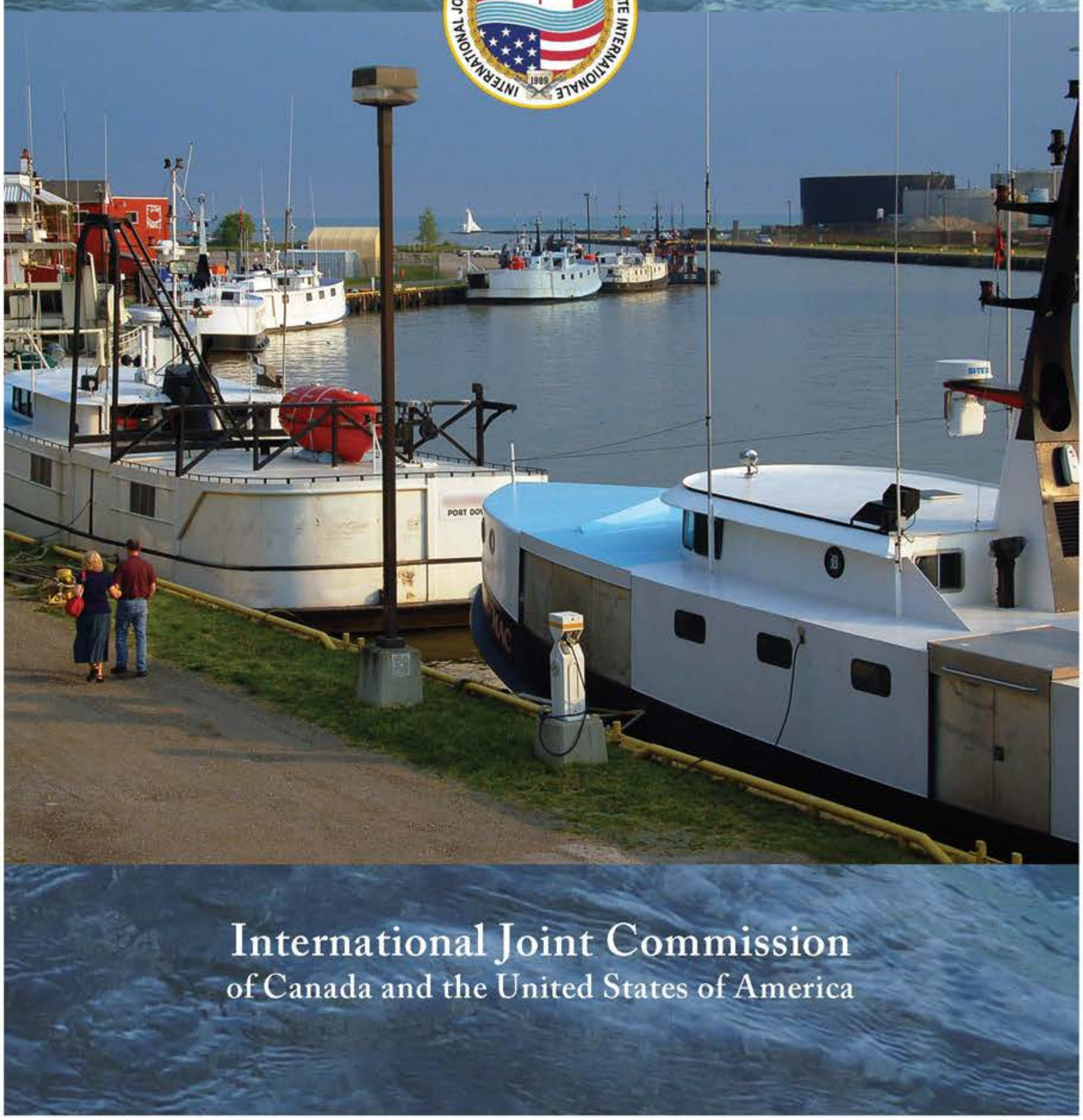
Assessment of Progress Made Towards Restoring and Maintaining Great Lakes Water Quality Since 1987

16th Biennial Report on Great Lakes Water Quality and Accompanying Technical Reports



International Joint Commission
of Canada and the United States of America

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

Sixteenth Biennial Report on Great Lakes Water Quality

April 15, 2013

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A summary of this report is available online at: www.ijc.org/en_/Great_Lakes_Quality

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Front cover photo of Port Stanley, Ontario: Glenn Cameron at roadstories.ca.

Dear Friends of the Great Lakes:

The International Joint Commission (IJC) is pleased to transmit our Sixteenth Biennial Report on Great Lakes Water Quality, concluding our responsibilities under the 1978 Canada-United States Great Lakes Water Quality Agreement, as amended by the 1987 Protocol. The goal of this report is to present a scientifically sound yet broadly accessible picture of how the health of the Great Lakes has changed over the 25 years since the Agreement was last revised. The data presented show significant achievements; however, the evidence equally demands sustained investment and action to protect and restore the Great Lakes for today, tomorrow and for generations to come.

In order to address the frequently heard question: "Are the Great Lakes getting healthier?" we made a concerted effort to locate data and work with experts from both sides of the border. Recognizing that there are no simple answers, authors of this report selected 14 well-documented indicators of chemical, physical and biological integrity, and two indicators of performance. Only indicators with data that spanned all or most of the 25-year period were included in this report and most data were from the State of the Lakes Ecosystem Conference (SOLEC).

The seven indicators of chemical integrity show mostly favorable or stable results since 1987, reflecting the success of policy changes implemented in both countries after the original 1972 Agreement. However, some data also reveal a leveling off or even a reversal of reductions in toxic chemicals and nutrient loadings in the past decade and earlier. For example, recent extreme algal blooms are in part a manifestation of excessive nutrient loadings. Clearly, past policy changes and investments have been effective, and our findings support the need for more comprehensive monitoring of these indicators and scientifically justifiable actions to protect the public.

The five biological indicators reveal mixed results, both among the indicators and over time. For instance, from 1987 to 2006, 34 new non-native species became established in the Great Lakes, causing extensive and costly damage to the ecosystem. However, since 2006 when modifications in ballast water management regulations were implemented, no new invasive species are known to have been introduced through ballast water, though two species were established via other routes. In addition to prevention measures, IJC recommendations include highly coordinated plans for rapid response to any future introductions and reduced ice cover. Such concerns about global climate change prompted the IJC to support further inquiry into adaptive management practices which provides a systematic approach to help minimize future damage to Great Lakes dependent communities. The report recognizes that water quality is the focus of the Agreement but draws attention to increasing concerns about water levels and the impacts of declining water levels on water quality.

Finally, two performance indicators reflect how well government programs were meeting objectives regarding restoration of 43 sites of historic contamination identified as Areas of Concern (AOC) under terms of the 1987 Protocol, and beach closings and advisories. Only four AOCs (three in Canada and one in the U.S.) have been remediated to the point of being delisted. Many individual beneficial use impairments (BUI) have been removed at a number of sites that have been partially remediated. Canada made its greatest gains in the early years of this reporting period, while the pace of remediation of the U.S. sites has picked up in recent years because of increased investment and effort under the U.S. Great Lakes Restoration Initiative and the Great Lakes Legacy Act. Beach closings and advisories have remained nearly unchanged over the full length of the reporting period with some year to year fluctuations.

Scientifically sound indicators applied consistently over time are essential to track changes in Great Lakes water quality. Collaboration between the IJC and the governments' own Great Lakes evaluation program, SOLEC, to select a core set of Great Lakes indicators is key among our recommendations. With these indicators in place, efforts could focus on setting goals or targets for each indicator and allocation of adequate resources for monitoring, prevention and remediation. To support this effort, the IJC has created an indicators work group that includes both government and academic scientists and policy experts. This group already has done considerable analysis and will recommend a specific suite of indicators. Another team of experts is identifying a core set of human health indicators. The Commission has greatly appreciated the support received for these initiatives from the governments.

The scope of work presented in this report constitutes a substantial representation of IJC Great Lakes projects. In addition, there are other projects supportive of IJC's assessment work, including:

- development of systems to support better access and more integration of data provided by academic and government sources in both countries;
- collaboration with stakeholders to improve understanding of factors affecting the reoccurrence of extreme algal blooms;
- extensive studies on forces affecting Great Lakes water levels, resulting in better understanding of precipitation, evaporation, historic dredging, control structures and hydropower facilities, ground water discharge and
- climate change.

Looking forward, the IJC congratulates the governments of Canada and the United States for successfully completing and signing a revised protocol of the Agreement in 2012. In particular, we appreciate that many of our recommendations were included.

We are particularly eager to implement the Agreement's new opportunities for more public engagement, knowing that an informed and committed public is essential for adequate investment in Great Lakes protection and restoration. We are very appreciative of the work of many federal, provincial and state experts who have made substantial contributions to the science underpinning this report. Combined with the continuing effort of these dedicated scientists and managers, we hope the findings and recommendations in this report will help both countries achieve the goals that our two nations have set for protecting and restoring the most precious freshwater ecosystem on earth.

Respectfully submitted,

The Commissioners

ABSTRACT

Under the Great Lakes Water Quality Agreement, the International Joint Commission (IJC) is responsible for assessing the progress of the governments in fulfilling the general and specific objectives of the Agreement. Over the years, various IJC studies have looked at certain attributes of water quality. Now that a protocol amending the existing Agreement has been signed by Canada and the United States, the IJC believes that an assessment of changes since the previous amendment in 1987 will provide important information and guidance for ongoing implementation. The IJC also believes that an assessment of progress now will provide useful recommendations for assessing progress under the new 2012 Agreement.

Sixteen indicators were used to assess progress. All seven indicators of chemical integrity showed mostly favorable or stable results since 1987, reflecting policy changes implemented in both countries after the original Agreement was signed in 1972. Atmospheric deposition of toxic chemicals has declined since 1987. Decreased concentrations of most measured toxic chemicals were observed in sediments, herring gulls, fish and mussels from 1987 to about 2000. Since that time trends vary by chemical, species, and location. Phosphorus input to the lakes decreased until the mid-1990s, but since then loading has increased and algal blooms have reoccurred. The five biological indicators yielded mixed results. From 1987 to 2006, 34 nonnative species became established in the Great Lakes. *Diporeia*, a small shrimp-like invertebrate and an integral part of the aquatic food web, has almost disappeared. Some native species, such as the burrowing mayfly and lake sturgeon, have started to return, but current lake trout populations are similar to 1987 populations and still below targets. The two physical indicators reveal rising surface water temperatures and reduced ice cover supporting concerns about global climate change. One indicator that evaluated program effectiveness found that 4 of 43 Areas of Concern were delisted and overall about one quarter of the beneficial use impairments have been restored. The final indicator found that beach closures are still common and their frequency has remained constant.

IJC recommendations associated with individual indicators included continued monitoring of many of them, and for some recommended changes to how the collection, provision and

reporting of information can be improved to further facilitate the assessment of progress task. While research and monitoring for many indicators is desirable, the IJC recognizes that assessments of progress towards the objectives of the Great Lakes Water Quality Agreement would be improved and more easily communicated to the public using a small set of indicators. Therefore, IJC recommends that the governments select a set of core indicators related to the objectives of the Agreement, monitor their status, and report on the trends over time. The IJC also recommends that goals or targets be established for each indicator and that adequate resources be allocated for prevention and remediation actions to achieve goals.

This report includes IJC policy, management, and research recommendations to governments along with a summary of IJC's current work related to improving assessments of progress. For example, the Commission has undertaken a project to recommend core indicators for use under the 2012 Agreement and governments have been supportive of this process.

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AUTHORS, REVIEWERS, CONTRIBUTORS, AND DEDICATION

The International Joint Commission (IJC) prepared this document with the input of numerous experts from Canada and the United States. Scientific experts from multiple government and other organizations in both countries contributed data and interpretation to the scientific chapters. IJC staff synthesized the information, provided input from other literature and developed policy recommendations.

An early draft of this report was released to the public on the IJC's website and at the 2011 Great Lakes Water Quality Biennial Meeting in Detroit from October 12-14, 2011. The draft report was revised based on comments received from multiple Great Lakes organizations, members of IJC's Great Lakes advisory boards, Environment Canada and USEPA. The IJC appreciates the comments from its many reviewers which help provide the perspectives of the Great Lakes community. However, any errors or omissions or opinions expressed are the sole responsibility of the IJC. Several IJC staff helped write this report. The lead author of the report was Vic Serveiss and other contributors were Dave Dempsey, Cindy Warwick, Raj Bejankiwar, Antonette Arvai, Joel Weiner, Paul Allen, and Bruce Kirschner.

The IJC would like to dedicate this report to Bruce Kirschner (1952-2012) who worked with the IJC's Great Lakes Regional Office in Windsor for 23 years and contributed to this report. We hope that this report will influence decisions to help protect and restore the Great Lakes and will be a memorial to his contributions.

CONTENTS

Page Number

EXECUTIVE SUMMARY

This report was developed to fulfill the International Commission's (IJC's) mandate to report biennially on the progress made by the governments towards achievement of the objectives of the Canada-United States Great Lakes Water Quality Agreement. Assessments of progress provide information to help guide environmental management decisions and supply the public with important information on this dynamic and fragile ecosystem. Assessments are also a useful exercise for reviewing the data, analysis and other information available for examining and evaluating progress. This, the IJC's 16th Biennial Report, assesses the progress that has been made towards restoring and maintaining Great Lakes water quality since 1987. This assessment was accomplished primarily by examining changes to chemical, physical, and biological measures that relate to Great Lakes water quality. The report also discusses how future assessments of progress could be improved under the new 2012 Agreement.

The Great Lakes Water Quality Agreement as amended in 1987 (hereafter referred to as 1987 Agreement) directed the governments of the United States and Canada to restore and maintain the chemical, physical, and biological integrity of the waters of Great Lakes Basin Ecosystem. Also, under the 1987 Agreement, the governments were responsible for reporting every two years to the IJC on progress made towards objectives of the Agreement. For example, under Annex 14 of the 1987 Agreement, the governments were required to report to the IJC on progress made towards remediating contaminated sediments.

The IJC was also responsible for issuing an assessment of progress report every two years. A protocol amending the 1987 Agreement was signed by Canada and the United States in September 2012. The revised 2012 Agreement continues various government and IJC reporting responsibilities, though the reporting cycle, the Annex numbers and some specific reporting requirements have changed.

Based on the progress reports prepared by the governments and other available information, the IJC is responsible for developing its own independent and binational assessment of progress. Prior to 1987, the IJC primarily based its biennial reports to the Governments on information developed by several specialized committees that were part of the IJC's advisory boards. However, the 1987 Agreement changed the protocol, the subcommittees were disassembled, and the responsibility of providing data to the IJC was transferred to the governments. When that organizational change was made, it became more of a challenge for the IJC to obtain data that were organized in a manner that clearly related to the objectives of the Agreement. More specifically, many of the Annexes in the 1987 Agreement required the governments to report to the Commission biennially on their progress towards achieving objectives of the Agreement. Since 1987, the Commission has not received assessment of progress reports on each of the annexes, nor have indicators been established that link to the purpose or objectives of each annex. As a result, recent IJC biennial reports have not been comprehensive assessments of progress and instead discussed particular topics related to Agreement objectives, such as wastewater treatment or the nearshore environment.

Now that a revised 2012 Agreement has been signed by Canada and the United States, the IJC believes that a comprehensive assessment of progress since the 1987 Agreement will provide important information and guidance for ongoing implementation. For this, the 16th and final Biennial Report, the IJC made the concerted effort to obtain and review the necessary information to perform a more comprehensive assessment of changes since 1987. The preparation of this report also pointed to ways that the reporting of progress could be improved to facilitate future assessments of progress. Under the 2012 Agreement the IJC will issue triennial reports.

The State of the Lakes Ecosystem Conference (SOLEC) provides a forum for information exchange among Great Lakes decision-makers, scientists, and stakeholders. SOLEC is organized by the governments of Canada and the United States. SOLEC reports provide most of the information and serve as the backbone of most of the indicators used by the

IJC in this comprehensive assessment of progress. SOLEC and its reports are valuable for assessing the state of the ecosystem and recent changes but have a different focus from IJC's role to measure progress made by the governments towards achieving the objectives of the Agreement. The SOLEC report could be even more helpful with some organizational improvements. With its web-based delivery system, SOLEC reports could be organized in such a manner to link its indicator reports to 2012 Agreement objectives to facilitate development of the IJC's assessment of progress report. Also, indicator reports could be sorted temporally, spatially, or by topic to better meet particular needs of resource managers. For instance, the system should allow a user to quickly find those indicator reports with information on a particular topic, such as harmful algal blooms.

