and reporting on conditions and the major pressures in the Great Lakes basin. The year following each conference, a State of the Great Lakes report is prepared, based on information presented and discussed at the conference and post-conference comments. Additional information about SOLEC and the Great Lakes indicators is available at www.binational.net.

The **State of the Great Lakes 2007** provides assessments of 63 of approximately 80 ecosystem indicators and overall assessments of the categories into which the indicators are grouped: Contamination, Human Health, Biotic Communities, Invasive Species, Coastal Zones and Aquatic Habitats, Resource Utilization, Land Use-Land Cover, and Climate Change. Within most of the main categories are sub-categories to further delineate issues or geographic areas.

Authors of the indicator reports assessed the status of ecosystem components in relation to desired conditions or ecosystem objectives, if available. Five status categories were used (coded by color in this report):

Good. The state of the ecosystem component is presently meeting ecosystem objectives or otherwise is in acceptable condition.

Fair. The ecosystem component is currently exhibiting minimally acceptable conditions, but it is not meeting established ecosystem objectives, criteria, or other characteristics of fully acceptable conditions.

Poor. The ecosystem component is severely negatively impacted and it does not display even minimally acceptable conditions.

Mixed. The ecosystem component displays both good and degraded features.

Undetermined. Data are not available or are insufficient to assess the status of the ecosystem component.

Four categories were also used to denote current trends of the ecosystem component (coded by shape in this Highlights report):

Improving. Information provided shows the ecosystem component to be changing toward more acceptable conditions.

Unchanging. Information provided shows the ecosystem component to be neither getting better nor worse.

Deteriorating. Information provided shows the ecosystem component to be departing from acceptable conditions.

? **Undetermined**. Data are not available to assess the ecosystem component over time, so no trend can be identified.

For many indicators, ecosystem objectives, endpoints, or benchmarks have not been established. For these indicators, complete assessments are difficult to determine.

In 2006, the overall status of the Great Lakes ecosystem was assessed as mixed because some conditions or areas were good while others were poor. The trends of Great Lakes ecosystem conditions varied: some conditions were improving and some were worsening.

Some of the good features of the ecosystem leading to the *Mixed* conclusion include:

- Levels of most contaminants in herring gull eggs continue to decrease
- Phosphorus targets have been met in Lakes Ontario, Huron, Michigan and Superior.
- The Great Lakes are a good source for treated drinking water.
- Sustainable forestry programs throughout the Great Lakes basin are helping environmentally friendly management practices.
- Lake trout stocks in Lake Superior have remained self-sustaining, and some natural reproduction of lake trout is occurring in Lake Ontario and in Lake Huron.
- Mayfly (*Hexagenia*) populations have partially recovered in western Lake Erie.

Some of the negative features of the ecosystem leading to the *Mixed* conclusion include:

- Concentrations of the flame retardant PBDEs are increasing in herring gull eggs
- Nuisance growth of the green alga *Cladophora* has reappeared along the shoreline in many places
- Phosphorus levels are still above guidelines in Lake Erie.
- Non-native species (aquatic and terrestrial) are pervasive throughout the Great Lakes basin, and they continue to exert impacts on native species and communities.
- Populations of *Diporeia*, the dominant, native, bottom-dwelling invertebrate, continue to decline in Lake Michigan, Lake Huron, and Lake Ontario, and they may be extinct in Lake Erie.
- Groundwater withdrawals for municipal water supplies and irrigation, and the increased proportion of impervious surfaces in urban areas, have negatively impacted groundwater.
- Long range atmospheric transport is a continuing source of PCBs and other contaminants to the Great Lakes basin, and can be expected to be significant for decades.
- Land use changes in favour of urbanization along the shoreline continue to threaten natural habitats in the Great Lakes and St. Lawrence River ecosystems.
- Some species of amphibians and wetland-dependent birds are showing declines in population numbers – in part due to wetland habitat conditions.

The listing of the **State of the Great Lakes 2007** indicator reports, the categories, and the indicator assessments for 2007, 2005, 2003, and 2001 are provided in the following summary table. A complete listing of all indicators in the Great Lakes suite can be found in Section 6.0.

2.0 Assessing Data Quality

Through both the biennial Conferences and the *State of the Great Lakes* reports (Technical Report, Highlights, Summary Series), 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 this quality standard, including the availability of reliable and useful data, is implicit in the main objectives of 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[1] in 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[2], information must be accurate, reliable, unbiased, useful and uncompromised though corruption or falsification. The U.S. EPA further amplified its Guidelines in 2003 with a review of "assessment factors" that the agency typically takes into account when evaluating the quality and relevance of scientific and technical information:[3]

- ***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 Agency's 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.*
- *Gaps in data availability are identified if data sets 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 are evaluated for feasibility of being incorporated into indicator reports. Considerations include 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 for indicator reporting meet criteria for objectivity, usefulness and integrity. 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.

The SOLEC indicator reporting process is intended to be open and collaborative. Indicator authors are generally subject matter experts who are the primary generators of data, who have direct access to the data, or who are able to obtain relevant data from one or more other sources and who can assess the quality of data for objectivity, usefulness and integrity. In some cases, authors may serve as facilitators or leaders to coordinate a workgroup of experts who collectively contribute their data and information, to arrange for data retrievals from agency or organization databases, or to review published scientific literature or conduct online data searches from trusted sources, e.g., U.S. census data or the National Land Cover Dataset.

Several opportunities are provided for knowledgeable people to review and comment on the quality of the data and information provided. These include:

- Coauthors - Most of the indicator reports are prepared by more than one author, and data are often obtained from more than one source. As the draft versions are prepared, the authors freely evaluate the data.
- Comments from the Author(s) - The section in each indicator report called "Comments from the Author(s)" provides an opportunity for the authors to describe any known limitations on the use or interpretation of the data that are being presented.
- Pre-SOLEC availability - The indicator reports are prepared before each Conference, and they are made available online to SOLEC participants in advance. Participants are encouraged to provide comments and suggestions for improvements, including any data quality issues.
- During SOLEC discussions - The Conferences have been designed to encourage exchange of ideas and interpretations among the participants. The indicator reports provide the framework for many of the discussions.
- Post-SOLEC review period - Following the Conferences, interested agencies, organizations and other stakeholders are encouraged to review and comment on the information and interpretations provided in the indicator reports.
- Preparation of *State of the Great Lakes* products - Prior to finalizing the Technical Report, Highlights, and Summary Series, any substantive comments on the indicator reports, including data quality issues, are referred back to the authors for resolution with the report editors.

The primary record and documentation of the indicator reports and assessments are the *State of the Great Lakes* reports. The *Technical Report* presents the full indicator reports as prepared by the primary authors. It also contains detailed references to the data sources. A *Highlights* report is also produced which refers to the detailed references and links. This approach of dual reports, one summary version and one with details and references to data sources, also satisfies *the Guidelines for Ensuring and Maximizing the Quality, Utility, and Integrity of Information Disseminated by Federal Agencies*, OMB, 2002, (67 FR 8452). The guidelines were developed in response to U.S. Public Law 106-554; H.R. 5658, Section 515 (a) of the Treasury and General Government Appropriations Act for Fiscal Year 2001.

[1]*Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies*, OMB, 2002, (67 FR 8452). The guidelines were developed in response to U.S. Public Law 106-554: H.R. 5658, Section 515(a) of the Treasury and General Government Appropriations Act for Fiscal Year 2001.

[2]*Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity, of Information Disseminated by the Environmental Protection Agency*. 2002. U.S. Environmental Protection Agency EPA/260R-02-008, 62pp.

[3]*Assessment Factors. A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information.* 2003. U.S. Environmental Protection Agency. EPA 100/B-03/001, 18pp.

3.0 What is being done to improve conditions?

In an effort to restore and preserve the Great Lakes, legislators, managers, scientists, educators and numerous others are responding to environmental challenges with multifaceted solutions. The responses and actions referenced here are intended to serve as examples of positive strides being taken in the Great Lakes basin to improve ecosystem conditions. Examples from both Canada and the United States and from each of the Great Lakes are included. There are many, many more actions that could have been recognized in this report. Each is an important part of our collective commitment to a clean and healthy Great Lakes ecosystem.

Strategic planning occurs at basin-wide, lake-wide and local scales. An example of strategic planning is the Canada-Ontario Agreement, a federal-provincial agreement that supports the restoration, protection, and conservation of the Great Lakes basin ecosystem. To achieve the collective goals and results, Canada and Ontario work closely with local and regional governments, industry, community and environmental groups. In the United States, more than 140 different federal programs help fund and implement environmental restoration and management activities in the basin. The Great Lakes Water Quality Agreement, Great Lakes Regional Collaboration and Federal Task Force, Great Lakes Binational Toxics Strategy, Lakewide Management Plans, Binational Partnerships, and Remedial Action Plans are other examples of strategic planning in the Great Lakes basin.

Research, monitoring and assessment efforts operating at various geographic scales are the backbone of management actions and decisions in the basin. Coordinated monitoring among Canadian and United States federal, provincial, state, and university groups began in 2003 to focus on monitoring physical, biological, and chemical parameters with monitoring occurring on a five-year rotation of one Great Lake per year. The International Joint Commission maintains a Great Lakes – St. Lawrence Research Inventory of the many funded projects that help increase our knowledge about the structure and function of the Great Lakes ecosystem.

Canada and the United States implement numerous **actions** across the basin at national, regional and local scales. For example, in Ontario, the City of Toronto is addressing water pollution through the Wet Weather Flow Management Master Plan, a long-term solution to reduce pollution from stormwater and combined sewer overflows.

Communities, states, the U.S. Environmental Protection Agency and local industry are working together to remediate contaminated sediments in U.S. Areas of Concern (AOCs) with funding provided through the U.S. Great Lakes Legacy Act. Since inception of the Act in 2002, sediment remediation has been completed at three U.S. AOC sites (Ruddiman Creek and Ruddiman Pond in Michigan, Black Lagoon in Michigan, and Newton Creek and Hog Island Inlet in Wisconsin).

The Oswego River AOC on Lake Ontario was delisted in 2006, the first removal of an AOC designation in the United States. In Canada, two AOCs have been delisted, both on Lake Huron (Collingwood Harbour in 1994 and Severn Sound in 2003). Delisting of an Area of Concern occurs when environmental monitoring has confirmed that the remedial actions taken have restored the beneficial uses in the area and that locally derived goals and criteria have been met.

