Assessment of Progress Made Towards Restoring and Maintaining Great Lakes Water Quality Since 1987
ABSTRACT

The International Joint Commission (the Commission) initiated an effort to assess progress in restoring and maintaining Great Lakes water quality, since 1987, when the Great Lakes Water Quality Agreement was last amended. Fourteen indicators were used to assess progress in this draft report. All seven indicators of chemical integrity showed mostly favorable or stable results since 1987. Atmospheric deposition of toxic chemicals has declined since 1987. Decreased concentrations of most measured toxic chemicals were observed in herring gulls, fish, sediments, and mussels. Most reductions occurred from 1987-2000 and it is not clear what the trends are since then. However, results since 1987 differ for newer developed chemicals. For example, the concentrations of PBDEs (flame retardants) in fish increased dramatically from 1980 to 2000 and have since started to decline. Biological indicators had mixed results. From 1987 to 2006, there were 34 non-native species introduced into the Great Lakes but none have become established since 2006. The burrowing mayfly and lake sturgeon have started to return, but lake trout populations are consistent with 1987 populations. Diporeia, a key part of the aquatic food web has almost disappeared. The one physical indicator examined in this analysis is surface water temperature which is rising. Rising temperatures change aquatic habitats and underscore concerns about global climate change. This draft report is a work in progress and is being shared with the public via the Commission’s website and the 2011 Great Lakes Water Quality Biennial Meeting held in Detroit on October 12-14, 2011. The Commission plans to publish a report in 2012 based on this draft document, consideration of comments received, and subsequent research. In the process of developing the report, the Commission reviewed literature on ecological indicators and recommends that the governments develop timely progress reports, related to the objectives of the Agreement, using a set of core indicators.
DISCLAIMER

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AUTHORS, REVIEWERS, AND CONTRIBUTORS

The International Joint Commission (IJC) prepared this document with the input of numerous experts from the United States and Canada. The authors and reviewers of each indicator report are listed on the front pages of every report. References are provided at the end of each chapter.

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International Joint Commission (IJC). TO BE INSERTED ONCE FINAL REPORT IS COMPLETED
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I. EXECUTIVE SUMMARY

The International Joint Commission (the Commission) has initiated an effort to assess progress made towards restoring and maintaining Great Lakes water quality since 1987. Periodic progress reports are needed to help determine what is working and what is not to help guide environmental management decisions. This draft assessment of progress report reflects work done to date and is being shared with the public via the Commission’s website and the 2011 Great Lakes Water Quality Biennial Meeting held in Detroit on October 12-14, 2011. The Commission plans to publish a report in 2012 based on consideration of comments received and subsequent research.

The Great Lakes Water Quality Agreement (the Agreement) states that the purpose of the governments of the United States and Canada within the context of the Agreement is to restore and maintain the chemical, physical, and biological integrity of the waters of Great Lakes Basin Ecosystem. The governments are also responsible for reporting on progress made towards various aspects of the Agreement, known as annexes, and to use indicators to develop these progress reports. Indicators are measurable features of environmental conditions that represent something important to environmental management objectives. Lake trout abundance is an example of an indicator of biological integrity.

The Commission is responsible for using reports prepared by the two countries to perform its own independent and binational assessment of progress towards achieving the purpose of the Agreement every two years. The Commission undertook this current effort because, in recent years, it has not been able to comprehensively report on progress. During this time, the Commission has not received the data needed to develop these reports from the governments. Since the government’s plan to renew the Agreement next year, and since the last time the Agreement was amended was 1987, the Commission decided to assess progress since that time. This preliminary draft report was developed using the best indicator data available that investigators could assemble within a short time period. The findings are based on 14 indicators
of condition and their changes over time back to 1987, or to the closest time periods with data available to make comparisons.

In the process of developing the report, the Commission reviewed related literature and offered several recommendations that all relate to the key message -- the need to provide timely progress reports using a set of core indicators. The science of indicators development and application can be improved over time and will always have limitations and uncertainty. Yet, progress reports should be developed based on the best available indicators at the time.

The report is also intended to help the public to better understand the resources of the Great Lakes Basin and appreciate the importance of protecting this fragile ecosystem. The report can be used to learn principles of environmental science in an applied manner. The scientific terms can be easily understood by referencing the glossary that is provided at the end of the report. An executive summary of the Commission’s overall findings is presented to provide an overview and precedes this introduction. Each indicator report starts off with a similar summary.

Fourteen indicators were selected based on availability of historical data, relevance to Agreement or environmental management objectives, ecological importance, availability of experts to contribute, and other criteria. The 14 indicator reports are categorized into three groups with 6 of the 14 indicators addressing chemical integrity, one addressing physical integrity, and six indicators addressing biological integrity. Each indicator report describes why the indicator is important, the methods used to acquire data, results and discussion, and potential future use of the indicator.

Synopsis of Overall Trends

All seven indicators of chemical integrity showed mostly favorable or stable results since 1987. The levels of many persistent toxic chemicals coming into the Great Lakes from atmospheric deposition are lower than they were in 1987. Concentrations of most measured persistent toxic chemicals decreased in herring gulls, fish, sediments, and mussels. Most reductions occurred from 1987-2000 period and it is not clear what the trends are since 2000. However,
concentrations of some chemicals of emerging concern have increased since 1987. For instance, PBDEs (used for flame retardants) concentrations in fish doubled every few years from 1980 to 2000 and since then started to decline slightly.

Biological indicators had mixed results. From 1987 to 2006, there were 34 non-native species introduced into the Great Lakes but none have become established since 2006. The burrowing mayfly and lake sturgeon have started to return, but lake trout populations are consistent with 1987 populations. Diporeia, a key part of the aquatic food web, and a food source for many fish has almost disappeared. Beach closings based on bacteria have remained fairly stable over the reporting period of about 10 years. The one physical indicator, measurements of surface water temperature indicates a warming trend, which is undesirable because of concerns about global climate change.

While the Commission recognizes fiscal constraints of the governments, programs that monitor, measure and report on a meaningful set of core Great Lakes indicators should be a priority, not an afterthought in ecosystem management; and they should not be sacrificed during times of budget austerity. For instance, the millions of dollars the governments are spending to prevent the Asian Carp from reaching the Great Lakes could save a several billion dollar fishery. Furthermore, monitoring and assessment efforts along with sound science are needed to make wiser management decisions and target limited resources for restoration and protection of Great Lakes water quality. The governments should commit to improved monitoring, measurements and reporting of both existing and emerging problems.

Summary of 14 Indicator Reports

Chemical Integrity
Herring Gulls

Herring gulls are colonial waterbirds that are permanent residents of the Great Lakes and as fish-eating birds they accumulate toxins more than other species. Persistent toxins such as dichlorodiphenyl-dichloroethene (DDE) and polychlorinated biphenyls (PCBs) accumulate through the food web and have impacted egg shells and development of many species of fish-eating birds. The Herring gull egg monitoring program has monitored these and four other contaminants since 1974. Levels of the studied chemical contaminants in herring gull eggs have declined by over 90 percent since 1974 and from 64 percent to 87 percent since 1987. However, in recent years declines have slowed and mercury levels have remained stable since the mid 1990s. Since herring gulls in polluted areas are experiencing more abnormalities than herring gulls in cleaner habitat, continued reductions in chemical concentrations are desirable and the monitoring program should continue.

Fish Consumption

The amount of persistent toxic chemicals that are in the portions of Great Lakes fish that humans eat began to decline rapidly in the 1970s and continued until the late 1980s to mid-1990s. Since then it is clear that the levels are not increasing. The concentrations are either declining at a slower rate or have stabilized with year-to-year fluctuations. Numerous restrictive fish consumption advisories remain in place for all of the Great Lakes. Most fish consumption advisories are issued to protect humans from PCBs.

Contaminants in Whole Fish

Since 1987, concentrations of several persistent toxic chemicals in whole fish (the entire fish including bones) have continued to decline. Reductions of polychlorinated biphenyls (PCBs), Dichlorodiphenyltrichloroethane (DDT), mirex, and dieldrin are occurring across the Great Lakes at rates of three percent to nine percent annually. Concentrations of mercury, may have decreased initially but have been stable or increasing in some areas of the Great Lakes since 1995. Toxic chemicals known as polybrominated diphenyl ethers (PBDEs) are added to many
products to make them less flammable. PBDE concentrations in fish doubled every few years from 1980-2000 but with voluntary reductions in their use, levels in fish have stabilized or decreased slightly.

Contaminants in Mussels

Bivalve mollusks (two-sided shellfish) are a key part of environmental monitoring worldwide because they accumulate persistent contaminants, are widely distributed, and are easy to collect. The U.S. Mussel Watch program started measuring contaminant levels in mussels in 1992. The majority of Great Lakes sites show no clear trend in legacy contaminants. This may be because concentrations are already at low background levels.

Contaminants in Sediments

Contaminated sediments can harm bottom-dwelling organisms and the toxins can move up the food chain as prey fish consume bottom dwellers. There have been significant declines between the 1970s and the late 1990s in concentrations of many contaminants in sediments including PCBs, DDT, lead, and mercury due to successful management actions.

Phosphorus Loading

Phosphorus loading is an important contributor to excessive algal growth in nearshore waters of the Great Lakes. Substantive reductions in loading from major wastewater treatment plants have been achieved, but combined sewer overflows still require additional control efforts. The National Center for Water Quality Research (NCWQR) began Lake Erie tributary monitoring for various parameters including total phosphorus and dissolved reactive phosphorus in 1975 and found reduced loading of total phosphorus (TP) and dissolved reactive phosphorus (DRP) through 1995. However, more recent increases in DRP, which is readily available for algae to consume, indicate the need for improved management controls and continued monitoring.

Atmospheric Deposition
Atmospheric deposition occurs when pollutants are carried through the air and then reach the earth’s surface. The amount of deposition of persistent toxic chemicals has declined since the 1970s and 1980s when many were banned. Atmospheric deposition of PCBs has declined even further to about half their 1990 levels. Concentrations of other banned or restricted pesticides, such as lindane and DDT, decreased even more. Concentrations of mercury have declined even further since 1987, but no recent trend is evident. For Lake Superior, levels of toxaphene deposited through atmospheric processes are uniquely high and may be the result of long-range transport from outside the Basin.

**Physical Integrity**

**Surface Water Temperatures**

Great Lakes surface water temperatures increased by an annual average of about .05° C from 1979-2006, which is consistent with a world-wide trend of warming of inland lakes. Increased surface water temperature helps the growth of harmful algal blooms that pose risks to ecosystem and human health. Warming is most pronounced in Lake Superior, the coldest and largest of the Great Lakes.

**Biological Integrity**

**Non-Native Species**

Non-native species have become established in the Great Lakes and have caused dramatic economic and ecological impacts. The number of established non-native aquatic species in the Great Lakes increased steadily from 1900 until the late 1990s. In the latter portion of this period, established non-native aquatic species were introduced mostly by unregulated ballast water discharges from transoceanic vessels. There were 34 non-native species introduced since 1987. However, due partly partly to the implementation of stricter ballast water regulations, no new species have been discovered since 2006. Since the economic and ecological costs of invasive
species can be huge, and these species are difficult to control once established, prevention and
detection activities are essential to stop any discovered species from becoming established. The
total number of non-native species in the Great Lakes and each basin should be tracked as an
indicator of integrity.

Hexagenia

The burrowing mayfly, Hexagenia is important to fish populations as a food source and is a
species sensitive to pollution. These mayflies all but disappeared from most nearshore waters of
the Great Lakes in the 1950s because of impacts from increased nutrients that came from urban
and industrial activities. Increased nutrients triggered a series of events resulting in increased
growth of algae, settlement of these plants to bottom substrates, low dissolved oxygen created
from decomposition of these plants, and loss of mayflies and other fauna. In western Lake Erie,
the mayfly disappeared in 1953, were absent for 40 years, began to recover in the mid-1990s,
and have sustained a recovery over the past 15 years. Continued reductions of pollution and
monitoring are likely to confirm ‘recovery’ of mayflies in western Lake Erie and other areas of
the Great Lakes. Therefore, continued monitoring of Hexagenia in suitable habitat is
recommended because they are important to fish and reflect the status of water quality.

Diporeia

The bottom dwelling amphipod (shrimp-like invertebrate) Diporeia is a native glacial relic that
was once the most abundant bottom-dwelling organism in cold, offshore regions of the Great
Lakes. It occurs in the upper few centimeters of sediments and feeds mainly on algal material
that freshly settles to the bottom from the water column. In turn, Diporeia is readily fed upon by
most fish species and thus serves as an important pathway by which energy is cycled through the
food web. Diporeia populations began to decline in Lakes Michigan, Huron, Ontario, and Erie
in the early 1990s just a few years after zebra and quagga mussels became established.
Presently, it is completely absent from large areas in each of these lakes. The loss of Diporeia
has affected the distribution, abundance, growth, and condition of fish species that relied on
Diporeia as a food resource, including commercially important species such as lake whitefish.
**Sturgeon Abundance**

Sturgeon populations were reduced to less than one percent of their historical abundance by the mid-1950s. Lake sturgeon is one of the few species sensitive to the chemicals used to reduce sea lamprey spawning. Lake sturgeon populations are beginning to increase in some locations within the Great Lakes. Since the mid-1980s, there has been renewed spawning success in several traditional habitats, including the Detroit River. This is likely due to water quality improvements and restoration of habitat or creation of artificial habitat. However, the species is still listed as threatened or endangered throughout much of the Great Lakes Basin, indicating that recovery is still uncertain. Continued monitoring will support adaptive management approaches for the species, and increase the long-term outlook for the species in the Basin.

**Lake Trout Abundance**

By the late 1950s, lake trout virtually disappeared from Lakes Ontario, Erie, and Michigan, and most of Lake Huron due to a combination of sea lamprey predation and overfishing. Lake Superior’s population has become self-sustaining since the mid-1980s, and there are recent indications of significant natural reproduction in areas of Lake Huron. Lake Huron populations are below target, but increased reproduction has been observed since 2004.

Lake Michigan and Lake Erie populations have been stable since the late 1990s but are far below target levels developed by the Great Lakes Fishery Commission, through its individual lake committees. Lake Ontario populations fell steeply between 1997 and 2007 to below target levels. Low reproduction rates are evident in Lake Ontario, and little reproduction has been documented for lakes Michigan and Erie. Major problems are thought to be excessive sea lamprey and alewives predation.

**Beach Closing and Advisories**
The number of Great Lakes beach closings and advisories has been relatively stable over the last decade. The proportion of beaches closed more than 10 percent of the time is roughly 10 percent for U.S. beaches and approximately 40 percent for Ontario beaches. Disease outbreaks related to swimming at Great Lakes beaches are likely under-reported. Further refinement of testing methods, controls on major pollution sources contributing to beach closings such as stormwater runoff and sewage overflows, and establishment of and data collection for a central swimming-related disease outbreak registry are recommended.
II. LIST OF ABBREVIATIONS AND ACRONYMS

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<th></th>
<th>Abbreviation</th>
<th>Description</th>
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<td>1</td>
<td>AIS</td>
<td>Aquatic Invasive Species</td>
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<td>2</td>
<td>AOC</td>
<td>Area of Concern</td>
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<td>3</td>
<td>BMP</td>
<td>Best management practices</td>
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<td>4</td>
<td>CAFO</td>
<td>Confined animal feeding operation</td>
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<td>5</td>
<td>CGLRM</td>
<td>Council of Great Lakes Research Managers</td>
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<td>6</td>
<td>CSO</td>
<td>Combined Sewer Overflow</td>
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<td>7</td>
<td>CWA</td>
<td>Clean Water Act</td>
</tr>
<tr>
<td>8</td>
<td>DO</td>
<td>Dissolved oxygen</td>
</tr>
<tr>
<td>9</td>
<td>DDE</td>
<td>Dichlorodiphenyl-dichloroethene</td>
</tr>
<tr>
<td>10</td>
<td>DRP</td>
<td>Dissolved reactive phosphorus</td>
</tr>
<tr>
<td>11</td>
<td>DDT</td>
<td>dichlorodiphenyltrichloroethane</td>
</tr>
<tr>
<td>12</td>
<td>EC</td>
<td>Environment Canada</td>
</tr>
<tr>
<td>13</td>
<td>EIS</td>
<td>Environmental Impact Statement</td>
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<td>14</td>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
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<td>15</td>
<td>ESA</td>
<td>Endangered Species Act</td>
</tr>
<tr>
<td>16</td>
<td>EPT</td>
<td>Ephemeroptera, Plecoptera, and Trichoptera</td>
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<td>17</td>
<td>FEQGS</td>
<td>Federal Environmental Quality Guidelines</td>
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<td>18</td>
<td>FWS</td>
<td>U.S. Fish and Wildlife Service</td>
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<td>19</td>
<td>GAO</td>
<td>General Accounting Office</td>
</tr>
<tr>
<td>20</td>
<td>GIS</td>
<td>Geographic information system</td>
</tr>
<tr>
<td>21</td>
<td>GLFC</td>
<td>Great Lakes Fishery Commission</td>
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<td>GLWQA</td>
<td>Great Lakes Water Quality Agreement</td>
</tr>
<tr>
<td>23</td>
<td>HAB</td>
<td>Harmful algal bloom</td>
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<tr>
<td>24</td>
<td>HCB</td>
<td>Hexachlorobenzene</td>
</tr>
<tr>
<td>25</td>
<td>HE</td>
<td>Heptachlor Epoxide</td>
</tr>
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<td>26</td>
<td>HPTF</td>
<td>Health Professionals Task Force</td>
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<td>IAAGLR</td>
<td>International Association for Great Lake Researchers</td>
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<td>IAQAB</td>
<td>International Air Quality Advisory Board</td>
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<td>29</td>
<td>IJC</td>
<td>International Joint Commission</td>
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<tr>
<td></td>
<td>ITFM</td>
<td>Intergovernmental Task Force on Monitoring Water Quality</td>
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<tr>
<td>2</td>
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<td>Index of Biotic Integrity</td>
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<td>3</td>
<td>LAMPS</td>
<td>Lakewide Area Management Plans</td>
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<td>4</td>
<td>NIS</td>
<td>nonindigenous species</td>
</tr>
<tr>
<td>5</td>
<td>NAS</td>
<td>non-native aquatic species</td>
</tr>
<tr>
<td>6</td>
<td>ng</td>
<td>nanogram ($10^{-9}$)</td>
</tr>
<tr>
<td>7</td>
<td>OECD</td>
<td>Organization for Economics Co-Operation Development</td>
</tr>
<tr>
<td>8</td>
<td>OMOE</td>
<td>Ontario Ministry of the Environment</td>
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<tr>
<td>9</td>
<td>PBT</td>
<td>Persistent bioaccumulative toxic</td>
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<tr>
<td>10</td>
<td>PCB</td>
<td>Polychlorinated biphenyl</td>
</tr>
<tr>
<td>11</td>
<td>PBDE</td>
<td>Polybrominated diphenyl ether</td>
</tr>
<tr>
<td>12</td>
<td>PCDD</td>
<td>polychlorinated dibenzodioxin</td>
</tr>
<tr>
<td>13</td>
<td>PCDF</td>
<td>polychlorinated dibenzofuran</td>
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<tr>
<td>14</td>
<td>PEL</td>
<td>Probable Effect LevelRAPS</td>
</tr>
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<td>15</td>
<td>SAB</td>
<td>Science Advisory Board</td>
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<tr>
<td>16</td>
<td>SOLEC</td>
<td>State of the Lakes Ecosystem Conference</td>
</tr>
<tr>
<td>17</td>
<td>TCDD</td>
<td>2,3,7,8-tetrachlorodibenzo-p-dioxin, commonly known as dioxin</td>
</tr>
<tr>
<td>18</td>
<td>TMDL</td>
<td>Total maximum daily load</td>
</tr>
<tr>
<td>19</td>
<td>TP</td>
<td>Total phosphorus</td>
</tr>
<tr>
<td>20</td>
<td>ug</td>
<td>microgram ($10^{-6}$)</td>
</tr>
<tr>
<td>21</td>
<td>WQB</td>
<td>Water Quality Board</td>
</tr>
<tr>
<td>22</td>
<td>WQS</td>
<td>Water quality standards</td>
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III. INTRODUCTION

The International Joint Commission (Commission) has initiated an effort to assess progress made towards achieving the purpose of the Great Lakes Water Quality Agreement (Agreement) since 1987. This work in progress is being shared with the public on the Commission’s website and at the 2011 Great Lakes Water Quality Biennial Meeting in Detroit on October 12-14, 2011. The Commission plans to publish a report in 2012 based on comments received and subsequent work.

Under the 1972 Agreement and its amendments in 1978 and 1987, the Commission has been responsible for reporting on progress made towards restoring and maintaining the chemical, physical, and biological integrity of the Great Lakes. However, since the Agreement’s further amendment in 1987, the Commission has been challenged in obtaining data and reports that relate to the objectives of the Agreement, or have consistent temporal frames of reference. As a result, the Commission has found it increasingly difficult to assess progress over time under the Agreement.

This draft report aims to initiate an assessment that covers the twenty-five years since 1987, when the Agreement was last amended, and that uses a relatively small set of indicators for which reliable data are available throughout the period. It is the Commission’s hope that the final report will help inform the next iteration of the Agreement, which is currently being renegotiated by the federal governments of Canada and the United States.

Responsibility to Report on Progress

As stated in Article II, the overall purpose of the Agreement is “to restore and maintain the chemical, physical, and biological integrity of the waters of Great Lakes Basin Ecosystem.” Article II also includes a three-part policy that elaborates the purpose. In addition, five general objectives are cited in Article III, an extensive list of specific objectives is contained in Annex 1, goals are identified in each of annexes 2-16 and the programs are committed to in Article VI.
The International Joint Commission’s responsibilities are outlined in Article 7 of the Agreement. Among them, in section 3, is the requirement to report on “progress toward achievement of the General and Specific Objectives including as appropriate, matters related to Annexes to this Agreement. This report shall include an assessment of the effectiveness of the programs and other measures undertaken pursuant to this Agreement, and advice and recommendations.”

Many of the annexes of the Agreement stipulate that governments must report on their progress in achieving the objectives of the Annex to the Commission. For example, the Annex 2 Remedial Action Plans and Lakewide Management Plans states:


The Annex also describes the link to the Commission’s responsibility to use the two reports generated by the two governments to perform an independent and binational assessment of progress: “Information from these reports shall be included in the Commission's biennial report under paragraph 3 of Article VII.” Further, Annex 11, Section 4 of the Agreement committed the Parties, in consultation with states and provinces, to develop ecosystem health indicators to help assess progress toward the objectives as outlined in the Annexes.

From 1972 to 1987, government officials, as members of a network of specialized subcommittees that were part of the Commission’s advisory boards, provided the necessary data on which the Commission would develop its biennial report. With the requisite data available, the biennial reports back then were more effective at assessing progress on objectives. As a result of the Agreement which changed the protocol, these subcommittees were dismantled and the responsibility of providing data to the Commission was transferred to the governments.

Since 1987, the Commission has not received any assessment of progress report under any of the annexes nor have indicators been established that link to the objectives of each annex. The
governments developed SOLEC to provide the progress reports but its role has evolved and
SOLEC conferences are now intended to provide a forum for exchange of information on the
ecological condition of the Great Lakes and surrounding lands (US EPA 2011). The SOLEC
reports do report on indicators, but those indicators are not linked to the annex objectives, nor do
they provide a consistent and historical trend analysis.

Another reporting mechanism is the Lakewide Area Management Plans (LaMPs). Although, all
five LaMPs are currently updated every two years. only particular sections are revised in any
one update and the reports, consequently, do not provide a composite understanding of what has
happened to each lake as a whole since the last update. Therefore, these reporting tools do not
give the Commission what is needed to adequately help it assess progress over time.