For this report, which was initiated well in advance of the signing of the 2012 Agreement, sixteen indicators were selected based on availability of historical data, relevance to the 1987 Agreement or environmental management objectives, ecological importance, availability of experts to contribute, and other commonly used criteria to select indicators. The report includes one chapter for each of the 16 indicators. Expanding upon the findings of the 16 indicator chapters, a review of relevant literature and a review of the 2012 revised Agreement, the final chapter of this report presents management implications and actions recommended by the IJC to better achieve 2012 Agreement objectives or to improve the assessment of progress under the Agreement.

The IJC recognizes that government programs do affect the health of the Great Lakes and that policies adopted by Canada and the United States have been successful in driving observed changes in chemical and biological indicators. Following up on these successes, the IJC recommends that the governments:

- Improve the web-based organization of existing SOLEC indicator reports to enable users to find information more easily.
- Continue to work with the IJC to identify a limited set of core indicators which measure the ecological and human health conditions and stressors most relevant to 2012 Agreement objectives.

- Ensure that resources are made available to collect the monitoring data needed to support these core indicators.
- Commit to establishing goals, targets, or standards for each of the core indicators.
- Provide resources for prevention and remediation actions that are necessary to achieve objectives.

These steps are necessary because sound monitoring data provide information to help protect environmental resources worth billions of dollars.

The report includes 16 scientific indicator chapters that are organized in four groups: 1) seven chapters on chemical integrity; 2) two on physical integrity; 3) five on biological integrity; and 4) two on evaluating the effectiveness of government programs. Overall trends and major findings of the indicator chapters are summarized below. In the main body of the report, each chapter describes why the indicator is important, methods, results, discussion and potential future use of the indicator. A glossary assists readers in better understanding the scientific terms included in the report.

Scientific experts from multiple government and other organizations in both countries contributed data and interpretation to the scientific chapters. IJC staff synthesized the information, provided input from other literature, and made policy recommendations. The Executive Summary, Introduction, and Conclusions/Recommendations chapters are solely the responsibility of the IJC.

Synopsis of overall trends

Since 1987, all seven indicators of chemical integrity have shown mostly favorable or stable results. The levels of many persistent toxic chemicals entering 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 to 2000, but since 2000 trends vary by chemical, location, and species. However, concentrations of some chemicals of emerging concern have increased since 1987. For instance, concentrations of polybrominated diphenyl ethers (PBDEs, harmful chemicals used in flame retardants) in fish doubled every few years from 1980 to 2000 and then started to decline slightly following voluntary phase-outs of two PBDE formulations by industry.

The five biological indicators show mixed results. From 1987 to 2006, 34 nonnative species became established in the Great Lakes mostly from ballast water discharges. However, no species have been introduced from ballast water since 2006. Populations of the burrowing mayfly and lake sturgeon have started to recover, but lake trout populations are consistent with 1987 levels. The number of lake trout in four of the five Great Lakes has been stable overall with year-to-year fluctuations, largely due to stocking, but are still below targets. *Diporeia*, a small shrimp-like invertebrate, a key part of the aquatic food web and a food source for many fish, has almost disappeared.

The two physical indicators, surface water temperature and ice cover, both indicate a warming trend, suggesting that global climate change is affecting the Great Lakes. This could lead to shifts in species composition, including increased frequency of harmful algal blooms.

One of the two performance indicators evaluated progress in restoring areas that were previously identified as degraded and officially designated as areas of concern (AOCs). Of the original 43 AOCs, four have been restored to the point that they are no longer considered AOCs and they have been delisted. Approximately 25 percent of the beneficial use impairments in the remaining AOCs have been removed because of the environmental improvements. The other performance indicator evaluated progress in keeping beaches safe and open. Beach closings based on bacteria levels have remained fairly stable over the reporting period of about ten years, but are still common.

Chemical integrity

Herring gulls

Persistent toxic chemicals such as DDT and PCBs have affected the thickness of egg shells and other aspects of development in many species of fish-eating birds. Herring gulls are colonial waterbirds that are permanent residents of the Great Lakes, and because they eat fish, they accumulate high concentrations of toxic chemicals from the food web. Environment Canada's herring gull egg monitoring program has monitored many contaminants since 1974. The eight discussed here are: PCBs, mercury, dichlorodiphenyl-dichloroethene (DDE), hexachlorobenzene (HCB), heptachlor epoxide (HE), mirex dieldrin, and dioxin. Levels of these chemicals in herring gull eggs have declined by more than 90 percent since 1974 and from 64 percent to 87 percent since 1987. However, in recent years, declines of some chemical concentrations have slowed and mercury levels have remained stable since the mid-1990s. Because herring gulls in polluted areas are experiencing more abnormalities than in cleaner habitats, continued reductions in chemical concentrations are desirable and the monitoring program should continue.

Fish consumption restrictions

The levels of persistent toxic chemicals in the edible portions of Great Lakes fish declined between the 1970s and 1987 and for a few years thereafter. Since about 1990, the levels of contaminants have either declined at a slow rate or have stabilized with year-to-year fluctuations. Numerous restrictive fish consumption advisories aimed at protecting human health from contaminant exposure remain in place for all of the Great

Lakes. The majority of these advisories are driven by elevated concentrations of PCBs, including dioxin-like PCBs.

Contaminants in whole fish

Contaminants in whole lake trout and walleye (the entire fish including bones and organs) are measured as an indicator of ecosystem health. Since 1987, concentrations of several persistent toxic chemicals in whole fish have declined at rates of three to nine percent per year. Concentrations of mercury, on the other hand, have been stable or increasing since about 1990. Concentrations of PBDEs in lake trout and walleye rose continuously through the early 2000s and have been declining since that time.

Contaminants in mussels

Bivalve mollusks (shellfish with paired shells) are a key part of environmental monitoring worldwide because they are widely distributed, accumulate persistent contaminants and are easy to collect. Mussel Watch chemistry data collected from 1992-2009 can be used to assess the status and trends of metals, along with legacy and emerging organic contaminants. Most of the Great Lakes sites did not show any trend in either metal or organic contaminant concentrations. However, since a few sites had large declines of contaminant concentrations, many of the metals and organic contaminants showed decreasing trends basinwide.

Contaminants in sediments

Contaminants that are in sediments can harm bottom-dwelling organisms, and the sediments can serve as a source of toxic chemicals in the food chain as prey fish consume bottom dwellers. Successful management actions led to significant declines between the 1970s and the late 1990s in concentrations of many contaminants in sediments, including PCBs, DDT, lead and mercury. It is not clear if levels have continued to decrease since that time. Canada and the United States 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.

Phosphorus loading

Phosphorus loading is an important contributor to excessive algal growth, especially in shallow and nearshore waters of the Great Lakes. Substantial reductions in loading from major wastewater treatment plants have been achieved, but combined sewer overflows still require additional control efforts. Since 1975, the National Center for Water Quality Research has been monitoring Lake Erie tributaries for various parameters, including total phosphorus (TP) and dissolved reactive phosphorus (DRP). Reduced loading of TP and DRP through 1995 is a sign that control programs were successful. Since that time and especially in the last few years, there has been a reemergence of harmful algal blooms in Lake Erie. These blooms are thought to be attributed to DRP because loadings of TP levels have been stable while loadings of DRP have increased, and DRP is easier for algae to consume. Improved management controls to reduce DRP loading from stormwater events, especially from agricultural lands are needed, along with associated monitoring.

Atmospheric deposition

Atmospheric deposition occurs when pollutants are carried through the air to the Earth's surface. The amount of deposition of most measured persistent toxic chemicals in the Great Lakes basin, as measured by the US-Canada Integrated Atmospheric Deposition Network (IADN), has declined since the 1970s and 1980s, when many were banned in North America. For instance, concentrations of PCBs, have continued to decline and are now at about half the 1990 level, although the rate of decline has slowed significantly. Concentrations of many banned or restricted pesticides, such as lindane and DDT, decreased considerably. Concentrations of several alternative flame retardants are increasing.

Physical integrity

Surface water temperatures

Significant warming since the mid-1980s is evident in surface temperatures of several of the Great Lakes. The annual average temperature of Great Lakes regional surface waters increased approximately 0.05 to 0.06 degrees C per year between 1985 and 2009. Warming is most pronounced in Lake Superior, the coldest and largest of the Great Lakes.

Ice cover

The Great Lakes are typically covered by ice during part of the winter and early spring. The number of days that each of the Great Lakes is covered by ice has generally declined on all lakes since 1987. One study found substantial declines of ice cover on all Great Lakes between 1973 and 2010, with the smallest decline of 37 percent on Lake St. Clair and the largest of 88 percent on Lake Ontario. Another study similarly found declines in ice cover on all lakes, with Lakes Superior and Michigan averaging less than half the number of days of ice cover than they had in the mid-1970s.

Biological integrity

Nonnative species

Nonnative species have become established in the Great Lakes and have caused dramatic economic and ecological impacts. The number of nonnative aquatic species in the Great Lakes increased steadily from 1900 until the late 1990s. In the latter portion of this period, nonnative aquatic species that became established were introduced mostly by unregulated ballast water discharges from transoceanic vessels. There were 34 nonnative species introduced since 1987. However, due partly to the implementation of stricter ballast water regulations by Transport Canada, U.S. Coast Guard and St. Lawrence Seaway Authorities, no invasions from ballast water have been detected 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.

Hexagenia density

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 of increased nutrients that came from urban and industrial activities. High loads of nutrients triggered a series of events resulting in increased growth of algae, settlement of algae to the bottom substrates and its decomposition causing low dissolved oxygen, which leads to losses of mayflies and other lake bottom fauna. In western Lake Erie, the mayflies 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 pollution reduction is likely to allow sustained recovery of mayflies in western Lake Erie and other shallow areas of the Great Lakes. Therefore, monitoring of *Hexagenia* is recommended because they are important to fish, reflect the status of water quality in shallow waters and are relatively efficient to sample.

Diporeia abundance

The bottom-dwelling amphipod (shrimp-like invertebrate) *Diporeia* is a native glacial relict that was once the most abundant bottom-dwelling organism in cold, offshore regions of the Great Lakes. *Diporeia*, with a maximum size of 10 mm, 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 serves as an important part of 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

Lake sturgeon abundance, which fell to one percent of historical levels by the mid-1950s, is beginning to increase in some locations within the Great Lakes. Since the mid-1980s, there has been renewed sturgeon 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 successful restoration of habitat or creation of artificial habitat by multiple levels of government and other organizations. However, the species is still listed as threatened or endangered throughout much of the Great Lakes basin, making recovery uncertain. Continued monitoring, habitat restoration and water quality improvements will be necessary to the survival of the species in the basin.

Lake trout abundance

Since the mid-1980s, populations in four of the five Great Lakes have been stable overall, largely because of stocking but natural reproduction remains below target. The exception is Lake Superior where self-sustaining populations of lake trout have been restored since the mid-1980s. Significant natural reproduction is now evident across most of Lake Huron. Low reproduction rates are evident in Lake 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, nonnative alewives preying on fry and thiamine deficiency from using alewives as a food source, resulting in early mortality syndrome. Dioxin-like substances may be inhibiting reproduction in the lower lakes.

Indicators of performance

Delisting areas of concern and removal of beneficial use impairments

Based on Annex 2 of the 1987 Agreement, the federal governments identified 43 areas of concern (AOCs), including 26 in the United States, 12 in Canada and five in shared waters. These designated areas had suffered serious bacterial or chemical degradation, failed to meet the 1987 Agreement's specific objectives and were likely to have compromised the area's ability to support aquatic life. At the outset, each of the 43 AOCs had at least one and as many as 14 beneficial use impairments (BUIs). Examples of BUIs include loss of fish habitat or contaminants in fish serious enough to prompt consumption warnings. There were a total of 409 BUIs spread across the 43 AOCs. In the past quarter century, only four of the AOCs have been restored to the point that they were delisted, and two of them improved enough to be considered areas in recovery. In the United States, 33 of 255 BUIs have been removed. In Canada, 54 of 154 were removed. Currently both governments are working hard to delist more AOCs and further remove BUIs. To accelerate progress toward meeting these objectives, adequate resources need to be made available by both federal governments, and accountability and responsibility need to be assigned to specific agencies.

Beach closings and advisories

The number of Great Lakes beach closings and advisories declined slightly from 1998 to 2007. The percentage of all US Great Lakes beaches closed more than ten percent of days during the beach season ranged from 12 percent in 1998 to nine percent in 2006-2007. The comparable Ontario figure was 54 percent in 1998 and 42 percent in 2006-2007. These data need to be interpreted with caution, because of changes in the number and set of beaches which were analyzed over time and because different states and Ontario use dissimilar criteria for closures. Disease occurrences related to swimming at Great Lakes beaches may be significantly underreported. The IJC recommends further refinement of testing methods; controls on major pollution sources contributing to beach closings, such as stormwater runoff and sewage overflows; and establishment of a system for data collection on swimming-related disease.

Improving the Assessment of Progress

This assessment of progress focused on 1987-2012 and used data and relevant indicators from that time period. The selected indicators used in this study were supported by reviewers. Yet, under the 2012 Agreement, the IJC would like to better assess progress under the Agreement and improve communication of findings to the public. Ideally, future assessment of progress reports would include discussion and stakeholder buy-in for all the indicators used by IJC, along with clarification of how the data would be collected, analyzed and reported. With that aim in mind, IJC briefly describes the proposed path forward for the government's and the IJC to improve assessments of progress under the 2012 Agreement.

Developing and using a core set of indicators

The IJC recommends that the governments develop their Progress Report of the Parties using a core set of indicators related to the objectives of the 2012 Agreement. Such core indicators provide the public and policy makers with scientifically sound information to make better monitoring, restoration and prevention decisions.

Although there is research and management value in having many indicators, having a core set provides a focus for monitoring, analysis, public communications and enables the tracking of progress for the lifetime of the updated Agreement. Targets, goals or standards should be developed for each of the core indicators and resources should be provided for protection and restoration actions to achieve the goals.

Environmental monitoring

Evaluating progress toward meeting 2012 Agreement objectives depends on a robust, long-term environmental monitoring program that is linked to core indicators. But monitoring has been insufficient for some core indicators related to critical Great Lakes conditions. Some of the data sets maintained by government agencies and discussed in this report lack spatial or temporal coverage, particularly for the identification of trends.

Overall, the Commission recommends the governments allocate sufficient resources to monitor a core set of indicators and enable scientific diagnosis of trends and causes as well as the design of remediation and prevention actions needed to achieve objectives. In particular, the Commission notes the need for indicators of disease resulting from Great Lakes environmental exposures and the need for long-term support for recent government investments in comprehensive lakewide monitoring of phosphorus loadings to Lake Erie and related research.

Reporting to the public

Accurate data analysis and effective communication of results promotes public awareness of challenges to the ecological integrity of the Great Lakes and helps the public understand the importance of effective programs designed to address those challenges. The IJC believes the updated 2012 Agreement provides an opportunity for the governments to make improvements in their reporting in order to inform and engage the public and strengthen accountability, helping to achieve a central goal of the new Agreement. In particular, the IJC recommends that: the governments establish a user-friendly, basinwide system for ecosystem status information; there should be a common system for accessing Great Lakes data, including a portal that is easy for scientists, managers, and the technically versed public to use; the governments should improve the organization of the SOLEC reports using a web-based delivery system; and the governments should create a useful reporting and communication system in a "report card" format, providing to the public plain-language descriptions of core indicators and discussion of trends.

Moving Forward under the 2012 Agreement

The recommendations in this report have been aimed at improvements in Great Lakes management, monitoring and reporting by the governments related to fulfilling the objectives of the 2012 Agreement. However, the IJC has also been working to address some of these issues, on its own or in collaboration with the governments.