Effective actions are often based on **collaborative work**. In 2005, the Nature Conservancy, the State of Michigan and The Forestland Group (a limited partnership), collaborated in a sale and purchase agreement that created the largest conservation project in Michigan's history. This purchase will protect more than 110,000 hectares (271,000 acres) through a working forest easement on 100,362 hectares (248,000 acres) and acquisition of 9,445 hectares (23,338 acres) in the Upper Peninsula of Michigan. By connecting approximately one million hectares (2.5 million acres), the project curbs land fragmentation and incompatible development by establishing buffers around conservation sites such as the Pictured Rocks National Lakeshore and Porcupine Mountains Wilderness State Park.

Lake Superior **communities** have embraced a goal of zero discharge of critical pollutants by engaging in a number of actions to remove contaminants. Efforts to reach this goal include electronic and hazardous waste collection events run by Earth Keepers, a faith-based environmental organization based in the Upper Peninsula of Michigan. On Earth Day 2006, over 272 metric tons (300 U.S. tons) of household hazardous waste, primarily household electronics, were collected, disposed of, or recycled. In Canada, more than 11,500 mercury switches from scrap automobiles were collected in 2005 through Ontario's mercury Switch Out program.

In many cases management and conservation actions are based on or supported by federal, state, provincial, or local **legislation**. For example, Ontario's Greenbelt Act of 2005 enabled the creation of a Greenbelt Plan to protect about 728,437 hectares (1.8 million acres) of environmentally-sensitive and agricultural land in the Golden Horseshoe region from urban development and sprawl. The Plan includes and builds upon approximately 324,000 hectares (800,000 acres) of land within the Niagara Escarpment Plan and the Oak Ridges Moraine Conservation Plan.

Proving that some **legislation** effectively crosses national borders, in December, 2005, the Great Lakes Governors and Premiers signed the *Annex 2001 Implementing Agreements* at the Council of Great Lakes Governors' Leadership Summit that will provide unprecedented protection for the Great Lakes–St. Lawrence River basin. The agreements detail how the states and provinces will manage and protect the basin and provide a framework for each state and province to enact laws for its protection, once the agreement is ratified.

Education and outreach about Great Lakes environmental issues are essential actions for fostering both a scientifically-literate public as well as informed decision-makers. The Lake Superior Invasive-Free Zone Project involves community groups in the inventorying and control of non-native invasive terrestrial and emergent aquatic plants through education. The project combines Canadian and United States programs at federal, state, provincial, municipal, and local levels and has the goal of eliminating non-native plants within a designated 291 hectare (720 acre) area.

A Shoreline Stewardship Manual developed for the Southeast shore of Lake Huron and promoted through workshops and outreach programs encourages sustainable practices to improve and maintain the quality of groundwater and surface water and the natural landscape features that support them. The Shoreline Stewardship Manual is a collaborative effort by the Huron County Planning Department, the University of Guelph, the Huron Stewardship Council, the Ausable Bayfield Conservation Authority, the Lake Huron Centre for Coastal Conservation, and the Friends of the Bayfield River, and a high level of community engagement has been instrumental in its success.

The Great Lakes Conservation Initiative of the Shedd Aquarium in Chicago aims to draw public attention to the value and vulnerabilities of the Great Lakes. With collaboration by Illinois-Indiana Sea Grant and the U.S. Fish and Wildlife Service, the Shedd Aquarium opened a new exhibit in 2006 which features many of the invasive species found in the Great Lakes. This exhibit provides public audiences with the opportunity to see many of these live animals and plants, and is also highlighted in teacher workshops.

As these examples show, there is much planning, information gathering, research and education occurring in the Great Lakes basin. Much more remains to be done to meet the goals of the GLWQA, but progress is being made with the involvement of all Great Lakes stakeholders.

4.0 Indicator Category Assessments and Management Challenges

Contamination

The transfer of natural and human-made substances from air, sediments, groundwater, wastewater, and runoff from non-point sources is constantly changing the chemical composition of the Great Lakes. Over the last 30 years, concentrations of some chemicals or chemical groups have declined significantly. There is a marked reduction in the levels of toxic chemicals in air, water, biota, and sediments. Many remaining problems are associated with local regions such as Areas of Concern. However, concentrations of several other chemicals that have been recently detected in Great Lakes have been identified as chemicals of emerging concern.

Levels of most contaminants in herring gull eggs continue to decrease in all the Great Lakes colonies monitored, although concentration levels vary from good in Lake Superior, to mixed in Lake Michigan, Lake Erie and Lake Huron, to poor in Lake Ontario. While the frequency of gross effects of contamination on wildlife has subsided, many subtle (mostly physiological and genetic) effects that were not measured in earlier years of sampling remain in herring gulls. Concentrations of flame-retardant polybrominated diphenyl ethers (PBDEs) are increasing in herring gull eggs.

Concentrations of most organic contaminants in the offshore waters of the Great Lakes are low and are declining, indicating progress in the reduction of persistent toxic chemicals. Indirect inputs of in-use organochlorine pesticides are most likely the current source of entry to the Great Lakes. Continuing sources of entry of many organic contaminants to the Great Lakes include indirect inputs such as atmospheric deposition, agricultural land runoff, and resuspension of contaminated sediments. Overall, mercury concentrations in offshore waters are well below water quality guidelines. Mercury concentrations in waters near major urban areas and harbors, however, exceed water quality criteria for protection of wildlife. Concentrations of polycyclic aromatic hydrocarbons (PAHs) and dioxins in offshore waters have declined below water quality guidelines, largely due to the control of point sources.

The status of atmospheric deposition of toxic chemicals is mixed and improving for polychlorinated biphenyls (PCBs), banned organochlorine pesticides, dioxins, and furans, but mixed and unchanging or slightly improving for PAHs and mercury across the Great Lakes. For Lake Superior, Lake Michigan, and Lake Huron, atmospheric inputs are the largest source of toxic chemicals due to the large surface areas of these lakes. While atmospheric concentrations of some substances are very low at rural sites, they may be much higher in some urban areas.

Juvenile spottail shiner, an important preyfish species in the Great Lakes, is a good indicator of nearshore contamination because the species limits its distribution to localized, nearshore areas during its first year of life. Total dichlorodiphenyltrichloroethane (DDT) in juvenile spottail shiner has declined over the last 30 years but still exceeds GLWQA criteria at most locations. Concentrations of PCBs in juvenile spottail shiner have decreased below the GLWQA guideline at many, but not all, sites in the Great Lakes.

The status of contaminants in lake trout, walleye and smelt as monitored annually in the open waters of each of the Great Lakes is mixed and improving for PCBs, DDT, toxaphene, dieldrin, mirex, chlordane, and mercury. Concentrations of PBDEs and other chemicals of emerging concern such as perflourinated chemicals, however, are increasing. Both the United States and Canada continue to monitor for these chemicals in whole fish tissues and have over 30 years of data to support the status and trends information.

Phosphorus concentrations in the Great Lakes were a major concern in the 1960s and 1970s, but private and government actions have reduced phosphorus loadings, thus maintaining or reducing phosphorus concentrations in open waters. However, high phosphorus concentrations are still measured in some embayments, harbors, and nearshore areas. Nuisance growth of the green alga *Cladophora* has reappeared along the shoreline in many places and may be related, in part, to increased availability of phosphorus.

Management Challenges:
Presently, there are no standardized analytical monitoring methods and tissue residue guidelines for new contaminants and chemicals of emerging concern, such as PBDEs.
PCBs from residual sources in the United States, Canada, and throughout the world enter the atmosphere and are transported long distances. Therefore, atmospheric deposition of PCBs to the Great Lakes will still be significant at least decades into the future.
Assessment of the capacity and operation of existing sewage treatment plants for phosphorus removal, in the context of increasing human populations being served, is warranted.
Monitoring of tributary, point source, and urban and rural non-point source contributions of phosphorus will allow tracking of various sources of phosphorus loadings.
Investigating the causes of *Cladophora* reappearances will aid in the reduction of its impacts on the ecosystem.

Chemical Integrity – What the Experts are Saying

Chemical Integrity of the Great Lakes – What the Experts are Saying
In addition to the ecosystem information derived from indicators, six presentations on the theme of "Chemical Integrity of the Great Lakes" were delivered at SOLEC 2006 by Great Lakes experts. The definition of Chemical Integrity proposed by SOLEC is "the capacity to support and maintain a balanced, integrated and adaptive biological system having the full range of elements and processes expected in a region's natural habitat." James R. Karr, 1991(modified)

The presentations focused on the status of anthropogenic (man-made) contaminants and imbalances in naturally-occurring chemicals in the Great Lakes basin. The key points of each presentation are summarized here.

Anthropogenic Chemicals
Ron Hites, Indiana University: While concentrations of banned or regulated toxic substances such as PCBs and PAHs have decreased over the past 30 years, the rate of decline has slowed considerably over the past decade. Virtual elimination of most of these chemicals will not occur for another 10 to 30 years despite restrictions or bans on their use. Further decreases in the environmental concentrations of PCBs, PAHs, and some pesticides may well depend on emission reductions in cities.

Derek Muir, Environment Canada: Some 70,000 commercial and industrial compounds are now in use, and an estimated 1,000 new chemicals are introduced each year. Several chemical categories have been identified as chemicals of emerging concern, including polybrominated diphenyl ethers (flame retardants), perfluorooctanyl sulfonate (PFOS) and carboxylates, chlorinated paraffins and naphthalenes, various pharmaceutical and personal care products, phenolics, and approximately 20 currently-used pesticides. PBDEs, siloxanes and musks are now widespread in the Great Lakes environment. Implementation of a more systematic program for monitoring new persistent toxic substances in the Great Lakes will require significant investments in instrumentation and researchers.

Joanne Parrot, Environment Canada: Some pharmaceuticals and personal care products appear to cause negative effects in aquatic organisms at very low concentrations in laboratory experiments. Some municipal waste water effluents within the Great Lakes discharge concentrations of these products within these ranges. There is some evidence that fish and turtles show developmental effects when exposed to municipal wastewater effluent in the laboratory. Whether these effects appear in aquatic organisms including invertebrates, fish, frogs, and turtles, in environments downstream of municipal wastewater effluent is not known, indicating the need for more research in this area.

Naturally-occurring Chemicals
Harvey Bootsma, University of Wisconsin-Milwaukee: Changes in levels of nitrate, chloride and phosphorus in Great Lakes waters are attributed to human activities, with potential effects on phytoplankton and bottom-dwelling algae. Changes in lake chemistry, shown through variations in calcium, alkalinity, and even chlorophyll, are linked to the biological activity of non-native

species. Non-native species also appear to be altering nutrient cycling pathways in the Great Lakes, by possibly intercepting nearshore nutrients before they can be exported offshore and transferring them to the lake bottom.