The Commission has drawn attention to this situation in the past. For instance, the 2006 13th
Biennial Report of Great Lakes Water Quality (IJC 2006a) addressed the general issue of
accountability and how objectives of the Agreement need to be met with performance measures
and reporting. In 2008, the 14th Biennial Report (IJC 2009) addressed the issue of progress made
toward improving wastewater treatment and provided recommendations for reducing these
loadings

The most recent and 15th Biennial Report (IJC 2011) covered several important and emerging
issues related to water quality in the nearshore zone of the Great Lakes. The report covered the
issues that were identified by the Commission and its advisory boards. Topics covered included
eutrophication, fish consumption, beaches, chemicals of emerging concern, rapid response to
invasive species, and groundwater. The biennial report was based predominantly on workgroup
reports developed by the Commission’s Great Lakes Boards and advisory bodies, namely, the
Great Lakes Water Quality Board, Great Lakes Science Advisory Board, Council of Great Lakes
Research Managers, Health Professionals Task Force and International Air Quality Advisory
Board. This report also included input from Commission staff and public input collected at the
Commission’s October 2009 biennial meeting at Windsor, Ontario.
Considering the difficulties acquiring data since 1987 and the governments’ plan to renew the Agreement, the Commission launched this project to assess progress made towards achieving the overall purpose of the Agreement since its last renewal in 1987.

The Importance of Great Lakes Indicators

Great Lakes managers and the general public can benefit from a scientifically sound set of core indicators that offer a means of tracking progress on restoring and maintaining Great Lakes Water Quality. These indicators should integrate data from a variety of monitoring and surveillance programs. The indicators cannot measure all the parameters desired to address progress under the Agreement, but they can help tell the story of progress and problems in the ecosystem.

The Commission has repeatedly emphasized the need to develop such core indicators in its biennial reports and in other communications and task force reports. The Commission recognizes that the science behind selecting and defining the state of the lakes is a key to assessing progress and will continuously evolve and improve. Alternative indicators and perhaps a longer list of indicators may be developed in the future. However, progress reports would never be developed if the decision was made to wait for the perfect set of indicators. Assessments of progress should proceed using the best available indicators and best available data so that governments and the public can effectively protect and restore the Great Lakes.

What is an Environmental Indicator?

For a long time, the Commission has been advocated using indicators to measure progress towards Agreement objectives. The Commission has issued reports on recommended criteria for indicators in 1985, 1996, and 2000 (IJC 1985, IJC 1996, IJC 2000). In the Commission’s 1996 report, Indicators to Evaluate Progress Under the Great Lakes Water Quality Agreement (IJC 1996), the Commission decided to use the definition of an environmental indicator that had been
developed by the U.S. Intergovernmental Task Force on Monitoring Water Quality (ITFM, 1996), an environmental indicator is a:

"measurable feature which singly or in combination provides managerially and scientifically useful evidence of environmental and ecosystem quality, or reliable evidence of trends in quality. . . . This definition is particularly useful when the measurable feature is associated with an explicit goal or desired outcome. Environmental indicators encompass a broad suite of measures, including tools for assessment of chemical, physical and biological conditions and processes at several scales."

The Commission, the Governments, other organizations, and scientists have been discussing how to better achieve the responsibility to assess progress using indicators and the general topic of environmental indicators for many years. Abundant ecological indicator literature exists. The U.S. Environmental Protection Agency’s (U.S. EPA 2011) report on vulnerability identified a list of 23 studies from government, academia, and consultants used by U.S. EPA as core literature for identifying indicators. Indicators have been defined and used to report generally on the condition of the overall environment (U.S. EPA 2008) or for more specific applications such as providing evidence for climate change (U.S. EPA 2010). The Commission reviewed its own, EPA’s, and other publications on indicator development. Based on this review, the Commission recommends that the governments develop timely progress reports, related to the objectives of the Agreement, using a set of core indicators.

Review of 2009 State of the Lake Ecosystem Conference (SOLEC)

From 1972 to 1987, government officials, as members of a network of specialized subcommittees that were part of the Commission’s Water Quality Board, provided the necessary data on which the Commission would develop its biennial report. With the requisite data available, the biennial reports back then were more effective at assessing progress on objectives. As a result of the 1987 Protocol, these subcommittees were dismantled and the responsibility of providing data to the Commission was transferred to the governments. The governments
developed the State of the Lakes Ecosystem Conference (SOLEC) to provide data needed for the Commission’s biennial progress reports. SOLEC’s work is accomplished with the uneven data available from existing monitoring programs, with a small budget, and relying on volunteer contributors and organization who contribute to the effort. As a result, the existing suite of SOLEC indicators is not conducive to measuring progress in meeting Agreement objectives. Also, SOLEC’s role has evolved and conferences are now intended to provide a forum for exchange of information on the ecological condition of the Great Lakes and surrounding lands (US EPA 2011). While, the SOLEC reports use indicators, SOLEC indicators are not linked to the annex objectives, nor do the indicators provide a consistent and historical trend analysis. SOLEC (2009) identified about 80 indicators that it hoped to use to evaluate the health of the Great Lakes Basin Ecosystem. SOLEC (2009) affirmed:

“Knowing the environmental condition of the Great Lakes can allow for effective decision-making by all Great Lakes stakeholders.” The report added that the indicators “provide independent, science-based reporting on the state of the health of the Great Lakes basin ecosystem.”

The Commission recognizes the extensive work done with limited resources by Great Lakes scientists and managers through SOLEC since 1991.

While constructing this report, the Commission reviewed the 2009 SOLEC indicators to see to what degree SOLEC indicators can be used to evaluate progress since 1987 and to see how well the SOLEC indicators address the Commission’s Indicators Implementation Task Force (IJC 2000) recommendations to address swimmability, fishability and drinkability. The Commission found only 10 of the 80 indicators were useful for evaluating progress since 1987. Several of the sources for this report came from outside of SOLEC. The Commission continues to be concerned that excessive effort is expended on too many indicators that have limited utility. Selecting and reporting on a smaller and continued set of core indicators should be the priority. The core set should include several with historical data back to 1987, several on the nearshore, a few on human health, and at least one on atmospheric deposition. These indicators and a report assessing progress based on those indicators should be provided by the governments in the next
reporting period.

Selection of Indicators for This Report

This effort started by reviewing SOLEC indicators and consulting with SOLEC managers. Besides SOLEC indicators, several other potential indicators were identified from presentations at the International Association for Great Lakes Researchers (IAGLR) in Duluth, Minnesota in May 2011. The Commission consulted scientific contributors to SOLEC, IAGLR and other experts for their concurrence to contribute to this report and the report writing began in June 2011.

Ecological indicators were selected based on existing criteria (US EPA 2000, OECD 2003), the best professional judgment of IJC staff, and the availability of experts with relevant data. Criteria include the availability of temporal and spatial information, preferably quantifiable, relevance to Agreement or environmental management objectives, costs, ecological importance (e.g., keystone species), quality of data, association with known stressors, and selection of sensitive species (i.e., pollution intolerant species).

Content and Format of this Report and Future Plans

This introduction of this preliminary draft report was written by Commission advisers without outside participation. The body of this draft, which is a work in progress, consists of 14 indicator reports. Indicator reports are sorted according to whether they assess chemical integrity, physical integrity, or biological integrity; consistent with the Agreement’s stated purpose of the role of the governments.

This work in progress is being shared with the public for review. Comments from biennial meeting participants and other reviewers are appreciated and will be considered in the completion of the final report in 2012. The final report is expected to cover 20-25 indicators. This work in progress focuses on changes and trends related to the integrity of the Great Lakes.
The plan for the final report is to compare these data with Agreement and Annex objectives and various standards and thresholds.

Comments are especially appreciated on:

- the merit of the indicators selected,
- other indicators that should be selected,
- the content of each indicator report, and
- plans for the final report.

Comments will be accepted until November 30, 2011 and should be submitted to

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The report can also be a useful way to learn about the condition of the Great Lakes and learn environmental science principles in an applied manner, and the environmental science terms can be easily understood by referencing the glossary that is provided at the end of the report. An executive summary of the Commission’s overall findings is presented to provide an overview and precedes this introduction. Each indicator report starts off with the same summary that is included in the executive summary.

As Canada and the United States (the governments) negotiate a renewed Agreement, the Commission seeks to inform their work through this report. This draft report, while not comprehensive, is as broad in scope as available data and resources permit. The Commission hopes the parties will strive to create a set of core indicators that, maintained over time, will promote understanding of progress and problems in the Great Lakes ecosystem.

References


IV. INDICATORS OF CHEMICAL INTEGRITY

CONTAMINANTS IN HERRING GULL EGGS


SUMMARY: Herring gulls are colonial waterbirds that are permanent residents of the Great Lakes and since they are fish eating birds accumulate more toxins from the Great Lakes than other species. Persistent bioaccumulative toxins such as DDT and PCBs have impacted egg shells and development of many species of fish-eating birds. The Herring gull egg monitoring program has monitored these and four other contaminants since 1974. Levels of the studied chemical contaminants in herring gull eggs have declined by over 90% since 1974 and 64-87% since 1987. However, in recent years declines have slowed down and mercury levels have remained stable since the mid 1990s. Since herring gulls in polluted areas are experiencing more abnormalities than herring gulls in cleaner habitat, continued reductions in chemical concentrations are desirable and the monitoring program should continue.

Importance of this indicator in measuring progress towards achieving Great Lakes Water Quality Agreement (GLWQA) objectives:

Colonial waterbirds, including gulls, terns, herons and cormorants, are among the top aquatic food web predators in the Great Lakes ecosystem, and they are very visible and well known to the public.

Of the species of colonial, waterbirds that breed on the Great Lakes, only the Herring Gull (*Larus argentatus*) is a permanent resident on the Lakes (Norstrom et al. 2002). Therefore, only the Herring Gull accumulates contaminants that come only from the Great Lakes, and, thus, they reflect Great Lakes conditions. Other colonial species accumulate contaminants from their wintering grounds, outside of the Great Lakes, and, are not true indicators of condition of the Great Lakes. The herring gull is also very visible and well-known to the public (SOLEC 2009).
Furthermore, the herring gull is an ideal indicator because the species eats primarily alewife (Alosa psedoharengus) and rainbow smelt (Osmerus mordax), the two most abundant prey fish in the Great Lakes (Norstrom et al. 2002). Thus, they are a very cost-efficient monitoring system and they facilitate comparisons over time and among lakes.

The Herring Gull Egg Monitoring Program was started in 1974, and the herring gull has been an indicator of toxic chemical concentrations in the Great Lakes since that time (Pekarik and Wesoleh 1998).

Persistent Bioaccumulative Toxins (PBTs) break down slowly in the environment and in biological organisms. Even when present at relatively low levels in the water column and in organisms lower down in the food web, PBT concentrations can accumulate thousands or millions of times in large predator fish and in fish-eating birds, as well as in humans who eat the fish. Because the Great Lakes Basin was one of the first watersheds in the world where high levels of PBTs were detected and effects on fish, wildlife and human health were suspected, research and data collection on PBTs in fish and wildlife has been conducted here for more than 40 years (Keith 1966, U.S. Fish and Wildlife Service 2010).

The Herring Gull Monitoring Program determines contaminant levels of up to 20 organochlorines, 65 polychlorinated biphenyl (PCB) congeners, 53 dioxins, and 16 brominated diphenyl ether congeners. The Canadian Wildlife Service leads the program and monitors 15 sites across the Basin with at least two sites on each Lake and several in each country. The program consistently has monitored six contaminants since 1974 – PCBs, dichlorodiphenyl-dichloroethene (DDE), hexachlorobenzene (HCB), heptachlor epoxide (HE), mirex, and dieldrin. Dioxins have been monitored since the 1980s.

Article II of the 1987 amended Great Lakes Water Quality Agreement (GLWQA) states that the purpose of the Agreement is to restore the chemical, physical, and biological integrity of the Great Lakes. With respect to chemical integrity, Article II also states that the policy of the two countries is to prohibit the discharge of toxic substances in toxic amounts and to virtually eliminate discharges of persistent toxic substances. Under Annex 10 of the Great Lakes Water
Quality Agreement (GLWQA), the Parties are required to develop and implement programs to minimize or eliminate the risk of release of hazardous polluting substances to the Great Lakes system. A list of hazardous and potentially hazardous polluting substances is listed in Appendix 1 and 2 of Annex 10. Appendix 1 to Annex 1 discloses specific objectives for levels of PCBs, DDT and metabolites (including DDE), HE, mirex, and dieldrin. Objectives relate to specific concentrations in water and edible portions of fish, to protect piscivorous birds (e.g., herring gulls) and human consumers of fish.

Methods:

Since 1974, 10-13 eggs have been collected annually from up to 13 nesting colonies in the Great Lakes and in connecting channels (Figure 1). Egg contents were selected because, collection is rather easy and inexpensive and because lipid contents in eggs is less variable than in other tissues (Weseloh et al 1979). Further details are described in Pekarik and Wesoleh (1998). Since this report focuses on changes in since 1987, a separate analysis was performed. Annual mean and standard error values were calculated for each contaminant across all 15 sites for the years 1987 to 2009. This allows for a complete Great Lakes picture for the selected contaminants rather than data from one or more sites, which may not be representative of all sites and a simple assessment of the variability among sites. The resulting temporal pattern for each compound was evaluated by linear/logistic regression. Data on spatial patterns were taken from Weseloh et al. (2006).

Results – Trend Analysis Since 1987

Most chemical contaminants monitored by this program in herring gull eggs have declined dramatically – over 90% -- since 1974 (Pekarik and Weseloh 1998). In this report, however, we focus on trends since 1987. PCBs and TCDD have declined by approximately 78% and 85%, respectively, but levels of these two contaminants have been fairly constant since 2004 (Figure 2). Levels of DDE and mirex have declined by approximately 87% and 73%, respectively despite a period of increase from 1987 through 1993-94, but they have declined steadily since that time (Figure 3). The final three legacy compounds under consideration, dieldrin, HE and
HCB, declined by approximately 91%, 88% and 64%, respectively (Figure 4). HE and dieldrin have declined fairly steadily since 1987; HCB has shown some fluctuations, especially during 1987-97. All three compounds have fluctuated to some extent since 2005.

In a separate study (Weseloh et al. in press) current concentrations and spatial and temporal trends of total mercury were assessed in eggs of herring gull over the period 1974-2009 at the same 15 sites in the Great Lakes. Current (2009) concentrations ranged from 0.064 µg/g (wet weight), at Chantry Island (Lake Huron) to 0.246 µg/g at Middle Island (Lake Erie). There were significant inter-colony differences in mean Hg concentrations (2005-2009). Mercury concentrations at 14 of 15 sites declined from 23% to 86% between when it was first measured (usually 1974) and 2009. Declining temporal trends over the entire period (1974-2009) were significant at 10 of the 15 sites. On the other hand, there were no significant trends in mercury over the last 15 years. More recently, declines in gull eggs were more evident than in smelt and may be partially explained by temporal changes in the gull diet (Hebert and Weseloh 2006).

Overall, Hg concentrations have declined in Great Lakes herring gull eggs over the period 1974 to 2009 but changes in the gull diet may be contributing, in part, to those declines. When gull Hg data were adjusted for temporal changes in the gull diet as inferred from stable nitrogen isotope values in eggs, significant declines in egg mercury levels were found only at 4 of 15 sites. Examination of contaminant temporal trends in multiple indicator species will ensure accurate inferences regarding contaminant availability in the environment.

Besides the value of temporal trends, assessing spatial patterns in the distribution of contaminants is important in identifying environmental “hotspots”. Detailed spatial assessments were made of eight legacy contaminants in gull eggs for the years 1998-2002 and the 15 sites were ranked based on contaminant levels (Weseloh et al. 2006). A weighted ranking scheme showed that eggs from sites in Saginaw Bay (Lake Huron), the St. Lawrence River and northern Lake Michigan were the most contaminated and those from eastern Lake Superior, southern Lake Huron and eastern Lake Erie were the least contaminated.

**Discussion of Results**
Herring gulls and other colonial waterbirds appear to be much healthier now than in the mid-1970s which is consistent the reduction in contaminant levels found in eggs (Figures 1, 2 and 3). However, more physiological abnormalities still occur in herring gulls at the monitored sites than at cleaner reference sites (Environment Canada 2003). These abnormalities were not monitored in the early years of the monitoring program, so it is not possible to evaluate long-term trends. Abnormalities of concern include male-biased sex ratio in hatchlings, elevated levels of embryonic mortality, indications of feminization in 10% of adult males, a reduced or suppressed ability to combat stress, an enlarged thyroid with reduced hormone production and a suppressed immune system. These effects are inconsistent with the goal of restoring the chemical and biological integrity of the Great Lakes Basin ecosystem.

Contaminants continue to be made available to the food chain through resuspension of sediments, underground leaks from landfill site and atmospheric deposition. Atmospheric deposition is offset by volatization (gas exchange out of the Lake). For many PBTs, gas exchange is the dominant pathway of atmospheric deposition. Therefore, the total net loading may also be out of the Lake if enough of the pollutant is volatilized- which can happen if the air is cleaner relative to the water. In the case of PCBs, the compounds have reached a state of equilibrium with volatilization and deposition in rough balance (U.S. EPA 2011).

The annual collection and analysis of herring gull eggs from 15 sites on both sides of the Great Lakes has been a permanent part of the Canadian Wildlife Service Great Lakes surveillance activities. Until the time comes that chemical concentrations of current and emerging concerns are at a level below which there are no adverse impacts to the well-being of the species, the monitoring program should be sustained.

The Great Lakes Herring Gull Egg Monitoring program uses the same top-of-the-food web indicator species in each of the Great Lakes. It is a very cost-efficient program; with a 35-year historical data set at the same monitoring sites, it is an extremely well-studied and well-known species on the Great Lakes.
Discussion of Future Use of this Indicator

The existing monitoring program should be supplemented with monitoring of levels of chemicals of emerging concern along with the seven existing monitored chemicals. Other research activities should be incorporated into routine monitoring e.g., evaluation of the avian immune system.

Although the concentrations of almost all contaminants are decreasing, the health implications of subtle effects and effects from chemicals of emerging concern are not well understood.

Investigation of sources of contamination and analysis are critical to the formation of management strategies to restore the chemical integrity of the Great Lakes Basin ecosystem as called for in the Great Lakes Water Quality Agreement.

References


Figure 1: Location of sampling sites

Figure 2. Mean (±SE) wet weight values of sum PCB (µg/g) and 2,3,7,8-TCD Doxin (ρg/g) measured in Herring Gull eggs collected at 15 IJC sampling colonies from 1987-2009 (sample sizes ranged from 13-15 colonies per year). Error bars are symmetrical around the means, but for clarity only a single tail is shown.
Figure 3. Mean (±SE) wet weight values of DDE (µg/g) and Mirex (µg/g) measured in Herring Gull eggs collected at 15 IJC sampling colonies form 1987-2009 (sample sizes ranged from 14-15 colonies per year). Error bars are symmetrical around the means, but for clarity, only a single tail is shown.

Figure 4. Mean (±SE) wet weight values of Dieldrin (µg/g) Heptachlor Epoxide (µg/g) and Hexachlorobenzene (µg/g) measured in Herring Gull eggs collected at 15 IJC sampling colonies form 1987-2009 (sample sizes ranged from 14-15 colonies per year). Error bars are symmetrical around the means, but for clarity, only a single tail is shown.
FISH CONSUMPTION - CONTAMINANT LEVELS

AUTHORS: Satyemdra Bhavsar, Ontario Ministry of the Environment, Vic Serveiss, International Joint Commission; Elizabeth Murphy, U.S. Environmental Protection Agency.

SUMMARY: The amounts of persistent toxic chemicals that are in the portions of Great Lakes fish that humans eat began to decline rapidly in the 1970s and continued until the late 1980s to mid 1990s. The concentrations are either declining, at a slow rate, or have stabilized with year-to-year fluctuations. Numerous restrictive fish consumption advisories, issued to protect human health, remain in place for all of the Great Lakes. The majority of these advisories are driven by concentrations of polychlorinated biphenyls or PCBs in edible portions of fish.

Importance of this indicator in measuring progress towards achieving Great Lakes Water Quality Agreement (GLWQA) objectives

Annex 2 of the Great Lakes Water Quality Agreement (United States and Canada 1987) requires Lakewide Management Plans (LaMPs) to define “…the threat to human health posed by critical pollutants… including their contribution to the impairment of beneficial uses.” Both the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (Great Lakes Sport Fish Advisory Task Force, 1993) and the Guide to Eating Ontario Sport Fish (OMOE 2011) are used to assess the status of the ecosystem by comparing contaminant concentrations in fish to levels that invoke consumption advice. Contaminants upon which consumption advisories are based in Canada and the U.S. include PCBs, dioxin/furans, mercury, toxaphene, chlordane and mirex.

The discovery of persistent bioaccumulative toxic contaminants in Great Lakes sport fish in the 1960s heightened concern about human health consequences of eating the fish and contributed to the banning of several of the chemicals of greatest concern in ensuing years, including DDT, PCBs, chlordane and toxaphene (EPA 2011). The discovery also
prompted public health advice on consumption of sport fish from federal, state and local
health agencies and long-term monitoring of sport fish contamination.

Sport fishing is enjoyed by millions of Great Lakes anglers, and consumption of sport
fish is a primary vector for human exposure to some contaminants. Therefore, it is
appropriate to use data on contaminants in sport fish in order to measure progress towards
achieving the GLWQA objectives.

Methods for collection and analysis of trend data
Various tribal, state/provincial, and federal agencies have monitored contaminant levels
in Great Lakes sport fish fillets at differing frequencies. The Ontario Ministry of the
Environment (OMOE) has been monitoring fish contaminant levels for over three
decades. OMOE and the Great Lakes States use their data to issue fish consumption
advisories.

Because monitoring has been conducted over the long term, in some cases decades, for a
suite of Great Lakes sport fish contaminants, OMOE data are readily available to support
long-term analysis. In the U.S., various State programs are responsible for issuing advice
to ensure safety via advisories. For this reason, different jurisdictions use different
sampling protocols and risk assessment methodologies to issue advice, and these data by
design are not suitable for trend analysis of contaminants in sport fish. However, many
States do use the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory
when setting advice.

In an attempt to categorize the status of fish consumption advice in the Great Lakes, a
new Fish Consumption Advisory Rating Scale Indicator was created jointly by U.S. EPA
and OMOE in 2011 to categorize the different levels of risk to sensitive populations
(children under 15 and women of child bearing age) from consuming certain fish species
in each of the Great Lakes. Because this is a new type of assessment, trends cannot be
discerned at this time. In this new assessment, scores on a scale of 1 to 5 were given
based on the type of consumption advisories for the sensitive population across all size
classes of a common species, Lake Trout, in each state and province. Lake Trout was chosen because it is a top predator fish and represents a ‘worst case scenario’ for fish consumption advisories. The average score across all states and provinces for a lake was used as the measure.

In 2011, the Michigan Department of Community Health (MiDCH) revised its advisory for Lake Michigan Lake Trout based upon dioxin-like chemicals. This change was incorporated following the 2008 adoption of the US EPA/WHO Toxic Equivalency Quotient calculation method for DLCs and the reporting of elevated DLC concentrations in lake trout fillets from Lake Michigan in 2011. The source of this DLC contamination in fish is not specifically known, but is likely to be historic. Human activities such as large-scale industrial waste incineration have produced air contamination that was deposited over time to lakes and rivers, where the fish take up and store the contaminants. Other potential sources include various PCB waste water discharge and non-point source runoff.

Results

PCBs are the cause of most fish consumption advisories on each side of the border (SOLEC 2009). Most of the remaining advisories in the Basin are based on mercury, dioxin, toxaphene, DDE or mirex contamination.