The IJC is currently examining how it can best fulfill its responsibility for assessing progress under the 2012 Agreement and assessing the extent to which programs and other measures are achieving the Agreement objectives. The IJC has established a working group of IJC advisory board members to assist in making recommendations to governments regarding specific indicators to be included in a limited set of core indicators that would be used for assessing progress toward Agreement objectives. The IJC established a second working group composed primarily of members of its Health Professionals Advisory Board to identify a set of core human health indicators to recommend to Governments. The IJC has welcomed the input of government representatives in both of these initiatives and hopes that this cooperation will lead to recommendations that are useful to all the progress reports. The IJC will also review current monitoring programs and make recommendations regarding monitoring to support the proposed indicators.

The Commission has also undertaken a three-year initiative to develop science-based advice to governments on reducing dissolved reactive phosphorus loads to Lake Erie and this should help to address the report's recommendations on phosphorus loading.

To help address the issue of nonnative aquatic species, the IJC, with funding from the Great lakes Restoration Initiative, has taken action to develop a pilot binational aquatic invasive species rapid response plan with input from representatives of affected U.S. and Canadian jurisdictions.

On the topic of physical integrity, the 2012 Agreement cites linkages between water quality and water quantity and identifies the need to identify, quantify, understand, and predict the climate change impacts on the quality of the Waters of the Great Lakes. In this regard, the IJC is considering the recommendations of the International Upper Great Lakes Study that governments implement an adaptive management framework supported by strengthened hydroclimatic modeling and monitoring and that the IJC has a key role to play in this process.

Conclusion

The 16 indicators provide insight into trends and changes since the 1987 Agreement. Sustained monitoring of a core set of indicators is essential. The IJC is currently working with governments to develop a core set of indicators to recommend for reporting progress. The IJC hopes that this report will contribute to the governments' ongoing efforts to improve the use and communication of Great Lakes indicators in implementing the revised Agreement. Additional and more specific recommendations are provided in the Conclusions and Recommendations chapter.

List of Abbreviations and Acronyms

1987 Agreement	Great Lakes Water Quality Agreement of 1987
2012 Agreement	Great Lakes Water Quality Agreement of 2012
AIS	aquatic invasive species
AOC	area of concern
ATSDR	Agency for Toxic Substances and Disease Registry
BEC	Binational Executive Committee
BFR	brominated flame retardants
BMP	best management practices
BUI	beneficial use impairment
CGLRM	Council of Great Lakes Research Managers
CWA	Clean Water Act
DLC	dioxin-like chemicals
DO	dissolved oxygen
DDE	dichlorodiphenyl-dichloroethene
DRP	dissolved reactive phosphorus
DDT	dichlorodiphenyltrichloroethane
EC	Environment Canada
ESA	Endangered Species Act
FEQGS	Federal Environmental Quality Guidelines
FWS	US Fish and Wildlife Service
GIS	geographic information system
GLANSIS	Great Lakes Aquatic Nonindigenous Species Information System
GLFC	Great Lakes Fishery Commission
GLNPO	Great Lakes National Program Office
GLOS	Great Lakes Observing System
GLRI	Great Lakes Restoration Initiative
GLWQA	Great Lakes Water Quality Agreement
HAB	harmful algal bloom
HCB	hexachlorobenzene
HE	heptachlor epoxide

IAGLR	International Association for Great Lake Researchers
IAQAB	International Air Quality Advisory Board
IJC	International Joint Commission
ITFM	Intergovernmental Task Force on Monitoring Water Quality
LAMP	lakewide area management plan
NAS	nonnative aquatic species
NCWQR	National Center for Water Quality Research
ng	nanogram (10^{-9})
OECD	Organisation for Economic Co-operation and Development
OMOE	Ontario Ministry of the Environment
PBT	persistent bioaccumulative toxicant
PCB	polychlorinated biphenyl
PBDE	polybrominated diphenyl ether
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PEL	probable effect level
PFA	perfluoroalklated substance
POP	persistent organic pollutant
RAP	remedial action plan
SAB	Science Advisory Board
SOLEC	State of the Lakes Ecosystem Conference
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin, commonly known as dioxin
TMDL	total maximum daily load
TP	total phosphorus
ug	microgram (10^{-6})
USEPA	US Environmental Protection Agency
WQB	Water Quality Board
WQS	water quality standards

Section 1. Introduction and Background

The Great Lakes Water Quality Agreement, of 1987 (hereafter referred to as 1987 Agreement), required the IJC to report biennially to the federal, state, and provincial governments concerning progress made towards achieving Agreement objectives and the effectiveness of programs and measures used to pursue objectives. This, the International Joint Commission's (IJC's) 16th Biennial Report, assesses progress by examining changes since 1987. The findings are intended to provide useful information for the implementers of the revised 2012 Agreement. The report also recommends improvements to research, monitoring and reporting that will enhance the reporting on progress by the governments under the 2012 Agreement. This in turn will help the IJC's assessment of progress and the communication of progress to key decision makers and the public. The ultimate goal is to provide advice to the governments to help them achieve the objectives of the 2012 Agreement.

Both the 1987 and 2012 versions of the Agreement require the governments of Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes. General objectives relate to keeping the water free from pollutants that are toxic to human, animal or aquatic life, or interfere with beneficial uses. Keeping the Great Lakes healthy is critical to the economic, human and ecological health of the basin. It is the policy of both governments that discharges of toxic substances at dangerous levels be prohibited and that the release of persistent toxic substances be virtually eliminated. Significant pollution of the Great Lakes can expose the 35 million basin residents to serious health problems while imposing recreational restrictions and economic losses. Children are particularly vulnerable to exposures that can cause life-long developmental deficits, and First Nations, tribes and Métis have lifestyles that are especially threatened because of their reliance on Great Lakes fish as a source of food and the waters as fundamental to their cultural values.

Government's responsibility to report on progress

Many of the Annexes in the 1987 Agreement required the governments to report to the Commission biennially on their progress towards achieving objectives of the Agreement. For example, Annexes 14 and 15 on Contaminated Sediment and Atmospheric Toxic Substances, respectively, required the governments to report biennially on their progress in implementing these Annexes to the Commission. From 1972 to 1987, government officials provided the biennial progress reports while serving as members of a network of specialized subcommittees that were part of the Commission's advisory boards. With the requisite data available, the biennial reports back then were more effective at assessing progress on objectives. However, the 1987 Agreement changed the protocol, the subcommittees were disassembled, and the responsibility of providing data to the IJC was transferred to the governments.

Since 1987, the Commission has not received assessment of progress reports on each of the annexes, nor are the reported indicators linked to the Agreement's objectives. The governments' State of the Lakes Ecosystem Conference (SOLEC) has reported on various indicators related to the chemical, biological and physical integrity of the waters of the Great Lakes, however, the reported indicators not clearly linked to the Agreement's objectives.

The Commission is pleased that the revised 2012 Agreement better clarifies the government's responsibility responsibilities. The governments are now responsible for reporting to the public on progress in achieving the objectives of the Agreement through the new Progress Report of the Parties, the State of the Great Lakes Report and the Lakewide Action and Management Plans.

IJC's responsibility to report on progress

The 1987 Agreement required the IJC to report biennially to the federal, state and provincial governments concerning progress made toward achieving objectives and the effectiveness of programs and measures used. This has become a triennial requirement under the 2012 revised Agreement. In both the 1987 and 2012 Agreements, the IJC is also tasked with providing advice and recommendations on many matters related to Great Lakes water quality and achievement of Agreement objectives.

The 1987 Agreement changed the process for the governments to provide data to the IJC upon which the IJC would develop its biennial assessment report. After that change it became a challenge for the IJC to obtain data that clearly related to the general and specific objectives of the 1987 Agreement, as discussed in the preceding section on the government's reporting requirements.

The IJC has drawn attention to this situation in the past. The 13th Biennial Report of Great Lakes Water Quality (IJC 2006a) was devoted to the challenge of accountability, including the need for the Parties to provide data. The report addressed the general issue of accountability and how objectives of the 1987 Agreement needed to be met with performance measures, management actions to achieve the measures and public reports on the status of these achievements.

Due to the challenge of obtaining data, the IJC's recent biennial reports have focused on particular aspects of the Agreement but were not the comprehensive assessments that the Agreement directs the IJC to undertake. For instance, as discussed, the 13th biennial focused on accountability. The 14th Biennial Report (IJC 2009) addressed wastewater treatment, and provided recommendations for reducing nutrient loadings from this source. The 15th biennial discussed issues related to water quality in the nearshore zone of the Great Lakes (IJC 2011).

In this 16th Biennial Report, the IJC re-initiates its comprehensive assessment of progress, more closely envisioned by both versions of the Agreement. Since this is the final report under the 1987 Agreement, the IJC made a concerted effort to obtain information and work with binational experts to perform a more rigorous assessment of progress. In particular, the report focuses on changes in the health of the Great Lakes since 1987, basing the bulk of its findings on measurements of 16 distinct indicators of Great Lakes conditions, stressors, or government programs.

This is the IJC's final Biennial Report. The revised 2012 Agreement improves the reporting responsibilities for both the governments and the IJC. Now that a revised Agreement has been signed by Canada and the United States, the IJC is pleased that the reporting responsibilities have been clarified and that 1) the governments are now responsible for developing progress reports towards objectives of the 2012 Agreement, as opposed to just reporting on progress towards individual Annexes as stipulated under the 1987 Agreement; and 2) the IJC is responsible for continuing to assess progress towards objectives and has the added responsibility for reviewing the government's progress report. This clarification of roles should help ensure development of comprehensive progress reporting by the governments and the IJC's independent binational assessment.

Importance of Great Lakes indicators

Scientifically sound indicators applied consistently over time are essential to track changes in Great Lakes water quality. The IJC has long advocated using indicators to measure progress toward Agreement objectives and has recommended criteria for selecting them (IJC 1991; IJC 1995; IJC 1996; IJC 2000; IJC 2006b). IJC has recognized that resources are only available to monitor and compile information on a limited set of indicators (IJC 2002).

Abundant ecological indicator literature exists beyond the IJC reports. The US Environmental Protection Agency's (2011) report on vulnerability identified a list of 23 studies from government, academia and consultants used by USEPA as core literature for selecting indicators. Indicators have been defined and used to report generally on the condition of the overall environment (USEPA 2008) or for more specific applications such as providing evidence for climate change (USEPA 2010).

IJC currently holds the view that there should be a set of 10-30 core indicators that should relate to the objectives of the 2012 Agreement and track changes over time. Most of these indicators should have historical data, some should address nearshore and open water conditions, a few of them should reflect human health, and at least one should consider atmospheric deposition. The IJC has tasked its IJC's advisory boards to provide a specific list of indicators based on this guidance. SOLEC representatives from EC and US EPA are consulting with the advisory boards in this process and this group will provide recommendations to the IJC. Based on those recommendations, IJC will issue more specific advice to the governments.

Having core indicators for which monitoring and prevention/remediation actions will be provided are essential. Such core indicators provide the public and policy makers with scientifically sound information to make better monitoring, restoration, and prevention decisions.

While the indicators must be scientifically based, take-home messages about condition and trends must also be accessible for the general public and readily understandable. Inevitably, any limited set of indicators will not measure all the parameters desired to address progress under the Agreement, but they should be sufficient to tell the story of progress and of problems in the ecosystem.

The IJC recognizes that the science behind selecting and defining the state of the lakes is important for assessing progress and that indicator selection and interpretation will continuously evolve.. However, progress reports would never be written if everyone waited for the perfect set of indicators. Assessments of progress must proceed using a manageable number of the best available indicators and data, so that governments and the public can continuously take steps to protect and restore the Great Lakes.

The IJC recommends that the governments develop their required progress reports related to the objectives of the Agreement, using a set of core indicators. The IJC also strongly recommends that the governments ensure the continued monitoring, assessment and reporting of status and trends for these indicators. Targets, goals or standards should be developed for each of the core indicators and resources should be provided for protection and restoration actions to achieve the goals.

Additional indicators, beyond the core set, can be valuable for research and resource management purposes. Provided resources are available for addressing the needs of the core indicators, resources could be allocated for monitoring data for additional indicators beyond the core set and these too should have targets, and governments should undertake the necessary actions to achieve them.

Relationship with the State of the Lakes Ecosystem Conference

One role of the IJC is to provide the governments of Canada and the United States with independent, binational science-based advice. To meet its responsibilities, the IJC needs to work in close collaboration with several government departments and agencies in both countries. In particular, the assessment of progress in achieving the goals of the Agreement requires a close exchange of information between the IJC and the agencies involved with creating the State of the Lakes Ecosystem Conference (SOLEC) reports.

SOLEC was established under the 1987 Agreement. The US Environmental Protection Agency and Environment Canada hosted conferences every two years on behalf of the two countries. Under the 2012 Agreement, the conferences will be held every three years. The conferences report on the state of the Great Lakes ecosystem and the major factors impacting it and provide a forum for exchange of information among Great Lakes decision makers, scientists and stakeholders. Tapping into the resources of multiple government agencies and other organizations, SOLEC reports assess the state of the Great Lakes ecosystem based on accepted indicators and help improve decision-making and resource management.

The SOLEC indicator reports can provide much of the information required by the IJC to write its periodic assessment of progress reports. The SOLEC reports by design are not intended to have the same purpose as IJC's own independent assessment of progress

report. The IJC has a complementary but different role to play.
While the SOLEC reports are broad in scope and useful in their content, they would be even more helpful if organized in a manner that clearly linked to the Agreement's objectives. More attention to consistent and historical trend analysis would enhance their value. Because the SOLEC report is web-based, it could be better organized to meet the diverse information needs of various users. These changes would make the SOLEC reports more useful for resource managers while also facilitating the IJC's progress report. SOLEC reports could be organized in such a manner to link its indicator reports to 2012 Agreement objectives to facilitate development of the IJC's assessment of progress report. Also, indicator reports could be sorted temporally, spatially, or by topic to better meet particular needs of resource managers. For instance, the system should allow a user to quickly find those indicator reports with data from 2000 to present, or for just Lake Erie, or find information on a particular topic, such as harmful algal blooms.

This report attempts to expand upon the SOLEC reports by sorting through the set of SOLEC indicators to identify those that have data focusing on the objectives of the Agreement, provide data back to 1987 (or close to that point in time), and meet other criteria for selecting indicators to best serve the needs of this report. The IJC determined that 13 of the 80 SOLEC indicators were useful for this particular purpose. Three other indicators used in this report came from outside of SOLEC. While the SOLEC indicator reports provided much of the material presented in this report, additional discussion was typically added to better describe the relationship to the Agreement's objectives and the methods used to compile the data. For many of the indicators presented, additional literature was reviewed, synthesized, and referenced.

Selection of indicators and approach for this report

The sixteen ecological indicators were selected by IJC based on existing criteria (USEPA 2000, OECD 2003). Criteria included the availability of historical and spatial information, relevance to Agreement or environmental management objectives, ecological importance (e.g., keystone species), availability of experts to contribute and quality of data.

The indicators selected for this report include measures of status and trends along with the drivers of those trends (the cause of a decline in status or the reason for an improvement). Examples of pressures or stressors are phosphorus loading and atmospheric deposition. Other indicators measure the government's performance, specifically on keeping beaches clean enough to stay open and improving conditions at many degraded areas, called Areas of Concern. Therefore, some of the indicators in this report reflect conditions while others reflect pressures or stressors and a third set reflect performance. Most of the indicators in this report reflect overall trends across the Great Lakes. In addition, considering the inherent variability across this large region, we have included a few indicators that are specific to a particular basin or region (for instance, burrowing mayfly density and phosphorus loading for western Lake Erie).

There are 16 chapters, one on each indicator, that were developed by a team of Great Lakes scientists and IJC staff. Most chapters include contributors from both countries, reflecting the shared binational goal to implement the Agreement and protect the Great Lakes. The indicator chapters are organized in four groups: 1) seven chapters on chemical integrity; 2) two on physical integrity; 3) five on biological integrity; and 4) two on evaluating the effectiveness of government programs. Each chapter initially discusses how the indicator relates to the objectives of the 1987 Agreement and then describes why the indicator is important, methods, results, discussion and potential future use of the indicator.