Susan Watson, Environment Canada: The causes and occurrences of taste and odor impairments in surface waters are widespread, erratic, and poorly characterized but are likely caused by volatile organic compounds produced by species of plankton, benthic organisms, and decomposing organic materials. In recent years, there has been an increase in the frequency and severity of nuisance algae such as *Cladophora* outbreaks in the Great Lakes, particularly in the lower Great Lakes. Type E botulism outbreaks and resulting waterbird deaths continue to occur in Lake Michigan, Lake Erie and Lake Ontario.

David Lam, Environment Canada: Models and supporting monitoring data are used to predict Great Lakes water quality. A post-audit of historical models for Great Lakes water quality revealed the general success of setting target phosphorus loads to reduce open water phosphorus concentrations.

Human Health

Levels of PCBs in sportfish continue to decline, progress is being made to reduce air pollution, beaches are better assessed and more frequently monitored for pathogens, and treated drinking water quality continues to be assessed as good. Although concentrations of many organochlorine chemicals in the Great Lakes have declined since the 1970s, sportfish consumption advisories persist for all of the Great Lakes.

The quality of municipally-treated drinking water is considered good. The risk of human exposure to chemicals and/or microbiological contaminants in treated drinking water is generally low. However, improving and protecting source water quality (before treatment) is important to ensure good drinking water quality.

In 2005, 74 percent of monitored Great Lakes beaches in the United States and Canada remained open more than 95 percent of the swimming season. Postings, advisories or closures were due to a variety of reasons, including the presence of *E. coli* bacteria, poor water quality, algae abundance, or preemptive beach postings based on storm events and predictive models. Wildlife waste on beaches can be more of a contributing factor towards bacterial contamination of water and beaches than previously thought.

Concentrations of organochlorine contaminants in Great Lakes sportfish are generally decreasing. However, in the United States, PCBs drive consumption advisories of Great Lakes sportfish. In Ontario, most of the consumption advisories for Great Lakes sportfish are driven by PCBs, mercury, and dioxins. Toxaphene also contributes to consumption advisories of sportfish from Lake Superior and Lake Huron. Monitoring for other contaminants, such as PBDEs, has begun in some locations.

Overall, there has been significant progress in reducing air pollution in the Great Lakes basin. However, regional pollutants, such as ground-level ozone and fine particulates, remain a concern, especially in the Detroit-Windsor-Ottawa corridor, the Lake Michigan basin, and the Buffalo-Niagara area. Air quality will be further impacted by population growth and climate change.

Management Challenges:
Maintenance of high-quality source water will reduce costs associated with treating water, promote a healthier ecosystem, and lessen potential contaminant exposure to humans.
Although the quality of treated drinking water remains good, care must be taken to maintain water treatment facilities.
One-fourth of monitored beaches still have beach postings or closures.
A decline in some contaminant concentrations has not eliminated the need for Great Lakes sportfish consumption advisories.
Most urban and local air pollutant concentrations are decreasing. However, population growth may impact future air pollution levels.

Biotic Communities

Despite improvements in levels of contaminants in the Great Lakes, many biological components of the ecosystem are severely stressed. Populations of the native species near the base of the food web such as Diporeia *and species of zooplankton are in decline in some of the Great Lakes. Native preyfish populations have declined in all lakes except Lake Superior. Significant natural reproduction of lake trout is occurring in Lake Huron and Lake Superior only. Walleye harvests have improved but are still below fishery target levels. Lake sturgeon are locally extinct in many tributaries and waters where they once spawned and flourished. Habitat loss and deterioration remain the predominant threat to Great Lakes amphibian and wetland-dependant bird populations.*

The aquatic food web is severely impaired in all the Great Lakes with the exception of Lake Superior. Zooplankton populations have declined dramatically in Lake Huron, and a similar decline is occurring in Lake Michigan. Populations of *Diporeia*, the dominant native benthic (bottom-dwelling) invertebrate in offshore waters, continue to decline in Lake Huron, Lake Michigan and Lake Ontario, and they may be locally extinct in Lake Erie. The decline of *Diporeia* coincides with the introduction of non-native zebra and quagga mussels. Both zooplankton and *Diporeia* are crucial food sources for many other species, so their population size and health impact the entire system.

The current mix of native and non-native (stocked and naturalized) prey and predator fish species in the system has confounded the natural balance within most of the Great Lakes. In all but Lake Superior, native preyfish populations have deteriorated. However, the recent decline of non-native preyfish (alewife and smelt) abundance in all Great Lakes except Lake Superior could have positive impacts on other preyfish populations. Preyfish populations are important for their role in supporting predator fish populations, so the potential effects of these changes will be a significant factor to be considered in fisheries management decisions.

Despite basin-wide efforts to restore lake trout populations that include stocking, harvest limits, and sea lamprey management, lake trout have not established self-sustaining populations in Lake Michigan, Lake Erie, and Lake Ontario. In Lake Huron, substantial and widespread natural reproduction of lake trout was observed starting in 2004 following the near collapse of alewife populations. This change may have been due to the reduced predation on juvenile lake trout by adult alewives and the alleviation of a trout vitamin deficiency problem caused by trout consuming alewives. In Lake Superior, lake trout stocks have recovered such that hatchery-reared trout are no longer stocked.

Reductions in phosphorus loadings during the 1970s substantially improved spawning and nursery habitat for many fish species in the Great Lakes. Walleye harvests have improved but are still below target levels. Lake sturgeon are now locally extinct in many tributaries and waters where they once spawned and flourished, although some remnant lake sturgeon populations exist throughout the Great Lakes. Spawning and rearing habitats have been destroyed, altered or access to them blocked. Habitat restoration is required to help re-establish vigorous lake sturgeon populations.

From 1995 to 2005, the American toad, bullfrog, chorus frog, green frog and northern leopard frog exhibited significantly declining population trends while the spring peeper was the only amphibian species that exhibited a significantly increasing population trend in Great Lakes coastal wetlands. For this same time period, 14 species of wetland-dependant birds exhibited significantly declining population trends, while only six species exhibited significantly increasing population trends.

The Great Lakes are now facing a challenge from viral hemorrhagic septicemia (VHS). This virus has affected at least 37 fish species and is blamed for fish kills in Lake Huron, Lake St. Clair, Lake Erie, Lake Ontario, and the St. Lawrence River.

Management Challenges:
Populations of *Diporeia* continue to decline in Lake Michigan, Lake Huron, and Lake Ontario, and may be locally extinct in Lake Erie. Management actions to address the declines may be ineffective until the underlying causes of the declines are identified.
The decline of *Diporeia* coincides with the spread of non-native zebra and quagga mussels. Cause and effect linkages between non-native species in the Great Lakes and ecological impacts are essential, however, they may be difficult to establish.
Identification of remnant lake sturgeon spawning populations should assist the selection of priority restoration activities to improve degraded lake sturgeon spawning and rearing habitats.
Protection of high-quality wetland habitats and adjacent upland areas will help support populations of wetland-dependent birds and amphibians.

Invasive Species

Activities associated with shipping are responsible for over one-third of the aquatic non-native species introductions to the Great Lakes. Total numbers of non-native species introduced and established in the Great Lakes have increased steadily since the 1830s. However, numbers of *ship-introduced aquatic species have increased exponentially during the same time period. High population density, high-volume transport of goods, and the degradation of native ecosystems have also made the Great Lakes region vulnerable to invasions from terrestrial non-native species. Introduction of these species is one of the greatest threats to the biodiversity and natural resources of this region, second only to habitat destruction.*

There are currently 183 known aquatic and 124 known terrestrial non-native species that have become established in the Great Lakes basin. Non-native species are pervasive throughout the Great Lakes basin, and they continue to exert impacts on native species and communities. Approximately 10 percent of aquatic non-native species are considered invasive and have an adverse effect, causing considerable ecological, social, and economic burdens.

Both aquatic and terrestrial wildlife habitats are adversely impacted by invasive species. The terrestrial non-native emerald ash borer, for example, is a tree-killing beetle that has killed more than 15 million trees in the state of Michigan alone as of 2005. The emerald ash borer probably arrived in the United States on solid wood packing material carried in cargo ships or airplanes originating from its native Asia.

Introductions of non-native invasive species as a result of world trade and travel have increased steadily since the 1830s and will continue to rise if prevention measures are not improved. The Great Lakes basin is particularly vulnerable to non-native invasive species because it is a major pathway of trade and is an area that is already disturbed.

Management Challenges:
A better understanding of the entry routes of non-native invasive species would aid in their control and prevention.
Prevention and control require coordinated regulation and enforcement efforts to effectively limit the introduction of non-native invasive species.
Prevention of unauthorized ballast water exchange by ships will eliminate one key pathway of non-native aquatic species introductions to the Great Lakes.
The unauthorized release, transfer, and escape of introduced aquatic non-native species and private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets need to be considered.

Coastal Zones and Aquatic Habitats

Coastal habitats are degraded due to development, shoreline hardening and establishment of local populations of non-native invasive species. Wetlands continue to be lost and degraded. In addition to providing habitat and feeding areas for many species of birds, amphibians and fish, wetlands also serve as a refuge for native mussels and fish that are threatened by non-native invasive species.

The Great Lakes coastline is more than 17,000 kilometers (10,563 miles) long. Unique habitats include more than 30,000 islands, over 950 kilometers (590 miles) of cobble beaches, and over 30,000 hectares (74,131 acres) of sand dunes. Each coastal zone region is subject to a combination of human and natural stressors such as agriculture, residential development, point and non-point sources of pollution, and weather patterns. The coastal zone is heavily stressed, with many of the basin's 42 million people living along the shoreline.

Wetlands are essential for proper functioning of ecosystems and. provide a refuge for native fish from predation by the non-native ruffe and provide refuge for native mussels from non-native zebra mussels. The Great Lakes coastline includes more than 200,000 hectares (494,000 acres) of coastal wetlands, less than half of the amount of wetland area that existed prior to European settlement of the basin. An inventory of Great Lakes coastal wetlands in 2004 demonstrated that Lake Huron and Lake Michigan still have extensive wetlands, especially barrier-protected wetlands. Reductions in wetland area are occurring, however, due to filling, conversion to urban, residential, and agricultural uses, shoreline modification, water level regulation, non-native species invasions, and nutrient loading. Stressors, such as these, may also impact the condition of remaining wetlands and can threaten their natural function. Coastal wetland plant community health, which is indicative of overall coastal wetland health, varies across the Great Lakes basin. In general, there is deterioration of native plant diversity in many wetlands as shoreline alterations may cause habitat degradation and allow for easier invasion by non-native species.

Naturally fluctuating water levels are essential for maintaining the ecological health of Great Lakes shoreline ecosystems, especially coastal wetlands. Wetland plants and biota have adapted to seasonal and long-term water level fluctuations, allowing wetlands to be more extensive and more productive than they would be if water levels were stable. In 2000, Great Lakes water levels were lower than the 140-year average water level measured from 1860-2000. Furthermore, many climate change models predict lower water levels for the Great Lakes. Coastal wetlands that directly border the lakes and do not have barrier beaches may be able to migrate toward the lakes in response to lower water levels. Inland and enclosed wetlands would likely dry up and become arable or forested land.