Using data from OMOE and other Great Lakes peer reviewed journal articles, it has been observed that PCB levels in edible portions of lake trout in Lakes Ontario, Huron and Michigan have declined since the 1980s and may still be decreasing at a lower rate (Bhavsar et al. 2007, Carlson et al. 2010, Stow et al. 2004). PCB concentrations in Lake Superior lake trout have remained roughly stable since 1990 and advisories limit consumption to two to four meals per month (Bhavsar et al. 2007, Carlson et al. 2010). In contrast, PCB levels in Lake Erie lake trout are weakly decreasing, stable or weakly increasing since the late 1980s (Bhavsar et al. 2007, Carlson et al. 2010, Sadraddini et al. 2011). See Figure 1.
The levels of dioxins and furans have generally declined in lake trout from Lakes Ontario and Huron over time since 1987 (Bhavsar et al. 2008). However, the levels appear to be stable in Lake Superior lake trout (Bhavsar et al. 2008).

In the St. Clair River/Lake St. Clair corridor of Canada, sharp declines in concentrations of PCBs, mercury and other chemical contaminants of concern in fish were observed through the 1990s, after which the decreases slowed or concentrations stabilized. Researchers hypothesized that sediments are a source of elevated concentrations of PCBs, mercury, octochlorostyrene, hexachlorobenzene, and DDT, and that PCB and mercury levels continue to be of concern for the health of sport fish consumers (Gewurtz et al 2010).

Toxaphene is uniquely high in Lake Superior. Concentrations in some large lake trout have supported advice to limit consumption. Mirex is still detected; however, only in Lake Ontario lake trout (Carlson et al. 2010). Concentrations of other contaminants such as DDT/DDE/DDD, chlordane, and dieldrin are generally declining, albeit at a slower rate (Carlson et al. 2010).

Discussion

Overall, levels of the major legacy contaminants such as PCB, dioxins/furans and mercury have generally declined in Great Lakes sport fish since the 1980s. However, some chemicals have stabilized with year-to-year fluctuations. For Lake Erie, a weak increasing trend has been observed in recent years for mercury and some legacy persistent organic pollutants such as PCB.

Fish consumption advisories for Lake Trout and Walleye in the Great Lakes range from unrestricted consumption to do not eat advisories. Although U.S. and Canadian data cannot be directly compared due to differences in the way consumption advisories are
issued, they do follow similar patterns in terms of the levels of consumption restrictions in the individual Great Lakes. Consumption advisories for Lake Trout are most restrictive in Lakes Ontario and Huron and least restrictive in Lake Superior (Figures 1 & 2). All lakes have do not eat advisories for at least some size classes of Lake Trout.

Differences in advisories within and between lakes reflect different levels of contaminant concentration in the air and sediment as well as differences in sampling regimes and locations between the states and Ontario. PCBs continue to drive most fish advisories despite the fact that they were banned in the U.S. and Canada in the 1970s. This is likely due to large amounts of PCBs still persisting in the environment and being released from old electrical equipment.

The slowing of the rate of decline or stabilization of levels of several high-importance PBTs monitored in Great Lakes sport fish has implications similar to those discussed for herring gull egg contaminants. Resuspension of contaminated sediments and/or long-range atmospheric transport of the contaminants may explain some of these trends. Since the importance has shifted from point to diffuse sources, new approaches will be required to support appropriate management and remedial strategies for further improvements.

Finally, new chemicals or chemicals of emerging concern or chemicals of current use have been detected in Great Lakes fish. Analysis of archive fish samples has revealed increased concentrations of some of these chemicals (e.g., polybrominated diphenyl ethers or PBDEs) since the 1980s. Consumption of Great Lakes sport fish containing chemicals of concern has been correlated with elevated levels of those chemicals in human blood serum (e.g., Anderson et al. 2008). As such, in addition to monitoring PBTs of long-standing concern, the Parties should work to assure monitoring and reporting of chemicals of emerging concern, including PBDEs (discussed in a separate report specifically, on PBDEs).

Health risk communication is a crucial component to the protection and promotion of human health in the Great Lakes. Enhanced partnerships between states and tribes
involved in the issuing of fish consumption advice will improve U.S. commercial and non-commercial fish advisory coordination. In Canada, acceptable partnerships exist between the federal and provincial agencies responsible for providing fish consumption advice to the public. At present, PCBs, mercury, and chlordane are the only PBT chemicals that have uniform fish advisory protocols across the U.S. Great Lakes basin. The Great Lakes Sport Fish Advisory Task Force is currently drafting additional uniform PBT advisories in order to limit confusion of the public that results from issuing varying advisories for the same species of sport fish across the basin.

Future use of this indicator
In order to best protect human health, increased monitoring and reduction of PBT chemicals needs to be made a priority. In particular, monitoring of contaminant levels in environmental media and biomonitoring of human tissues need to be addressed, as well as assessments of frequency and type of fish consumed. Through the Great Lakes Restoration Initiative, the Agency for Toxics Disease Registry (ATSDR) is undertaking a large-scale human biomonitoring project in the Great Lakes Basin. ATSDR established programs with Minnesota, Michigan and New York health departments to measure environmental toxin levels in people (measuring toxins in blood & urine samples) who live in the Great Lakes basin. The purpose of the study is to determine if there is a higher amount of toxins in those with greater exposure, such as people who eat Great Lakes fish. This information will guide actions that the state health departments take to protect citizens. In addition, improved understanding of the potential negative health effects from exposure to PBT chemicals is needed. An increased focus on emerging chemicals is occurring in monitoring programs in the United States and Canada. While U.S.EPA’s GLNPO no longer collects or analyzes sport fish fillets, GLNPO has instituted an Emerging Chemicals Surveillance Program in whole fish that looks to identify the presence or absence of emerging chemicals of interest and will inform State monitoring and advisory programs. 2011 will be the first year of this program and results will be shared through various outlets, including SOLEC, as they are received.
The Ontario Ministry of the Environment continues to monitor contaminants of long term concern such as PCBs, dioxins/furans, mercury and organochlorine pesticides. Recently, the ministry has started analyzing some chemicals of emerging concern for the Great Lakes environment such as polybrominated diphenylethers (PBDEs), perfluorinated compounds (PFCs) and polychlorinated naphthalene in selected fish samples.

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Figure 1. Long-term trends of total-PCB in Great Lakes lake trout. Data were adopted for skin-on lake trout fillets samples from Lake Michigan from Stow et al. 2004 and for skin-off lake trout fillet samples from the other lakes from Bhavsar et al. 2007.
Figure 2. U.S. Fish Consumption Advisory Rating Scale

Figure 3. Canada Fish Consumption Advisory Rating Scale
CONTAMINANTS IN WHOLE FISH

AUTHORS: Daryl McGoldrick, Mandi Clark (EC), Elizabeth Murphy (USEPA),
Elizabeth Tromp, Rick Rediske (Annis Water Resources Institute), Vic Serveiss (IJC).

SUMMARY: Since the Agreement was amended in 1987, concentrations of several
persistent toxic chemicals in whole fish (the entire fish including bones) have continued
to decline annually at rates of 3 - 9%. Concentrations of mercury on the other hand, have
been stable or increasing since 1990. Concentrations of PBDEs in Lake Trout and
Walleye rose continuously through to the early 2000s and have been declining since that
time.

Importance of this Indicator

Top predator fish integrate exposure to pollutants from precipitation, water, sediments,
and their food sources into their bodies and are thus good indicators of overall
environmental conditions in the Great Lakes. Data on status and trends of contaminant
conditions, using fish as biological indicators, support the requirements of the GLWQA
Annexes 1 (Specific Objectives), 2 (Remedial Action Plans and Lakewide Management
Plans), 11 (Surveillance and Monitoring), and 12 (Persistent Toxic Substances) to
monitor progress made toward restoring and maintaining the chemical, physical, and
biological integrity of the waters of the Great Lakes.

Methods for Collection and Analysis of Trend Data

Long-term (greater than 25 years), basin-wide monitoring programs that measure whole
body concentrations of contaminants in top predator fish (Lake Trout and/or Walleye) are
conducted by both the U.S. Environmental Protection Agency (U.S. EPA) Great Lakes
National Program Office through the Great Lakes Fish Monitoring and Surveillance
Program (U.S. EPA 2010), and Environment Canada’s (EC) Water Quality Monitoring
Surveillance Division, through the Fish Contaminants Monitoring and Surveillance Program (EC 2011). Lake trout are collected annually from stations situated in all Great Lakes except for the western basin of Lake Erie where walleye are far more abundant. Contaminants of current interest are measured immediately and sub-samples of all fish collected by both U.S. and Canadian programs are kept frozen in specimen banks to permit retroactive analyses and generate trends through time for new contaminants as they emerge. EC reports annually on contaminant burdens in whole body homogenates of similarly aged individual Lake Trout and Walleye (4+ through 6+ year range). The U.S. EPA monitors contaminant burdens in composited samples of similarly sized whole body Lake Trout (600-700 mm total length) and Walleye (Lake Erie, 400-500 mm total length) annually from alternating locations by year in each of the Great Lakes.

Unless stated otherwise, trends through time were assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines. Trends were deemed significant if the slope of model was greater or less than zero at α = 0.05. Contaminant concentrations and trends are compared to criteria established in the Agreement or other relevant guidelines developed to protect ecosystem quality.

Three persistent bioaccumulative toxics (PBTs) are the primary topic of discussed in this indicator report: polychlorinated biphenyls (PCBs), mercury, and polybrominated diphenyl ethers (PBDEs). These PBTs were selected for a variety of reasons. Despite being banned in the 1970s, PCB levels decreased after they were banned in the 1970s but fish from the Great Lakes still have levels that are higher than the criterion established in the Agreement. Mercury has many toxic and human/wildlife health effects and concentrations appear to be increasing in some locations, and PBDEs are of a group of chemicals of recent concern due to demonstrated negative ecotoxicological effects and they are found in fish tissues at concentrations exceeding Federal Environmental Quality Guidelines established by Environment Canada. Brief discussions of other PBTs are also provided based on the 2009 SOLEC report.
Results and Discussion

PCBs

Total PCB concentrations in Great Lakes top predator fish have continuously declined since their phase-out in the 1970s. Median PCB concentrations in Lake Trout in Lakes Superior, Huron, and Ontario and Walleye in Lake Erie continue to decline; however, they are still above the target of 0.1 µg/g in the Agreement. Recent studies have suggested that rates of decline of PCB residues in the edible portions of fish are slowing or have stopped in some lakes in recent years (Bhavsar et al. 2007; Carlson et al. 2010). Despite potential changes in annual rates of decline, first-order log-linear regression models are still a good fit to observed concentrations through time. Since the last amendments to the GLWQA in 1987, concentrations of PCBs have declined at rates ranging from ~4 to 9% per year (Figure 1). Results generated in the next few years of monitoring should clarify whether or not the rates of decline are slowing and statistical methods to assess trends will be altered as required.

Mercury

Long term monitoring of total mercury concentration in top predator fish by EC and the U.S. EPA show that the declines in concentrations observed up until approximately 1990 have ceased and that mercury concentrations in fish have started to increase (Figure 1). These observations are consistent with those of several other studies of mercury in fish from the Great Lakes Region (Bhavsar et al. 2010; Monson et al. 2011; Zananski et al. 2011). Median concentrations of mercury in fish measured in 2009 are at or approaching levels recorded in 1987 across the basin. It is important to note that median concentrations of mercury in all top predator fish collected in Lakes Ontario, Erie, Huron and Michigan in 2009 were below the GLWQA guideline of 0.5 µg/g and exceedances of the guideline occurred only in ~4% of the Lake Trout captured in Lake Superior.

PBDE
Polybrominated diphenyl ethers (PBDEs) were among the most widely used flame retardants and have recently received much research and monitoring attention because of their biomagnification potential, detection in a variety of media, and toxic effects. PBDE contamination has negative health effects on wildlife, birds and humans that eat fish (Danerud 2003, Letcher et al. 2010, Naert et al. 2007). PBDEs are a class of flame retardants that are used in many household products throughout the world including textiles, building material, electronics, furnishings and plastics (Turyk et al., 2008). They are similar to polychlorinated biphenyls (PCBs) in chemical structure, persistence and bioaccumulative properties (Birnbaum and Staskal, 2004; Figure 1). Since PBDEs are additive flame retardants and are not chemically bonded with the products that contain them, they are more likely to leach out into the surrounding environment (Hutzinger and Thoma, 1987).

In a national survey of PBDE concentrations in top predator fish from lakes across Canada, the highest concentrations were observed in fish from the Great Lakes (Gewurtz et al. 2011). In fish tissues >95% of detected PBDEs were either tetra-, penta-, or hexa-brominated diphenyl ethers, congeners with 4, 5, and 6 bromine atoms, respectively, and components of the technical mixtures used as flame retardants. Retrospective analyses of archived Lake Trout tissues from the Great Lakes by the U.S. EPA (Zhu & Hites, 2004) and Environment Canada have provided a timeline of PBDE contamination in Great Lakes fish from 1977 to the present day. The majority of tetra-BDE and all hexa-BDE concentrations reported for Lake Trout and Walleye in 2009 from all the Great Lakes were below Environment Canada’s Federal Environmental Quality Guidelines (FEQGs) (Environment Canada 2010). However, all measured penta-BDE concentrations are well above the FEQG of 1.0 ng/g wet weight (ww).

Concentrations of all PBDE congeners in fish tissue rose continuously through to the early 2000s and have been declining since (Figure 1). The annual rates of decline of penta-BDE were statistically significant in Lake Ontario (-6.4%/year) and in Lake Michigan (-17%/year). Similar rates of annual decline were also observed for tetra- and
hexa-BDEs. The production and use of three popular formulations of PBDEs have or are being voluntarily phased out in North America; however, these compounds could still be in use in other countries and be transported to the Great Lakes region in consumer products or by atmospheric transport.

Other chemicals DDT, mirex, dieldrin, and chlordane

The concentration of DDT and its metabolites, DDD and DDE, (sumDDT) in Great Lakes top predator fish have continuously declined since the use of the chemical was banned in 1972. Concentrations measured since the last SOLEC indicator report (2006-2009) remain well below the GLWQA target of 1.0 µg/g ww across the basin. Based on data collected at EC monitoring locations, annual rates of decline are 6.8% in L. Superior, 7.1% in L. Huron, 7.5% in L. Erie, and 7.3% in L. Ontario. Since the last indicator report, the rates of decline appear to be consistent with historical trends. Annual rates of decline determined using U.S. EPA data are slightly lower at 4.5% in L. Superior, 5.9% in L. Michigan, 5.9% in L. Huron, 6.0% in L. Erie, and 6.7% in L. Ontario. Decreases in the U.S. monitoring stations over the last 3 years are at a faster rate than preceding years in lakes Michigan, Huron, and Ontario compared to historical trends while rates remain consistent with historical trends in Lakes Superior and Erie.

Mirex is regularly detected only in fish from Lake Ontario due to historical releases in the Niagara River and other locations within the lake’s watershed. Since the last indicator report (2006-09), median concentrations in Lake Trout were 0.061 µg/g ww (EC) and 0.041 µg/g ww (U.S. EPA). Declines in the concentration of mirex in Lake Trout from Lake Ontario are still declining at historical rates of between 4 and 12 % annually.

The highest concentrations of dieldrin (and related compounds endrin and andrin) in top predator fish are observed in Lake Michigan (median = 0.034 µg/g ww) and Lake Ontario (median = 0.021 ug/g ww). Concentrations have declined substantially since monitoring began in the lakes and are still declining basin wide at rates ranging from 2 to 18% annually. There is no guideline for dieldrin in whole fish in the GLWQA.
Concentrations of chlordane in whole Lake Trout and Walleye have consistently declined since the chemical was banned by the U.S. EPA in 1988. In recent years, the concentrations in fish appear to have reached a steady state with no significant increases or decreases. The highest observed median concentrations since the last indicator report (2006-2009) are in Lake Trout from Lake Michigan (0.018 µg/g ww), followed by Lake Ontario (0.012 µg/g ww). Median concentration in Lakes Superior, Huron, and Erie are all below 0.01 µg/g ww. There is no target for chlordane in whole fish in the GLWQA.

References


Figure 1. Concentrations of total PCB, total mercury, and sum of penta-BDE (median & IQR) for individual (Environment Canada - red) and composited (U.S. Environmental Protection Agency - blue) whole body Lake Trout or Walleye collected from each of the Great Lakes. Solid lines show log-linear regression model for PCB and penta-BDE, and 2-segment piecewise regression model for total mercury. Statistically significant annual rates of decline since 1987 are provided for PCBs ($\alpha = 0.05$). Dashed green line denotes when the GLWQA was last amended (1987).
CONTAMINANTS IN MUSSELS

AUTHORS: Annie Jacob, Edward Johnson, Kimani Kimbrough and Gunnar Lauenstein (National Oceanic and Atmospheric Administration), Antonette Arvai and Vic Serveiss (International Joint Commission)

REVIEWERS:

Summary

Bivalve molluscs (two-sided shellfish) are a key part of environmental monitoring worldwide because they accumulate persistent contaminants, are widely distributed, and are easy to collect. Mussel Watch chemistry data can be used to assess the environmental impact of metals, and legacy and emerging organic contaminants. Great Lakes Mussel Watch metals and organic contaminants data, collected since 1992, were used to assess contaminant trends in Great Lakes basin. The majority of the Great Lakes sites show no discernable trend in either metal or organic contaminant concentrations. At the few sites were trends were evident, the majority of those showed decreases. Part of the difficulty in observing a trend at most of the sites is that the concentrations are already at low background levels.

Importance of this Indicator

The National Oceanic and Atmospheric Administration (NOAA) National Status & Trends Mussel Watch Program has been monitoring spatial and temporal trends in contaminants in coastal waters of United States since 1986 using bivalves as indicators (O’Connor and Lauenstein, 2006). Since 1992, following the successful invasion and proliferation of Ponto-Caspian mussels in Great Lakes, the Mussel Watch Program has routinely monitored the status and trends of a wide array of contaminants, including metals, legacy contaminants, and contaminants of emerging concern in Great Lakes.
The ability to bioconcentrate pollutants with limited metabolizing potential, high
tolerances to many contaminants, sessile nature, cosmopolitan distribution, and ease of
collection renders mussels an ideal environmental indicator for chemical contamination
(Cantillo, 1991). Filter-feeding mussels are readily exposed to contaminants from the
dissolved and particulate phases of the water column (Hellou et al., 2003). Water
concentrations of contaminants change in response to direct and indirect sources of
pollution such as runoff, atmospheric deposition and industrial releases. Bivalves
integrate the contaminant signal over long periods of time allowing for a better time-
integrated indication of environmental contamination than would be possible from abiotic
water or surficial sediment samples.

MusselWatch chemistry data is used to assess the environmental impact of metals,
legacy and emerging organic contaminants, the effectiveness of pollution prevention
legislation, and remediation programs. This foundational data set has served as a
baseline for natural and man-made environmental disasters such as Hurricanes Katrina
and Rita, the attack on the World Trade Center, and several oil spills (Kimbrough et al.,
2010; Johnson et al., 2008; Lauenstein and Kimbrough, 2007). Along with the bivalve
contaminant bioaccumulation data, the assessment of their histological response to
pollution is an added metric that is quantified. The program monitors the health of the
bivalve populations by quantifying the prevalence of nearly 70 diseases and parasites
found in bivalves. MusselWatch also participates in specimen banking, allowing for
retrospective analysis of bivalve samples. MusselWatch thus provides a suite of
monitoring data to evaluate the trends and extent of chemical contamination in Great
Lakes that are beneficial to resource managers and policymakers.

This article summarizes the status and trends in chemical contamination in Great Lakes,
since 1992 when the Mussel Watch Program started. The last amendment of Great Lakes
Water Quality Agreement (GLWQA) was passed in 1987. Article II of the 1987
amended GLWQA states that the purpose of the Agreement is to restore the chemical,
physical, and biological integrity of the Great Lakes. With respect to chemical integrity,
Article II also states that the policy of the two countries is to prohibit the discharge of
toxic substances in toxic amounts and to virtually eliminate discharges of persistent toxic
substances. Under Annex 10 of the GLWQA the parties are required to develop and
implement programs to minimize or eliminate the risk of release of hazardous polluting
substances to the Great Lakes system. However, the Great Lakes are the largest fresh
water system in the world and its basin is home to roughly 35 million people and is under
constant threat of pollution arising from anthropogenic use and misuse of chemicals.
Hence, there is a need for ongoing and comprehensive monitoring efforts.

Methods for Collection and Analysis of Data

The Mussel Watch Program monitors over 300 estuarine, lakeshore and coastal sites
distributed in the continental U.S., Alaska, Puerto Rico and Hawaii (Kimbrough et al.,
2008). In the Great Lakes, the Mussel Watch Program established 12 sites in the
inaugural biennial year (1992-1993) and since then, new sites have been added
periodically. There are 23 core Mussel Watch sites within the Great Lakes that have
long-term data, and 45 sites that are a part of the current monitoring effort (Fig. 1) from
which *Dreissena polymorpha* (zebra mussels) and *Dreissena bugensis* (quagga mussels)
are collected for analysis. Mussel Watch sites have been established in Great Lakes Area
of Concern (AOC), National Estuarine Research Reserves, and National Marine
Sanctuaries with the purpose of providing data to aid in management decisions.
Sites are sampled on a biennial basis; Lakes Ontario and Erie sites are sampled in odd
years and Lakes Huron, Superior, and Michigan sites in even years. The mussels are
collected by hand or dredged in near-shore zone, from natural substrates, usually at
depths of less than 20 feet. Upon collection, they are brushed clean, packed in ice and
shipped to an analytical laboratory within two days. Protocols for sample collection and
preparation, analytical methods for metals and organic contaminants and site description
are detailed in Lauenstein and Cantillo (1998 and references therein), Kimbrough and
Figure 1. Map depicting Great Lakes Mussel Watch sites

The Mussel Watch program conducts monitoring on a large suite of contaminants, but the presentation of trend data and analysis in this report will be limited to those identified as hazardous and potentially hazardous polluting substances listed in the GLWQA, Appendix 1 and 2 of Annex 10 (Table 1). In this report, Chlordane refers to alpha-Chlordane, DDT refers to the sum of 6 compounds and PCB refers to the sum of 18 PCB congeners (refer Kimbrough et al., 2008). Sites with 6 or more years of data were used for statistical analyses.

Table 1. Select Mussel Watch metals and organic contaminants presented in this report.

<table>
<thead>
<tr>
<th>METALS</th>
<th>ORGANIC CONTAMINANTS</th>
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</thead>
<tbody>
<tr>
<td>Arsenic</td>
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</tr>
<tr>
<td>Cadmium</td>
<td>DDT</td>
</tr>
<tr>
<td>Copper</td>
<td>Dieldrin/Aldrin</td>
</tr>
<tr>
<td>Lead</td>
<td>PAH- Benzo[e]pyrene</td>
</tr>
<tr>
<td>Mercury</td>
<td>PCB</td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
</tr>
</tbody>
</table>
The temporal trends in chemical contamination were determined using Spearman’s Rank Correlation (Gauthier, 2001), a non-parametric technique that is free of assumptions about concentrations being normally distributed with a common variance about sites. The variables used for the Spearman’s statistical test were year and contaminant concentration. The status summary of contaminants was determined using clustering analysis on the most recent data set (2008-2009). This analysis allows ‘clustering’ of contaminant concentrations into ‘high’, ‘medium’ and ‘low’ groups such that the numbers contained within a group are more like each other than any other number in a different group. Clustering provides relative descriptive statistics that allows for discussion of results. However, results in the medium and high categories are not representative measurements that have exceeded any regulatory thresholds; rather, it denotes that they are significantly higher than the preceding category. The low category can be considered as near background levels.