All of the indicators relate to at least one of the general objectives or Annexes of the Agreement (Table 1) and some relate to several objectives. In general, the scientific experts contributed data and interpretations of data. IJC staff provided input from additional literature review, synthesized information and edited information provided by the experts. The balance of the report, the Executive Summary, Introduction and Conclusions/Recommendations chapters, represents the IJC's own independent viewpoints. The report makes recommendations regarding how the collection, provision and reporting of information can be improved to further facilitate the assessment of progress task. The IJC in formulating its recommendations considered the input of many binational experts and comments from reviewers.

This introduction, along with the executive summary and conclusions/recommendations chapters are written in language to provide accessible information to federal, state, provincial and local governments as well as private organizations, businesses and individuals. The three general chapters are supported by 16 science chapters, with one chapter on each indicator and many references provided.

This report was initiated in spring 2011. An early draft of this report was released to the public on the IJC's website and at the 2011 Great Lakes Water Quality Biennial Meeting in Detroit on October 12-14, 2011. The draft report was revised based on comments received from multiple other Great Lakes organizations and subsequent work resulted in another draft report. That draft was revised again based on comments from members of IJC's Great Lakes advisory boards, Environment Canada and USEPA. The IJC appreciates the comments from its many reviewers which help provide the perspectives of the Great Lakes community.

Conclusion

The International Joint Commission offers this 16th biennial report to assist the Canadian and US governments, state and provincial governments and the public in better understanding the achievements and the challenges associated with protecting and restoring the Great Lakes. This is true both with respect to measures to be taken and improvements to the understanding and reporting of progress relative to core indicators

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Table 1. Comparison of indicators used in this report with the 1987 Great Lakes Water Quality Agreement objectives.

	CHEMICAL							PHY.	BIOLOGICAL					
INDICATORS / **GLWQA OBJECTIVES**	Contaminants in Herring Gull Eggs	Fish Consumption - Contaminant Levels	Contaminants in Whole Fish	Contaminants in Mussels	Contaminants in Sediment Cores	Phosphorus Loading	Atmospheric Deposition of Toxic Contaminants	Source Water Temperature & Ice Cover	Aquatic Invasive Species	Burrowing Mayfly Density	Diporeia Abundance	Lake Sturgeon Abundance	Lake Trout Abundance	Beach Closings and Advisories
General Objectives (**Article III**)														
Free from substances that ….settle to form putrescent or sludge deposits, or that will adversely affect aquatic life or waterfowl	X	X	X											
Free from materials and heat…that will produce conditions that are toxic or harmful to human, animal or aquatic life	X	X	X				X	X						
Free from nutrients….as a result of human activity in amounts that create growths of aquatic life that interfere with beneficial uses						X								
Specific Objectives (**Annex 1**)														
CHEMICAL														
Persistent Toxic Substances, Organics														
Pesticides														
Aldrin/Dieldrin	X			X										
Chlordane		X		X										
DDT and Metabolites	X			X										
Heptachlor/Heptachlor Epoxide	X													
Mirex	X	X												
Toxaphene		X												
Other Compounds														
PCB, Mercury	X	X		X	X									
Fish (whole): ≤ 0.1 (PCB); ≤ 0.5 (Hg) µg/g wwt			X											
Unspecified Organic Compounds (demonstrated to be persistent and likely toxic)	X		X		X									
Persistent Toxic Substances, Inorganic Metals														
Arsenic				X										
Cadmium				X										

Chromium														
Copper				X										
Lead				X	X									
Mercury				X	X									
- Fish (whole): ≤ 0.5 µg/g wwt			X											
Nickel				X										
Nutrients						X								
Phosphorus (Based on the maximum annual phosphorus loads listed in Annex 3)														
no change in temperature that would adversely affect any local or general use of the waters								X						

MICROBIOLOGICAL

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 disease or infection														X
Annex 2 – RAPs, LaMPs and BUIs	X	X	X	X	X	X	X		X	X	X	X	X	X
Annex 3 - Control of Phosphorus						X								
Annex 6 - Pollution from Shipping Sources									X					
Annex 10 - Hazardous Polluting Substances	X	X	X	X	X									
Annex 11 - Surveillance and Monitoring	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Annex 12 - Persistent Toxic Substances	X	X	X	X	X		X							
Annex 13 - Pollution from Nonpoint Sources						X								
Annex 14 - Contaminated Sediment					X									
Annex 15 - Airborne Toxic Substances							X							

Section 2. Indicators of Chemical Integrity

2.1 Contaminants in Herring Gull Eggs

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Summary

Persistent toxic chemicals such as DDT and PCBs have impacted the thickness of egg shells and other aspects of development in many species of fish-eating birds. Herring gulls are colonial waterbirds that are permanent residents of the Great Lakes, and because they eat fish they accumulate high concentrations of toxicants from the food web. Environment Canada's Herring Gull Egg Monitoring Program has monitored many contaminants since 1974. The eight discussed here are: PCBs, mercury, dichlorodiphenyl-dichloroethene (DDE), hexachlorobenzene (HCB), heptachlor epoxide HE, mirex dieldrin, and dioxin. Levels of these chemical contaminants in herring gull eggs have declined by over 90% since 1974 and 64-87% since 1987. However, in recent years declines of some chemical concentrations have slowed and mercury levels have remained stable since the mid-1990s. Because herring gulls in polluted areas are experiencing more abnormalities than herring gulls in cleaner habitats, continued reductions in chemical concentrations are desirable and the monitoring program should continue.

Importance for measuring progress toward objectives

Colonial waterbirds, including gulls, terns, herons and cormorants, are among the top aquatic food web predators in the Great Lakes ecosystem and are very visible and well known to the public (SOLEC 2009). 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 (Weseloh 1984, Norstrom et al. 2002). Therefore, only the herring gull accumulates contaminants that come only from the Great Lakes, and, thus, only they reflect Great Lakes conditions. Since other colonial species accumulate contaminants from their wintering grounds outside of the Great Lakes, they may not reflect the condition of the Great Lakes. Furthermore, the herring gull is an ideal indicator because the species eats primarily small forage fish including alewife (*Alosa psedoharengus*) and rainbow smelt (*Osmerus mordax*) (Norstrom et al. 2002). Therefore, they are a very cost-efficient monitoring system and they facilitate comparisons over time and among lakes.

Persistent bioaccumulative toxicants (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, concentrations of PBTs can accumulate thousands or millions of times in large predator fish and in fish-eating birds. PBTs also accumulate 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 have been conducted here for more than 45 years (Keith 1966, US Fish and Wildlife Service 2010).

Environment Canada's 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 Weseloh, 1998). This monitoring program now determines contaminant levels of up to 20 organochlorines, 65 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 seven contaminants since 1974: PCBs, mercury, dichlorodiphenyl-dichloroethene (DDE, a breakdown product of DDT), hexachlorobenzene (HCB), heptachlor epoxide (HE), mirex and dieldrin. Dioxins have been monitored since the 1980s.

Article II of the 1987 Great Lakes Water Quality Agreement (1987 Agreement) states that its purpose 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 1987 Agreement, 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 given in Appendices 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. Finally, toxic chemicals in herring gull eggs are related to bird or animal deformities or reproduction problems, which is one of the Beneficial Use Impairments listed in Annex 2, Section 1c. of the 1987 Agreement.

Methods

Since 1974, Environment Canada has collected 10-15 eggs annually from up to 13 nesting colonies in the Great Lakes, in connecting channels and the international section of the St. Lawrence River (Figure 1). Egg contents were selected because collection is rather easy and inexpensive, and because lipid contents in eggs are less variable than in other tissues (Weseloh et al. 1979, Hebert et al. 1999, de Solla et al. 2010a, 2010b). Further details and temporal trends for 1974-1995 are described in Pekarik and Weseloh (1998). Since this report focuses on changes in eggs since 1987, a separate specific analysis was performed. Annual mean and standard error values were calculated for each contaminant across all 15 sites for the years 1987-2009. This approach provides an assessment of overall changes in the Great Lakes. The method assesses changes for the selected contaminants rather than focusing on individual site data that may vary due to local site conditions such as changes in the local food web, and provides a simple assessment of the variability among sites. The resulting temporal pattern for each compound was evaluated by linear/logistic regression on log transformed data using SAS 9.1. Data on spatial patterns were taken from Weseloh et al. (2006).

Results

Most chemical contaminants 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 dioxin (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 have 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. 2011), current concentrations and spatial and temporal trends of total mercury were analyzed in eggs of herring gulls 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 intercolony differences in mean mercury concentrations (2005-2009). Mercury concentrations declined from 23% to 86% between when they were first measured (usually 1974) and 2009. Declining temporal trends over the entire period (1974-2009) were significant at 10 of the 15 sites. However, there were no significant temporal trends in mercury over the last 15 years. More recently, declines of mercury 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). Specifically, because of declines in the availability of small fish in the Great Lakes, herring gulls have largely shifted to a more terrestrial diet. While this doesn't entirely contradict their use as indicators of Great Lakes contaminants, it is possible that observed declines in eggs may be due to shifts in food as opposed to declining levels in the ecosystem (Hebert et al. 2008).

Overall, mercury 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 mercury data in gulls 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

Herring gulls and other colonial waterbirds appear to be much healthier now than in the mid-1970s (Environment Canada 2003) which is consistent with the reduction in contaminant levels found in eggs (Figures 2, 3 and 4). Yet, contaminants continue to be made available to the food chain from multiple sources including resuspension of sediments, underground leaks from landfill sites and atmospheric deposition. More abnormalities still occur in herring gulls at some of the monitored sites than at cleaner reference sites in the Great Lakes (Environment Canada 2003). Most of these abnormalities were not monitored in the early years of the program, so it is not possible to evaluate long-term trends. Abnormalities of concern include elevated levels of embryonic mortality, indications of feminization in 10% of adult males, an enlarged thyroid gland with reduced hormone production and a suppressed immune system. Though progress has been made in reducing chemical levels these observed effects indicate more progress is needed to fully meet the goal of restoring the chemical and biological integrity of the Great Lakes Basin Ecosystem.

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 when 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 38-year historical data set at the same monitoring sites. The herring gull is an extremely well-studied and well-known species on the Great Lakes.

Future use of indicator

The existing monitoring program could be supplemented with monitoring of levels of chemicals of emerging concern along with the seven existing monitored chemicals (Gauthier et al. 2008, Gebbink et al. 2011, Chen et al. 2012). Other research activities could 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 1987 Agreement and the 2010 Agreement.

Overall, this indicator is used for tracking long-term trends in contaminants across the Great Lakes. It is one of the most consistent, long-term programs for Great Lakes trends and integrates many trophic levels. It truly tracks trends at colony and lake levels. Monitoring of contaminants in herring gull eggs is a core indicator for measuring progress towards the objectives of the 1987 and 2010 versions of the Agreement

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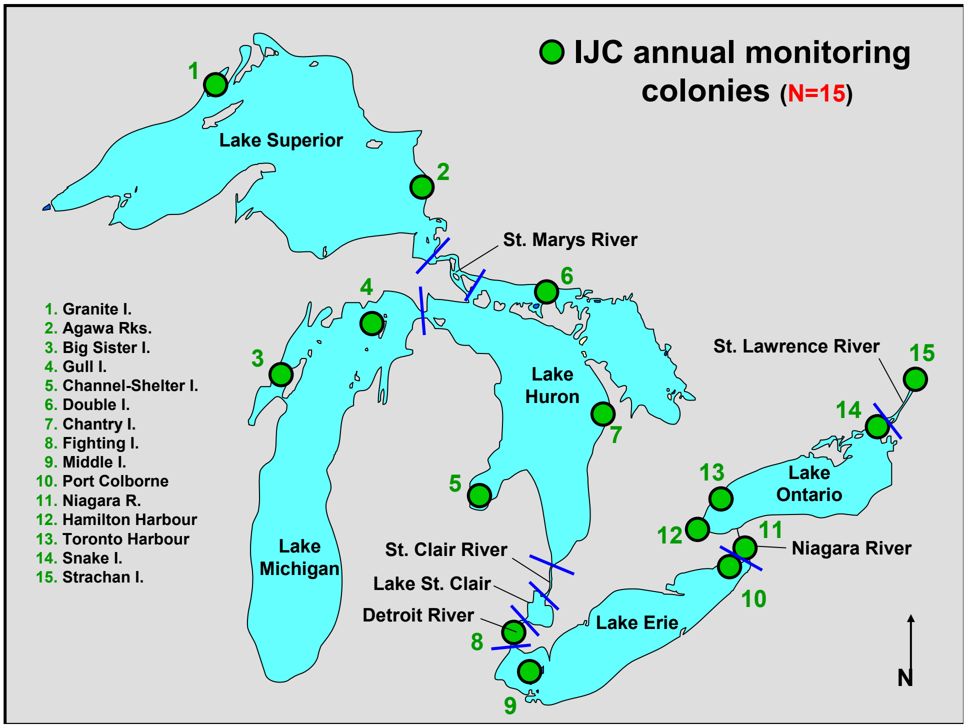

Figure 1. Location of sampling sites.

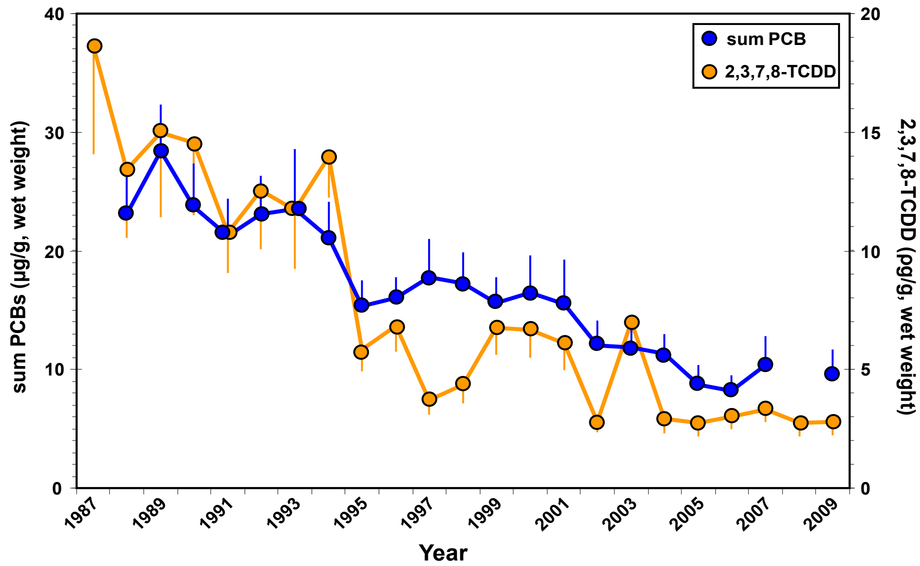

Figure 2. Mean (±SE) wet weight values of sum PCBs (µg/g) and 2,3,7,8-TCD dioxin (ρg/g) measured in herring gull eggs collected at 15 IJC sampling colonies from 1987-2009 (sample sizes ranged from 13-15 colonies per year). Error bars are symmetrical around the means, but for clarity only a single tail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

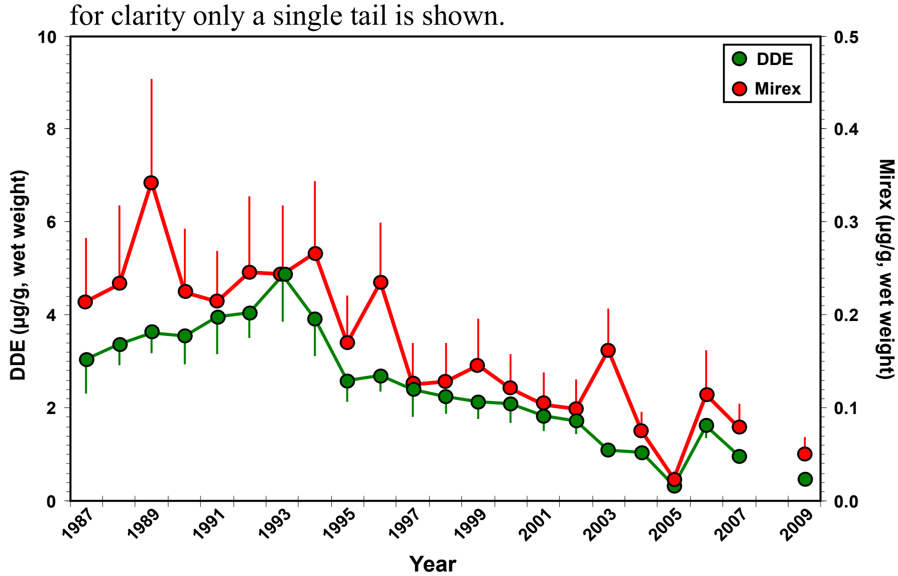

Figure 3. Mean (±SE) wet weight values of DDE (µg/g) and mirex (µg/g) measured in herring gull eggs collected at 15 IJC sampling colonies from 1987-2009 (sample sizes ranged from 14-15 colonies per year). Error bars are symmetrical around the means, but for clarity only a single tail is shown.