Shoreline hardening, primarily associated with artificial structures that attempt to control erosion, can alter sediment transport in coastal regions. When the balance of accretion and erosion of sediment carried along the shoreline by wave action and lake currents is disrupted, the ecosystem functioning of coastal wetlands is impaired. The St. Clair, Detroit, and Niagara Rivers have a higher percentage of their shorelines hardened than anywhere else in the basin. Of the five Great Lakes, Lake Erie has the highest percentage of its shoreline artificially hardened, and Lake Huron and Lake Superior have the lowest percentages artificially hardened.

Groundwater is critical for maintaining Great Lakes aquatic habitats, plants and animals. Human activities such as groundwater withdrawals for municipal water supplies and irrigation, and the increased proportion of impervious surfaces in urban areas, have detrimentally impacted groundwater. On a larger scale, climate change could further contribute to reductions in groundwater storage.

Management Challenges:

Despite improvements in research and monitoring of coastal zones, the basin lacks a comprehensive plan for long-term monitoring of these areas. Long-term monitoring should be an important component of a comprehensive plan to maintain the condition and integrity of the coastal zones and aquatic habitats.

An educated public is essential to ensuring wise decisions about the stewardship of the Great Lakes basin ecosystem.
Protection of groundwater recharge areas, conservation of water resources, informed land use planning, raising of public awareness, and improved monitoring are essential actions for improving groundwater quality and quantity.

Resource Utilization

Although water withdrawals have decreased, overall energy consumption is increasing as population and urban sprawl increase throughout the Great Lakes basin. Human population growth will lead to an increase in the use of natural resources.

The population of the Great Lakes basin is approximately 42 million. Growth forecasts for the western end of Lake Ontario (known as the Golden Horseshoe) predict that this portion of the Canadian population will grow by an additional 3.7 million people by 2031. Population size, distribution, and density are contributing factors to resource use in the basin, although many trends have not been adequately assessed. In general, resource use is connected to economic prosperity and consumptive behaviors.

Although the Great Lakes and their tributaries contain 20 percent of the world's supply of surface freshwater, less than one percent of these waters is renewed annually through precipitation, run-off and infiltration. The net basin water supply is estimated to be 500 billion liters (132 billion gallons) per day. In 2000, water from the Great Lakes was used at a rate equal to approximately 35 percent of the available daily supply. The majority of water withdrawn is returned to the basin through discharge or run-off. However, approximately seven percent is lost through evapo-transpiration or depleted by human activities. Due to the shutdown of nuclear power facilities and improved water efficiency at thermal power plants, water use in Canada and the United States has decreased since 1980. In the future, increased pressures on water resources are expected to come from population growth in communities bordering the basin, and from climate change.

Population size, geography, climate, and trends in housing size and density all affect the amount of energy consumed in the basin. Electricity generation was the largest energy consuming sector in the Great Lakes basin.

Population growth and urban sprawl in the basin have led to an increase in the number of vehicles on roads, fuel consumption, and kilometers/miles traveled. Over a ten year period (1994-2004) fuel consumption increased by 17 percent in the U.S. states bordering the Great Lakes and by 24 percent in the province of Ontario. Kilometers/miles traveled within the same areas increased 20 percent for the United States and 56 percent for Canada. The increase in registered vehicles continues to outpace the increase in licensed drivers.

Management Challenges:
Increasing requests for water from communities bordering the basin, where existing water supplies are scarce or of poor quality will require careful evaluation.
Energy production and conservation need to be carefully managed to meet current and future energy consumption demands.

Population growth and urban sprawl are expected to challenge the current and future transportation systems and infrastructures in the Great Lakes basin.

Land Use-Land Cover

The Great Lakes basin encompasses an area of more than 765,000 square kilometers (295,000 square miles). How land is used impacts not only water quality of the Great Lakes, but also biological productivity, biodiversity, and the economy.

Data from 1992 and 2002 indicate that forested land covered 61 percent of the Great Lakes basin and 70 percent of the land immediately buffering surface waters, known as riparian zones. The greater the forest coverage in a riparian zone, the greater the capacity for the watershed to maintain biodiversity, store water, regulate water temperatures, and limit excessive nutrient and sediment loadings to the waterways. Urbanization, seasonal home construction, and increased recreational use are among the general demands being placed on forest resources nationwide. Additional disturbances caused by lumber removal and forest fires can also alter the structure of Great Lakes basin forests. However, the area of forested lands certified under sustainable forestry programs has significantly increased in recent years, exemplifying continued commitment from forest industry professionals to practices that help protect local ecosystem sustainability. Continued growth in these practices will lead to improved soil and water resources and increased timber productivity in areas of implementation.

Under the pressure of rapid population growth in the Great Lakes region, urban development has undergone unprecedented growth. Sprawl is increasing in rural and urban fringe areas of the Great Lakes basin, placing a strain on infrastructure and consuming habitat in areas that tend to have healthier environments than those that remain in urban areas. This trend is expected to continue, which will exacerbate other problems, such as longer commute times from residential to work areas, increased consumption of fossil fuels, and fragmentation of habitat. For example, at current development rates in Ontario, residential building projects are predicted to consume some 1,000 square kilometers (386 square miles) of the countryside, an area double the size of Toronto, by 2031. Also, vehicle gridlock could increase commuting times by 45 percent, and air quality could decline due to an estimated 40 percent increase in vehicle emissions.

In 2006, The Nature Conservancy Great Lakes Program and the Nature Conservancy of Canada Ontario Region released the *Binational Conservation Blueprint for the Great Lakes*. The Blueprint identified 501 areas across the Great Lakes that are a priority for biodiversity conservation. The Blueprint was developed by scientifically and systematically identifying native species, natural communities, and aquatic system characteristics of the region, and determining the sites that need to be preserved to ensure their long-term survival.

Management Challenges:
As the volume of data on land use and land conversion grows, stakeholder discussions will assist in identifying the associated pressures and management implications.
Comprehensive land use planning that incorporates “green” features, such as cluster development and greenway areas, will help to alleviate the pressure from development.

Managing forest lands in ways that protect the continuity of forest cover can allow for habitat protection and wildlife species mobility, therefore maintaining natural biodiversity.
Policies that favor an economically viable forestry industry will motivate private and commercial landowners to maintain land in forest cover versus conversion to alternative uses such as development.

Climate Change

A qualitative assessment of the indicator category Climate Change could not be supported for this report. Some observed effects in the Great Lakes region, however, have been attributed to changes in climate. Winters are getting shorter; annual average temperatures are growing warmer; extreme heat events are occurring more frequently; duration of lake ice cover is decreasing as air and water temperatures are increasing; and heavy precipitation events, both rain and snow, are becoming more common.

Continued declines in the duration and extent of ice cover on the Great Lakes and possible declines in lake levels due to evaporation during the winter are expected to occur in future years. If water levels decrease as predicted with increasing temperature, shipping revenue may decrease and the need for dredging could increase. Northward migration of species naturally found south of the Great Lakes region and invasions by warm water, non-native aquatic species will likely increase the stress on native species. A change in the distribution of forest types and an increase in forest pests are expected. An increase in the frequency of winter run-off and intense storms may deliver more non-point source pollutants to the lakes.

Management Challenges:
Increased modeling, monitoring and analysis of the effects of climate change on Great Lakes ecosystems would aid in related management decisions.
Increased public awareness of the causes of climate change may lead to more environmentally-friendly actions.

Salmon and Trout
Indicator #8

Overall Assessment

Status: **Mixed**
Trend: **Improving**
Primary Factors Determining Status and Trend: **The number of stocked salmonines per year is decreasing due to improvements in suppressing the abundance of the non-native preyfish, alewife. Many of the introduced salmonines are also reproducing successfully in the Great Lakes. The combined effect of a decrease in the number of alewife, as well as the increased health and reproduction of the salmonines is creating an improvement in the Great Lakes ecosystem.**

Lake-by-Lake Assessment

Lake Superior

Status: **Fair**
Trend: **Improving**
Primary Factors Determining Status and Trend: The number of stocked salmonines per year in Lake Superior is decreasing at a steady rate. Populations of salmon, rainbow trout and brown trout are being stocked at suitable rates to restore and manage indigenous fish species in Lake Superior.

Lake Michigan

Status: **Mixed**
Trend: **Slightly Improving**
Primary Factors Determining Status and Trend: The number of salmonines stocked each year in Lake Michigan is slightly declining. The goal for Lake Michigan is to establish self-sustaining lake trout populations. Currently, there are more salmon than lake trout stocked, which suggests that the lake trout are beginning to meet the self-sustaining goal for a balance in the ecosystem. This lake has the highest stocking rates out of all the Great Lakes.

Lake Huron

Status: **Fair**
Trend: **Improving**
Primary Factors Determining Status and Trend: The number of salmonines stocked each year in Lake Huron is declining. This lake has the second highest number of stocked salmonines, but the numbers are decreasing faster than Lake Superior, suggesting a larger reproduction rate and a balance in the ecosystem.

Lake Erie

Status: **Good**
Trend: **Improving**
Primary Factors Determining Status and Trend: Lake Erie is one of the lowest stocked out of all the Great Lakes. The objective for Lake Erie is to provide sustainable harvests of valued fish including lake trout, rainbow trout, and other salmonoids. Fisheries

restoration programs in Ontario and New York State have established regulations to conserve the harvest and increase fish populations for the next five years.

Lake Ontario

Status: **Mixed**

Trend: **Unchanging**

Primary Factors Determining Status and Trend: Lake Ontario has the second largest stocking rates (after Lake Michigan). The number of stocked salmonines has slightly declined in the last couple decades, but stocking numbers have been fairly constant in the last four years. The main objective for Lake Ontario is to have a diversity of naturally produced salmon and trout, with an abundance of rainbow trout and the top predator to be Chinook salmon. There is an abundance of rainbow trout and Chinook salmon, but the salmon and trout are not being naturally produced based on the high numbers of stocked fish each year.

Purpose

•To assess trends in populations of introduced salmon and trout species;
•To infer trends in species diversity in the Great Lakes basin; and
•To evaluate the resulting impact of introduced salmonines on native fish populations and the preyfish populations that supports them.

Ecosystem Objective

In order to manage Great Lakes fisheries, a common fish community goal was developed by management agencies responsible for the Great Lakes fishery. The goal is:

"To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic environment" (GLFC 1997).