Results and Discussion

Metals

Metals are naturally occurring in the environment, but human use of metals can contribute to elevated concentrations in the environment. Living organisms require trace amounts of certain essential metals, such as copper, iron, and zinc; however, excessive amounts can be detrimental to biota. The presence of non-essential metals, such as mercury, lead, and cadmium in surface water is of particular concern due to their impacts on aquatic life.
Figure 2. Trends in median concentration of metals in bivalve tissue in the Great Lakes from 1992-2009.

Figure 2 shows the lakewide metal trends in Great Lakes and Figure 3 shows the site-specific trends. Overall, there is no discernable trend in metals concentrations in Great Lakes, however there are observable trends in some metals in specific lakes (e.g., cadmium decreases in Lakes Erie and Ontario, Figure 2). Where trends do exist, they are predominantly decreasing trends. Arsenic and cadmium have the highest number of sites with decreasing trends, whereas copper is the only metal examined that exhibits increasing trends (Figure 3). Arsenic has the the highest number of sites within the ‘high’ category but they are distributed throughout the Great Lakes region with no apparent spatial pattern.
Figure 3. Map (Left) depicting Mussel Watch metal contaminant tissue concentrations (µg/g dry weight) based on cluster analysis of 2008-2009 data and map (Right) depicting site-specific metal contaminant trends (↘ decreasing, ● no trend and ↑ increasing) based on 1992-2009 data.
Organic contaminants can be released to the environment via runoff (i.e. pesticides), manufacture or disposal processes. These compounds are of concern due to their adverse impacts on both human health and aquatic life. Many of the organic compounds are classified as persistent organic pollutants and have been associated with various impacts to aquatic life including adverse effects on reproduction, neurological development and birth defects (US EPA, 2002). In humans, effects include adverse impact on immune and nervous functions, and cognitive skills (US EPA, 2002).

Figure 4. Trends in median concentration of organic contaminants in bivalve tissue in the Great Lakes from 1992-2009.
The median concentration of the organic contaminants examined, except benzo[e]pyrene, exhibited more decreasing than increasing trends (Figure 4). A majority of sites show no discernable trend in organic contaminant concentrations, mainly because the concentrations are at low, background levels (Figure 5). Dieldrin has the highest number of sites with decreasing trends; chlordane and benzo[e] pyrene have the fewest number of sites with decreasing trends. A majority of the sites have organic contaminant concentrations in the ‘low’ category. Many of the sites with ‘high’ concentrations do not show concomitant decreasing trends (Figure 5). This emphasizes the relevance of this long-term indicator dataset in identifying contaminated sites that may require remediation.
Figure 5. Map (Left) depicting Mussel Watch organic contaminant tissue concentrations (ng/g dry weight) based on cluster analysis of 2008-2009 data and map (Right) depicting site-specific organic contaminant trends (decreasing, no trend and increasing) based on 1992-2009 data.

Several of these classes of organic compounds have been banned in both the U.S. and Canada, including DDT, dieldrin/aldrin, PCBs and chlordane. The years of their ban range from as early as 1972 for DDT to as recent as 1989 for dieldrin/aldrin. However,
these compounds are still ubiquitous in the environment due to their low degradation rates. In addition, some of these compounds can be transported through the atmosphere from other areas around the globe (Gouin et al., 2004) and be deposited in the Great Lakes in the form of wet and dry particles.

Due to the increased concern over controlling pollution, during the 1970s and 1980s several regulatory and non-regulatory initiatives were implemented in the U.S. and Canada, such as the US Clean Water Act, the Canada Water Act and the GLWQA. The GLWQA of 1987 included the provision of developing and implementing remedial action plans (RAPs) to restore significantly degraded waters around the Great Lakes, known as Areas of Concern (AOC). Several of the Mussel Watch sites coincide with or are very near to these AOCs (Figure 1), which implemented RAPs in the late 1980s and early 1990s. These areas are in the near shore and are most susceptible to high levels of contaminants from a variety of sources including, wastewater treatment effluents, industrial discharges, spills, and urban and agricultural runoff. Many of the RAPs in these areas have implemented actions with respect to improving wastewater treatment facilities, removing contaminated sediments, storm water management, reduction of combined sewer overflows and storm sewer by-passes, and pre-treatment of industrial waste. The actions taken under RAPs can contribute to the reduction in loadings of contaminants observed, particularly metals and organic contaminants.

Discussion of Future Use of this Indicator

Mussels have been long recognized as environmental sentinels and are used in environmental monitoring programs worldwide. This report built on the results of NOAA’s Mussel Watch program in Great Lakes spanning over a decade emphasizes the value of this indicator in providing relevant data to track the status and trends of metals and legacy contaminants in the Great Lakes. NOAA (Kimbrough et al., 2008) reviewed the status and trends of contaminants over the past two decades with a national and regional (including Great Lakes) perspective and the ensuing discussion is based on NOAA’s findings.
Currently, more than 45 near shore sites in the Great Lakes are monitored biennially for a wide array of contaminants including metals and legacy contaminants (Fig.1). Given the extensive area of the Great Lakes basin (10,000 miles of shoreline) and the high environmental variability in the concentration of pollutants, intensifying the future zebra mussel monitoring efforts both spatially and temporally is recommended. Addition of offshore Mussel Watch sites (open water) can complement the data from near shore sites and can together provide a better assessment of the extent of chemical contamination within the Great Lakes basin and help identify ‘hotspots’. Additionally, establishment of sites near known point sources of pollution (e.g wastewater treatment plants) and in locations with varied land-use plans will aid in finding meaningful correlations and patterns in the generated contaminant data that could prove useful to resource managers and policy makers. The ability to detect temporal and spatial trends in contaminant concentrations is confounded by a host of factors such as the age, size, lipid content and reproductive status of mussels and the inherent environmental and analytical variability. Therefore, seasonal sampling along with existing quantification of lipid content and replicate analyses of mussels at each site should be considered in future monitoring efforts, which together can provide an accurate assessment of the status and trends of contaminants in mussels. We also recommend extending the current monitoring of zebra mussels to other shellfish in locations where zebra mussels have not been successful in proliferating especially in tributaries and upstream locations in rivers. Though differences in contaminant uptake rates exist among species, bivalve monitoring across species could provide added spatial coverage. However, these recommended measures can be cost-prohibitive and no single organization may have the necessary resources to undertake such comprehensive monitoring efforts. As such, future partnerships at the national (with local, state, federal, non-profit organizations and universities) and international level are warranted. Initial efforts have already been made to collaborate with the Ontario Ministry of the Environment to assess the extent and concentration of legacy contaminants on both side of the international border.
Further, as no environmental indicator by itself can provide an assessment of ecosystem health of a system as enormous and complex as the Great Lakes and faced with multiple environmental challenges, we recommend future efforts to use Mussel Watch data in conjunction with data from other biotic monitoring programs to provide crucial data to facilitate a better understanding of the trophic transfer and cycling of contaminants in the food web. For example, future mussel monitoring in open water sites (proposed in partnership with other federal agencies and universities) can be integrated with EPA’s Great Lakes Fish Monitoring program that mainly aims to monitor contaminant trends in the open waters of the Great Lakes using fish as indicators. Linking fish and mussel measurements can help identify the direct and indirect trophic transfer link of contaminants from the base of the food web to the top predators. Coupling sediment sampling with Mussel Watch activities or establishing Mussel Watch sites in areas where other agencies routinely monitor sediment contaminant concentration can further help identify the extent to which contaminants are remobilized from the sediment into biota. Efforts are currently underway to conduct biomarkers studies with zebra mussels to characterize the status and recovery of Great Lakes ecosystems in partnership with other federal agencies and contractors. Biomarkers are measurements of biochemical and or physiological changes in organisms related to the presence of contaminants and toxic effects of contaminants (Lafonatine et al., 2000). While tissue bioaccumulation can provide some information on the bioavailability of contaminants from the environment, it is limited by its usefulness to adequately predict biological effects. Further, it is nearly impossible to monitor all contaminants, both anthropogenic and naturally occurring to characterize the quality of an aquatic system. In contrast, biomarkers can help better assess the quality of the aquatic environment by providing information on the potential impact of toxic pollutants on the health of organisms especially in ecosystems such as the Great Lakes that are contaminated with multiple chemicals and containing analytically undetectable contaminants (e.g. contaminants of emerging concern). Moreover, biomarkers can be used to track recovery of impaired ecosystems in a timely manner to consider the effectiveness of mitigation strategies. Together with tissue contaminant data, biomarker data will be particularly useful in aiding a variety of management efforts and
decisions including ecological risk and damage assessment, implementation of Remedial Action Plan, delisting of beneficial use impairment targets and AOCs.

Bivalves whether native or non-native, are bioindicators that are in line with the ‘Pressure-State-Response’ model framework proposed by Organization for Economic Co-operation and Development for developing environmental indicators (OECD, 2003). As shown in this report, the bivalve monitoring data can characterize the ‘state’ of the Great Lakes with respect to chemical contamination. The extensive historical baseline data available, together with the recommended intensive future sampling efforts can help identify the ‘drivers’ or ‘pressures’ within the system contributing to pollution. Further, the proposed mussel monitoring in AOCs is a classic example of how this indicator can be used to assess ‘responses’ within the Great Lakes systems. We recommend continuing Mussel Watch monitoring in Great Lakes building on the existing foundational data set and drawing on the expertise of the United States’ longest running coastal monitoring program that is national in scope to help work towards the protection, restoration and sustainable use of Great Lakes.

References:


CONCENTRATIONS OF CONTAMINANTS IN SEDIMENT CORES

AUTHORS: Chris Marvin, Environment Canada; Vic Serveiss, International Joint Commission

SUMMARY: Contaminated sediments can harm bottom-dwelling organisms and the toxins can move up the food chain as prey fish consume bottom dwellers. There have been significant declines between the 1970s and the late 1990s in concentrations of many contaminants in sediments including PCBs, DDT, lead, and mercury due to successful management actions. It is not clear if levels have continued decreasing since that time. The United States and Canada have recently placed more emphasis on understanding the occurrence, distribution and fate of concentrations of chemicals of emerging concern including brominated flame retardants and perfluoroalkylated substances because of their potential to harm ecosystems and human health.

Importance of this indicator in measuring progress towards achieving Great Lakes Water Quality Agreement (GLWQA) objectives

Agricultural, industrial, and municipal activities discharge contaminants that may flow into the Great Lakes. Contaminants frequently bind to sediments and settle to the substrate. Sediments in the Great Lakes represent a primary sink for contaminants, and can act as a source of contamination for biota through resuspension and subsequent redistribution within the individual lakes. However, burial in sediments also represents a primary mechanism by which contaminants are sequestered and prevented from re-entering the water column. Bottom sediment contaminant surveys conducted in the Great Lakes from 1968-1974 and from 1997-2010 along with sediment cores provide information on the spatial distribution of contaminants and the consequences of local historical sources. In the substrate, the fine organic rich particles typical of depositional zones bind contaminants more effectively than larger sized particles (Pierard et al 1996).
Contaminant levels then are influenced not just by both chemical sources and loadings, but physical characteristics of aquatic systems including sedimentology, bathymetry and current regimes. A better understanding of the spatial and temporal distribution of toxic substances in the Great Lakes helps assess the impact of human activities, and the effectiveness of contaminant discharge reduction strategies.

Article II of the Agreement states that the policy of the two countries is to prohibit the discharge of toxic substances in toxic amounts and to virtually eliminate discharges of persistent toxic substances. Under Annex 10 of the Great Lakes Water Quality Agreement (GLWQA), the Parties are required to develop and implement programs to minimize or eliminate the risk of release of hazardous polluting substances to the Great Lakes system. A list of hazardous and potentially hazardous polluting substances is listed in Appendix 1 and 2 of Annex 10. Appendix 1 to Annex 1 discloses specific objectives for levels of PCBs, DDT and metabolites (including DDE), HE, mirex, and dieldrin in water which are influenced by levels in the surficial layer of sediment. Furthermore, levels of contaminants in sediment impact ability to achieve Beneficial uses, as listed in Annex 2, Section 1c., in particular for benthos (1c.(vi)) and also for other biota.

Methods

Surficial sediment samples were collected using mini box core sampling procedure to sample the top 3 cm of the sediment. Samples were collected in jars, frozen, and transported to the laboratory. Butyrate core tubes (6.7 cm in diameter) were used to obtain samples to depths of 40 cm and cut into sections on board the vessel. Marvin et al. (2003) provides an expanded discussion of methods.

Results and Trends since 1987

Comparisons of surficial sediment contaminant concentrations with sub-surface maximum concentrations indicate that contaminant concentrations have generally decreased by more than 35% and in some cases by up to 80% since their peak levels (Table 1). Studies of persistent organic pollutants indicate peak concentration show
that peak concentrations occurred in the 1960-1980 period (Pearson et al. 1998; Wong et al., 1995; Schneider et al., 2001).

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<tr>
<th>Parameter</th>
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<th>Erie %Reduction</th>
<th>St. Clair %Reduction</th>
<th>Huron %Reduction</th>
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<td>74</td>
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</table>

Table 1. Estimated percentage declines in sediment contamination in the Great Lakes based on comparison of surface sediment concentrations with maximum concentrations at depth in sediment cores. Source: Environment Canada published in SOLEC 2009.

Spatial distributions in mercury contamination generally represent those of other toxics, both other metals and organics such as polychlorinated biphenyls (PCBs), as accumulation of a broad range of contaminants on a lake-by-lake basis can be the result of common sources, e.g., chlor-alkali production. The highest concentrations of mercury in sediments of Lakes Michigan, St. Clair, Erie and Ontario are observed in offshore depositional areas characterized by fine-grained sediments (Figure 1 - FIGURE 1 FROM SOLEC 2009).

SOLEC (2009) summarized existing spatial trends and found Mercury contamination is generally quite low in Lakes Huron, Michigan and Superior. Elevated concentrations of mercury are found in the central and east-central areas of Lake St. Clair, the western basin of Lake Erie, and the three major depositional basins of Lake Ontario. There is an apparent spatial distribution in contamination in Lake Erie with decreasing concentrations from the western basin to the eastern basin, and from the southern area to the northern area of the central basin. The spatial pattern in Lake Erie is influenced by industrial activities in the watersheds of major tributaries, including the Detroit River, and areas along the southern shoreline.
Marvin et al (2003) examined spatial and temporal trends in Lake Ontario and found:

- Average levels of mercury decreased from 0.79 ug/g in 1968 to 0.59 in 1998.
- Average levels of lead decreased from 125 to 69 ug/g
- Core profiles of most metals show a gradient of increasing concentrations from the surface to a depth of 5-10 cm (1970-1980) then decreasing concentrations down to a depth of about 40 cm (pre-1900) and then relatively constant concentrations to the bottom of the core.

Marvin et al. 2008 compared findings with data collected in 1969 and 1973 in Lakes Huron and Superior

- Sediment concentrations of PCBs, OCs, and PAHS were generally low and about 1 % of the levels in Lakes Erie and Ontario. However, concentrations of metals such as arsenic, copper, and nickel were comparable to the lower Lakes.
- In general, concentrations of these chemicals did not change much over time, this may be due to slow sediment accumulation.
- However, DDT and lead levels in Lake Huron decreased to half their 1973 levels, while mercury decreased to 1/5 of their earlier levels in Lake Huron and Georgian Bay.

A comparison of contaminant levels in Lake Erie (Painter et al. 2001) found:

- PCB averages decreased from 136 ng/g in 1971 to 43 ng/g in 1997 in all three basins; this decrease was also seen in core sampling results.
- Concentrations of contaminants in Lake Erie decreased significantly from 1971 to 1997/98.
- Core profiles showed increasing concentrations down to about 10 to 20 cm (corresponding to about 1970), then decreasing gradients to 20-40 cm in depth and then stable concentrations beyond that.

In Lake St. Clair similar results were found as in Lake Erie by Gewurtz et al. (2007):
• Lakewide mean concentrations of PCBs, mercury, lead and total DDT decreased respectively by 32%, 89%, 70% and 63%; averages decreased from 136 ng/g in 1971 to 43 ng/g in 1997 in all three basins; this decrease was also seen in core sampling results.

• Overall concentrations were low relative to sediment quality guidelines and in comparison to Lakes Erie and Ontario.

Discussion of Results

The current degree of contamination in these areas is substantially lower than peak levels that occurred in the mid-1950s through the early 1970s. However, the similarity in spatial patterns between recent and historical surveys indicates significant sources within the individual lake basins continue to influence contaminant distributions over large areas. Areas of the major connecting channels including the Niagara River, lower Detroit and upper St. Clair Rivers, are all associated with historical mercury cell chlor-alkali production; these areas were also intensively industrialized and were primary sources of a variety of persistent toxics to the open lakes, including PCBs. Localized areas of highly contaminated sediment, and/or hazardous waste sites associated with these industrial historical sources, may continue to act as sources of these contaminants and influence their spatial distributions. Conversely, these local sources may no longer be predominant, and the spatial patterns observed in our most recent surveys may reflect re-suspension, intra-lake mixing and deposition of existing sediment inventories. In this case, further declines would be expected as these contaminants are ultimately deposited and buried in the sediments.

Surficial sediment concentrations can also be assessed against guideline values established for the protection of aquatic biota, e.g., the Canadian Sediment Quality Guidelines Probable Effect Level (CCME, 1999). These guidelines can be applied as screening tools in the assessment of potential risk, and for the determination of relative sediment quality concerns. For metals and PCBs, Probable Effect Level (PEL) guideline exceedances were frequent in Lake Ontario for lead, cadmium and zinc.
Guideline exceedances were rare in all of the other lakes, with the exception of lead in Lake Michigan where the PEL (91.3 ug/g) was exceeded at over half of the sites. There were no PEL (277 ng/g total PCBs) guideline exceedances for PCBs in any of the Great Lakes sediments.

Management efforts to control inputs of historical contaminants have resulted in decreasing contaminant concentrations in the Great Lakes open-water sediments for the standard list of chemicals. However, additional chemicals such as brominated flame retardants and current-use pesticides may represent emerging issues and potential future stressors to the ecosystem. These results corroborate observations made globally, which indicate that large urban centers act as diffuse sources of chemicals that are heavily used to support our modern societal lifestyle.

The presence of new persistent toxics represents an emerging threat to the health of the Great Lakes ecosystem. These compounds include perfluoroalklated substances (PFAs) and brominated flame retardants (BFRs), the latter of which are heavily used globally in the manufacturing of a wide range of consumer products and building materials. The BFRs have been found to be bioaccumulating in Great Lakes fish and in breast milk of North American women. Assessment of the occurrence and fate of these new compounds has recently been incorporated into bottom sediment monitoring programs. While government initiatives for reducing indiscriminant urban and industrial discharges of legacy compounds like PCBs have resulted in decreasing trends, the new and emerging compounds have not shown corresponding trends. While end-of-pipe discharges may not be responsible for ongoing contamination, modern urban/industrial centers can act as diffuse sources of current inputs. Sediment core profiles of polybrominated diphenyl ethers (PBDEs) and PFAs in Lake Ontario suggest that accumulation of these chemicals has only recently peaked, or continues to increase (Fig. 2). The Lake Ontario BDE profile indicates a leveling off of accumulation in the past decade, presumably as a result of voluntary cessation of production of these compounds in North America. However, the deca-substituted BDE 209 is the predominant congener in sediment, and is still currently produced. The occurrence and distribution of PBDEs in
the Great Lakes is shown in Figure 3. Despite these trends, maximum concentrations of many BFRs and PFAs remain well below maximum concentrations of contaminants such as DDT and PCBs observed in past decades.

Discussion of Future Use of this Indicator

Further work should evaluate temporal trends by examining changes in contaminant concentrations at various depths of a sediment core collected from each of the lakes. This work is part of The Great Lakes Binational Toxics Strategy which needs to be maintained to identify and track the remaining sources of legacy contaminants and to explore opportunities to accelerate their elimination. In addition, targeted monitoring to identify and track down local sources of pollution should be considered for those chemicals whose distribution in the ambient environment suggests local or sub-regional sources. Ongoing monitoring programs in the Great Lakes connecting channels (e.g., Detroit River, Niagara River) provide valuable information on the success of binational management actions to reduce or eliminate discharges of toxic substances to the Great Lakes. The Great Lakes Binational Toxics Strategy also needs to be proactive in addressing issues related to the distribution and fate of chemicals heavily used by our modern urban/industrial society.

References


Figure 2. Core profiles of perfluoroalkyl substances (PFAS) and brominated diphenyl ethers (BDEs) in sediment cores from the central (Mississauga Basin) basin of Lake Ontario. Sources: Environment Canada and Ontario Ministry of the Environment.

Figure 3. Distribution of polybrominated diphenyl ethers (PBDEs) in open-water areas of the Great Lakes.
PHOSPHORUS LOADING

AUTHORS: Dave Baker, Heidelberg University, United States; Murray Charlton, Environment Canada (retired); Bruce Kirschner, International Joint Commission

SUMMARY: Phosphorus loading is an important contributor to excessive algal growth in nearshore waters of the Great Lakes. Phosphorus inputs from point and non-point sources that resulted in nuisance algal blooms in Lake Erie and elsewhere in the Great Lakes Basin were targeted for control under the Agreement (U.S. EPA 2009). An annual phosphorus target of 11,000 metric tons was set to control water quality issues associated with excessive phosphorus enrichment. This target was first met in 1981. Substantive reductions in loading from major wastewater treatment plants have been achieved, but combined sewer overflows still require additional control efforts. The National Center for Water Quality Research (NCWQR) began Lake Erie tributary monitoring for various parameters including total phosphorus and dissolved reactive phosphorus in 1975. Reduced loading of total phosphorus (TP) and dissolved reactive phosphorus (DRP) through 1995 are indicative of successful control programs. However, more recent increases in DRP, which is readily available for algae to consume, indicate the need for improved management controls and continued monitoring (Baker 2011).

Importance of this Indicator

Excessive phosphorus loading to waters in the nearshore has resulted in degraded water quality conditions and led to oxygen depletion and fish kills. Benefits derived from controlling phosphorus loading from any one of the large array of non-point and point sources are difficult to estimate. Therefore, a cumulative approach is needed. Measurement of TP and DRP and estimation of annual tributary loadings provide a cost effective means of tracking potential environmental benefits from nutrient control activities. More targeted nutrient strategies will be necessary to focus on the specific non-point source agricultural nutrient problem areas in a cost-effective manner. Such focused efforts will require suitable detailed data for nutrient load estimation.
Methods for Collection and Analysis of Trend Data

The NCWQR began monitoring nutrient levels in the major U.S. tributaries to Lake Erie in 1975. Daily precipitation data are obtained from the National Oceanic and Atmospheric Administration National Climate Data Center for the major weather stations. Flow data are daily mean flows, and they are provided by the U.S. Geological Survey (USGS). Samples for nutrient analyses are obtained at or near USGS gaging stations on five major tributaries to Lake Erie. Water samples are taken using refrigerated autosamplers (since 1988) and the sampling frequency is three times per day. One sample per day is analyzed except during periods of high flow or high turbidity when all samples are analyzed. The NCWQR methods for analysis parallel U.S. Environmental Protection Agency protocols (Richards et al 2010).

Daily flow-weighted mean concentrations are calculated by dividing the daily load by the daily discharge. The daily load is the sum of the sample loads obtained by multiplying the observed concentration by the instantaneous flow at the time of the sample and a sample time window. The daily discharge is similarly calculated as the sum of the sample discharges, each of which is the product of the flow at the time of each sample and the sample time window. Daily loads are then calculated as the product of daily flow-weighted mean concentration and the official daily mean flow reported by the USGS.

Results and Discussion

The Maumee River is the largest tributary to Lake Erie and its 6,500 square mile watershed is largely dedicated to agriculture. As shown in figure 1, the total phosphorus loads in the Maumee River have generally been decreasing over the entire period of measurement. This trend is not statistically significant. Activities to promote the adoption of conservation practices on row-crop acreages within the Maumee River basin appear to have contributed to the reduced loading of total phosphorus.
Dissolved reactive phosphorus (DRP) is one hundred percent available to algae, and its transport from cropland in the Maumee River basin, as shown in figure 2, has increased over the past fifteen years. DRP moves much differently than particulate phosphorus and it requires monitoring and modeling in order to devise corrective management programs.