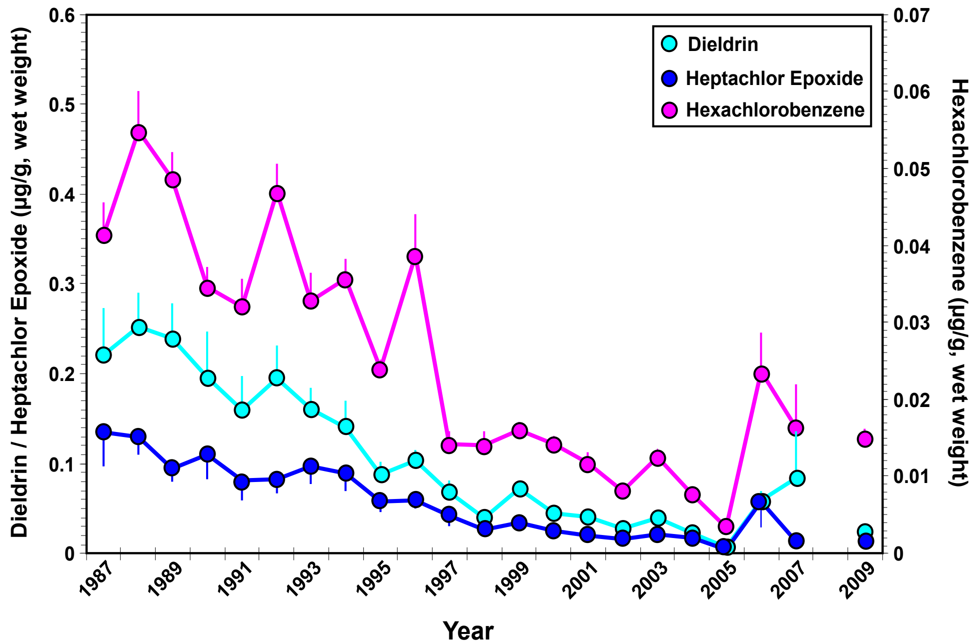

Figure 4. Mean (±SE) wet weight values of dieldrin (µg/g), heptachlor epoxide (µg/g) and hexachorobenzene (µg/g) measured in herring gull eggs collected at 15 IJC sampling colonies from 1987-2009 (sample sizes ranged from 14-15 colonies per year). Error bars are symmetrical around the means, but for clarity only a single tail is shown.

2.2 Fish Consumption Restrictions

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Summary

The levels of persistent toxic chemicals in the edible portions of Great Lakes fish declined between the 1970s and 1987 and for a few years thereafter. Since about 1990 the levels of contaminants have either declined at a slow rate or have stabilized with year-to-year fluctuations. Numerous restrictive fish consumption advisories aimed at protecting human health from contaminant exposure remain in place for all of the Great Lakes. The majority of these advisories are driven by concentrations of polychlorinated biphenyls or PCBs (including dioxin-like PCBs).

Importance for measuring progress toward objectives

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

Annex 2 of the 1987 Great Lakes Water Quality Agreement (1987 Agreement) requires development of lakewide area 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), its addendum, A Protocol for Mercury-based Fish Consumption Advice (2007) 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 total PCB, dioxin/furan/dioxin-like PCB, mercury, toxaphene, chlordane and mirex.

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 toward achieving the objectives of the 1987 and the revised 2012 Agreement.

Methods

Various tribal, state/provincial and federal agencies have monitored contaminant levels in Great Lakes sport fish fillets at differing frequencies. For the Canadian side, the Ontario Ministry of the Environment (OMOE) has been monitoring fish contaminant levels for over three decades and issues consistent advisories for the Canadian waters of the Great Lakes generally based on tolerable daily intakes from Health Canada. OMOE and the Great Lakes states use their data to issue fish consumption advisories.

In the United States, various state and tribal programs are responsible for issuing advisories. For this reason, different jurisdictions use different sampling protocols and risk assessment methodologies to issue advice. However, many states use the Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory (Great Lakes Fish Advisory Task Force, 1993) and the 2007 addendum, A Protocol for Mercury-based Fish Consumption Advice, when issuing their advice. Additionally, all of the eight Great Lake states routinely share data, use similar messaging and work collaboratively as they seek to provide similar advice basin-wide.

OMOE’s long-term data are appropriate to use for long-term trend analysis. In contrast, the combined monitoring data from varying agencies using different protocols on the US side by design is not suitable for trend analysis of contaminants in the edible portions of sport fish.

In an attempt to categorize the status of fish consumption advisories in the Great Lakes for summary reporting, a new Fish Consumption Advisory Rating Indicator was created jointly by USEPA and OMOE in 2011. In this new rating method, scores on a scale of 1 to 5 were assigned to each advisory based on the severity of the restriction on fish consumption (Table 1). The scores were based on the advisories issued by the Great Lakes states and OMOE for two common species— lake trout (*Salvelinus namaycush*) and walleye (*Sander vitreus*)—according to size class and the common contaminant PCB. Lake trout was used by USEPA for all the lakes and by OMOE for all the lakes except Lake Erie, where walleye was used. Lake trout and walleye were chosen because they are top predator fatty fish and they represent a reasonable "worst case scenario" for fish consumption advisories that are largely driven by organic chemicals such as PCB. Average scores for each lake were derived by taking the mean of the applicable states' and Ontario's scores for each lake. Because this is a new type of assessment, trends cannot be readily discerned at this time nor does it have any bearing on state or provincial fish consumption advice.

Results

Most of these results were presented in the SOLEC report, Contaminants in Sport Fish, Indicator #4201 (SOLEC 2009). Total PCBs and dioxin-like PCBs are the cause of most fish consumption advisories on each side of the border. Most of the remaining advisories in the basin are based on mercury, dioxins/furan, toxaphene, DDE or mirex contamination (Table 2).

Overall, total PCB levels in edible portions of lake trout in Lakes Ontario, Huron and Michigan have declined since the 1980s by as much as an order of magnitude and may still be decreasing, albeit at a lower rate (Figure 1; Bhavsar et al., 2007; Carlson et al., 2010; Stow et al. 2004). Total PCB concentrations in Lake Superior lake trout declined in the 1980s by more than 80%; however, the concentrations have remained stable since 1990 and advisories limit consumption to two to four meals per month (Bhavsar et al., 2007; Carlson et al., 2010; OMOE 2011). In contrast, total PCB trends in Lake Erie lake trout are not clear and may be weakly increasing during the last two decades; however, the levels are among the lowest in the Great Lakes fish (Figure 1; Bhavsar et al., 2007; Carlson et al., 2010; Sadraddini et al., 2011a).

The levels of dioxins and furans generally declined in lake trout from Lakes Ontario, Huron and Superior during the 1980s and appear to be either declining or stable during the 1990s (Bhavsar et al. 2008). Reports on measurements from the 2000s onward are needed to understand the more recent trends of dioxins and furans.

Mercury levels were historically the highest and lowest in Lakes Superior and Erie lake trout, respectively, and differed by a factor of 2-3; however, these spatial differences have diminished in recent years largely due to declines in Lake Superior fish concentrations (Bhavsar et al., 2010). Lake trout mercury levels in Lakes Superior, Huron and Ontario have declined by more than 50% since the 1970s, and either continue to decline at a slower rate or are stable (Bhavsar et al. 2010). In contrast, Lake Erie fish show a weak increasing trend in recent times (Bhavsar et al. 2010; Sadraddini et al. 2011b).

Toxaphene is highest in Lake Superior fish (Xia et al., 2012). Concentrations in some large lake trout have supported advice to limit consumption (Bhavsar et al., 2011; OMOE 2011). Mirex is still detected only in Lake Ontario lake trout (Carlson et al., 2010). Fish concentrations of other contaminants such as DDT/DDE/DDD and dieldrin are not a major concern for human consumption (Bhavsar et al. 2011; OMOE 2011) and are generally declining, albeit at a slower rate (Carlson et al. 2010).

In the St. Clair River/Lake St. Clair corridor of Canada, declines in concentrations of total PCB, mercury and other chemical contaminants of concern in fish were observed through the 1980s and 1990s, after which the decreases slowed or concentrations stabilized. Researchers hypothesize that sediments are now a source of elevated contaminant levels, and have confirmed that the PCB and mercury levels continue to be of concern for the health of sport fish consumers (Gewurtz 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, all lakes have some restrictions and levels of some chemicals continue pose the most severe restrictions of lake trout in Lakes Huron and Ontario. There are “do not eat” restrictions in the United States and in Canada consumption is limited to six times per year for similar sized fish. Despite the considerable declines in contaminant levels from 40 years ago, in recent years 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”. Although U.S. and Canadian data cannot be directly compared due to a number of reasons including differences in the way consumption advisories are issued, they do follow similar patterns in terms of the severity of consumption restrictions in the individual Great Lakes. According to the average lake score, consumption advisories for lake trout are most restrictive in Lakes Ontario and Huron and least restrictive in Lake Superior (Figures 2 and 3). 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. PCB continue to drive most fish advisories despite the fact that this class of chemicals was banned in the U.S. and Canada in the 1970s. This is likely due to large amounts of PCB still present in the environment due to their persistent nature and also possible on-going release at lower levels from old electrical equipment and other sources.

The slowing of the rate of decline or stabilization of levels of several high-importance persistent, bioaccumulative, and toxicants (PBTs) monitored in Great Lakes sport fish has implications similar to those discussed for herring gull egg contaminants. Mobilization from contaminated sediments, changes in the foodweb structure due to invasive species 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 of PBTs, 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. 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 responsible agencies are working to assure monitoring and reporting of chemicals of emerging concern, including PBDEs which are discussed in a separate indicator report.

Health risk communication is a crucial component to the protection and promotion of human health in the Great Lakes region. Partnerships between states and tribes, involving the issuing of fish consumption advice, are improving U.S. fish advisory coordination. In Canada, partnerships exist between the federal and provincial agencies responsible for providing fish consumption advice to the public. At present, PCB, mercury, and chlordane are the only PBTs 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 indicator

In order to best protect human health, increased monitoring and reduction of PBTs 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 Toxic Substances and 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 contaminant levels in blood and urine samples from people who live in the Great Lakes basin. The purpose of the study is to determine if there is a higher amount of contaminants in people with greater exposure, such as those who eat substantial amounts of Great Lakes fish. This information will guide actions that the state health departments take to protect citizens. OMOE, recently conducted a province-wide survey of fish consumption including the Great Lakes region. This survey is expected to result in a better understanding of the sport fish consumption pattern on the Canadian side of the Great Lakes.

In addition, improved understanding of the potential negative health effects from exposure to PBTs is needed. An increased focus on emerging chemicals is occurring in monitoring programs in Canada and the United States. While USEPA's Great Lakes National Program Office (GLNPO) no longer collects or analyzes sport fish fillets, GLNPO has instituted an Emerging Chemicals Surveillance Program in whole fish to identify the presence or absence of emerging chemicals of interest and inform state monitoring and advisory programs. The first year of this program is 2011 and results were shared through various outlets, including the State of the Lakes Ecosystem Conference (SOLEC).

The Ontario Ministry of the Environment continues to monitor contaminants of long term concern such as PCB, dioxins/furan, mercury and organochlorine pesticides in edible portions (i.e., skin-less fillet) of Great Lakes fish. Both federal and provincial Canadian agencies have initiated monitoring of various contaminants of emerging concerns in selected Great Lakes fish. It is believed that these monitoring efforts will result in increased knowledge on the significance of these chemicals for the health of humans consuming Great Lakes fish.

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Data sources

Sport fish consumption advisory programs

Ontario Ministry of the Environment - www.ontario.ca/fishguide

Minnesota Department of Health - http://www.health.state.mn.us/divs/eh/fish/index.html

Illinois Department of Public Health - http://www.idph.state.il.us/envhealth/factsheets/fishadv.htm

Indiana Department of Health - http://www.idph.state.il.us/envhealth/factsheets/fishadv.htm

Michigan Department of Community Health - http://www.michigan.gov/mdch/0,1607,7-132-54783_54784_54785---,00.html

New York Department of Environmental Conservation - http://www.dec.ny.gov/outdoor/7736.html

Ohio Environmental Protection Agency - http://www.epa.state.oh.us/dsw/fishadvisory/index.aspx

Pennsylvania Department of Environmental Protection - http://www.portal.state.pa.us/portal/server.pt/community/fish_consumption/10560

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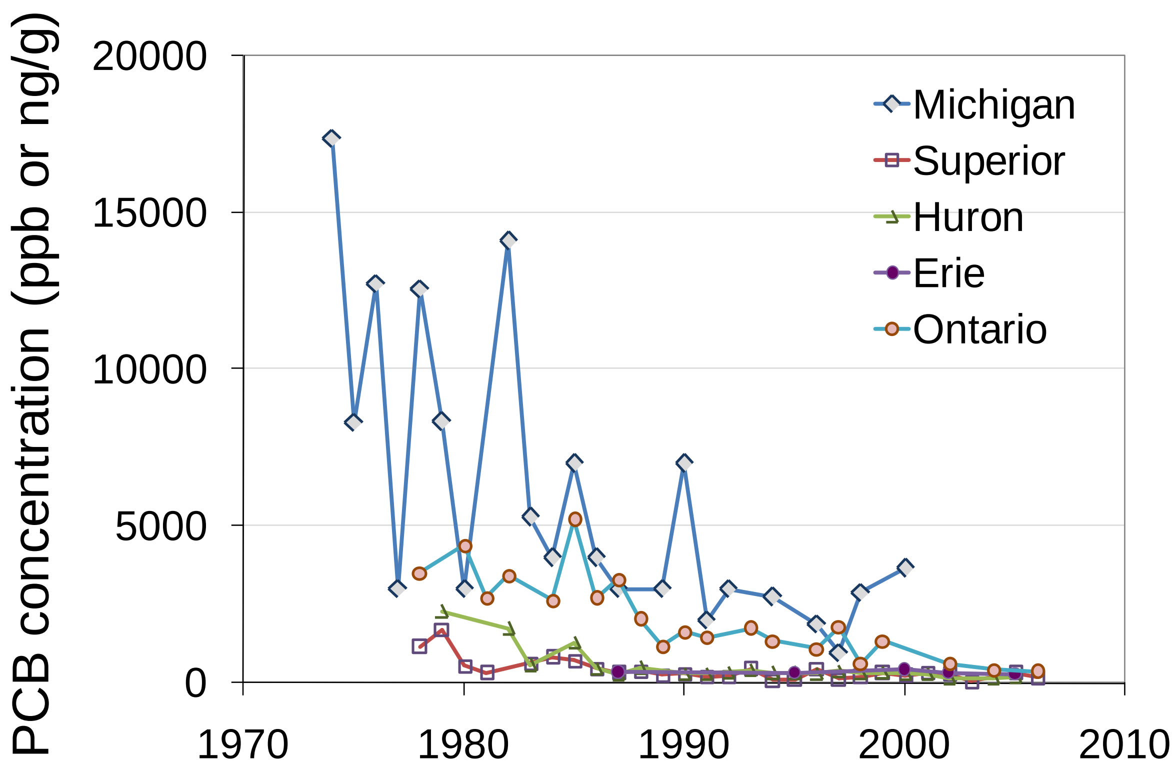

Figure 1. Long-term trends of total PCBs in Great Lakes lake trout. Data were adopted for skin-on lake trout fillet samples from Lake Michigan from Stow et al. (2004) and for skin-off lake trout fillet samples from the other lakes from Bhavsar et al. (2007).