Fish Community Objectives (FCOs) for each lake address introduced salmonines such as chinook and coho salmon, rainbow and brown trout (see Table 1 for definitions of fish terms). The following objectives are used to establish stocking and harvest targets consistent with FCOs for restoration of native salmonines such as lake trout, brook trout, and, in Lake Ontario, Atlantic salmon:

Lake Ontario (1999): Establish a diversity of salmon and trout with an abundant population of rainbow trout and the chinook salmon as the top predator supported by a diverse preyfish community with the alewife as an important species. Amounts of naturally produced (wild) salmon and trout, especially rainbow trout that are consistent with fishery and watershed plans.

Lake Erie and Lake St. Clair (2003): Manage the eastern basin to provide sustainable harvests of valued fish species, including…lake trout, rainbow trout, and other salmonids.

Lake Huron (1995): Establish a diverse salmonine community that can sustain an annual harvest of 2.4 million kg with lake trout the dominant species and stream-spawning species also having a prominent place.

Lake Michigan (1995): Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout, and establish self-sustaining lake trout populations.

Lake Superior (2003): Manage populations of Pacific salmon, rainbow trout, and brown trout that are predominantly self-sustaining but may be supplemented by stocking that is compatible with restoration and management goals established for indigenous fish species.

Term	Definition
Salmonine	Refers to salmon and trout species
Salmonid	Refers to any species of fish with an adipose fin, including trout, salmon, whitefish, graying, and cisco
Pelagic	Living in open water, especially where the water is more than 20 m deep

Table 1. Glossary of various terms used in this report

State of the Ecosystem

First introduced to the Great Lakes in the late 1870s, non-native salmonines have emerged as a prominent component of the Great Lakes ecosystem and an important tool for Great Lakes fisheries management. Fish managers stock non-native salmonines to suppress abundance of the non-native preyfish, alewife, thereby reducing alewife predation and competition with native fish, while seeking to avoid wild oscillations in salmomine-predator/alewife-prey ratios. In addition, non-native salmonines are stocked to create recreational fishing opportunities with substantial economic benefit (Rand and Stewart 1998).

After decimation of the native top predator (lake trout) by the non-native, predaceous sea lamprey, stocking of non-native salmonines increased dramatically in the 1960s and 1970s. Based on stocking data obtained from the Great Lakes Fishery Commission (GLFC), approximately 922 million non-native salmonines were stocked in the Great Lakes basin between 1966 and 2005. This estimate excludes the stocking of Atlantic salmon in Lake Ontario because they are native to this lake. Non-native salmonines also reproduce in the Great Lakes. For example, many of the chinook salmon in Lake Huron are wild and not stocked. This includes mostly Chinook salmon, followed by Rainbow trout. Since 2002, 74 million non-native salmonines have been stocked in the Great Lakes. Although, this is a large amount of fish being stocked, the number of stocked salmonines has actually decreased 32% from 2002 to 2004.

Of non-native salmonines, chinook salmon are the most heavily stocked, accounting for about 45% of all non-native salmonine releases (Figure 1). Rainbow trout are the second highest non-native stocked species, accounting for 25% of all non-native salmonine releases. Chinook salmon, which prey almost exclusively on alewife, are the least expensive of all non-native salmonines to rear, thus making them the backbone of stocking programs in alewife-infested lakes, such as Lakes Michigan, Huron and Ontario (Bowlby and Daniels 2002). Like other salmonines, chinook salmon are also stocked in order to provide an economically important sport fishery. While chinook salmon have the greatest prey demand of all non-native salmonines, an estimated 76,000 tonnes of alewife in Lake Michigan alone are consumed annually by all salmonine predators (Kocik and Jones 1999).

Data are available for the total number of non-native salmonines stocked in each of the Great Lakes from 1966-2005 (Figure 2).

Of the five major Great Lakes (excluding Lake St. Clair), Lake Michigan is the most heavily stocked, with a maximum stocking level in 1998 greater than 16 million non-native salmonines. In contrast, Lake Superior has the lowest rates of stocking, with a maximum greater than 5 million non-native salmonines in 1991. Lakes Huron and Erie both display a similar overall downward trend in stocking, especially in recent years. Lake Ontario has a constant, yet slightly declining trend in stocking. In Lake Ontario, this trend can be explained by stocking cuts implemented in 1993 by fisheries managers to lower prey consumption by salmonine species by 50% over two years (Schaner et al. 2001). Since the late 1980s, the number of non-native salmonines stocked in the Great Lakes has been nearly constant or slightly declining with the exception of a 1998 peak in Lakes Michigan and Huron.

Overall, the Great Lakes are improving based on a general trend of reduced numbers of stocked salmonines. The goal of creating a balanced ecosystem within each lake is occurring at different levels for each individual lake. Lakes Superior and Erie are improving at the fastest rates with the lowest stocking levels, while Lake Ontario is improving at the slowest rate out of all of the Great Lakes. Lake Michigan's stocking levels are declining slightly more than Lake Ontario's levels, but it also has the highest number of stocked salmon and trout. Lake Huron has higher stocking rates than Lake Erie and Superior, but the levels have been decreasing faster each year than any other lake.

The number of stocked salmonines per year in Lake Superior is decreasing at a steady rate. Populations of salmon, rainbow trout and brown trout are being stocked at suitable rates to restore and manage indigenous fish species in Lake Superior. Stocking rates have decreased in the last 5 years suggesting successful reproduction rates and suitable conditions for an improvement towards a balanced ecosystem in the near future.

The number of salmonines stocked each year in Lake Michigan is slightly declining. The goal for Lake Michigan is to establish self-sustaining lake trout populations. Currently, there are more salmon than lake trout stalked, which suggests that the lake trout are beginning to meet the self-sustaining goal for a balance in the ecosystem. This lake has the highest stocking rates out of all the Great Lakes.

The goal for Lake Huron is to make the lake trout the dominant species. The lake trout is one of the few native deepwater predators found in the Great Lakes. Their populations in Lake Huron and Lake Michigan were decimated in the 1950's by over-fishing and predation by the exotic sea lamprey (US Fish and Wildlife Service, 2005). The number of lake trout has increased in the last decade due to the decrease in the number of sea lampreys (Madenjian and Desorcie, 2004). This lake has the second highest number of stocked salmonines suggesting a low reproduction rate, but an improvement in the balance of the ecosystem since these stocking levels are decreasing.

Lake Erie is one of the lowest stocked out of all the Great Lakes. The objective for Lake Erie is to provide sustainable harvests of valued fish including lake trout, rainbow trout, and other salmonoids. Based on figure 1, the need for stalking has dropped dramatically over the last few years, suggesting that sustainable harvests are occurring in Lake Erie. Fisheries restoration programs in Ontario and New York State have established regulations to conserve the harvest and increase fish populations for the next five years (Lake Erie Lamp, 2003). This program is well on its way since there have already been improvements in the fish populations.

Lake Ontario has the second largest stocking rates, following Lake Michigan. The number of stocked salmonines has slightly declined in the last couple decades, but stocking numbers have been fairly constant in the last four years. The main objective for Lake Ontario is to have a diversity of naturally produced salmon and trout, with an abundance of rainbow trout and the top predator to be Chinook salmon. Rainbow trout are the second highest stocked fish in Lake Ontario, following Chinook salmon. Therefore, part of this goal has been met since the Chinook salmon are readily available as the top predator, and Rainbow trout are abundant in Lake Ontario because of the high stocking levels. However, the objective of having naturally producing salmon and trout has not been met due to the need for high stocking rates in Lake Ontario. The salmon and trout are not naturally producing based on the high numbers of stocking each year. Lake Ontario received a “mixed” rating rather than deteriorating rating because, although the objectives have not been met, there is still a need for high stalking levels. Salmon and trout are stalked not only to create a balance in the ecosystem, but for a popular recreational activity. Sport fishing has been a very popular activity in Lake Ontario for many years. Native lake trout are at the top of the food chain and would have disappeared if they weren't being stocked for sport fishing. Sport fishing is a $3.1 billion annual business, according to a recent industry study (Edgecomb, 2006). High stocking rates are needed to keep up with the popularity of sport fishing in Lake Ontario, which explains the increased need for higher stocking levels in Lake Ontario.

Pressures
The introduction of non-native salmonines into the Great Lakes basin, beginning in the late 1870s, has placed pressures on both the introduced species and the Great Lakes ecosystem. The effects of introduction on the non-native salmonine species include changes in rate of survival, growth and development, dispersion and migration, reproduction, and alteration of life-history characteristics (Crawford 2001).

The effects of non-native salmonine introductions on the Great Lakes ecosystem are numerous. Some of the effects on native species are; 1) the risk of introducing and transferring pathogens and parasites (e.g. furunculosis, whirling disease, bacterial kidney disease, and infectious pancreatic necrosis), 2) the possibility of local decimation or extinction of native preyfish populations through predation, 3) competition between introduced and native species for food, stream position, and spawning habitat, and 4) genetic alteration due to the creation of sterile hybrids (Crawford 2001). The introduction of non-native salmonines to the Great Lakes basin is a significant departure from lake trout’s historic dominance as key predator.

With few exceptions (such as kokanee salmon), introduced salmonines are now reproducing successfully in portions of the basin, and they are considered naturalized components of the Great Lakes ecosystem. Therefore, the question is no longer whether non-native salmonines should be introduced, but rather how to determine the appropriate abundance of salmonine species in the lakes.

Within any natural system there are limits to the level of stocking that can be maintained. The limits to stocking are determined by the balance between lower and higher trophic level populations (Kocik and Jones 1999). Rand and Stewart (1998) suggest that predatory salmonines have the potential to create a situation where prey (alewife) is limiting and ultimately predator survival is reduced. For example, during the 1990s, chinook salmon in Lake Michigan suffered dramatic declines due to high mortality and high prevalence of Bacterial Kidney Disease (BKD) when alewife were no longer as abundant in the preyfish community (Hansen and Holey 2002). Salmonine predators could have been consuming as much as 53 percent of alewife biomass in Lake Michigan annually (Brown et al. 1999). While suppressing alewife populations, managers seek to avoid extreme "boom and bust" predator and prey populations, a condition not conducive to biological integrity. Currently managers seek to produce a predator/prey balance by adhering to stocking ceilings established for lakes such as Michigan and Ontario, based on assessment of forage species and naturally produced salmonines.

Because of their importance as a forage base for the salmonine sport fishery, alewife are no longer viewed as a nuisance by some managers (Kocik and Jones 1999). However, alewives prey on the young of a variety of native fishes, including yellow perch and lake trout, and they compete with native fishes for zooplankton. In addition, the enzyme thiaminase in alewives causes Early Mortality Syndrome (EMS) in salmonines that consume alewife, threatening lake trout rehabilitation in the lower four lakes and Atlantic salmon restoration in Lake Ontario. As alewife populations increase, massive over-winter die-offs can occur, particularly in severe winters, fouling local beaches that are used for recreation and impacting the health of the surrounding ecosystem.