Phosphorus loading from nonpoint sources tends to increase along with increases in annual precipitation. Phosphorus loading is also affected by discharges from point sources such as combined sewer overflows. Years with lots of rainfall, stormwater runoff, and combined sewer overflows are expected to have more phosphorus loading than years with less rainfall and fewer storm runoff events.

Budgetary cuts in monitoring and research for Lake Erie tributaries have occurred and current activities of the NCWQR are not secured by long-term stable funding. Managing non-point source TP and DRP exports to the nearshore waters of Lake Erie is a considerable challenge given that over eighty percent of the 6,500 square mile basin is agricultural and intensive surface and subsurface drainage systems readily transport soluble nutrients into receiving waters.

Discussion of Future Monitoring

Many recent algal blooms are evidence that the phosphorus load to Lake Erie is too high. A significant portion of the load is present as DRP and TP from watershed sources. Tributary monitoring of TP and DRP to measure the response of loads to further controls is needed and this may have to be more intensive to allow for evaluation of implementation activities at a sub-watershed level.
Figure 2

Maumee River, Annual Dissolved Phosphorus Loads

References


ATMOSPHERIC DEPOSITION OF TOXIC CONTAMINANTS

Authors: Dave Dempsey, IJC.
Reviewer: Vic Serveiss, IJC.

Summary: Atmospheric deposition occurs when pollutants are transferred from the air to the earth's surface. Levels of persistent toxic chemicals banned in the 1970s and 1980s and deposited through both wet and dry processes continue to decline, although at slower rates than in the decade after banning. Concentrations of mercury have declined since 1987, but have recently showed no trend. Higher levels of deposition of PCBs are associated with urban areas. Air concentrations of banned pesticides show a seasonal pattern, with highest levels during warm summer months. For Lake Superior, levels of toxaphene deposited through atmospheric processes are uniquely high and may be from long-range transport from outside the Basin.

Section 1. Importance of this indicator in measuring progress towards achieving +Great Lakes Water Quality Agreement (GLWQA) objectives.

The GLWQA defines the virtual elimination of toxic substances as one of its specific objectives. Further, GLWQA general objective (d) is that the Great Lakes “should be free from materials entering the water as a result of human activity that will produce conditions that are toxic to human, animal or aquatic life.”

The discovery of PCBs and DDT in fish in Siskowit Lake on Isle Royale in the 1970s was a significant milestone in the understanding of the role of atmospheric transport and deposition of toxic substances (Swain 1978). Because the lake was remote, free of both point and direct nonpoint runoff sources of toxic chemicals, and within a national park, it was apparent that the contaminants originated relatively far from the lake and were transported and deposited there through the atmosphere. Since that time, understanding of the role of the atmosphere as an important vector for toxic pollution of the Great Lakes has significantly increased.
Atmospheric deposition has been shown to be a significant source of pollutants to the Great Lakes and other water bodies. Pollutants can get from the air into the water through rain and snow, falling particles, and absorption of the gas form of the pollutants into the water (EPA 2011). Contaminants may also migrate from the Great Lakes to air when its fugacity is lower in air than in water. When PCBs were regionally banned, their concentration in air reduced dramatically and PCBs vented from the lakes into the air, according to EPA’s 1994-1995 Lake Michigan Mass Balance Study (EPA Lake Michigan Mass Balance Project 2009.).

Section 2. Methods for collection and analysis of trend data.

To measure the contribution of both local and long-range transport of chemical contaminants and their deposition in the Great Lakes Basin, the U.S. and Canada have operated the Integrated Atmospheric Deposition Network (IADN) since 1990. IADN was a specific commitment of the U.S. and Canada in Annex 15 of the Great Lakes Water Quality Agreement. The monitoring network consists of five master monitoring sites, one near each of the Great Lakes, and several satellite monitoring stations (SOLEC 2009). Six satellite monitoring stations for precipitation measurements are located within the Canadian portion of the Great Lakes Basin (Environment Canada 2011).

The network measures and evaluates more than 150 pollutant concentrations in the atmosphere (airborne vapor, airborne particles, and precipitation) at a lake-wide level of detail. Organic pollutants of particular interest include chlorinated pesticides, PCBs, several polycyclic aromatic hydrocarbons, and more recently, brominated and chlorinated flame retardants (Hites 2010).

Several networks supplement IADN data, including three Great Lakes stations that are part of the Canadian Atmospheric Mercury Measurement Network and stations that are part of the U.S. Mercury Deposition Network.
Results – Trends since 1987

Trends among sentinel contaminants include:

- Concentrations of gas-phase PCBs generally decreased over time since 1990, but showed the slowest rate of decline among all the chemicals measured by IADN. Concentrations of PCBs in air around the Great Lakes have been decreasing since 1990 but halving time is a relatively slow 17 plus or minus two years (Venier and Hites 2010). Increases were noted during the late 1990s for Lake Michigan and Lake Erie and during 2000-2001 for Lake Superior. Causes for these increases are uncertain, but may be attributable to global atmospheric circulation phenomena such as El Nino (Ma, Hung and Blanchard 2004). Since then, levels have declined for all three lakes. The Lake Erie monitoring site has recorded relatively elevated gas-phase concentrations compared to other stations which may be the result of possible influences from upstate New York and the East Coast (Hafner and Hites, 2003).

- Banned or restricted organochlorine pesticides such as lindane, hexachlorocyclohexane and DDT have decreased more rapidly than PCBs since 1990. Air concentrations of chlordane were about ten times higher at urban stations, possibly as a result of previous use of chlordane as a building termiticide (SOLEC 2009). Dieldrin was also elevated in urban areas. Endosulfan and atrazine, still in use, show seasonal increases during summer agricultural use.

- Monitored as part of the Canadian Atmospheric Mercury Measurement Network (CAMNet), air concentrations of mercury in the gas phase measured between 1996 and 2005 decreased by 2.2 %, 16.6 % and 5.1 %, at three Canadian IADN sites, Egbert, Point Petre and Burnt Island, respectively. Combined results of the MDN, the Michigan Mercury Monitoring Network and IADN showed that concentrations of mercury in wet deposition in the Great Lakes region were unchanged between 2002-2008 (Risch et al 2011).
• Concentrations in fish of a banned organochlorine pesticide, toxaphene, have decreased but are uniquely high in Lake Superior, exceeding water quality standards and driving some fish consumption advisories (U.S. EPA 2009). Atmospheric sources are implicated (Ma et al 2005). Lake Superior’s cold waters and long residence time help keep toxaphene’s levels high (Moen 2007). Toxaphene is a probable human carcinogen (U.S. Department of Health and Human Services 2011).

Discussion

For almost all chemicals monitored by IADN, concentrations in air and precipitation have declined since 1987, in some cases significantly. This suggests both in-Basin source reduction activities such as collection and disposal of transformers laden with PCBs and products containing mercury have had beneficial results. Mercury emission standards for coal-fired power plants both in and outside the Basin may also be contributing to mercury’s decline in the gas phase over the period.

One of the few chemicals deposited by the atmosphere that continues to exceed water quality standards in the Great Lakes (Lake Superior) is toxaphene, one of the most heavily used pesticides in U.S. history and a composite of more than 670 chemicals.

Toxaphene exists in a predominantly gaseous form in the atmosphere. It is known for its tendency to remain in cold waters and be degraded in warm, nutrient-filled waters (Wania and Mackay 1993, Moen 2007). Because the U.S. and Canada banned toxaphene use, atmospheric deposition from distant sources is a suspected contributor (Visser 2007).

Future Use of This Indicator
As a long-lived, statistically valid measure of atmospheric deposition of toxic chemicals, maintenance of IADN and reporting of data are important to measuring the chemical integrity of the Great Lakes.

Consideration should also be given to adding emerging chemicals of concern to IADN monitoring in order to determine trends in atmospheric transport and resultant human health and aquatic exposures.

References


VI. INDICATOR OF PHYSICAL INTEGRITY

SURFACE WATER TEMPERATURES

AUTHORS: Dave Dempsey, IJC

REVIEWERS: Jay Austin, University of Minnesota-Duluth; Don Scavia, University of Michigan; Vic Serveiss, IJC.

SUMMARY: Significant warming in surface temperatures of several of the Great Lakes since the mid-1980s may be contributing to stress in native fish communities and to algal blooms that pose human health risks, and may signal climate change. Warming is most pronounced in Lake Superior, the coldest and largest of the Great Lakes.

Importance of this indicator in measuring progress towards achieving Great Lakes Water Quality Agreement (GLWQA) objectives

Great Lakes surface water temperatures are important to the chemical, biological and physical integrity of the Great Lakes. Warmer surface water temperatures in combination with nutrients and/or light levels are associated with the frequency and severity of algal blooms, including cyanobacteria, which are known as blue-green algae.

Mandrak (1989) predicted that with climate warming, 19 warmwater fish species from the Mississippi or Atlantic Coastal basins might invade the lower Laurentian Great Lakes (Ontario, Erie, and Michigan) and that 8 warmwater fish species present in the lower Great Lakes could invade the upper Great Lakes (Huron and Superior).

Blooms of cyanobacteria (blue-green algae), particularly toxin-producing species, are increasing in the Great Lakes (Fahnenstiel, personal communication). The most significant cyanobacteria bloom species in the Great Lakes, *Microcystis aeruginosa*, produces a toxin (microcystin) that has both chronic and acute effects (Carmichael...
Microsystis growth is stimulated with higher temperatures and increased sunlight (Liu et al 2010). In the past decade, some of the highest concentrations of Microcystis and microcystin have been noted in the Great Lakes. In late July 2011, a large Microcystis bloom in western Lake Erie had toxin concentrations exceeding 1000 ug/l. To put this in context, the World Health Organization recommends levels of microcystin concentration not exceed 1 ug/l for drinking water and 20 ug/l for recreational exposure, e.g., swimming, boating, fishing, etc.

Another toxin-producing cyanobacteria, Cylindrospermopsis raciborskii, has recently been found in the Great Lakes and is increasing in abundance in several regions of the Great Lakes basin. In the past, this cyanobacteria has been found chiefly in sub-tropical regions, but recently has moved north across the United States. Cylindrospermopsis raciborskii, poses health risks to humans and animals coming in contact with these so-called blue-green algae (NOAA 2011). Further, all cyanobacteria can produce skin irritants under certain conditions (NOAA 2011).

Human health risks from Cylindrospermopsis raciborskii are both acute and chronic. Cylindrospermopsis raciborskii has caused liver damage and even death in humans when the species occurs in water supply systems (Bernard et al. 2003; Falconer and Humpage 2006). It has the potential to be genotoxic or carcinogenic in humans and to cause acute skin reactions in people on contact (Falconer and Humpage 2001; Shen et al. 2002; Stewart et al. 2006). The species has been associated in some studies with neurological disease in humans (Cox et al 2005).

Besides the influence of temperature on cyanobacteria, increased water temperatures in the water column can threaten native fish communities most vulnerable to climate-driven invasive species (Shuter et al 2005). Changes in temperatures may be lethal to or cause redistribution of native species (Great Lakes Fishery Commission 1987). Warmer water temperatures can move the southernmost range of coldwater fishes such as brook trout and lake trout to the north while permitting survivability of warmwater fish not native to the Great Lakes in southern Great Lakes habitat (Chu et al 2005).
Phencie (2011) supports the addition of lake surface water temperatures as a SOLEC indicator within the category of resource use and physical stressors.

Methods For Collection And Analysis Of Trend Data

For Lake Superior, data were drawn from three surface buoys maintained by the National Oceanic and Atmospheric Administration in the western, central and eastern basins from April through November (Austin and Colman 2007). The buoys make hourly measurements of near-surface water and air temperatures and have been in operation since 1981, 1979 and 1980, respectively. Data were analyzed for the period 1979-2006.

In a second analysis of Lake Superior temperatures, surface water temperatures were estimated from nighttime thermal infrared imagery of 167 large inland water bodies worldwide, including the Great Lakes, from 1985 to 2009 and additional technical details are described by Schneider and Hook 2010.

In a third analysis, data on lake surface water temperatures for Lakes Huron, Erie and Ontario were compiled from Fisheries and Oceans Canada, Environment Canada, the Ontario Ministry of Natural Resources, the U.S. National Oceanic and Atmospheric Administration’s National Data Buoy Center, the U.S. National Weather Service, the U.S. Great Lakes Environmental Research Laboratory, the U.S. Environmental Protection Agency STORET, the EPA Great Lakes National Program Office and the Michigan Department of Natural Resources for the period May-October 1968-2002 (Dobiesz and Lester 2009).

In another analysis, used only as supporting documentation for this indicator because data were assessed only through the mid-1990s, data were drawn from temperatures at seven water intake sites (Bay City, Michigan; Green Bay, Wisconsin; Sault Ste. Marie, Michigan; St. Joseph, Michigan; Sandusky Bay, Ohio; Put-in-Bay, Ohio; and Erie,
Pennsylvania (McCormick and Fahnensteil 1999). For most of the intakes, data were available for at least three decades ending in the mid-1990s.

Results – Trends since 1987

Consistent with a trend toward warming of inland lakes worldwide, the annual average temperature of Great Lakes regional surface waters increased approximately 0.05 degrees C to 0.06 degrees C per year between 1985 and 2009 (Schneider and Hook 2010).

Austin and Colman (2007) reviewed temperature changes in Lake Superior and noted rapid warming summer (July-September) surface water temperatures increased approximately 2.5 degrees C overall between 1979-2006. This is significantly in excess of regional atmospheric warming and it is hypothesized that declining winter ice cover contributes to an earlier period of the stratified season in the lake (Austin and Colman 2007).

Dobiesz and Lester reviewed temperatures during August in Lakes Huron, Ontario and Erie over the 34-year period 1968-2002. Surface water temperature during August has been rising at statistically significant annual rates of 0.084 °C (Lake Huron) and 0.048 °C (Lake Ontario) resulting in increases of 2.9 °C and 1.6 °C, respectively. (Dobiesz and Lester 2009). Surface water temperatures in Lake Erie also increased, but not at a statistically significant rate.

Discussion

Significant increases in surface water temperatures of four of the five Great Lakes have been noted since 1987. Coupled with an increased number and abundance of non-native invasive species, these surface water temperatures, which may be associated with changes in temperatures in the water column, may be impacting native fish communities, thus undermining the biological integrity of the Great Lakes. An increase in the number
and severity of algal blooms containing cyanobacteria may also be linked to the rise in surface water temperatures.

While there are several valuable sources of long-term, geographically distributed surface water temperatures in the Great Lakes, routine analysis of these data is not conducted. For example, records of surface water temperatures for several Great Lakes locations, including the St. Marys River and Buffalo, are available as far back as 1906 (McCormack and Fahnensteil 1999) and 1927 (NOAAab 2011), respectively. Data are available from the National Data Buoy Center (NOAAC 2011) extending back to approximately 1980, but with the primary exception of Colman and Austin (2007) for Lake Superior, long-term analysis has not been done.

Analysis of surface water temperatures should be made routine given the relatively low costs and data availability. Further, changes in temperature in the water column should be routinely monitored and analyzed.

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VII. INDICATORS OF BIOLOGICAL INTEGRITY

AQUATIC INVASIVE SPECIES

AUTHORS: Vic Serveiss (IJC), Antonette Arvai (IJC), Rochelle Sturtevant (National Oceanic and Atmospheric Administration), United States, Hugh MacIsaac (University of Windsor – Great Lakes Institute for Environmental Research), Canada
Reviewer: Mark Burrows (IJC)

SUMMARY: Non-native species have become established in the Great Lakes and have caused economic and ecological impacts. The number of established non-native aquatic species in the Great Lakes increased steadily from 1900 until the late 1990s. There were 34 new non-natives introduced since 1987. However, due partly to regulation of ballast water discharges from transoceanic vessels, no new species have been discovered since 2006. Since the economic and ecological costs of invasive species can be huge, and these species are difficult to control once established, prevention and detection activities are essential to stop any discovered species from becoming established.

Significance of Indicator

The introduction of non-native aquatic species (NAS) is one of the most important issues affecting the biodiversity of lakes and coastal ecosystems, and they are a key threat to the biological integrity of the Great Lakes, as they may degrade habitats, cause adverse effects to native species, and disrupt food webs. Documenting trends in the number of NAS, their pathway of introduction, and the status of their populations is an important contribution to assessing progress in maintaining and restoring Great Lakes biological integrity.

NAS in the Great Lakes, by impacting native species, have impacted biological integrity. Furthermore, NAS have impaired several beneficial uses listed under Annex 2, 1 (c)
including fish and wildlife consumption, and fish wildlife populations. The current GLWQA indirectly addresses NAS under Annex 6, with respect to review of practices and procedures of vessel wastewater and the threat that can be posed by NAS via the ballast water vector. The Governments of the United States and Canada have indicated in public webinars that they are considering making Aquatic Invasive Species a higher priority and listing them as a separate Annex in a renewed Agreement (BEC 2010).

The Great Lakes basin is among the most highly invaded aquatic ecosystem in the world (Ricciardi, 2006). The Great Lakes have been subjected to biological invasions since the 1830s, with the stocking of brown trout in Lake Ontario tributaries. NAS can be introduced by a variety of vectors including intentional releases (i.e. fish stocking) and unintentional releases (e.g. aquaculture facilities, recreational vessels and commercial shipping). Ballast water release has been attributed to 65% of all invasions in the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Ricciardi, 2006).

Ricciardi (2006) reported 182 NAS are established in the Great Lakes. NAS can cause alterations to ecosystem structure or function as well as facilitate further invasion by other NAS, through provision of food or habitat and can exacerbate each other’s impacts (Bailey, et al., 2005a; Ricciardi, 2006).

However, not all non-natives have adverse effects. Thirteen NAS were reported as causing serious impacts (Mills et al., 1993). Additional species such as quagga mussels (Dreissena rostriformis bugensis), round- (Neogobius melanostomus) and tube-nosed gobies and (Proterorhinus marmoratus) could be added to such a list.

The term aquatic invasive species (AIS) is subject to inconsistent usage (NOAA 2011), but we use it here to differentiate between the species more likely to cause substantial adverse impacts to the environment, human health, or the economy in the Great Lakes. For instance, the sea lamprey (Petromyzon marinus) is recognized as an AIS because the species has contributed to the near destruction of native lake trout and has undermined salmon and other sportfish populations despite sustained, costly control programs.
Another example of an AIS is Alewife (*Alosa pseudoharengus*), which significantly disrupted the Great Lakes food web and caused unpleasant aesthetic impacts in the 1950s and 1960s through large annual dieoffs (O’Sullivan and Reynolds 2005). Zebra (*Dreissena polymorpha*) and quagga mussels have significant impacts on food webs as well as economic impacts, such as increased costs for treatment of drinking water and operation of electricity generation plants (Colautti *et al*., 2006, Lodge and Finnof, 2008). Dreissenids also promote conditions suitable for the growth of nuisance algae, by increasing water clarity and retaining nutrients, particularly phosphorus, in nearshore zones of the lower Great Lakes (Auer *et al*., 2010).

New invaders can interact with previously established invaders, creating synergistic impacts. An example is the recurring outbreaks of avian botulism in the lower Great Lakes, attributed to the synergistic interactions of the round goby and zebra mussels. It is hypothesized that the mussels create environmental conditions that promote the growth of the pathogenic bacterium and that the gobies, by consuming the mussels, transfer the bacterial toxin from the mussels to higher levels of the food web (SOLEC, 2009).

Once established in the waters of the Great Lakes basin, it is virtually impossible to eradicate NAS populations, making it unlikely that the number of NAS in the Great Lakes will ever decrease. Furthermore, it can be very costly or impossible to limit and control the spread of NAS, as well as to mitigate their impacts.

**Methods**

The National Oceanic and Atmospheric Administration’s (NOAA) Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) program provides information on established NAS in the Great Lakes (NOAA 2011). Several criteria are used for determining which species to include in the GLANSIS database:
**Geographic criterion:** Species are established in the Great Lakes basin below the ordinary high water mark -- including connecting channels, wetlands and waters ordinarily attached to the Lakes.

**Aquatic criterion:** GLANSIS includes only aquatic species. USDA wetland indicator status is used as a guideline for determining whether wetland plants should be included in the list.

**Nonindigenous criterion:** Species are considered nonindigenous within the Great Lakes basin according to the following definitions and criteria (based on Ricciardi 2006):

1. the species appeared suddenly and had not been recorded in the basin previously;
2. it subsequently spreads within the basin;
3. its distribution in the basin is restricted compared with native species;
4. its global distribution is anomalously disjunct (i.e. contains widely scattered and isolated populations);
5. its global distribution is associated with human vectors of dispersal;
6. the basin is isolated from regions possessing the most genetically and morphologically similar species.

**Established criterion:** A nonindigenous species is considered established if it has a reproducing population within the basin, as inferred from multiple discoveries of adult and juvenile life stages over at least two consecutive years.

**Results and Discussion**

The National Oceanic and Atmospheric Administration (NOAA), currently reports 182 NAS, the same number reported by Ricciardi (2006). Figure 1 illustrates the cumulative number of NAS discoveries in the Great Lakes since the 1840s and shows more invasions occurred in the decades from 1950 to 2000 than the preceding or most recent decade. While the NOAA database shows 34 invasions since 1987, no new species have been discovered since 2006.
The rate of NAS discovery increased significantly after the opening of the modern St. Lawrence Seaway in 1959 (pre-Seaway was 0.76 discoveries per year versus 1.66 discoveries per year post-Seaway) (NOAA, 2011). The change in invasion discovery rate between the pre- and post-Seaway opening periods is in concordance with changes in vector; that is, a shift from invasions caused by fish stocking or accidental release to shipping-related invasions, as illustrated in Figure 2. The number of ship-introduced NAS increased, with the opening of the St. Lawrence Seaway in 1959 (Bailey et al., 2011). As noted previously, the ballast water vector was responsible for about 65% (estimates range from 55-70%) of these NAS since the St. Lawrence Seaway opened, including zebra and quagga mussels, round- and tube-nosed gobies, and Eurasian ruffe (Gymnocephalus cernuus). New introductions between 1995 and 2006 include 7 parasites/pathogens (40%), 4 sediment associated organisms attributed to NOBOBs (24%), and 6 ballast-water associated organisms (35%). No new ship-mediated invasions have been observed since 2006, possibly owing to implementation of more stringent ballast water management practices (Bailey et al., 2011). It should be noted, however, that three additional ANS have been reported in Lake St. Clair in 2010 (water hyacinth and water lettuce) and in 2011 (Mississippi grass shrimp), though it is not known whether these species are actually established (see below). Furthermore, the vector of introduction for these species is almost certainly the aquarium and pond trade rather than commercial shipping.

Ballast water management regulations were first introduced by the United States in 1993 requiring vessels to conduct mid-ocean ballast water exchange (BWE). BWE greatly reduces the number of freshwater organisms since most will be purged when tanks containing freshwater are replaced with seawater, and any remaining individuals will die due to the high salinity of the loaded water (MacIsaac et al., 2002, Wonham et al., 2005). Ballast water management has been mandatory since 1993 for fully ballasted vessels.
However, vessels with “No-Ballast-On-Board” (NOBOB) contain residual waters and sediments that can harbour species. The large proportion (up to 90% of traffic) of unregulated NOBOB vessels may partially account for the accumulation and number of species discovered in the Great Lakes subsequent to the implementation of the 1993 US BWE regulations (Bailey, et al., 2005b).