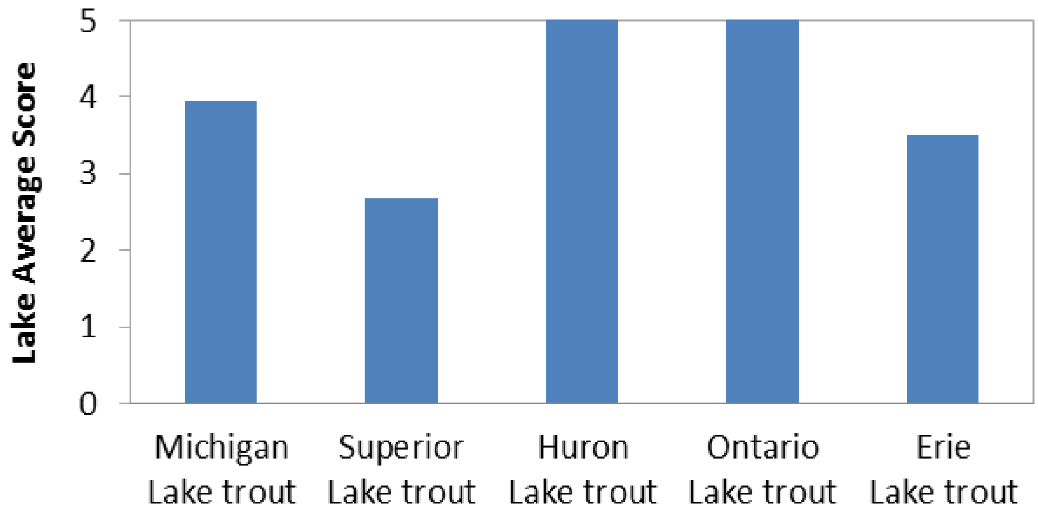

Figure 2. US Fish Consumption Advisory Rating (Source: US State Consumption Advisory Programs. Compiled by USEPA, Great Lakes National Program Office).

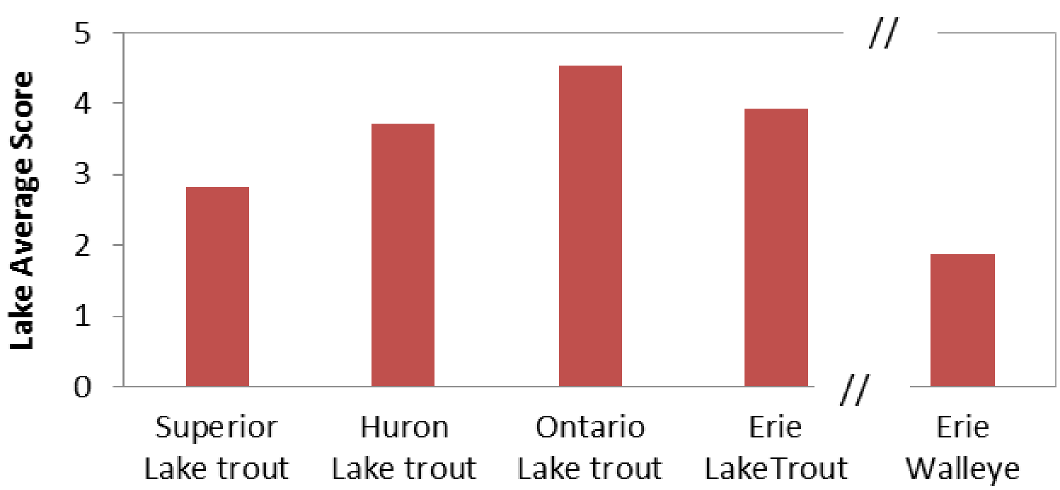

Figure 3. Canada Fish Consumption Advisory Rating (Source: Ontario Ministry of the Environment. Compiled by USEPA, Great Lakes National Program Office).

Table 1: Consumption advisory scores used to calculate Fish Consumption Advisory Rating

Consumption Advisory	Score
Unrestricted (8 meals / month)	1
1 meal/week (4 meals / month)	2
1 meal/month	3
6 meals/year	4
Do not eat	5

Table 2: Contaminants responsible for great lakes fish consumption advisories.

Lake	State/Province	PCB	Dioxin	Mercury	Chlordane	Mirex	Toxaphene
Superior	Michigan	x		x	x		
	Wisconsin	x	x	x			
	Minnesota	x		x			
	Ontario	x	x	x			x
Huron	Michigan	x	x				
	Ontario	x	x	x			
Erie	New York	x					
	Ohio	x					
	Pennsylvania	x					
	Michigan	x					
	Ontario	x	x	x			
Ontario	New York	x	x			x	
	Ontario	x	x	x			
Michigan	Illinois	x			x		
	Michigan	x			x		
	Indiana	x					
	Wisconsin	x					

*Not all states issue advisories for all of the listed contaminants

2.3 Contaminants in Whole Fish

Author: Vic Serveiss, International Joint Commission.
Reviewers: Daryl McGoldrick, Mandi Clark, Environment Canada; Elizabeth Murphy, US Environmental Protection Agency

Summary

Contaminants in whole lake trout and walleye (the entire fish including bones) are measured as an indicator of ecosystem health. Since 1987, concentrations of several persistent toxic chemicals in whole fish have continued to decline at rates of 3–9 percent per year. On the other hand, concentrations of mercury have been stable or increasing since about 1990. Concentrations of polybrominated diethyl ethers (PBDEs), found in flame retardants, in lake trout and walleye rose continuously through the early 2000s and have been declining since that time.

Importance for measuring progress toward objectives

Top predator fish integrate exposure to many bioaccumulative pollutants from their food webs reflecting inputs 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 chemical indicators, support the requirements of the Great Lakes Water Quality Agreement (1987 Agreement) 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. The whole fish indicator is distinct from the fish consumption indicator presented in the preceding chapter. While both indicators, in part, monitor trends of contaminants in fish tissue, this indicator uses the whole body (bone, skin, organs, etc.) in analysis. Additionally, samples for this indicator are collected in the open waters of the Great Lakes while the previous indicator collects samples from near shore areas. Sources of contamination vary greatly between these two zones. Ultimately, the previous indicator should be one that is considered a measure of risk to human health while the contaminants in whole fish indicator is one of ecosystem health.

Methods

The description of methods is largely based on the background information presented in SOLEC (2011). ”Long-term (greater than 25 years), basinwide monitoring programs that measure whole body concentrations of contaminants in top predator fish, such as lake trout (*Salvelinus namaycush*) and walleye (*Sander vitreus*), are conducted by both the US Environmental Protection Agency (USEPA) Great Lakes National Program Office through the Great Lakes Fish Monitoring and Surveillance Program (USEPA 2010), and Environment Canada’s (EC) Water Quality Monitoring Surveillance Division, through the Fish Contaminants Monitoring and Surveillance Program (EC 2011).

EC and USEPA collect lake trout 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 subsamples of all fish collected by both Canadian and US 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). USEPA 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 each year in each of the Great Lakes. These differences affect the variance structure of each dataset and the meaning of concentrations derived—the overall comparability of the data generated from each program was high, based on the data shown in the report.

Unless stated otherwise, trends through time were assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines.

For this report, EC and USEPA determined that trends were significant if the slope of model was greater or less than zero at $\alpha = 0.05$. Contaminant concentrations and trends are compared with criteria established in the 1987 Agreement (Annex 1, Specific Objectives) or other relevant guidelines developed to protect ecosystem quality.

This chapter focuses on three persistent bioaccumulative toxicants (PBTs): PCBs, mercury and polybrominated diphenyl ethers (PBDEs). These PBTs were selected for a variety of reasons. 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 1987 Agreement. Mercury has many toxic and human/wildlife health effects and concentrations appear to be increasing in some locations. 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.

Spatial variability is inherent to the process of large lake monitoring. Analysis of within lake site differences for specific chemicals has been conducted by Environment Canada and USEPA. In general, there are insignificant spatial differences in Lakes Ontario, Michigan and Huron for compounds such as PCBs and PBDEs. Environment Canada collects and analyzes two different species in Lake Erie, walleye in the western basin and lake trout in the eastern basin, and therefore cannot determine spatial differences in the lake. Statistically significant differences for some monitored chemicals are present among the stations situated in Lake Superior. The use of lake-wide averages for individual chemicals does ignore the spatial variability; however, lake-wide averages are used here to remain consistent with historical reporting and to present concise information in this very limited format. Individual data are available through both programs upon request to the EC and USEPA authors.

Results and Discussion

The results reported are largely based on the results reported in SOLEC (2011).

PCB

Total PCB concentrations in Great Lakes top predator fish have continuously declined since their phaseout 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 1987 Agreement target of 0.1 μg/g. 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 Agreement 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 USEPA 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 1987 Agreement 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 USEPA and Environment Canada have provided a timeline of PBDE contamination in Great Lakes fish since 1977 (SOLEC 2011, Figure 1). 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-BDE. 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 may be transported to the Great Lakes region in consumer products or by atmospheric transport.

Future use of indicator

Fish chemical concentrations are important to the ecosystem and to socioeconomics, and are relevant to chemical integrity and Agreement objectives. Since apex predators such as lake trout and walleye are dependent on complex biological and physiochemical interactions both within and outside of the Great Lakes basin, multiple variables that affect contaminant levels in Great Lake fish should be considered. increased collaboration between media monitoring groups (i.e., birds, fish, sediments, water, air) can yield more focused and efficient monitoring.

A changing climate and associated changes to temperature, precipitation and wind currents may alter food webs, the influx of contaminants, and the contaminant transfer through food webs. Aquatic invasive species also alter food webs and change energy and contaminant dynamics in the lakes. For instance, invasive Dreissenid filter feeders provide a new pathway by which sediment contaminant pools could be mobilized and transferred to fish.

Many current contaminants of concern are found in consumer products, personal care products and pharmaceuticals. As a result, wastewater treatment effluents are an important conveyor of contamination to aquatic ecosystems. . Monitoring programs may require modifications to adequately characterize contaminant concentrations in fish and the effect of these effluents. Much of the current monitoring and reporting focuses on legacy chemicals whose use has been previously restricted through various forms of legislation but that continue to be the source of the highest levels of contaminants detected in fish, e.g., PCBs. However, both the Canadian and US programs are making efforts to incorporate the monitoring and surveillance of emerging chemicals into their routine work. Chemicals of interest that could be considered for an expanded monitoring program are being identified through scientific studies (e.g., Howard and Muir, 2010), and though risk assessments by regulatory bodies.

Fostering collaboration between Canadian and US monitoring programs for various media will be beneficial, especially in times of fiscal restraint. In 2009, an informal binational group was formed to bring together government representatives and researchers working on identifying new chemicals in the Great Lakes ecosystem to seek and provide information on emerging contaminant surveillance, monitoring and chemical methods development. The group is led by Environment Canada's Water Quality Monitoring and Surveillance Division and US EPA's Great Lakes National Program Office and consists of EC and EPA monitoring program leaders and ~~funded~~ researchers The group provides a binational forum to communicate work plan and outcomes, and seek areas of potential collaboration, The group facilitates information exchange and collaboration on similar chemicals or classes of chemicals in differing media, provides an excellent opportunity for cost sharing, an accelerated rate of discovery of future toxic chemicals for consideration (early warning), and a validation of results among the Great Lakes research and monitoring community. Although the group was never formalized it could help the Chemicals of Mutual Concern Committee develop and regulate a list of chemicals of mutual concern, which is a required activity under the 2012 Agreement.

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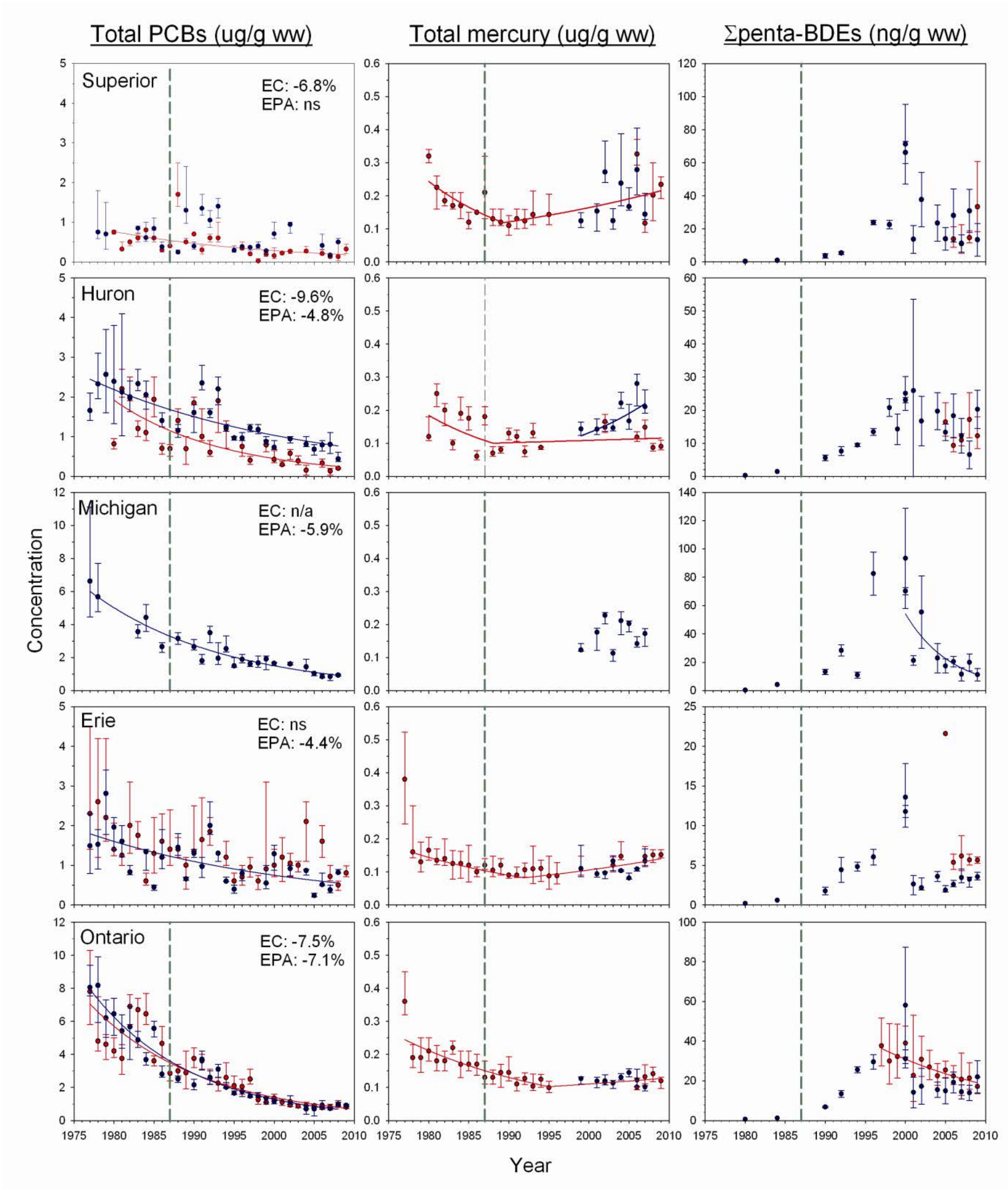

Figure 1. Concentrations of total PCB, total mercury and sum of penta-BDE (median & IQR) for individual (Environment Canada - red) and composited (US Environmental Protection Agency - blue) whole body lake trout or walleye collected from each of the Great Lakes. Solid lines show log-linear regression 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 1987, the earlier Agreement amendment.

2.4 Contaminants in Mussels

Authors: Annie Jacob, Edward Johnson, Kimani Kimbrough and Gunnar Lauenstein, National Oceanic and Atmospheric Administration; Antonette Arvai and Victor Serveiss, International Joint Commission.

Summary

Bivalve mollusks (two-sided shellfish) are a key part of environmental monitoring worldwide because they are widely distributed, accumulate persistent contaminants and are easy to collect. Mussel Watch chemistry data collected from 1992-2009 can be used to assess the status and trends of metals, along with legacy and emerging organic contaminants. Most of the Great Lakes sites did not show any trend in either metal or organic contaminant concentrations. However, since a few sites had large declines of contaminant concentrations, many of the metals and organic contaminants showed decreasing trends basinwide.