Management Implications

In Lakes Michigan, Huron and Ontario, many salmonine species are stocked in order to maintain an adequate population to suppress non-native prey species (alewife) as well as to support recreational fisheries. Determining stocking levels that will avoid oscillations in the forage base of the ecosystem is an ongoing challenge. Alewife populations, in terms of an adequate forage base for introduced salmonines, are difficult to estimate as there is a delay before stocked salmon become significant consumers of alewife; meanwhile, alewife can suffer severe die offs in particularly severe winters.

Fisheries managers seek to improve their means of predicting appropriate stocking levels in the Great Lakes basin based on the alewife population. Long-term data sets and models track the population of salmonines and species with which they interact. However, more research is needed to determine the optimal number of non-native salmonines, to estimate abundance of naturally produced salmonines, to assess the abundance of forage species, and to better understand the role of non-native salmonines and non-native prey species in the Great Lakes ecosystem.
Chinook salmon will likely continue to be the most abundantly stocked salmonine species in Lakes Michigan, Huron, and Ontario because they are inexpensive to rear, feed heavily on alewife, and they are highly valued by recreational fishers. Fisheries managers should continue to model, assess, and practice adaptive management with the ultimate objective being to support fish

community goals and objectives that GLFC lake committees established for each of the Great Lakes.

Comments from the author(s)

This indicator should be reported frequently as salmonine stocking is a complex and dynamic management intervention in the Great Lakes ecosystem.

Acknowledgments

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Figure 2. Total number of non-native salmonines stocked in the Great Lakes, 1966-2005 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking)

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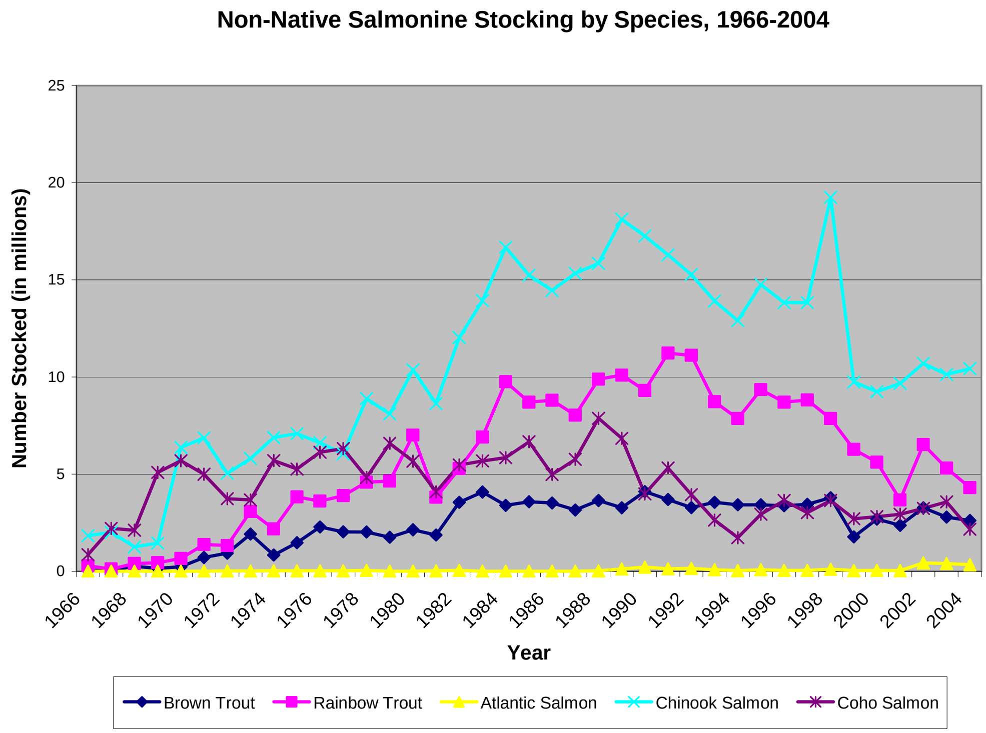

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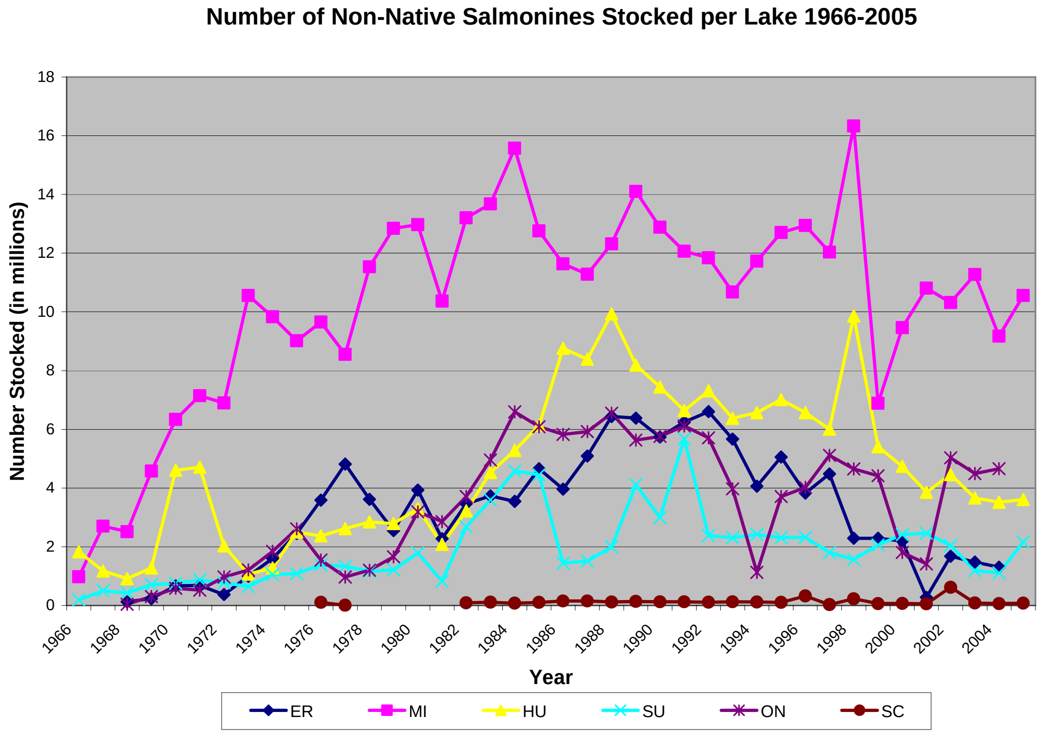

Figure 2. Total number of non-native salmonines stocked in the Great Lakes, 1966-2005 excluding Atlantic salmon in Lake Ontario and brook trout in all Great Lakes.
Source: Great Lakes Fishery Commission Fish Stocking Database (www.glfc.org/fishstocking)

Walleye
Indicator #9

Overall Assessment

Status: **Fair**
Trend: **Unchanging**
Primary Factors Determining Status and Trend: **An exceptionally strong 2003 hatch has bolstered walleye abundance in nearly all of the Great Lakes and should keep them at low to moderate levels for the next several years. Low reproductive success post-2003 will not permit populations to increase in many areas. Fisheries harvests have improved in recent years but remain below targets in nearly all areas**.

Lake-by-Lake Assessment

Lake Superior

Status: Not Assessed Since Last Report
Trend: Undetermined
Primary Factors Determining Status and Trend: Recent harvest estimates were not available for this report. Through 2003, commercial yields were below the historical average while tribal harvest was above average.

Lake Michigan

Status: Fair
Trend: Undetermined
Primary Factors Determining Status and Trend: Recreational harvest was below historical levels in 2004-2005. Tribal fishery yields were not available but were well-above average in the four most recent years where data exist (2000-2003). Green Bay stocks appear to be stable, perhaps improving. Fishery yields remain well below targets of 100-200 metric tons per year.

Lake Huron

Status: Fair
Trend: Unchanging
Primary Factors Determining Status and Trend: Fishery yields are at historical average levels but far below targets of 700 metric tons each year. Commercial harvest trends continue to decline while recreational harvest trends are flat or perhaps improving. Reproductive success has greatly improved between 2003 and 2005 in Saginaw Bay and perhaps other parts of the lake, and is attributed to the decline of alewives.

Lake Erie

Status: Fair
Trend: Unchanging
Primary Factors Determining Status and Trend: The fisheries objective of sustainable harvests lake wide has not been realized since the late-1990s but has improved recently with contributions from the strong 2003 hatch. Commercial harvest increased substantially in 2005 while recreational fisheries remained static due to size restrictions. Harvest by both fisheries is expected to increase substantially in 2006.

Below-average reproductive success in 2004-2005 will reduce adult abundance over the next few years but the 2003 hatch should keep the population at low to moderate levels of abundance.

Lake Ontario

Status:	Fair
Trend:	Unchanging
Primary Factors Determining Status and Trend	After a decade long decline, walleye populations appear to have stabilized. Fishery yields are roughly half of the average over the past 30 years. Recent hatches should keep the population at current levels of abundance for the next several years.

Purpose

•To show status and trends in walleye populations in various Great Lakes habitats;
•To infer changes in walleye health; and
•To infer ecosystem health, particularly in moderately productive (mesotrophic) areas of the Great Lakes.

Ecosystem Objective

Protection, enhancement, and restoration of historically important, mesotrophic habitats that support natural stocks of walleye as the top fish predator are necessary for stable, balanced, and productive elements of the Great Lakes ecosystem.

State of the Ecosystem

Reductions in phosphorus loadings during the 1970s substantially improved spawning and nursery habitat for many fish species in the Great Lakes. Improved mesotrophic habitats (i.e., western Lake Erie, Bay of Quinte, Saginaw Bay and Green Bay) in the 1980s, along with interagency fishery management programs that increased adult survival, led to a dramatic recovery of walleyes in many areas of the Great Lakes, especially in Lake Erie. High water levels also may have played a role in the recovery in some lakes or bays. Trends in annual assessments of fishery harvests generally track walleye recovery in these areas, with peak harvests occurring in the mid-1980s to early 1990s followed by declines from the mid-1990s through 2000, and increases in most areas after 2000 (Figure 1). Total yields were highest in Lake Erie (annual average of about 4,500 metric tons, 1975-2005), intermediate in Lakes Huron (average of 90 metric tons) and Ontario (average of 224 metric tons), and lowest in Lakes Michigan (average of 14 metric tons) and Superior (average of 2 metric tons). Declines after the mid-1990s were possibly related to shifts in environmental states (i.e., from mesotrophic to less favorable oligotrophic conditions), variable reproductive success, influences from invading species, and changing fisheries. Recent improvements in abundance are due to a strong 2003 hatch across the Great Lakes Basin, presumably due to ideal weather conditions. Reproductive success has remained very strong since 2003 in Saginaw Bay, and perhaps other parts of Lake Huron, and is attributed to the decline of alewives in that lake during the same time period. In general, walleye yields peaked under ideal environmental conditions and declined under less favorable (i.e., non-mesotrophic) conditions. Overall, environmental conditions remain improved relative to the

1960s and early 1970s but concerns about food web disruption, pathogens (e.g., botulism, viruses), noxious algae, and watershed management practices persist.