In 2006, Canada introduced regulations for mid-ocean BWE as well as flushing of NOBOB vessels. Since 2006, no new documented ballast-associated discoveries have been made, possibly due to the implementation and enforcement of mandatory ballast water management regulations for NOBOB ships by Canadian, U.S., and St. Lawrence Seaway authorities (Bailey et al. 2011). The St. Lawrence Seaway Development Corporation published regulations, which became effective at the start of the 2008 navigation season, requiring all NOBOB vessels that operate outside the exclusive economic zone (usually 200 miles from the United States) to conduct saltwater flushing of their ballast tanks before transiting the St. Lawrence Seaway, regardless of whether their destination is a U.S. or Canadian port (73 FR 37, p. 9,950).

Prior to the 2006 regulations implemented by the United States and Canada, the ballast water pathway was viewed as the vector posing the most risk, while other vectors of concern were the live food fish industry, and the ornamental pet/aquarium trade (Holeck et al. 2004; Kerr 2005). However, these and other non-ship vectors are now predicted to pose a greater risk of introducing new NAS to the Great Lakes than ships (MacIsaac, H., personal communication, August 12, 2011).

While ballast water continues to be a highly monitored vector for NAS introduction, the potential establishment of non-native bighead and silver carp (Hypophthalmichthys nobilis and Hypophthalmichthys molitrix) to the lakes via the Chicago Sanitary and Ship Canal (which links the Mississippi River and Lake Michigan) is a major concern. Red swamp crayfish (Procambarus clarkia) has recently become established in the Chicago lagoons contiguous with Lake Michigan (Surtevant, R., personal communication, August 28, 2011). These crayfish are commonly used as live
experimental animals in classrooms as well as being available in the live seafood markets. Their establishment is attributed to unintentional or deliberate unauthorized release. In 2010, two NAS macrophytes, the water hyacinth (*Echhornia crassipes*) and water lettuce (*Pistia stratiotes*), were reported in Lake St. Clair, almost certainly introduced via the pond trade (Adebayo *et al*., 2011). More recently, the Mississippi grass shrimp (*Palaemonetes kadiakensis*) was found in Lake St. Clair in June, 2011, likely introduced by the aquarium trades (MacIsaac, H., personal communication, August 12, 2011). Regulators in both the USA and Canada should consider formal assessments of the species involved in the home aquarium/pets/pond trades, and the risk these species may pose to the Great Lakes if introduced successfully.

Discussion of the Use of this Indicator

The cumulative number of NAS and AIS along with the rate of new introductions can be used as measures of ecosystem integrity. The presence of NAS can have both beneficial and adverse impacts on the ecosystem, but only a limited number have undergone significant and rigorous research to characterize the type and extent of their impact.

Once NAS become established it is typically impossible to eradicate them, and very costly and difficult to limit or control their spread. Therefore the Commission, first and foremost, supports efforts to prevent invasions and spread from all potential pathways, as this approach is the most likely to succeed and is the most cost-effective form of management (IJC 2011). It is recommended that NOAA and others continue to track the total number of NAS and AIS, as well as their presence/absence in each of the Great Lakes, as indicators of biological integrity. Within LAMPs, the presence, absence, and level of abundance of NAS should continue to be tracked at the basin level, such as western, central and eastern Lake Erie.

In order to prevent new invasions it is recommended that governments in both countries increase their detection and monitoring efforts, use the best available technologies, and continue to develop improved technologies for prevention, detection, and monitoring.
Harmonized regulatory standards, consistent and shared techniques are also advised. Prevention needs to focus on the linkages between the source of NAS and their vectors. With the implementation of more stringent ballast water regulations, remaining vectors will rise in importance, and state, provincial, and federal governments need to develop policies to ensure that these vectors cannot introduce NAS to the lakes. As an example, risk assessments should be conducted to determine what species are sold where and whether they constitute an invasion threat.

References


**Figure 1.** Cumulative number of non-native aquatic species discovered in the Great Lakes basin since 1840.

*Source: NOAA GLANSIS Program, [http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html](http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html)*
Figure 2. Distribution of non-native aquatic species introduced to the Great Lakes by various vectors since 1840.

Source: NOAA GLANSIS Program, [http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html](http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html)
BURROWING MAYFLY (*HEXAGENIA*) DENSITY


SUMMARY: The burrowing mayfly, *Hexagenia*, is important to fish populations and as an indicator to monitor water quality. These mayflies all but disappeared from most nearshore waters of the Great Lakes in the 1950s because of impacts from increased nutrients which came from urban and industrial activities. The increased nutrients triggered a series of events resulting in increased growth of algae, settlement of these plants to bottom substrates, low dissolved oxygen created from decomposition of these plants, and loss of mayflies and other fauna caused by a lack of oxygen in the water.

In western Lake Erie, the location with the best records in the Great Lakes, the mayfly disappeared in 1953, were absent for 40 years, began to recover in the mid-1990s, and have sustained a recovery over the past 15 years. Continued reductions of pollution and monitoring are likely to confirm ‘recovery’ of mayflies in western Lake Erie and other areas of the Great Lakes. Therefore, continued monitoring of *Hexagenia* in suitable habitat is recommended because they are important to fish and reflect the status of water quality.

Importance of *Hexagenia*

*Great Lakes Water Quality Agreement*

*Hexagenia* is relevant to several aspects of the Great Lakes Water Quality Agreement (Agreement). Article II of the 1987 amended Agreement states the purpose of the Agreement is to restore chemical, physical, and biological integrity of the Great Lakes. Excess nutrient input from human activities can cause alterations to water quality which can interfere with beneficial uses. Beneficial uses are listed in Annex 2, Section 1c. of the Agreement are impairments that can be linked to (among other things) excess nutrient
input which has resulted in degraded benthos and (directly and indirectly) fish
populations. The relevance to the impairment of beneficial use degradation of fish
wildlife populations (item iii) is discussed in the next Section (Use By Fishes).

Article III also states that Great Lakes waters should be free of materials (e.g., excess
phytoplankton biomass) that interfere with beneficial uses. Since excess phosphorus
input causes eutrophication, which causes low dissolved oxygen, resulting in harm to
Hexagenia, phosphorus controls linked to the Agreement are relevant. Annex I, Section
3 states phosphorus concentrations should be limited to the extent necessary to prevent
nuisance growths of algae. Annex 3, ‘Control of Phosphorus,’ devotes 6 pages of
detailed programs to minimize phosphorus eutrophication. Burrowing mayflies, such as
Hexagenia, are not only an important prey item for fishes but they are important to the
GLWQA because they are excellent indicators of habitat quality, and loss of fish and
wildlife habitat is beneficial use item #xiv. The relevance to the impairment of habitat
and eutrophication is discussed in the Section, Use of Habitat and Eutrophication
Indicator.

Use by Fish

Hexagenia are known to support large populations of valuable fish species, such as
yellow perch (Perca flavescens), which supported commercial fisheries (Clady and
Hutchinson 1976; Hayward and Margraf 1987). Prior to the early-1950s, Hexagenia was
found in relatively shallow, soft-bottom mesotrophic substrates typical of river mouths,
harbors, and nearshore waters of the Great Lakes (Figure 1). Hexagenia disappeared
from many of these waters in the 1950s, and their use as a high-energy source of food to
fishes was eliminated (Britt 1955; Schloesser et al. 2000; Cavaletto et al. 2003).
For instance, in Lake Erie in 1947 and 1948, Daiber (1952) found mayfly nymphs were an important component of fish diets and occurred in 67% of all fishes. However, by 1983 no mayflies were found in Lake Erie fish diets (Hayward and Margraf 1987).

Use as Habitat and Eutrophication Indicator

Burrowing mayflies, such as *Hexagenia*, are not only an important prey item for fishes but they are important to the Agreement because they are excellent indicators of habitat quality and eutrophication. Mayflies are sensitive to industrial and organic pollution, especially mesotrophic water/substrate conditions (Britt 1955; Fremling 1964; Hiltunen and Schloesser 1983; Rasmussen 1988; Schloesser 1988; Reynoldson et al. 1989; Edsall et al. 1991).

The two main characteristics that makes *Hexagenia* a good and useful bio-indicator of eutrophication and nearshore habitat are that; (1) *Hexagenia* is sensitive to low concentrations of dissolved oxygen (DO) typical of eutrophic waters and (2) *Hexagenia* prefer to inhabit soft-depositional substrates in nearshore areas where soft sediments are deposited before ultimately being transported to open waters of the Great Lakes (Britt 1955; Erickson 1963; Fremling 1964; Fremling and Johnson 1990). *Hexagenia* cannot survive DO concentrations below about 1 mg/L (Eriksen 1963).

Such low DO levels are almost always associated with highly enriched organic substrates and water stratification caused by seasonal-temperature gradients that occur in relatively deep lakes. Low DO in deep stratified waters has a unique and identifiable benthic fauna that allows DO to be used in bio-monitoring (as a SOLEC benthos indicator). However, in nearshore waters, stratification rarely occurs, and it is difficult to monitor because of this ephemeral characteristic. In addition, the benthic fauna used to bio-monitor habitats is less understood and it is relatively expensive to obtain because of variability in abundance and the high numbers of species and individuals present.
The second reason *Hexagenia* is an excellent indicator or habitat is because it inhabits soft-depositional substrates that settle in nearshore waters before being transported to deeper open-lake waters. For this reason, mayflies are believed to have once been abundant in most harbor and river mouths of the Great Lakes prior to the 1950s. Such habitats include many rivers and harbors of the Great Lakes (e.g., AOCs; Figure 1a). In addition, many nearshore waters and interconnecting channels, such as Green Bay (Lake Michigan), Saginaw Bay (Lake Huron), Bay of Quinte (Lake Ontario) in portions of the interconnecting channels, St. Mary’s River, St. Clair River. Lake St. Clair and the Detroit River of the Great Lakes are also believed to have once supported populations of *Hexagenia* (Figure 1b) (SOLEC 2009; Schloesser et al. 2000; unpublished).

Therefore, the sensitivity of *Hexagenia* nymphs to low DO and their overlap in habitat preference to pollutants discharged into watersheds make them an excellent surrogate indicator for measurements of dissolved oxygen and pollutants in nearshore waters where stratification rarely occurs and continuous monitoring of oxygen is impractical.

As a result of the importance of *Hexagenia* to native fishes and their economic value and its sensitivity to eutrophication, mayfly populations also became widely recognized as indicators of environmental health not just in the Great Lakes but in other places in North America and in Europe (Fremling and Johnson 1990 for the Mississippi River; bij de Vaate et al. 1992 for the Netherlands; Krieger et al 2007, Schloesser et al. 2000, and SOLEC 2009 for western Lake Erie). In the Great Lakes region, reestablishment of *Hexagenia* to pre-1953 populations became a management goal for pollution-abatement programs in the late-1980s and became a reality in western Lake Erie in the late 1990s (Reyndolson *et al.* 1989, Ohio Lake Erie Commission 1998).

**Methods**

The most standard method to monitor *Hexagenia* is by collection of nymphs with a Ponar grab which has been shown to be the most efficient and adaptable sampling devices (Schloesser and Nalepa 2002). The Ponar has been found to collect higher densities of
mayflies than the Ekman, Petersen, and Petite Ponar grabs (Schloesser and Nalepa 2002). Higher density collections with the Ponar were attributed to its relatively heavy weight and uniform sides which allows it to sample deeper and wider in the sediments and its screened top which reduces hydraulic shock waves.

Nymphs are the best life stage to monitor because this stage lasts about 23 months, whereas, other stages last about 2 days in the Great Lakes (Schloesser et al. 1984) Hexagenia typically hatch from eggs in August and spend almost two years as nymphs borrowed in the lake bed at depths up to 5 to 10 cm in water depths usually less than 30 m deep. Depth is associated with densities because food supplies may be tied to the photic zone, which may explain why nymphs are primarily found nearshore. Nymphs emerge from the river in late June or early July, swim to the surface of the water, and fly to land. After resting one to three days, the molt to become adults, fly, mate, deposit eggs and die and the life-cycle starts again. Therefore, samples should be taken in April or May before the nymphs leave the substrate (U.S. EPA 2009).

Results and Discussion

Compilation of all available abundance data (1929 to 2009) indicate Hexagenia was: abundant before 1954, absent in 1955, at minimal to non-existent abundance between 1955 and the early-1990s, found at low abundance in 1993, and present at historical abundances between 1993 and 2009 (Figure 2). By 1997, basin-wide densities of nymphs approached pre-1950 levels.

In the early 1990s, coincident with the invasion and colonization by zebra mussels, anecdotal observations of adults along shores indicate Hexagenia began to recolonize several areas of the Great Lakes after absences of half a decade. Two likely factors that may have facilitated Hexagenia recovery are (1) four decades of pollution-abatement programs which has lowered plant production, decomposition, and low DO and, (2) zebra mussel which filter water and remove sediments, phytoplankton, and zooplankton and deposit the material on substrates providing food energy to benthic populations, including
Hexagenia (MacIsaac 1996). However, a sustained recovery of mayflies has only been documented in western Lake Erie (Krieger et al. 2007, Schloesser et al 2000).

Recovery of mayflies in western Lake Erie suggests the basin has returned to a moderately productive and mesotrophic condition. Krieger et al (2007) reported an apparent temporary expansion of nymphs from the western basin of Lake Erie to the south shore of the central basin from 1997 through 2000. However, the near disappearance of nymphs from the south shore in 2001-2004 suggests one or more environmental factors again limited survival of mayfly populations and Krieger et al (2007) speculated predation by round gobies (Negobius melanostomous) may have limited the abundance of, and therefore, our ability to detect, Hexagenia nymphs where they had become established between 1997 and 2000.

Although the sustained recovery of Hexagenia is well documented, there were large fluctuations in mayfly abundance between 1997 and 2009 (Figures 1, 2). It is possible these fluctuations are due to predation by round goby. Another possible cause for large fluctuations may be residual pollution which causes only one stage of the life-cycle of Hexagenia to be impacted (Schloesser and Hiltunen 1984). For example, Bridgeman et al. (2006) found frequency of possible stratification events corresponded to low young-of-the-year mayfly recruitment. Stratification models indicated low DO could be brought on by high temperatures and low wind speed could contribute to hypoxia and reduced mayfly recruitment (Bridgeman et al. 2006).

Recommendations for Future Use of this Indicator
To better track this important ecosystem indicator, Great Lakes managers should collect data from traditional Hexagenia habitats building on studies conducted over the last 20 years (Edsall et al. 2005).

DO levels in suitable habitat should be monitored annually; the EPA Guardian cruises do this in deep waters but this may be impractical in nearshore waters. Therefore, the
density of Hexagenia is a useful surrogate measure of DO using the methods prescribed and a systematic and a regular monitoring regime. Areas where sampling should be added include historic habitats of the Bay of Quinte, Lake Ontario, Presque Isle Bay, Lake Erie, Saginaw Bay, St. Marys River, Lakes Superior and Huron, Green Bay and south shore, Lake Michigan (we have anecdotal reports of all these places once supporting mayflies), and several river mouths. Periodic data collection in these habitats will provide support for ecosystem trend analysis in the future.

References


Figure 1. River mouths and harbors (AOCs) where it is believed habitat would have been suitable for colonization by mayfly nymphs of the genus *Hexagenia* (a) and nearshore areas where *Hexagenia* were known to be abundant prior to 1950s (b) (Schloesser et al. 2000; unpublished).
Figure 2. Density of *Hexagenia* nymphs in western Lake Erie 1929-2009 (Schloesser et al. 2000; unpublished, K. Krieger, Heidelberg College, Tiffin, Ohio).
DIPOREIA

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SUMMARY: The bottom dwelling amphipod (shrimp-like invertebrate) *Diporeia* is a native glacial relic that was once the most abundant bottom-dwelling organism in cold, offshore regions of the Great Lakes. It occurs in the upper few centimeters of sediments and feeds mainly on algal material that freshly settles to the bottom from the water column. In turn, *Diporeia* is readily fed upon by most fish species and thus serves as an important pathway by which energy is cycled through the food web. *Diporeia* populations began to decline in Lakes Michigan, Huron, Ontario, and Erie in the early 1990s just a few years after zebra and quagga mussels became established. Presently, it is completely gone from large areas in each of these lakes. The loss of *Diporeia* has affected the distribution, abundance, growth, and condition of fish species that relied on *Diporeia* as a food resource, including commercially important species such as lake whitefish.

Significance of this indicator

Because of its abundance, wide distribution, and important role in the food web, the benthic amphipod *Diporeia* was considered to be a keystone species in the Great Lakes (Nalepa et al. 2006) and a good indicator of a healthy ecosystem. Overall, *Diporeia* abundances were a good indicator of lake productivity, and abundances were often lower in nearshore areas subject to pollution (Mozley and Howmiller 1977). *Diporeia* was readily available as prey for many species of Great Lakes fish, and was rich in calories because of a high lipid content (Gardner et al. 1985). Historical surveys showed that changes in abundances were mostly related to changes in nutrient loads, pelagic productivity, and predation (Robertson and Alley 1966, Nalepa 1987). Long-term trends of *Diporeia* abundances were influenced by greater abundances of phytoplankton and hence greater amounts of food settling to the bottom. Short term changes in abundances
have mostly been attributed to shifts in abundances of fish predators Johnson and McNeil 1986). While some natural variation in population abundances occurred prior to the early 1990s, the large-scale decline and total disappearance of Diporeia across lakes after the early 1990s is totally unprecedented. Diporeia populations have declined to levels that make it no longer relevant as a food web component and insignificant as a food source for fish (Mohr and Nalepa 2005, Nalepa et al. 2009).

Diporeia are a keystone species and important in maintaining the biological integrity of the Great Lakes because they are a source of food for many fish species and cycle energy to the preyfish community, and some commercial species (lake whitefish). Furthermore, decreased abundance of Diporeia impacts some of the Beneficial uses, as listed in Annex 2, Section 1c. of the Agreement, in particular item iii. whereby Diporiea declines cause degradation of fish and wildlife populations.

Methods

Methods for sampling Diporeia and estimating abundances are generally similar across the Great Lakes. Samples of bottom substrates are collected with a Ponar grab and the contents are are washed through a screen (or net mesh) with 0.5 mm openings. Since the minimum size of young Diporeia is about 1 mm, all organisms living in the substrate are retained in the screen. Organisms are immediately preserved, and later counted and identified. Densities are reported as number per square meter. Nalepa et al. (2009) provides additional details about the methods used for sampling and analyzing abundances.

Results and Trend Analysis Since 1987

Beginning in the early 1990s, Diporeia populations declined dramatically in Lakes Michigan (Nalepa et al. 2009), Huron (Nalepa et al. 2007) and Ontario (Watkins et al. 2007), and appear to be disappeared from Lake Erie (Barbiero et al. 2011). Declines first occurred in shallow, nearshore areas and then extended to deep, offshore areas
(Nalepa et al. 2009). Presently, populations have almost entirely disappeared from shallow (< 90 m) sites in lakes Ontario, Huron, and Michigan (Barbiero et al 2011). Populations in Lake Superior are still abundant with no directional trends apparent, although substantial interannual variability is evident (Barbiero et al. 2011). The loss of *Diporeia* became apparent soon after zebra and quagga mussels became established. A common hypothesis is that these non-native mussels are out-competing *Diporeia* for available food, but individual *Diporeia* shows no physiological signs of starvation (Nalepa et al. 2006).

Changes in densities over time in each of the lakes illustrate the extent *Diporeia* declines. At depths of 30-90 m, mean densities in Lake Michigan declined from 6,300/m² in 1994/95 to 49/m² in 2010, densities in Lake Ontario declined from 5,167/m² in 1994 to 7/m² in 2008, and densities in Lake Huron declined from 1,397/m² in 2000 to 93/m² in 2007 (Figure 1). Despite annual sampling from 1997-2010, Barbiero et al (2011) did not find any *Diporeia* in Lake Erie, confirming that *Diporeia* is now effectively absent from that lake.

In mainly offshore sites (> 90 m), interannual changes in Diporeia densities in Lake Huron and Lake Michigan have been somewhat similar, with periods of rapid decline (1997–2000, 2003–2004) alternating with periods of little change or even increase (2001–2002, 2005–2009) (Barbiero et al. 2011). In Lake Michigan, populations were still found at six of seven deep sites in 2009, with densities ranging from 57 to 1409/m². Spatial patterns of decline in Lake Michigan between the mid-1990s and 2010 are given in Figure 2.

**Discussion**
The decline of Diporeia in all the Great Lakes except Lake Superior has had an adverse impact on the fish community. For instance, coincident with the loss of Diporeia, the condition, energy density, and growth of lake whitefish has declined in Lakes Michigan, Huron, and Ontario (Mohr and Nalepa 2005). Lake whitefish is an important commercial species that historically fed heavily on Diporeia. Other fish species such as alewife, sculpin, and bloater have also been affected (Madenjian et al. 2006, Hondorp et al. 2005). These fish serve as prey for the larger piscivores such as salmon and trout.

Besides having a direct impact on fish, the loss of Diporeia may also have an indirect affect on other food web components as fish seek alternate food. Recent studies have shown that pelagic invertebrates fed upon by fish such as zooplankton and the opossum shrimp Mysis are also declining (Barbiero et al. 2009, Pothoven et al. 2001). Such declines may also be a result of lowered food availability from mussel filtering activities. Nonetheless, the loss of a keystone species in the food web such as Diporeia will likely have cascading effects on other components.

Discussion of Future Use of this Indicator

While the decline of Diporeia is temporally coincident with the establishment, spread, and increase of zebra and quagga mussels in Lakes Michigan, Huron, Ontario, and Erie, the exact reason for the negative response of Diporeia to mussels is not entirely clear. Continued monitoring of Diporeia populations will build upon existing information and provide further insights into potential reasons for the decline. While quagga mussels are still increasing in many offshore areas, at some point populations will stabilize or decline. When this occurs, it would be important to document the response of Diporeia and assess the potential for recovery.

Several federal agencies are currently monitoring populations of both Diporeia and mussels, and combined these data sets provide broad spatial (lake-wide) and temporal (annual) coverage to accurately assess relative trends. Such broad coverage is necessary since the loss of Diporeia has occurred at different rates in different areas of the lakes.
Such temporal and spatial variability may also be apparent if the population ever recovers.

Finally, the loss of *Diporeia* and the coincident increase in mussels means that future food web models and energy-flow paradigms must account for a benthic community that no longer transfers energy as efficiently to other food web components, and thus no longer able to support the level of fish resources found in the past.

References


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Figure 1. Mean density (No. per m²) of Diporeia spp. at 30-90 m in Lakes Michigan, Ontario, and Huron. Data derived from Nalepa et al. 2007, 2008, Watkins et al. 2007, Nalepa unpublished, Lozano unpublished).
Figure 2. Density (No. per m² x 10^3) of *Diporeia* spp. in Lake Michigan in 1994/95, 2000, 2005, and 2010. Small red crosses indicate sampling sites. (Nalepa et al. 2008, Nalepa unpublished)
LAKE STURGEON ABUNDANCE

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SUMMARY: Lake sturgeon abundance, which fell to 1% of historical levels in the mid-1950, is beginning to increase in some locations within the Great Lakes. Since the mid-1980s, there has been renewed spawning success in several traditional habitats, including the Detroit River where spawning had not taken place in decades. This is likely due to water quality improvements and restoration of habitat or creation of artificial habitat. However, the species is still listed as threatened or endangered throughout much of the Great Lakes Basin making the recovery uncertain. Continued monitoring, habitat restoration and water quality improvements will be necessary to the survival of the species in the Basin.

Importance of this indicator in measuring progress toward meeting Great Lakes Water Quality Agreement objectives.