Importance for measuring progress toward objectives

The National Oceanic and Atmospheric Administration (NOAA) National Status and 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 invasion and proliferation of Ponto-Caspian mussels in the Great Lakes, the Mussel Watch Program expanded into the Great Lakes to monitor a wide array of contaminants, including metals, legacy contaminants and contaminants of emerging concern.

Mussels are a proven, viable and reliable ecological bioindicator with a long history of use worldwide (Cantillo 1998). The attributes that make mussels good bioindicators in environmental monitoring are: 1) widespread distribution and ease of collection; 2) sedentary nature; 3) tolerance to wide range of environmental conditions; 4) high bioconcentration capacity due to high filtration rates; 5) limited ability to metabolize hydrophobic organic contaminants; and 6) utility for monitoring biological effects of exposure to chemicals and other stressors (Farrington 1983; de Lafontaine et al. 2000). While all these factors make them valuable, unique indicator species, the notable quality that differentiates mussels from other indicators is its sessile nature. As mussels are sessile organisms, they integrate the contaminant exposure at the specific location where they are found, unlike many other mobile indicator organisms. Further, filter-feeding mussels are readily exposed to contaminants from the dissolved and particulate phases of the water column (Hellou et al. 2003) and the tissue burden of contaminants in mussels is indicative of the concentration in the ambient water column.

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. More importantly, contaminant tissue burden in mussels that reside at the base of the food chain reflect contaminant bioavailability and bioaccumulation potential, and thus provide information about environmental contamination and effects that cannot be defined by abiotic matrices.

Mussel Watch chemistry data are 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 manmade 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). Mussel Watch also participates in specimen banking, allowing for retrospective analysis of bivalve samples.

The purpose of the Great Lakes Water Quality Agreement of 1987 (1987 Agreement), as stated in Article 2, is to restore the chemical, physical and biological integrity of the Great Lakes. With respect to chemical integrity, Article II also commits both countries to prohibit “the discharge of toxic substances in toxic amounts and to virtually eliminate the discharge of persistent toxic substances." Under Annex 10 of the 1987 Agreement, the governments 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 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. This chapter summarizes the status and trends of chemical contamination in mussels, since the Mussel Watch Program started monitoring in the region in 1992.

Methods

The Mussel Watch Program monitors over 300 estuarine, lakeshore and coastal sites distributed in the continental United States, Alaska, Puerto Rico and Hawaii (Kimbrough et al. 2008). In the Great Lakes, Mussel Watch sites have been established basinwide (either within the harbors or lakes proper) from which *Dreissena polymorpha* (zebra mussels) and *Dreissena bugensis* (quagga mussels) are collected for analysis. No data are reported for Lake Superior because Mussel Watch monitoring did not begin there until 2006. There are 23 core Mussel Watch sites within the Great Lakes that have long-term data, and 30 sites that are a part of the more targeted current monitoring effort. Of the 23 long-term sites in the region, five sites (Milwaukee Bay, Calumet Breakwater, Saginaw River, Niagara Falls and Rochester) are located in areas of concern (AOCs), which are significantly degraded areas designated by the IJC, and the rest are integrative sites that are representative of the local area (Figure 1). Those sites in AOCs represent the urban and industrial nature of the watershed and provide perspective to the measurements from integrative sites distributed basinwide.

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 zones, from natural substrates, usually at depths of less than 20 feet but more than 3 feet. Upon collection, they are brushed clean, placed in Ziploc bags, packed on 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 descriptions are detailed in Lauenstein and Cantillo (1998 and references therein), Kimbrough and Lauenstein (2006) and Kimbrough et al. (2006).

Figure 1. Map depicting long-term (●) and newly established (▲) Great Lakes Mussel Watch sites. Labels presented only for long-term sites for which trend analyses have been done. Mussel Watch sites are generally nearshore and do not represent the main stem of any of the lakes.

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 1987 Agreement, Appendix 1 and 2 of Annex 10 (Table 1).

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

Metals	Organic Contaminants
Arsenic Cadmium Copper Lead Mercury Nickel	Chordane (alpha-chlordane) DDT (sum of 6 compounds) Dieldrin/Aldrin PAH- Benzo[e]pyrene PCB (sum of 18 congeners)

The temporal trends in chemical contamination (basinwide and site specific) are determined using Spearman's Rank Correlation (Gauthier 2001), a nonparametric technique that is free of assumptions about concentrations being normally distributed with a common variance about sites. All Great Lakes data were pooled from all sites for each contaminant. The status summary of contaminants is determined using cluster 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. 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 occur naturally in the environment, but human use of metals can contribute to elevated levels. 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 nonessential metals, such as mercury, lead and cadmium in surface water is of particular concern due to their impacts on aquatic life. Mercury for example, in the form of methylmercury, can alter behavior (e.g., predator-prey interactions) and negatively impact growth and reproduction (USEPA 1997). Cadmium has been found to inhibit growth, impair reproduction and reduce survival of freshwater aquatic organisms (CCME 1999).

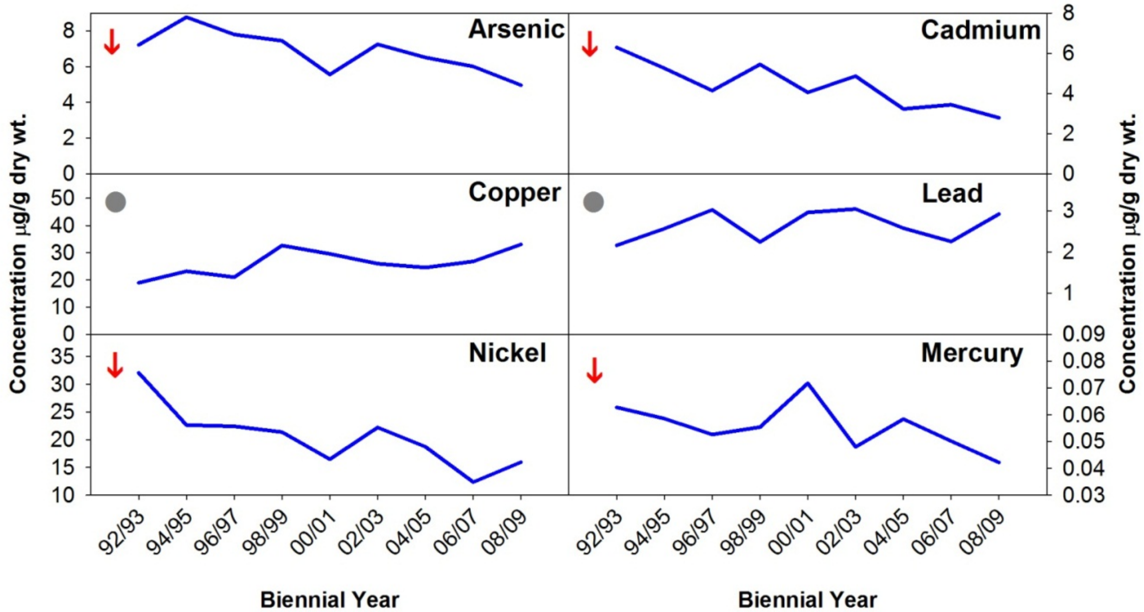

Figure 2. Basinwide trends in mean concentrations (µg/g dry weight) of select metals (↓decreasing trend and ●no trend) in dreissenid mussels from long-term Mussel Watch sites in the Great Lakes from 1992-2009.

Of the metals examined, arsenic, cadmium, mercury and nickel show statistically significant ($p < 0.05$) decreasing trends basinwide, whereas copper and lead exhibit neither decreasing nor increasing trends in the Great Lakes (Figure. 2). Further, trend analysis at the site level shows that there is no discernible trend for metals at a majority of the sites. Where trends do exist, they are predominantly decreasing, except for copper, which shows an increasing trend, but only at less than 10% of the sites. More site-specific data can be found in Kimbrough et al. (2008) and data can be downloaded at http://NSandT.noaa.gov.

The concentration of metals in dressenid mussels reported herein is similar to the findings in studies elsewhere and in the region (Richman and Somers, 2010; Lowe and Day, 2002; Berny et al. 2003). A majority of the sites for all metals except for cadmium, have concentrations in the low group that are indicative of background levels (Figure 3). The elevated concentrations (i.e., the concentration in the high group; Figure 3) of metals at few of the Great Lakes sites may be either due to natural factors or associated with anthropogenic influence. Though identifying the sources is beyond the scope of the program, it points to the utility of Mussel Watch data in identifying sites with elevated concentrations (relative to other measurements from the region) that may require further investigation.

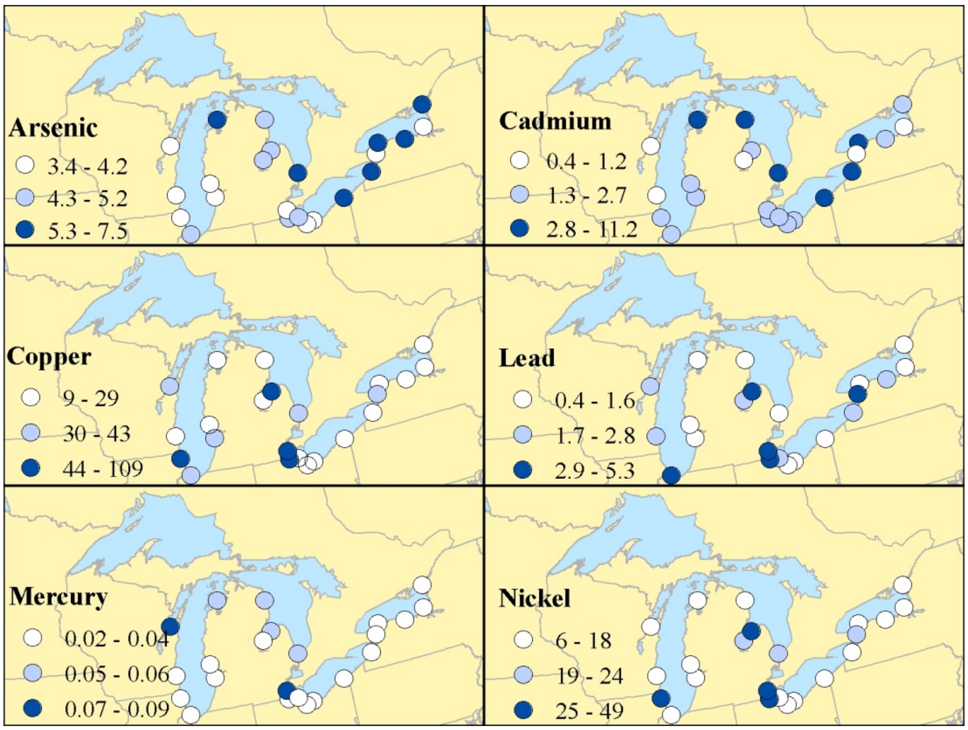

Figure 3. Map depicting Mussel Watch metal contaminant tissue concentrations (μg/g dry weight) based on cluster analysis of 2008-2009 data.

Organic Contaminants

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 (USEPA 2002). In humans, effects include adverse impact on immune and nervous functions, and cognitive skills (USEPA 2002).

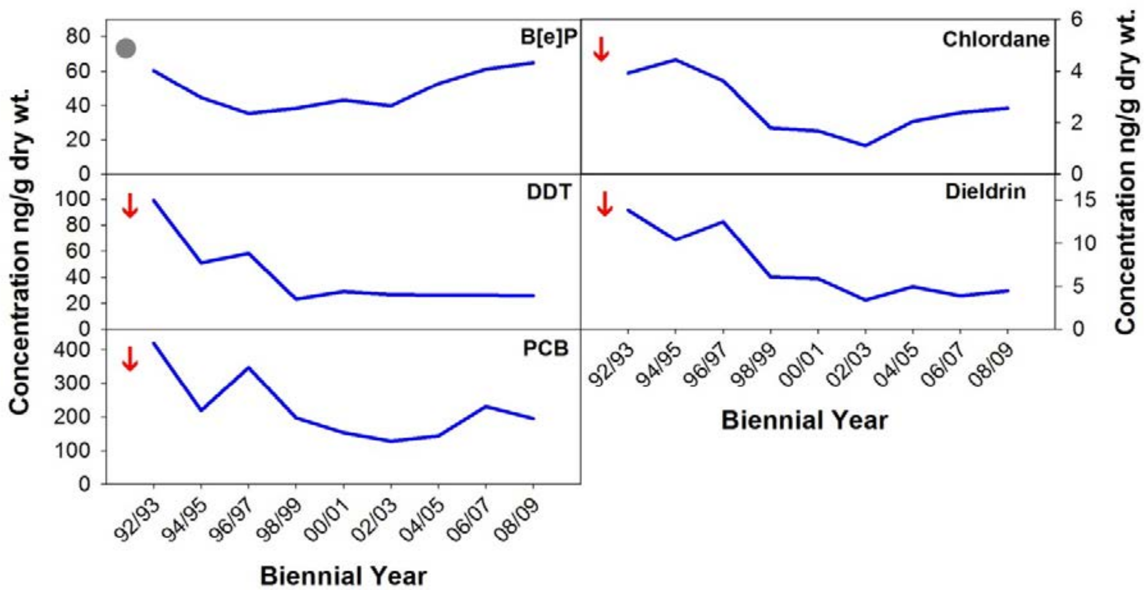

Figure 4. Basinwide trends in mean concentrations (ng/g dry weight) of select organic contaminants (↓decreasing trend and ●no trend) in dreissenid mussels from long-term Mussel Watch sites in the Great Lakes from 1992-2009.

The concentrations of the legacy organic contaminants in dreissenid mussel tissues exhibit statistically significant ($p < 0.05$) decreasing trends while benzo[e]pyrene, a representative high molecular weight polycyclic aromatic hydrocarbon (PAH), shows neither increasing nor decreasing trends (Figure. 4). The concentrations are at low background levels at a majority of the sites (Figure 5), and site-specific trend analysis shows no discernible trend at a majority of the sites. At the site level where trends exist, they are predominantly decreasing for all the organic contaminants examined except one: benzo[e]pyrene shows an increasing trend at a few (less than 5%) of the sites.

Further, the highest levels of many organic compounds were found in Lake Michigan (Figure 5) and these findings are consistent with results from the US Great Lakes Fish Monitoring Program (Carlson and Swackhamer, 2006). Sites with elevated concentrations identified here may require remediation to reach the baseline levels. Our data also show that these legacy organic compounds, though banned decades ago, are still ubiquitous in the environment (Figure 5), possibly due to their slow degradation rates or continued leaching from source areas. In addition, some of these compounds can be transported through the atmosphere from other areas around the globe (Gouin et al. 2004) and deposited in the Great Lakes.

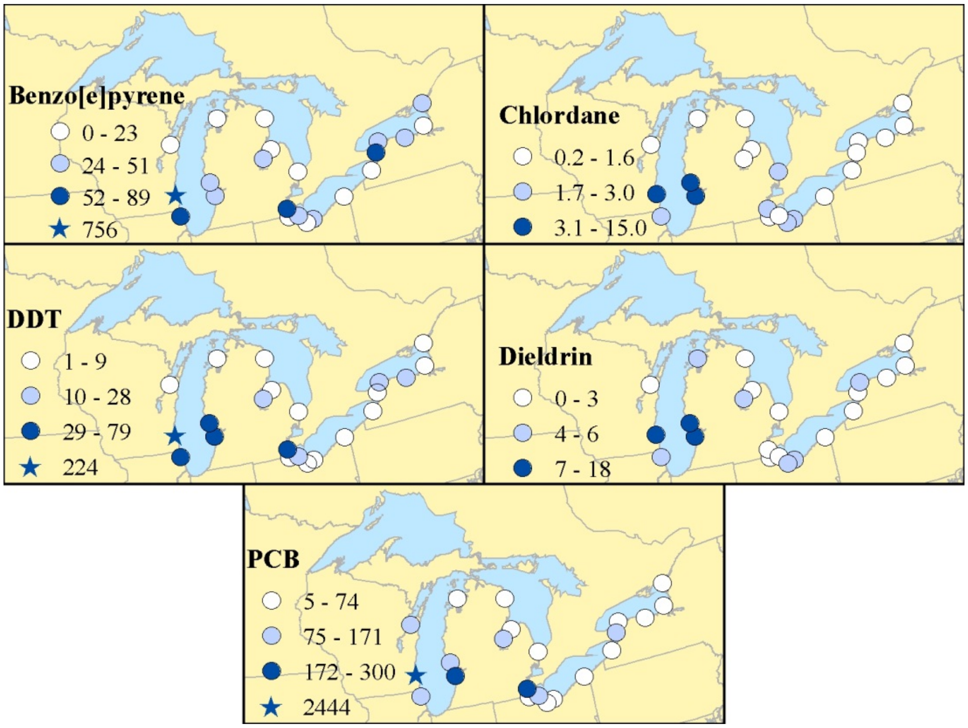

Figure 5. Map depicting Mussel Watch organic contaminant tissue concentrations (ng/g dry weight) based on cluster analysis of 2008-2009 data.