Pressures

Natural, self-sustaining walleye populations require adequate spawning and nursery habitats. In the Great Lakes, these habitats exist in tributary streams and nearshore reefs, wetlands, and embayments, and they have been used by native walleye stocks for thousands of years. Degradation or loss of these habitats is the primary concern for the health of walleye populations and can result from both human causes, as well as from natural environmental variability. Increased human use of nearshore and watershed environments continues to alter the natural hydrologic regime, affecting water quality (i.e., sediment loads) and rate of flow. Environmental factors that affect precipitation patterns ultimately alter water levels, water temperature, water clarity and flow. Thus, global warming and its subsequent effects on temperature and precipitation in the Great Lakes basin may become increasingly important determinants of walleye health. Non-native invaders, like zebra and quagga mussels, ruffe, and round gobies continue to disrupt the efficiency of energy transfer through the food web, potentially affecting growth and survival of walleye and other fishes through a reduced supply of food. Recent experience in Lake Huron has elevated the concern over the predatory and competitive effects of the non-native alewife on walleye. In their absence, walleye reproductive success has surged, indicating that the deleterious effect of alewife predation on larval walleye may have been much greater than previously realized. Alterations in the food web can also affect environmental characteristics (like water clarity), which can in turn affect fish behavior and fishery yields. Pathogens, like viral hemorrhagic septicemia and botulism, may also be affecting walleye populations in some areas of the Great Lakes.

Management Implications

To improve the health of Great Lakes walleye populations, managers must enhance walleye reproduction, growth and survival rates. Most walleye populations are dependent on natural reproduction, which is largely driven by uncontrollable environmental events (i.e., spring weather patterns 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 are essential for the long term health of walleye populations. Elimination of additional introductions of invasive species and control of existing non-native species, where possible, is also critical to future health of walleyes and other native species.

Comments from the author(s)

Fishery yields are appropriate indicators of walleye health but only in a general sense. Yield assessments are lacking for some fisheries (recreational, commercial, or tribal) or in some years for all of the areas. Moreover, measurement units are not standardized among fishery types (i.e., commercial fisheries are measured in pounds while recreational fisheries are typically measured in numbers), which means additional conversions are necessary and may introduce errors. Also, “zero” values are not differentiated from “missing” data in the figure. Therefore, trends in 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, I recommend a 10-year reporting cycle on this indicator. Many agencies have developed, or are developing, population estimates for many Great Lakes fishes. Walleye population estimates for selected areas (i.e., Lake Erie, 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 I recommend switching to them as they become available in all areas.

Acknowledgments
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Data Sources
Fishery harvest data were obtained from the following sources:
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Lake Erie: Roger Knight, ODNR, roger.knight@dnr.state.oh.us
Lake Ontario: Jim Hoyle, OMNR, jim.hoyle@mnr.gov.on.ca
Lake Ontario: Steve Lapan, NYSDEC, srlapan@gw.dec.state.ny.us

Various annual Lake Erie fisheries reports from the Ontario Ministry of Natural Resources, Ohio Department of Natural Resources, and the Great Lakes Fishery Commission commercial fishery data base were used as data sources.

Fishery data should not be used for purposes outside of this document without first contacting the agencies that collected them.

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Figure 1. Recreational, commercial, and tribal harvest of walleye from the Great Lakes. Fish Community Goals and Objectives are: Lake Michigan, 100-200 metric tons; Lake Huron, 700 metric tons; Lake Erie, sustainable harvest in all basins.
Source: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources ,Wisconsin Department of Natural Resources

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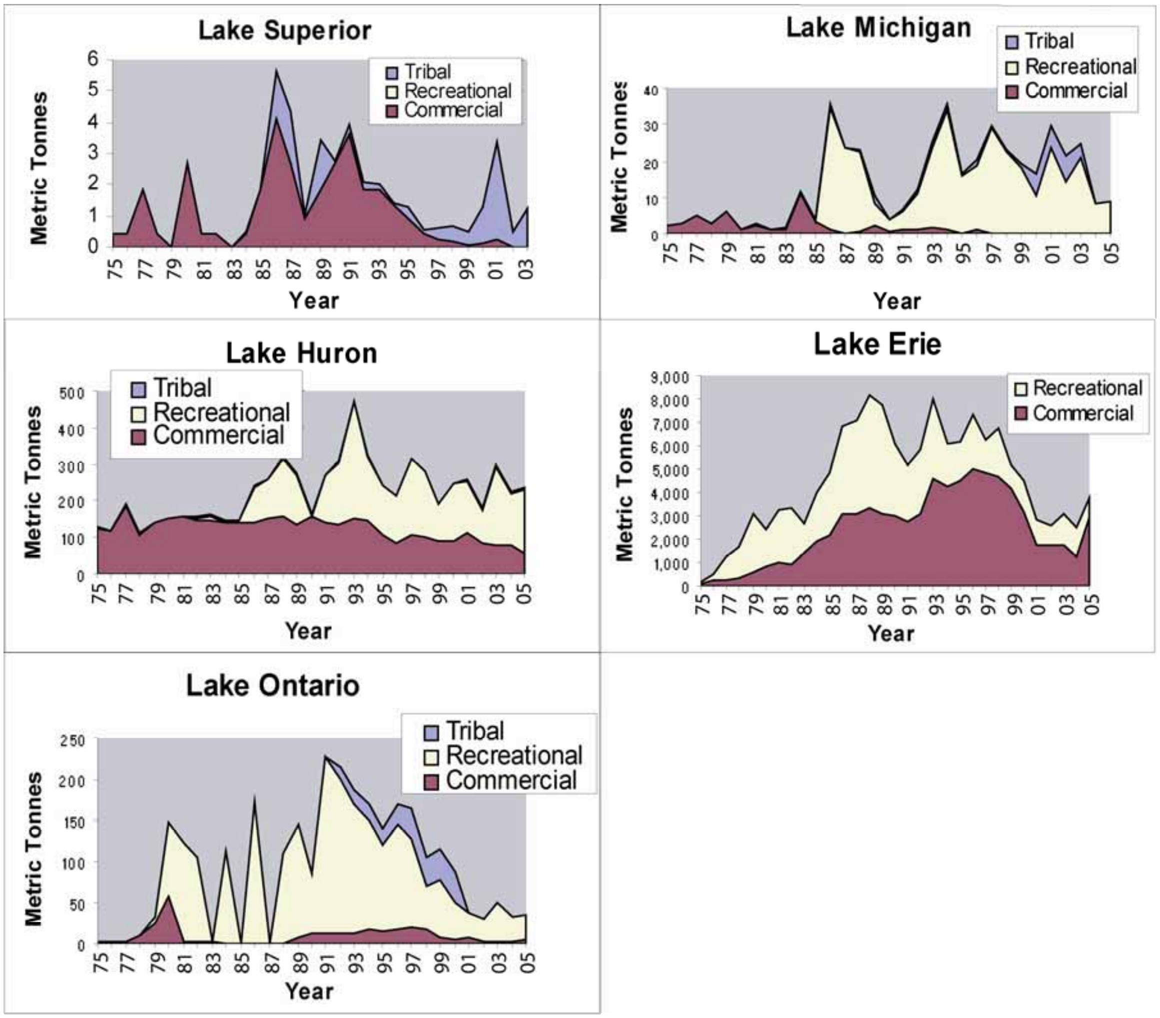

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Source: Chippewa Ottawa Resource Authority, Michigan Department of Natural Resources, New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Ohio Department of Natural Resources ,Wisconsin Department of Natural Resources

Preyfish Populations
Indicator #17

Overall Assessment

Status: **Mixed**
Trend: **Deteriorating**

Lake-by-Lake Assessment

Lake Superior

Status: Mixed
Trend: Improving

Lake Michigan

Status: Mixed
Trend: Deteriorating

Lake Huron

Status: Mixed
Trend: Deteriorating

Lake Erie

Status: Mixed
Trend: Deteriorating

Lake Ontario

Status: Mixed
Trend: Deteriorating

Purpose
- To assess the abundance and diversity of preyfish populations; and
- To infer the stability of predator species necessary to maintain the biological integrity of each lake.

Ecosystem Objective

The importance of preyfish populations to support healthy, productive populations of predator fishes is recognized in the Fish Community Goals and Objectives for each lake. For example, the fish community objectives 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.

State of the Ecosystem

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 leading to a better understanding of the processes that shape the fish community and to identify those characteristics critical to each species. Populations of lake trout, Pacific salmon, and other salmonids have been established as part of intensive programs designed to rehabilitate (or develop new) game 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 lake herring, 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 both pelagic and benthic species – that prey on invertebrates for their entire life history. As adults, preyfish depend on diets of crustacean zooplankton and macroinvertebrates Diporeia and Mysis. 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*), lake herring (*Coregonus artedi*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and deepwater sculpins (*Myoxocephalus thompsonii*), and to a lesser degree species like lake whitefish (*Coregonus clupeaformis*), ninespine stickleback (*Pungitius pungitius*), round goby (*Neogobius melanostomus*) and slimy sculpin (*Cottus cognatus*) constitute the bulk of the preyfish communities (Figure 1). The successful colonization of Lakes Michigan, Huron, Erie, and Ontario by non-native dreissenids, notably the 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 shunting pelagic planktonic production to mussels, an energetic dead end in the food chain as few native fishes can eat the mussels. As a result of profound ongoing changes in trophic structure in four Great Lakes, these ecosystems will continue to change, and likely in unpredictable ways. 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 shiners (*N. hudsonius*), silver chubs (*Hybopsis storeriana*), trout-perch (*Percopsis omiscomaycus*), round gobies, and rainbow smelt (grouped as soft-rayed); and age-0 yellow (*Perca flavescens*) and white perch (*Morone americana*), and white bass (*M. chrysops*) (grouped as spiny-rayed).