Lake sturgeon abundance is an important indicator of the chemical and biological integrity of the Great Lakes for several reasons. First, lake sturgeon, especially first year juveniles, are of the few species sensitive to 3-trifluoromethyl-4-nitrophenol (TFM) treatments (Johnson et al. 1999), which are used to suppress sea lamprey spawning. As adults, due to their great physical strength and numerous sensory receptors the head and on the barbels, sturgeon detect and avoid unpleasant stimuli before other less sensory-equipped species such as Catostomids, or Cyprinids, so their absence can be used as an indicator of chemical contamination. Lake sturgeon juveniles are respond strongly chemical exposure (usually dying).
Lake sturgeons are also sensitive to low dissolved oxygen (DO) levels. As benthic-feeding fish, oxygen concentrations, metals, and organic debris will be more concentrated than higher in the water column. They are known to avoid perturbed systems and will not cross areas of low oxygen (Mike Friday, OMNR, per. comm.).

Second, they accumulate contaminants. Sturgeons live to great age, often over 100 years (Harkness and Dymond 1961) and over this long lifespan accumulate contaminants.

Third, sea lamprey are known to leave scars on sturgeon and these may be an indicator of presence/absence or even concentration of lamprey in some systems (Patrick et al. 2007).

Fourth, their increased presence in nearshore waters can indicate health of systems and their ability to return to natal streams indicate good river health and connectivity and conserve imprinting cues. The lake sturgeon utilizes a diverse habitat throughout its life. Life begins for sturgeon as an egg in the clean, clear upper reaches of streams and rivers. As hatched larvae they then drift downstream to find supportive refuge and feeding habitat in mouth regions of rivers. Some stay within a river system while others move into open nearshore Great Lake habitats. Rivers with unperturbed, large wetlands are known to support the largest stocks of sturgeon, so sturgeon abundance can indicate wetland health as well (Cookman 2011). Finally, for 15-20 years the fish move freely about the Great Lakes before returning to spawn in natal streams. They spend time in shallow water as well as deep water environments.

Methods for collection and analysis of trend data.

Although there are few long term data bases on lake sturgeon in the Great Lakes and few long-term consistent surveys to determine trends in populations, data collection has increased in the last three decades. Data on incidental catches are obtained from commercial catch, Department of Natural Resources and U.S. Fish and Wildlife surveys, and tribal reports. Data exist for the Sturgeon River population in the Upper Peninsula of Michigan (Auer and Baker 2002), for Black Lake stock (Crossman et al. 2009), Manistee stock (Mann et al. 2011) and St. Clair/Lake Erie stock (Thomas and Haas 1999, 2004) in
lower Michigan. Commercial or sport harvest affects populations on all of these waters but the Sturgeon and Manistee Rivers.

A variety of methods have been used to assess populations in individual streams. In a study of Wisconsin rivers (Elliott and Gunderson 2008), methods included use of electrofishing gear to collect adult lake sturgeon below the lowermost dams; dip nets to collect lake sturgeon below the first dam on two rivers during the peak of spawning; use of large-mesh gill net at river mouths, in deep pools within rivers, and below the lowermost dams on rivers; use of setlines baited with chunks of white sucker (*Catostomus commersoni*) and round goby (*Neogobius melanostomus*) flesh; and visual observations of lake sturgeon on spawning grounds.

Results – Trends since 1987

SOLEC (2009) reported that Sturgeon reproduction continues in at least 10 of 22 historical tributary locations in Lake Superior, where population are believed highest among the five Great Lakes. The Lake Michigan population was estimated at less than 10,000, but the abundance of spawners appears to have increased in several tributaries. No trend was evident for Lakes Huron and Erie. Incidental catch in research nets on Lake Ontario since 1997 may indicate an improvement in the population. In the Sturgeon River, the annual spawning run increased by approximately 100 adults in the mid-1980s to a total of 350 to 400 in 2004 (Auer 1996a and 1996b).

In the absence of statistically valid sampling and data, studies of specific spawning locations and subpopulations contribute to understanding of trends. In the St. Clair River, based on age of sturgeon captured, researchers found consistent recruitment during the 1970s and 1980s, but low recruitment prior to 1973 and after 1994 (Thomas and Haas 2004). The researchers documented an area of consistently high lake sturgeon density in Lake St. Clair. Estimated abundance of lake sturgeon in a 255-ha section of that area of the lake at over 29,000 fish in 1999 and about 5,000 fish in 2000.
Populations in the Peshtigo River, Wisconsin, part of the Lake Michigan drainage basin grew over a 20-year period (U.S. Fish and Wildlife Service 2011). In another study, the vast majority of sturgeon in the Peshtigo River were under 20 years of age, although a partial cause is believed to be high adult mortality from a hydroelectric facility (Elliott and Gunderman 2008). A study suggested populations in the river could be further increased through management actions designed to reduce large early life stage mortality (Caroffino et al 2010).

Beginning in 2000, in the Lake Michigan Basin, production of sturgeon larvae has been documented in the lower Fox, Oconto, Peshtigo, Menominee, Manistee, Grand, and Muskegon Rivers, and fall young-of-the-year (YOY) have been documented in the Menominee, Manistee, Oconto, and Peshtigo Rivers (Elliott 2008).

In 2009, spawning success was reported on a constructed reef near Fighting Island in the Detroit River, and there has been continued, albeit low number spawning in the river for the first time since approximately 1960 (U.S. Fish and Wildlife Service 2009).

Discussion

While recent spawning success in the Detroit River and other traditional spawning habit is encouraging, recovery cannot be assumed. Some data are beginning to suggest that timing of peak spring flood flows in Great Lake tributary rivers may be changing the spawning time and possible success of hatch and larval dispersal. Flood flow trends in upper Michigan’s Sturgeon River have become unpredictable and vary widely within the last 20 years than in the previous 60 years (Auer in press). Although some efforts have begun to rehabilitate stocks in the Great Lakes region, more variable climate patterns may add additional challenges to recovery efforts. Sustained, long-term monitoring of Great Lakes lake sturgeon populations is critical to support adaptive management of the species in a time of change, and funding for such monitoring should be a priority.
An additional impediment to sturgeon recovery is the presence of dams on many spawning streams. For example, on the lower Menominee River, separating upper Michigan and Wisconsin, five hydro dams prevent lake sturgeon from migrating up the river from Lake Michigan to get to their prime spawning and rearing habitat. The loss of habitat has caused a drastic decline in the number of lake sturgeon in Lake Michigan, from an estimated two million at their peak to about 3,000 sturgeon today. The U.S. Fish and Wildlife Service has received a $3 million grant from the Great Lakes Restoration Initiative to construct fish passage at the lower two dams, but dams remain a impediment on many other spawning streams.

Future Use of This Indicator

Population measurements are needed from a greater and geographically distributed set of locations, particularly spawning streams, where sampling is most efficient. Juvenile populations are an important sampling target. As an iconic Great Lakes fish species, lake sturgeon recovery is particularly useful as a measure of the biological integrity of the Great Lakes, underscoring the value of this indicator.

References


LAKE TROUT ABUNDANCE

AUTHOR: Dave Dempsey, IJC staff

REVIEWER: John Dettmers, Great Lakes Fishery Commission; Vic Serveiss, IJC.

SUMMARY: Since the mid 1980s, populations in four of the five Great Lakes have been stable overall, largely because of stocking. But self-sustaining populations of lake trout have been restored in Lake Superior since the mid-1980s. Significant natural reproduction is now evident across most of Lake Huron. Low reproduction rates are evident in Lakes Ontario, and little reproduction has been documented for Lakes Michigan, and Erie. Major impediments are thought to be excessive adult mortality due to sea lamprey predation, fishing predation on fry by non-native alewives, as well as thiamine deficiency induced by alewives resulting in early mortality syndrome (EMS).

Importance of this indicator in measuring progress towards achieving Great Lakes Water Quality Agreement (GLWQA) objectives

Article II of the Agreement states its purpose as “to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem.” As a native top predator, the health and robustness of lake trout populations is a key component of the ecosystem’s biological integrity.

Article III (a) of the Agreement establishes a general objective that the Great Lakes Basin ecosystem will be “free from substances that directly or indirectly enter the waters as a result of human activity and will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life or waterfowl.” To the extent that contaminants are limiting reproductive success of lake trout, this objective has not yet been achieved.
Specific Objectives Supplement to Annex 1, Subsection 3(a) of the Agreement, Lake Ecosystem Objectives, holds that Lake Superior “should be maintained as a balanced and stable oligotrophic ecosystem with lake trout as the top aquatic predator…”

Methods for collection and analysis of trend data

The most reliable trend data for lake trout is compiled for the Great Lakes Fishery Commission from individual reports submitted by state, federal, tribal and provincial agencies in Technical Committees.

Methodologies vary by jurisdiction and lake but are generally based on relative abundance in gill-net surveys of the population at large or some segment of interest. Lake Superior U.S. waters relative abundance is measured by the number of fish caught per kilometer of net per night. For Lake Michigan, the metric is fish per 1,000 feet of net set for one-night; for Lake Huron U.S. waters and Lake Erie, fish per kilometer of net; and for Lake Ontario, the number of females greater than equal to 4.0 kg per kilometer of net (Bronte et al 2008, SOLEC 2009).

Fishery managers have set target yields for each of the Great Lakes that approximate historical levels of harvest, or levels adjusted to accommodate stocked non-native predators such as Coho and Chinook salmon. These yields are based on what is believed to be populations that can be supported by each lake. Measured abundance is then compared with the targets.

Results – Trends since 1987

Lake trout population trends have differed among the lakes. Lake Superior and Lake Huron populations have fluctuated year by year but remained at levels comparable to those of the mid-1980s. Lake Superior populations are fully restored based on comparison of current to historical measures of abundance. Lake Huron populations are below target, but increased reproduction has been observed since 2004 (Riley et al 2007).
Lake Michigan populations have been stable since the late 1990s but are far below targets set by the Great Lakes Fishery Commission through its lake committees. The same is true for Lake Erie during 1992-2007. Lake Ontario populations fell steeply between 1997 and 2007 to below target levels.

Discussion

Lake trout were historically the top salmonine predator in Lakes Superior, Huron, Erie and Michigan, and shared this position with Atlantic salmon in Lake Ontario. Before European settlement, they were a key source of sustenance for Native Americans. Ecologically, the lake trout represents the endemic salmonine atop the food chain, and have been "keystone predator" in control of the Great Lakes ecosystem. Lake trout is a long-lived species with individuals living over 40 years in lightly exploited populations (Schram and Fabrizio 1998). For a variety of reasons, then, lake trout are an excellent indicator of ecosystem health (Bronte et al (b) 2008).

Between the early 1940s and the late 1950s, lake trout were virtually extirpated from Lakes Ontario, Erie, and Michigan, most of Lake Huron, and ultimately from most nearshore waters of Lake Superior (Hansen 2000). Small remnant nearshore populations and most offshore populations survived in Lake Superior. Sea lamprey predation combined with overfishing was the main cause of the steep decline (Wilberg et al 2003). With the advent of successful and sustained sea lamprey control programs and limited fishing, and annual stocking programs, lake trout numbers began to increase in the 1960s. Recovery was earliest in Lake Superior because of the existence of remnant stocks. Lake trout are now self-sustaining and stocking for rehabilitation has been discontinued. Lake Superior provides high quality habitat for lake trout because of its cold water temperatures, undisturbed physical habitat, low contaminant levels, and few invasive species. Lake trout in all other Great Lakes face pressures from high adult and fry mortality, sea lamprey predation, habitat alteration from quagga mussels and other invasive species, and thiamine deficiency.
Thiamine deficiency is hypothesized to be induced when lake trout ingest non-native alewives, a species harboring high thiaminase activity, and has been linked to egg and fry mortality or EMS in salmonines (Brown et al 2005). Increases in lake trout reproduction in Lake Huron after 2004 are correlated with a collapse in alewife stocks, which may be consistent with the hypothesis; however there was a simultaneous increase in parental stocks (egg deposition) that makes conclusions difficult. Regardless, management policies supporting a more diverse forage base will be necessary to restore self-sustaining lake trout populations.

Persistent bioaccumulative toxins known as halogenated aromatic hydrocarbons, particularly dioxins, have been implicated as potentially one of many factors in low lake trout reproduction rates in the lower Great Lakes in a retrospective risk assessment for the second half of the 20th Century (Tillitt et al 2005). Although levels of these contaminants declined before 1987, there is no longer a clear up or down trend.

References


BEACH CLOSINGS AND ADVISORIES

AUTHOR: Dave Dempsey, IJC

REVIEWER: Vic Serveiss, IJC

SUMMARY: The number of Great Lakes beach closings and advisories has been relatively stable over the last decade. The proportion of beaches closed more than 10% of the time is 9% for U.S. beaches and 42% for Ontario beaches. Disease outbreaks related to swimming at Great Lakes beaches are likely significantly under-reported. Further refinement of testing methods, controls on major pollution sources contributing to beach closings such as stormwater runoff and sewage overflows, and establishment of and data collection for a central swimming-related disease outbreak registry are recommended.

Importance of this indicator in measuring progress towards achieving Great Lakes Water Quality Agreement (GLWQA) objectives

A specific objective of the Agreement is that “Waters used for body contact recreation activities should be substantially free from bacteria, fungi, or viruses that may produce enteric disorders or eye, ear, nose, throat and skin infections or other human diseases and infections.”

Biological integrity is not achieved when organisms impair water quality such that closings and advisories are implemented. Closings and advisories for recreation on Great Lakes beaches are an indicator of local water quality and help shape public perceptions of the health of the Great Lakes ecosystem and may be linked to human health. A study has confirmed an association between swimming at two Great Lakes beaches and gastroenteritis (Wade et al 2006, Wade et al 2008).
The number of beach closings and postings is a rough measure of trends in water quality and risks to public health as jurisdictions differ in criteria for closing and posting beaches (IJC 2009). Concerns also exist about the use of E. coli as the standard indicator of potential health risks. Until standardized measures are developed and data generated under them reported and compiled, this indicator serves only as a surrogate for the health of public bathing beaches and associated water quality.

Methods
SOLEC 2009 used data collected and reported by U.S. local and state health agencies, and from the Ontario Ministry of the Environment, which collected data from local public health units. Due to implementation of the U.S. BEACH Act, the number of Great Lakes beaches covered by reporting rose from 303 in 1998 to 1445 in 2007. An increased but unspecified number of Ontario beaches that reported data in later years were analyzed by SOLEC.

Health-related beach closing days used as measures by SOLEC are usually a result of the detected presence of E. coli in beach water, which can serve as an indicator of the presence of pathogens that can cause health effects through body contact.

Results
For the period of time for which SOLEC has reported beach closing – roughly 1998-2007 – the average number of days that Great Lakes beaches were closed and advisories were issued has remained nearly unchanged, but with significant year-to-year fluctuations (SOLEC 2009). To a large extent, these fluctuations are the result of variations in precipitation and temperature from one swimming season to the next.

The percentage of U.S. beaches open the entire season was roughly the same during the period 1998-2007, averaging 74%. The Ontario average was 49%.

The percentage of U.S. beaches closed more than 10% of the time ranged from 12% in 1998-1999 to 9% in 2006-2007. The comparable Ontario figure for was 54% in earlier
years and 42% in 2006-2007. Among public health units reporting in Ontario, the leading beach pollution source was wildlife (Fletcher 2010).

The Natural Resources Defense Council, a U.S. nongovernmental organization, issues an annual report on beach closures using public data. According to the organization’s 2011 Testing the Waters report, U.S. Great Lakes beaches had 3,766 days of closings and advisories and 6 extended (361 days total) and 1 permanent (110 days total) closings and advisories. The number of days of closings and advisories was 14% higher in 2010 than 2009, possibly the result of changes in weather conditions. In addition to the 84% of closings and advisories that resulted from e. coli detection, 7% of beaches were closed as a precautionary measure because of stormwater runoff and 4% in response to known pollution events (NRDC 2011). Data have been collected by NRDC only since the 2003 swimming season and not consistently been presented for Great Lakes beaches, so it is not possible to discern long-term trends.

Discussion

One limitation of the SOLEC and NRDC data is that year-to-year fluctuations are largely attributable to the number and intensity of rainfall events. Heavy rainfall is associated with bacteriological contamination from combined sewage overflows and runoff from urban and agricultural lands, among other sources (IJC 2009).

Another limitation in the use of beach closings and advisories as both an indicator and a public health protection measure is the delay between sample collection and analysis (IJC 2009). Until recently, standard analysis methods have resulted in a 24-hour waiting period after sample collection until public advice is offered, when appropriate. This means that beach water quality may have returned to acceptable levels at the time of beach closing, and can make it difficult to determine the source of bacteriological contamination. Finally, the increase in reporting of more beaches is year is beneficial, the expansion of the monitored beaches over time, reduces the validity of year-to-year comparisons.
Since most beach closures and postings caused by human activities appear to be related to combined sewage overflows and urban and agricultural runoff, better control of these sources is necessary to reduce impacts on recreation. The possibility that a significant proportion of closures and advisories is related to wildlife should be further explored.

The number of closings and advisories associated with Great Lakes bathing beaches does not yield useful primary trend information on the health of the Great Lakes Basin ecosystem. But its importance to public health and public perception of ecosystem health supports its future use as an indicator, with qualifications. Great Lakes jurisdictions are now attempting to standardize data assessment and reporting.

Human health impacts have been associated with swimming at Great Lakes beaches in two studies (Wade et al 2006, Wade et al 2008), and therefore, better data on swimming-related disease outbreaks should be collected and reported. In Wade et al 2006, beachgoers were asked about swimming and other beach activities and 10-12 days later were asked about the occurrence of gastroenteritis symptoms. Researchers tested water samples for Enterococcus and Bacteroides species using the quantitative polymerase chain reaction (PCR) method and observed positive trends between increased gastroenteritis and Enterococcus at the Lake Michigan beach and a positive trend for Enterococcus at the Lake Erie beach.

In a second study, researchers completed 21,015 interviews of beachgoers at four Great Lakes beaches and tested 1359 water samples (Wade 2008). Enterococcus QPCR cell equivalents (CEs) were positively associated with swimming-associated gastroenteritis. The association between GI illness and QPCR CE was stronger among children aged 10 years and below. Nonenteric illnesses were not consistently associated with Enterococcus exposure, although rash and earache occurred more frequently among swimmers.

Future Use of This Indicator

To improve the indicator, governments should:

- Develop and report on additional measures of public health as affected by use
of Great Lakes Basin waters for swimming. In particular, a central Great Lakes registry should be established for closings, advisories and waterborne disease resulting from swimming at public beaches. Disease outbreaks related to use of recreational waters should be reported to the registry, investigations of the cause of outbreaks should be conducted, and reports on these outbreaks should be made available to the public and to researchers.

As of 2004, governmental agencies had reported only one recreational water-related closure that resulted in human health impacts from Great Lakes waters since 1978 (Yoder et al 2004). It took place among persons swimming at a Wisconsin state park beach in 2002. Attributed to S. sonnei and Cryptosporidium, as well as norovirus, the incident resulted in 44 primary and 22 secondary cases of gastroenteritis. In light of the associations documented between gastroenteritis and swimming at other Great Lakes beaches in the Yoder studies, there is likely significant under-reporting of Great Lakes beach-related disease outbreaks. Without more consistent data collection and centralized reporting, it is difficult to determine the exact impact of Great Lakes beach quality on human health.

- As recommended by IJC, develop binational, standardized basin-wide surveillance and monitoring protocols in conjunction with preventive risk management strategies, and adopt binational standardized criteria for beach postings.
- Continue to improve monitoring methods to support real-time assessments of beach water quality and support timely closings and advisories to protect beach users. In Wade et al 2008, researchers recommended the quantitative polymerase chain reaction (QPCR) as a faster method to assess recreational water quality and predict swimming-associated illnesses than the E. coli measurement.

References


VII. CONCLUSION AND RECOMMENDATIONS

Using Indicators to Evaluate Great Lakes Progress and Problems

The Commission has consistently emphasized the need for a core set of Great Lakes indicators, and believes there is ample literature on environmental indicators to select a set of them to report on progress made toward Agreement objectives. In this closing chapter of the report we review literature on indicators to measure progress restoring and maintaining Great Lakes Water Quality. Source include a report issued by the Commission in partnership with the Great Lakes Fishery Commission, which was developed before 1987; several other Commission reports; and various other US EPA, Environment Canada, and international literature. The compilation of recent literature on SOLEC is treated separately. This section concludes with recommendations based partly on the literature review and partly on other Commission viewpoints.

Review of 1985 IJC Partnership with the Great Lakes Fishery Commission (GLFC)

In 1985, an IJC-Great Lakes Fishery Commission work group on indicators of ecosystem quality for the Great Lakes observed:

“A prerequisite for appropriate application of an ecosystem approach is the need to determine the current state of health of the environment and its contained resources and to identify the areas where the ecosystem may be unduly stressed by cultural interventions.” (IJC/GLFC 1985).

In order to develop this concept, the workgroup advocated using biological indicators and used lake trout (Pontoporeia hoyi) as an example of a potential bioindicator of the health of the Great Lakes ecosystem. The workgroup also developed a general set of criteria for selecting indicators for biological organisms. They should have broad distribution; be indigenous and integrative in nature; have well documented and quantified niche dimensions; will exhibit a graded response to human intervention; will serve as a diagnostic tool for specific stresses; will not overlap other indicators markedly with
regard to their indicative capabilities; will have historic, preferably quantified
information pertaining to their abundance and other critical factors; may be easily
collected; will maintain itself through natural reproduction; may be useful in laboratory
experiments; responds to stresses in a manner that will both be identifiable and
quantifiable; and will be important to humans and readily recognized by them.

Review of Selected Commission Literature

The Commission’s next major effort was developed by a task force assembled by the
Commission. The Indicators Evaluation Task Force discussed the purpose of indicators
in their report (IJC, 1996):

“Environmental indicators communicate information about the environment and
about the human activities that affect it. When communicated effectively, the indicator
highlights problems and draws attention to the effectiveness of current policies. The
target audiences are the public and the decisionmakers (i.e. governments). To command
their attention, indicators must be relevant, and they must communicate value. Choosing
an indicator reflects a set of values that is perceived as being important. Examples of
effective indicators for certain purposes are the Dow Jones industrial average, the gross
national product, incident solar radiation, and pollen count.”

The Indicators Evaluation Task Force proposed a framework for indicators based on nine
desired environmental outcomes, with many related to Annex 2, which discusses
Remedial Action Plans (RAPs) and Lakewide Area Management Plans (LAMPs) (IJC
1996).

Given the Commission’s continued inability to acquire environmental data from the
governments, in 2000, the Commission’s Indicators Implementation Task Force
recommended that the governments focus effort on developing indicators to assess
progress towards three desired public outcomes: Drinkability, Swimmability, and
Fishability (fish safe for human consumption) (IJC 2000a).
The Implementation Task Force report (IJC 2000a) recognized it would take time to develop a useful suite of indicators and recommended that the Parties (Federal governments, states, and provinces) start reporting on indicators for the three desired outcomes at the SOLEC 2000 conference. The report further recommended that indicators related to persistent toxic substances and three specific indicators related to physical integrity should be reported on in 2002. The task force noted that indicators can help the public easily understand the environmental condition of places they care about. One of the Task Force’s guiding principles was that indicators should be based on terms easily understood by the public.

“Develop reliable data and accessible information to support indicators for the three desired outcomes of Drinkability, Swimmability and Fishability (fish that are safe to eat). This action should have priority status in the indicator process.”

“Expand indicator development and reporting on additional desired outcomes only where resources are sufficient to access scientifically valid and reliable data.”

In the same report, the Commission observed that the usefulness of SOLEC’s indicator of fishability was complicated by the lack of a uniform protocol for determining fish consumption advisories. Such related collaboration is quite a challenge, because each state and province issues its own fish consumption advisories to cover not just the Great Lakes but all the waters in their respective jurisdictions. The Commission also noted that the usefulness of SOLEC’s drinkability indicator was complicated by the condition of source, or raw water, which was not reflected in the indicator at that time (and was addressed only in part in 2009). The swimmability indicator is also similarly complicated and there is a lack of standard testing protocols making it difficult to obtain a statistically valid sample of beaches. The Commission also pointed out that many of the roughly 80 SOLEC indicators are not pertinent to the Agreement, and SOLEC excludes endpoints or milestones, which are essential for determining success (IJC 2000a).
The Commission summarized some of the recommendations made in the Task Force Report in its 10th Biennial Report (IJC 2000b). Also, in the 10th Biennial the Commission reiterated the general need for indicators:

“Monitoring and surveillance programs have logistic and economic constraints. These programs cannot measure all the parameters desired to assess progress under the Agreement. Indicators offer a means of tracking progress and provide integration of data”.

The Commission discussed indicators again in its 11th Biennial Report on Water Quality (IJC 2002) which called for a refined framework for developing indicators and issued recommendations to the governments that were similar to those in the Implementation Task Force Report:

The need for indicators and progress reports that measure progress towards objectives was also discussed in the Commission’s 2006 Advice to Governments Report on their review of the Great Lakes Water Quality Agreement (IJC 2006). One of the recommendations was:

“Make provisions for clear and achievable goals, accountability, binational coordination, program integration, adaptive management, data management, substantive reporting, research, monitoring, and surveillance.

Review of Selected literature Outside the Commission

There is abundant ecological indicator literature. The U.S. Environmental Protection Agency’s (U.S. EPA 2011) report on vulnerability identified a list of 23 studies from government, academia, and consultants that they used as core literature for identifying indicators. Indicators have been defined and used to report generally on the condition of the overall environment (U.S. EPA 2008) or for more specific applications such as providing evidence for climate change (U.S. EPA 2010).
U.S. EPA (2000) developed 15 criteria (called guidelines) for evaluating ecological indicators and illustrated how these technical guidelines can be used to ensure the reliability of ecological indicators for their intended applications.

The U.S. General Accounting Office (2003) recommended that EPA in coordination with Canadian officials develop environmental indicators and a monitoring system for the Great Lakes that could be used to measure overall restoration progress and requires that these indicators be used to evaluate, prioritize, and make funding decision on the merits of alternative restoration projects.

Environment Canada’s (EC, 2011) Canadian Environmental Sustainability Indicators (CESI) initiative reports on environmental indicators that track long-term trends for issues of key concern to Canadians. These indicators track air quality, water quality, progress in protecting natural areas, habitat, wildlife, and biological resources across Canada.

On an international level, the Organization for Economic Co-operation and Development (OECD, 2003) carries out environmental performance reviews, refines a set of core environmental indicators, and contributes to development of sustainable development indicators. As part of the development of improved indicators, the OECD and others have developed criteria for evaluating ecological indicators. OECD (2003) identified 12 criteria based on policy relevance and utility of users, analytical soundness, and measurability.

Review of 2009 State of the Lake Ecosystem Conference (SOLEC)

Since SOLEC was established to provide the data needed for the Commission’s progress reports and has made strides towards this goal. SOLEC (2009) identified about 80 indicators that it hoped to use to evaluate the health of the Great Lakes Basin Ecosystem. SOLEC (2009) affirmed:
“Knowing the environmental condition of the Great Lakes can allow for effective decision-making by all Great Lakes stakeholders.” The report added that the indicators “provide independent, science-based reporting on the state of the health of the Great Lakes basin ecosystem.”

Further, the report declared, “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.”

While constructing this report, the Commission reviewed the 2009 SOLEC indicators to see to what degree they can be used to evaluate progress since 1987 and to see how well they address the Commission’s Task Force recommendations to address swimmability, fishability and drinkability. The Commission found only several of the 80 indicators were useful for evaluating progress since 1987. Several of the sources for this report came from outside of SOLEC. The Commission continues to be concerned that excessive effort is expended on too many indicators that have limited utility. Selecting and reporting on a smaller and continued set of core indicators should be the priority. The core set should include some with historical data back to 1987, some on the nearshore and some on human health. These indicators and a report assessing progress based on those indicators should be provided by the governments in the next reporting period.

The Commission found that some SOLEC indicators do provide useful information on “swimmability.” However, the existing SOLEC indicator on whole fish should not be used to report on fish consumption; those data were obtained from another source outside of SOLEC. The Commission also recognizes that treated drinking water from the Great Lakes is overwhelmingly drinkable. Indicator data to report on treated drinking water are
not sufficient to support analysis of the “drinkability” of Great Lakes waters and trends. Data associated with these uses of Great Lakes waters are also not uniformly collected and centrally reported. Standards for acceptability of waters for these uses vary among jurisdictions. There is also uncertainty whether appropriate parameters are measured.

In 2010, an Independent Expert Panel convened by Environment Canada and U.S. EPA (EC and EPA 2010) released a report assessing and evaluating the indicators used by SOLEC. The Panel concluded that the SOLEC indicators lacked definition of desired endpoints or outcomes, making it difficult to obtain useful information on ecosystem statistics and trends. Therefore, the report cannot inform management decisions. Another reason the report is difficult to use is that the 400 page format is ineffective. Web-based tools should be used to facilitate sorting of information and selection of desired information.

Recommendations about Indicators Based on Literature Review

Just as the Commission would now like to assess progress under the Agreement since 1987, ten or twenty years from now, independent assessors should be able to make a statement about how Great Lakes ecosystem health has changed over time, since 1987, or from today. Therefore, specific objectives and indicators are needed to assess whether progress is being achieved and to facilitate adaptive management and causal analysis. Indicators can change somewhat over time, with some new indicators being introduced, removed or modified, however, a core set of indicators should be developed and maintained over time.

Commitments by governments are essential to ensuring that indicator development occurs and that monitoring to support the indicators is conducted. As the governments continue to negotiate a renewed Agreement, based on the Commission’s works and review of indicators literature, the Commission can make a number of preliminary recommendations for concepts to be included in a renewed Agreement and to be implemented in the governments’ next Great Lakes reporting cycle, in particular:
Within 6 months of the signing of a renewed Agreement, the governments should make commitments under a new Agreement to agree upon an initial set of core (12-24) indicators to use to measure progress towards general objectives and specific objectives of Annexes.

The governments should use the expertise of the Commission’s staff and Boards to select these indicators.

At least several of the core indicators should have data back to 1987 or earlier, and at least several core indicators should relate to the nearshore and human health.

The “core” indicators should be used in the Governments’ proposed triennial Progress Reports and should be evaluated in every reporting cycle.

Revised indicators should be developed within 24 months that include a clear definition of the indicator objective and a corresponding detailed description of how this objective will be met, including monitoring methods, procedures for quality assurance/control, data analysis and work products.

Progress reports should distinguish indicators with scientifically credible data to assess progress from a limited set of other indicators being developed or considered for the future.

Efforts should be increased to secure stronger sponsorship and funding for developing, monitoring, and reporting on the set of essential prioritized “core” indicators.

Assessment of progress using the core indicators should commence in the next Great Lakes reporting cycle and continue every cycle.

**Progress Reporting must Proceed with an Imperfect Set of Indicators**

The Commission’s final recommendation is based on the carefully crafted Agreement and also recognizes that progress reporting facilitates adaptive management and causal analysis, which should be used to improve decision making. The Commission recognizes
that the science behind selecting and defining improved is a key to assessing progress and
will continuously evolve and improve. Better, alternate, and possibly more indicators
should be developed. However, progress reports would never be developed if the
mindset was to wait for the best criteria to select indicators, identifying the best
indicators, and then finding, analyzing, publishing the data. Great Lakes progress reports
and other large scale assessment reports, such as U.S. EPA’s Report on the Environment
do not allow time for development of additional indicators, as noted in that report (U.S.
EPA 2000). Assessments of progress should proceed using the best available indicators
and their best available data.

Using indicators for reporting, in any discipline, involves uncertainty. Uncertainty in
this report was reduced by predominantly using data published in government reports or
peer reviewed literature. Further, the reports were written by experts from both countries
that wrote much of the source material.

While imperfect, the Commission’s report is a guide to the Parties as they continue to
refine indicators. In turn, these indicators will facilitate the Commission’s biennial
reports concerning progress toward the achievement of Great Lakes Water Quality
Agreement objectives, its assessment of the effectiveness of the programs and other
measures undertaken pursuant to the Agreement, and its advice and recommendations as
required by Article VII (4) of the Agreement.

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VIII. GLOSSARY

Alewife: A small silver-colored fish that is not native to the Great Lakes.

Algae: Simple rootless plants that grow in sunlit waters in proportion to the amount of available nutrients. They can affect water quality adversely by lowering the dissolved oxygen in the water. They are food for fish and small aquatic animals.

Algal blooms: Sudden spurts of algal growth, which can affect water quality adversely and indicate potentially hazardous changes in local water chemistry.

Areas of Concern (AOCs): Specific geographical locations in the Great Lakes where degraded environmental conditions have created an impairment to human or ecological use of the water body. These AOCs have been designated by the two federal governments as having serious water pollution problems requiring remedial actions and the development and implementation of Remedial Action Plans.

Benthic invertebrate: Refers to animals with no backbone or internal skeleton that live on the bottom of lakes, ponds, wetlands, rivers, and streams, and among aquatic plants. Benthic invertebrates provide an essential source of food for young and adult fish, wildlife, and other animals. Examples include caddisflies, midge larvae, scuds, waterfleas, crayfish, sponges, snails, worms, leeches, and nymphs of mayflies, dragonflies, and damselflies. The benthic invertebrate Diporeia, is an ecosystem indicator.

Benthic organism (benthos): A form of aquatic plant or animal life that is found near the bottom of a stream, lake, or ocean. Benthic populations are often indicative of sediment quality.

Bioaccumulative substances: Substances that increase in concentration in living organisms as they breathe contaminated air or water, drink contaminated water, or eat contaminated food. These substances are very slowly metabolized or excreted.
**Bioaccumulation:** The accumulation by organisms of contaminants through ingestion or contact with skin or respiratory tissue. The net accumulation of a substance by an organism as a result of uptake from all environmental sources. Bioaccumulation of a toxic substance has the potential to cause harm to organisms, particularly to those at the top of the food chain. Also see biomagnification.

**Bioavailability:** Degree of ability to be absorbed and ready to interact in organism metabolism.

**Bioconcentration:** The accumulation of a chemical in tissues of an organism (such as a fish) to levels greater than in the surrounding medium in which the organism lives.

**Biological integrity:** The ability to support and maintain balanced, integrated, functionality in the natural habitat of a given region.

**Biological magnification/Biomagnification:** Refers to the process whereby certain substances such as pesticides or heavy metals move up the food chain, work their way into rivers or lakes, and are eaten by aquatic organisms such as fish, which in turn are eaten by large birds, animals or humans. The substances become concentrated in tissues or internal organs as they move up the chain.

**Bloom:** A proliferation of algae and/or higher aquatic plants in a body of water; often related to pollution, especially when pollutants accelerate growth.

**Blue green algae:** A common name for Cyanobacteria, a phylum of bacteria that obtain energy through photosynthesis. Named because of their blue color. See Cyanobacteria.

**Brominated flame retardants (BFRs):** Chemicals containing bromine that are used to inhibit the ignition of combustible materials. There are more than 75 different BFRs recognized commercially. Some, such as the polybrominated biphenyls (PBBs), are no longer being produced. The PBBs were removed from the market in the early 1970s.
because of poisonings in Michigan attributed to the inadvertent mixing of a bag of Firemaster FF-1, a commercial PBB mixture, into animal feed. There are five major classes of BFRs: brominated bisphenols, diphenyl ethers, cyclododecanes, phenols, and phthalic acid derivatives.

Burrowing mayflies: See Hexagenia.

Bythotrephes: A cladoceran, or water flea.

Bythotrephes longimanus: the spiny water flea, is a non-indigenous invasive species with a barbed tail spine that competes with fish for zooplankton. The tail spine makes it unattractive to other predators and it has flourished. The impact that this new predator will have on the Great Lakes has yet to be determined, though it may compete for food with some fish.

Cladophora: A long filamentous type of green algae that attaches to hard surfaces, particularly near the shoreline. Abundant growth is an indicator of phosphorous enrichment.

Climate change (also referred to as 'global climate change'): The term 'climate change' is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, 'climate change' has been used synonymously with the term, 'global warming'; scientists however, tend to use the term in the wider sense to also include natural changes in climate.

Combined sewer overflow (CSO): A discharge of untreated wastewater from a combined sewer system at a point prior to the headworks of a publicly owned treatment works. CSOs generally occur during wet weather (rainfall or snowmelt). During periods of wet weather, these systems become overloaded, bypass treatment works, and discharge directly to receiving waters.
**Congeners:** Chemicals that are related such as elements in the same group of the periodic table or derivatives thereof. For example, there are 209 congeners of polychlorinated biphenyls and 209 congeners of polybrominated diphenyl ethers.

**Contaminant:** Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

**Cyanobacteria:** Single-celled prokaryotic autotrophic organisms that live in fresh, brackish, and marine water. Cyanobacteria use sunlight to make their own food. In warm, nitrogen- and phosphorus-rich environments, microscopic cyanobacteria can grow quickly, creating blooms that spread across the water’s surface. Such blooms, when visible, can be an aesthetic nuisance to recreation. Many taxa can produce toxins, which pose a direct health threat, as well as other compounds that cause taste and odor problems in drinking water as well as react with disinfectants to produce disinfection by-products. Because of the color, texture, and location of these blooms, the common name for cyanobacteria is blue-green algae.

**Diatoms:** A class of planktonic one-celled algae with skeletons of silica. They are an important part of the food web.

**Dioxins:** Dioxin is the common name used to refer to the chemical 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD. In addition to dioxin itself there are other compounds, such as the polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and some polychlorinated biphenyls (PCBs), that have similar structures and activity as dioxin. These are often commonly referred to as dioxin-like compounds or "dioxins".

**Diporeia:** An amphipod that is an important food source for whitefish, lake trout, and smelt. Diporeia has declined dramatically in the eastern Great Lakes basin due to impacts from the quagga mussel.
**Ecological exposure:** Exposure of a nonhuman receptor or organism to a chemical, or radiological or biological agent.

**Ecological Indicator:** A characteristic of an ecosystem that is related to, or derived from, a measure of biotic or abiotic variable, that can provide quantitative information on ecological structure and function. An indicator can contribute to a measure of integrity and sustainability.

**Effluent:** Wastewater--treated or untreated--that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

**Emission:** Pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities; from residential chimneys; and from motor vehicle, locomotive, or aircraft exhausts.

**Environmental Indicator:** A measurement, statistic or value that provides a proximate gauge or evidence of the effects of environmental management programs or of the state or condition of the environment.

**Ephemeral:** Transitory, short-lived objects or events. Adult stages of Hexagenia (mayflies) are an excellent example.

**Escherichia coli (E. coli):** A type of fecal coliform bacteria, of which a particular strain, called E. coli 0157:H7, has been found to be extremely harmful to humans if ingested. E. coli does not naturally occur in water; the presence of these bacteria indicates recent contamination by human or animal feces.

**Eurasian Ruffe:** A non-indigenous species of fish now found in Lake Superior and Lake Huron. This relatively new invader is a member of the perch family. It is usually less than six inches long, has a perch-like body shape, and is very slimy when handled. This fish may be competing with native perch and other fish for food. There is a great deal of
concern over the potential for this fish to expand its range into other North American waters.

**Eutrophication:** The increase and accumulation of primary producer biomass in a waterbody through time. Eutrophication is caused by the addition of nutrients into natural waters that stimulate primary production. The process can be natural when natural sedimentation increases nutrient availability and decreases the depth of a waterbody, but is more commonly unnatural in response to human induced sedimentation and/or nutrient enrichment of surface waters.

**Eutrophic lakes:** Shallow, murky bodies of water with concentrations of plant nutrients causing excessive production of algae.

**Exposure Indicator:** A characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's exposure to a chemical or biological stress.

**Game fish:** Species like trout, salmon, or bass, caught for sport. Many of them show more sensitivity to environmental change than "rough" fish.

**Global warming:** An increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is most often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases. Scientists generally agree that the Earth's surface has warmed by about one degree Fahrenheit in the past 140 years. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that increased concentrations of greenhouse gases are causing an increase in the Earth's surface temperature and that increased concentrations of sulfate aerosols have led to relative cooling in some regions, generally over and downwind of heavily industrialized areas.
**Harmful algal bloom (HAB):** An algal bloom that can occur when certain species of microscopic algae grow quickly in water, reaching concentrations that may harm the health of the environment, plants, or animals. HABs can deplete oxygen and block sunlight that other organisms need to live, and some HAB-causing algae release compounds toxic to animals and humans.

**Hexagenia:** Bottom-dwelling, burrowing Mayfly larvae (*Hexagenia*) are indicators of high water quality. In the 1950s, mayflies were wiped out in Lake Huron due to poor water quality. Low numbers of mayflies are an indicator of low amounts of dissolved oxygen.

**Hypoxia/Hypoxic waters:** Waters with dissolved oxygen (DO) concentrations of less than 2 ppm, the level generally accepted as the minimum required for most marine life to survive and reproduce.

**Indicator:** Any biological entity or processes, or community whose characteristics show the presence of specific environmental conditions.

**Littoral Zone:** 1. The portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants. 2. A strip of land along the shoreline between the high and low water levels.

**Mercury (Hg):** Heavy metal that can accumulate in the environment and is highly toxic if breathed or swallowed.

**Mesotrophic:** Reservoirs and lakes that contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

**Metabolites:** Any substances produced by biological processes, such as those from pesticides.
Metric: A calculated term or enumeration representing some aspect of biological assemblage, function, or other measurable aspect and is a characteristic of the biota that changes in some predictable way with increased human influence. A multimetric approach involves combinations of metrics to provide an integrative assessment of the status of aquatic resources.

Microcystin: A naturally-occurring, potent liver toxin produced by the cyanobacteria Microcystis.

Microcystis: A cyanobacteria that causes algae blooms under eutrophic, high phosphorus conditions. It can be toxic to aquatic life and humans if ingested in sufficient quantities due to the presence of microcystin.

Non-indigenous species: Species that are not native to an area. They could be exotics that originate in a foreign country, or transplants into a region to which they are not native, but is still within their country of origin. Those species found beyond their natural ranges or natural zone of potential dispersal. Also referred to as exotic species.

Non-point sources: Diffuse pollution sources (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants are generally carried off the land by storm water. Common non-point sources are agriculture runoff, forestry, urban runoff, mining, construction, dams, channels, land disposal, and city streets.

Nutrient: Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater, but is also applied to other essential and trace elements.

Nutrient pollution: Contamination of water resources by excessive inputs of nutrients. In surface waters, excess algal production is a major concern.
Nymph: An immature insect stage with the nymph of the pollution-intolerant Hexagenia spp. of particular interest in the Great Lakes. Nymphs of Hexagenia spp. returned to Lake Erie in the early 1990s after an absence of 40 years.

Oligotrophic: The state of a poorly-nourished, unproductive lake that is commonly oxygen rich and low in turbidity. Relatively low amounts of nutrients (phosphorus and nitrogen) in the water column. Refers to an unproductive, nutrient poor lake that typically has very clear water.

Oligotrophic Lakes: Deep clear lakes with few nutrients, little organic matter and a high dissolved-oxygen level.

Outfall: The place where effluent is discharged into receiving waters.

Parts per billion (ppb)/Parts per million (ppm): Units commonly used to express contamination ratios, as in establishing the maximum permissible amount of a contaminant in water, land, or air.

Pelagia: Biological community existing in the open waters. Includes organisms floating in the water column or at the surface, as well as free-swimming organism.

Pelagic: Related to or living in the open lake, rather than waters adjacent to the land.

Periphyton: Algae that grow attached to surfaces such as rocks or larger plants.

Persistent bioaccumulative toxic (PBT) chemicals: Chemicals that persist in the environment and bioaccumulate in animal and human tissues.

Phytoplankton: Microscopic forms of aquatic plants. Plant microorganisms that float in the water, such as certain algae. Algae that grow suspended in the water column or open waters of a lake.
**Piscivores:** Fish-eating fish.

**Planktivores:** Plankton-feeding fish.

**Plankton:** A term used to describe bacteria, tiny plants (phytoplankton), and animals (zooplankton) that live in the water column of lakes.

**Point source:** Any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock concentrated animal feeding operation (CAFO), landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural stormwater runoff.

**Pollutant:** Generally, any substance introduced into the environment that adversely affects the usefulness of a resource or the health of humans, animals, or ecosystems.

**Polybrominated diphenyl ethers (PBDE):** Polybrominated diphenyl ethers (PBDE) are a class of widely used fire retardants most commonly employed in building materials, textiles, furnishings, electronics, and plastics.

**Polychlorinated biphenyls:** A group of toxic, persistent chemicals used in electrical transformers and capacitors for insulating purposes, and in gas pipeline systems as lubricant. The sale and new use of these chemicals, also known as PCBs, were banned by law in 1979.

**Quagga mussel:** A close cousin to the zebra mussel, this exotic mussel was brought into the Great Lakes in the ballast water of transoceanic ships and is expected to have impacts similar to those of the zebra mussel. Although some evidence suggests that it prefers the deeper waters of the Great Lakes, it has, like the zebra mussel, quickly infested inland river systems. The name quagga comes from an extinct member of the zebra family.
**Sea Lamprey:** An exotic, eel-like animal that attaches to fish with a sucking disk and sharp teeth. A native of the Atlantic Ocean, the lamprey made its way into all the Great Lakes following the opening of the Welland Canal in 1829 and its deepening in the 1900’s. By the 1930s, sea lamprey were found in all of the Great Lakes. During the 1940s and 1950s, lamprey caused the collapse of lake trout, whitefish, and chub populations in all the Great Lakes with the exception of Lake Superior. It has been estimated that one sea lamprey can kill up to 40 pounds of lake trout during its lifespan.

**Sentinel species:** A species used as an indicator of overall environmental conditions, particularly contaminants. For example, mayflies (hexagenia), and bald eagles.

**Soluble reactive phosphorus:** A form of phosphorus that is readily bioavailable.

**Stratification:** Separating into layers. Thermal stratification in Lake Erie is especially of importance when instances of associated dissolved oxygen depletion in the dense, bottom layer of water (hypolimnion) occur.

**Stressor indicator:** A characteristic of the environment that is suspected to elicit a change in the state of an ecological resource, and they include both natural and human-induced stressors.

**Total phosphorus:** Total phosphorus is the measure of the total concentration of phosphorus present in a water sample from point and nonpoint sources. Point sources of phosphorus are mainly from municipal and industrial discharges and nonpoint-sources of phosphorus include runoff from urban areas, construction sites, row-crop agricultural lands, and animal waste transported in runoff from feeding operations.

**Trophic:** Status characterization of the condition of a body of water as eutrophic, oligotrophic or mesotrophic. Indicators or certain characteristics of a lake are used to
measure the productivity of a lake. Indicators can be chemical, physical or biological in nature.

**Watershed:** The land area that drains into a stream; the watershed for a major river may encompass a number of smaller watersheds that ultimately combine at a common point.

**Watershed approach:** A coordinated framework for environmental management that focuses public and private efforts on the highest priority problems within hydrologically-defined geographic areas taking into consideration both ground and surface water flow.

**Zebra mussel:** An exotic species originally introduced into the Great Lakes via the ballast water of transoceanic ships. This small bivalve mussel poses a multibillion dollar threat to industrial, agricultural, and municipal water supplies across North America by clogging water intake pipes. It can also have impacts on fisheries, native freshwater mussels, and natural ecosystems. By moving along contiguous waters of the Great Lakes, attached to ships, barges, and recreational boats, this Eurasian native has rapidly spread throughout the Mississippi River basin and many of its major tributaries, such as the Ohio River. Free-swimming larvae are also spread by river currents.

**Zooplankton:** Small, mostly microscopic animals that float or swim in open water. Zooplankton eat algae, detritus, and other zooplankton and in turn are eaten by fish.

**Glossary sources**