State of Preyfish Populations

Lake Ontario: Mixed, deteriorating

The non-native alewife, and to a lesser degree non-native rainbow smelt, dominate the preyfish community. Their populations remain at levels well below that of the early 1980s. Rainbow smelt have an abbreviated age and size structure that suggests the population is under heavy predation pressure. Abundance of the non-native round goby is increasing and round goby have the potential to negatively impact native, bottom-dwelling, preyfishes such as slimy and deepwater sculpins, and trout-perch. Deepwater sculpin, not reported from the lake since 1972, were collected sporadically in 1996-2004. During 2005-2006, catches of deepwater sculpin increased and juveniles dominated the catches suggesting that the long-depressed population was recovering. Deepwater ciscoes, however, have not been reported from the lake since 1983 and the large area of the lake they once occupied is largely devoid of fish for much of the year.

Lake Erie: Mixed, deteriorating
The preyfish community in all three basins of Lake Erie has shown declining trends. In the eastern basin, rainbow smelt (part of soft-rayed group) have shown declines in abundance over the past two decades. The declines have been attributed to lack of recruitment associated with expanding Driessenid colonization and reductions in productivity. The western and central basins also have shown declines in preyfish abundance associated with declines in abundance of age-0 white perch and rainbow smelt, although slight increases for white perch have been reported in the past couple years. The clupeid component of the preyfish community is at the lowest level observed since 1998 and well below the mean biomass during 1987-2005.. The biomass estimates for western Lake Erie were based on data from bottom trawl catches, depth strata extrapolations (0-6 m, and >6 m), and trawl net measurements using acoustic mensuration gear.

Lake Michigan: Mixed, deteriorating
Bloater abundance in Lake Michigan fluctuated greatly during 1973-2005, as the population showed a strong recovery during the 1980s but rapidly declined during the late 1990s. Bloaters may be cycling in abundance 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 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 by deepwater sculpins by feeding upon deepwater sculpin fry. Slimy sculpin abundance appeared to be primarily regulated by predation by juvenile lake trout. Slimy sculpin is a favored prey of juvenile lake trout. Temporal trends in abundance of rainbow smelt were difficult to interpret. Yellow perch year-class strength in 2005 was the highest on record dating back to 1973. Thus, early signs of a recovery by the yellow perch population in the main basin of Lake Michigan were evident. The first catch of round gobies in our annual lakewide survey occurred in 2003, and round goby abundance in the main basin of the lake has remained low through 2005.

Lake Huron: Mixed, deteriorating
The Lake Huron fish community changed dramatically during 2003-2006, primarily due a 99% decline in alewife numbers. Loss of alewife appears due to heavy salmonid predation that resulted from increased Chinook salmon abundance as a result of wild reproduction. Alewife decline was followed immediately by increased reproduction of other fish species; record year classes of walleye and yellow perch were produced in Saginaw Bay, while in the main basin increased reproduction by bloaters (chubs), rainbow smelt, and deepwater sculpins was observed. In 2004, USGS surveys captured 22 wild juvenile lake trout -- more than had been captured in the 30 year history of those surveys. However, despite increased reproduction by prey species, biomass remains low because newly recruited fish are still small. No species has taken the place of alewife, and prey biomass has declined by over 65%. Salmon catch rates by anglers declined, as did average size and condition of those fish. The situation is exacerbated by changes at lower trophic levels. The deepwater amphipod Diporeia has declined throughout Lake Huron's main basin, and the zooplankton community has grown so sparse that it resembles the assemblage

found in Lake Superior. The reasons underlying these changes are not known, but the most widely held hypothesis is that zebra and quagga mussels are shunting energy into pathways that are no longer available to fish.

Lake Superior: Mixed, improving
Since 1994, biomass of the Lake Superior preyfish has declined compared to the peak years in 1986, 1990, and 1994, a period when lake herring was the dominant preyfish species and wild lake trout populations were starting to recover. Since the early 1980s, dynamics in preyfish biomass have been driven largely by variation in recruitment of age-1 lake herring. Strong year classes in 1984, 1988-1990, 1998, and most recently 2003 were largely responsible for peaks in lake herring biomass in 1986, 1990-1994, 1999, 2004-2005. Prior to 1984, the nonnative rainbow smelt was the dominant preyfish, but fluctuating population levels and recovery of native coregonids after 1984 resulted in reduced biomass and rank among preyfish species. During 2002-2004, rainbow smelt biomass declined to the lowest levels in the time series, though a moderate recovery occurred in 2005. There is strong evidence that declines in rainbow smelt biomass are tied to increased predation by recovered lake trout populations. Biomass of bloater and lake whitefish has increased since the early 1980s, and biomass for both species has been less variable than that of lake herring. 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 increased predation by recovered wild lake trout stocks and, to a lesser degree, the resumption of human harvest of lake trout, lake herring, and lake whitefish.

Pressures
The influences of predation by salmon and lake trout on preyfish populations appear to be common across all lakes. Additional pressures from *Dreissena*, which is linked to the collapse of Diporeia are strong in all lakes save Superior. Bottom-up effects on the preyfishes have already been observed in Lakes Ontario, Huron, and Michigan suggesting that dynamics of preyfish populations in those lakes could be driven by bottom-up rather than top-down effects in future years, Moreover, the effect of non-native zooplankters, *Bythotrephes* and *Cercopagis*, on preyfish populations, although not fully understood at present, has the potential to increase bottom up pressure.

Management Implications
Recognition of significant predation effects on preyfish populations has resulted in recent salmon stocking cutbacks in Lakes Michigan and Huron and only minor increases in Lake Ontario. However, even with a reduced population, alewives have exhibited the ability to produce strong year classes when climatic conditions are favorable such that the continued judicious use of artificially propagated predators seems necessary to avoid domination by alewife. It should be noted that this is not an option in Lake Superior because lake trout and salmon are almost entirely lake-produced. Potential bottom-up effects on preyfishes would be difficult to mitigate owing to our inability to affect changes. This scenario only reinforces the need to avoid further introductions of exotics into the Great Lake ecosystems.

Comments from the author(s)

It has been proposed 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. 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 lakes other than 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 realized.

Continued monitoring of the fish communities and regular assessments of food habits of predators and preyfish will be required to quantify the food-web dynamics in the Great Lakes. This recommendation is especially supported by continued changes that are occurring not only in the upper but also in the lower trophic levels. Recognized sampling limitations of traditional capture techniques (bottom trawling) have prompted the application of acoustic techniques as another means to estimate absolute abundance of preyfishes in the Great Lakes. Though not an assessment panacea, hydro-acoustics have provided additional insights and have demonstrated utility in the estimates of preyfish biomass.

Protecting or reestablishing rare or extirpated members of the once prominent native preyfishes, most notably the various members of the whitefish family (*Coregonus* spp.), should be a priority in all the Great Lakes but especially in Lake Ontario where vast areas of the lake once occupied by extirpated deepwater ciscoes are devoid of fish for much of the year. This recommendation should be reflected in future indicator reports. 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 preyfishes, and the lower trophic levels on which they depend, the appropriate frequency to review this indicator is on a 5-year basis.

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List of Figures

Figure 1. Preyfish trends based on annual bottom trawl surveys. All trawl surveys were performed by USGS - Great Lakes Science Center, except for Lake Erie, which was conducted by the USGS, Ohio Division of Wildlife and the Ontario Ministry of Natural Resources (Lake Erie Forage Task Group), and Lake Ontario, which was conducted jointly by USGS and the New York State Department of Environmental Conservation.

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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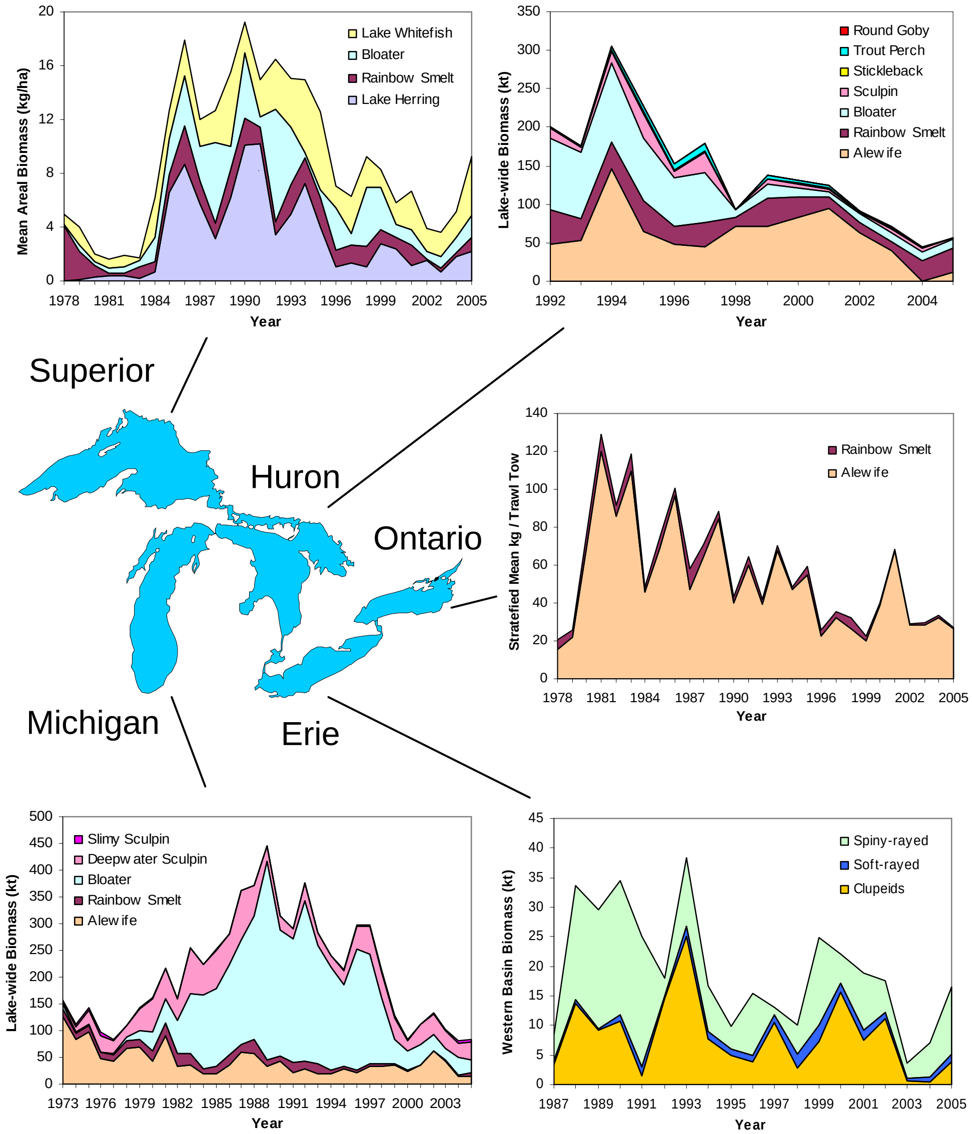

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