Due to the increased concern over controlling pollution, during the 1970s and 1980s several regulatory and nonregulatory initiatives were implemented in Canada and the United States, such as the US Clean Water Act, the Canada Water Act and the Great Lakes Water Quality Agreement. The 1987 Agreement included the provision of developing and implementing remedial action plans (RAPs) to restore significantly degraded waters around the Great Lakes. Many of the RAPs in these nearshore areas have implemented actions with respect to improving wastewater treatment facilities, removing contaminated sediments, stormwater management, reduction of combined sewer overflows and storm sewer by-passes, and pretreatment of industrial waste. The actions taken under RAPs can contribute to the reduction in loadings of contaminants observed, particularly metals and organic contaminants.

Future use of indicator

Mussels have been long recognized as environmental sentinels and are used in environmental monitoring programs worldwide. This report based on the data of NOAA's Mussel Watch program spanning over a decade emphasizes the value of dreissenid mussels as an indicator to track the status and trends of metals and legacy contaminants in the Great Lakes.

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 dreissenid mussel monitoring efforts both spatially and temporally is recommended. Currently, more than 45 nearshore sites in the Great Lakes are monitored for a wide array of contaminants including metals and legacy contaminants (Figure 1). The recently established sites (~25 sites) are in AOCs, which together with long-term integrative sites provide relevant data to aid in the cleanup and subsequent delisting of AOCs. A comprehensive report on the Mussel Watch data collected from all US AOCs, as part of the Great Lakes Restoration Initiative, is forthcoming. Further, addition of offshore Mussel Watch sites (open water) would complement the data from nearshore sites and can together provide a better assessment of the extent of chemical contamination within the Great Lakes basin. The open water samples would add little additional costs because they would be collected as part of ongoing offshore monitoring efforts.

No environmental indicator by itself can provide an assessment of ecosystem health of a system as enormous and complex as the Great Lakes. 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. Moreover, dreissenid mussels are rapidly expanding in the Great Lakes and their significant role in contaminant cycling and biomagnification of pollutants (indirectly via deposition of feces and psuedofeces and directly via predation) in the food chain is well documented. Multiple species including diving ducks, crayfish, round goby, freshwater drum, white perch and yellow perch prey upon dreissenid mussels. Therefore, linking contaminant measurements from fish, birds and invertebrates, such as mussels, could help identify the direct and indirect trophic transfer link of contaminants from the base of the food web to the top predators. Coupling mussel biomonitoring with abiotic (sediment, water, air) monitoring efforts can further help identify the fate and transport of contaminants between living and nonliving system components.

The continued presence of legacy organic contaminants coupled with the threat of a multitude of newer emerging contaminants in the Great Lakes necessitates incorporation of newer approaches, particularly effects-based monitoring to the traditional chemical-based contaminant monitoring. Mussel Watch has proposed to include the use of mussel biomarkers, which have been successfully used to conduct both long-term and short-term ecological assessments (Krishnakumar et al. 1994; Cajaraville et al. 2006) and have been incorporated into other routine monitoring programs (JAMP 1998a, b). Biomarkers are measurements of biochemical and or physiological changes in organisms related to the presence of contaminants and toxic effects of contaminants (de Lafontaine et al. 2000). In the Great Lakes, biomarkers could be used to track recovery of impaired ecosystems in a timely manner and study the effectiveness of mitigation strategies. To this end, both generalized biomarkers such as condition index and gonadal indices and specific biomarkers (acetyl cholinesterase inhibition as a marker of organophosphate exposure and induction of ethoxyresorufin-O-dethylase-EROD activity as a marker of exposure to dioxin-like chemicals) could be used in tandem. Together with tissue contaminant data, mussel biomarker data would be useful in aiding a variety of management efforts and decisions including ecological risk and damage assessment, implementation of RAPs, removal of beneficial use impairment targets and delisting of AOCs. This would be possible only with dreissenid mussels as they are the only bivalve of abundant, basinwide distribution that can be used effectively for contaminant monitoring in both nearshore and offshore environments in the Great Lakes.

Dreissenid mussels have become a keystone species of the Great Lakes ecosystem since their introduction a quarter of century ago (Vanderploeg et al. 2002) and the use of these mussels as an indicator is critical to the assessment of the overall health and ecological forecasting of the Great Lakes. We therefore recommend continuing and expanding dreissenid mussel contaminant monitoring in the Great Lakes to help provide scientific information to assess progress and target protection and restoration efforts.

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2.5 Contaminants in Sediment Cores

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Contributors: Chris Marvin, Debbie Burniston, Environment Canada

Summary

Contaminants that are in sediments can harm bottom-dwelling organisms, and the sediments can serve as a source of toxic chemicals to 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 to decrease since that time. Canada and the United States 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 for measuring progress toward 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, but remobilization of contaminants from the sediments into the water column is an important source of contamination for biota. However, burial in sediments also represents a primary mechanism by which contaminants are sequestered and prevented from reentering 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 chemical sources and loadings, but also by 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 Great Lakes Water Quality Agreement (1987 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 1987 Agreement, the governments 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 dichlorodiphenyl-dichloroethene, or DDE), heptachlor epoxide (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., especially for benthos (#vi) and also for other biota.

Methods

Environment Canada has collected surficial sediment samples using minibox core sampling procedures 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 the methods used by Environment Canada.

Results

Environment Canada's work found that comparisons of surficial sediment contaminant concentrations with subsurface 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 that peak concentrations occurred in the 1960-1980 period (Pearson et al. 1997; Wong et al. 1995; Schneider et al. 2001).

Parameter	Ontario %Reduction	Erie %Reduction	St. Clair %Reduction	Huron %Reduction	Superior %Reduction
Mercury	73	37	89	82	0
PCBs	37	40	49	45	15
Dioxins	70	NA	NA	NA	NA
HCB	38	72	49	NA	NA
Total DDT	60	42	78	93	NA
Lead	45	50	74	43	10

Table 1. Estimated percentage declines from peak levels of sediment contaminations based on comparison of surface sediment concentrations with maximum concentrations in sediment cores. Source: Environment Canada as published in SOLEC 2009.

Spatial distributions in mercury contamination generally represent those of other toxic contaminants. 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 (Fig. 1, SOLEC 2009).

Environment Canada staff wrote the State of the Lakes Ecosystem Conference indicator report on sediments (SOLEC 2009) which 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.

Environment Canada examined spatial and temporal trends in Lake Ontario and reported their findings in Marvin et al. (2003):

- 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), decreasing concentrations down to a depth of about 40 cm (pre-1900) and then relatively constant concentrations to the bottom of the core.

Environment Canada compared findings with data collected in 1969 and 1973 in Lakes Huron and Superior and Marvin et al. (2008) reported:

- Sediment concentrations of PCBs, organochlorines, and polycyclic aromatic hydrocarbons (PAHs) were generally low at 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 its earlier level 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), 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 with Lakes Erie and Ontario.

Discussion

The current degree of contamination in these four lakes is substantially lower than peak levels that occurred in the mid-1950s through the early 1970s. However, the analysis conducted by Environment Canada shows similarity in spatial patterns between recent and historical surveys indicates significant sources within the individual lake basins continue to influence distributions over large regions. 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 expanses were also intensively industrialized and were primary sources of a variety of persistent toxics to the open lakes, including PCBs. Localized places 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 resuspension, intralake 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 sediment dwelling organisms, i.e., 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 manifest through binational initiatives such as the Great Lakes Binational Toxics Strategy 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 support our modern 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 under the Monitoring and Surveillance component of Canada's Chemicals Management Plan. While government initiatives for reducing indiscriminant urban and industrial discharges of legacy compounds like PCBs have resulted in decreasing numbers, 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 one type of BFR, 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 PBDE 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 PBDE 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. PBDEs in sediment are generally below regulatory criteria in open-lake sediments (Klecka et al. 2010).

Future use of indicator

Further work could evaluate temporal trends by examining changes in contaminant concentrations at various depths of a sediment core collected from each of the lakes. . Targeted monitoring to identify and track down local sources of pollution could be considered for those chemicals whose distribution in the ambient environment suggests local or subregional origins. 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.

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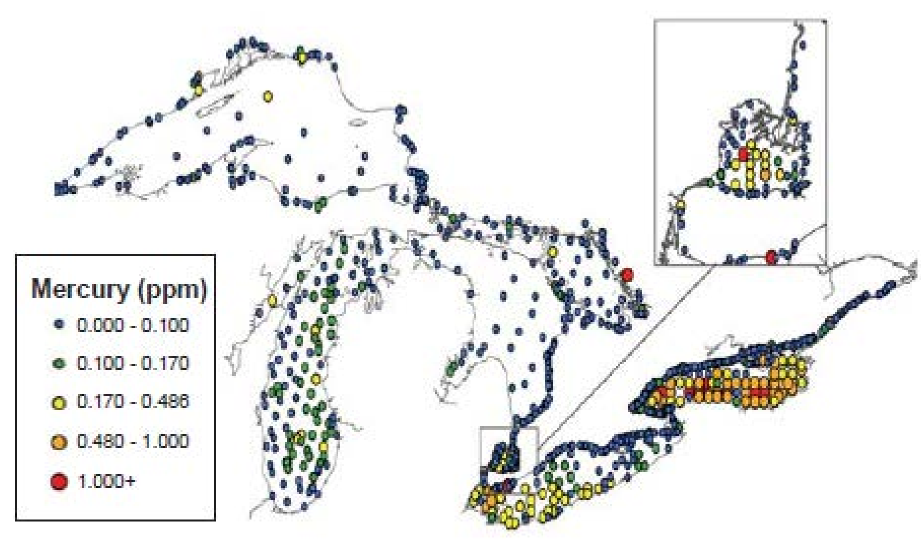

Figure 1. Spatial distribution of mercury contamination in surface sediments in open lake areas and tributaries of the Great Lakes.
Sources: Environment Canada and USEPA.

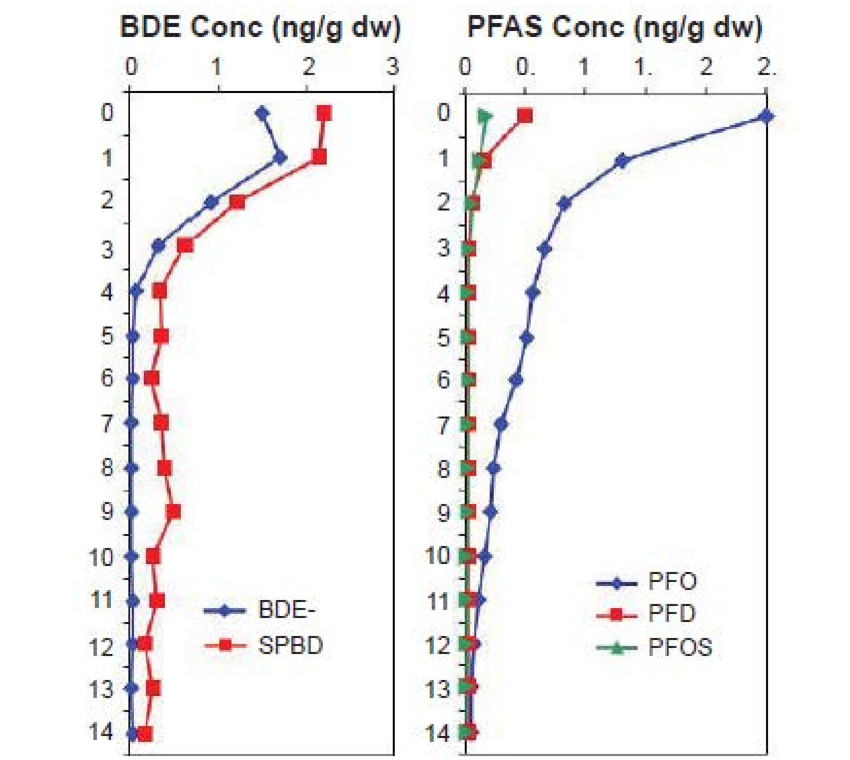

Figure 2. Core profiles of perfluoroalkyl subtances (PFAS) and brominated diphenyl ethers (BDEs) is sediment cores from the central (Mississauga Basin) basin of Lake Ontario.
Sources: Environment Canada and Ontario Ministry of the Environment.

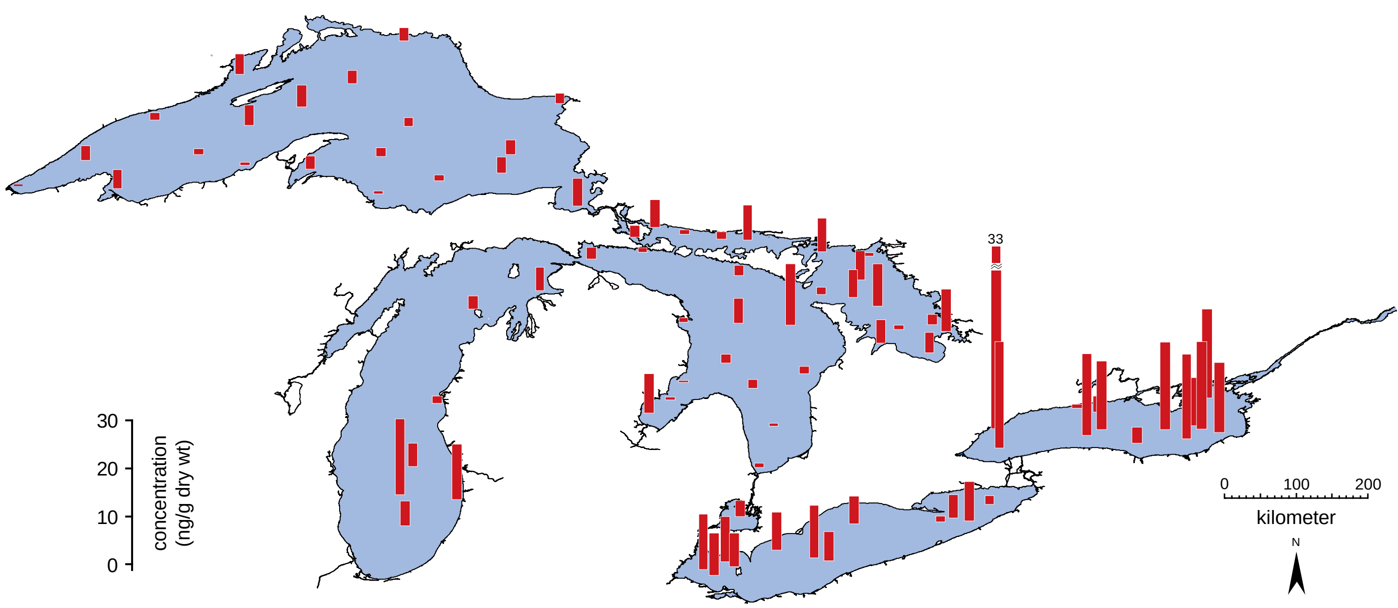

Figure 3. Distribution of polybrominated diphenyl ethers (PBDEs) in open-water areas of the Great Lakes.

2.6 Phosphorus Loading

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Summary

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 has been monitoring Lake Erie tributaries for various parameters including total phosphorus (TP) and dissolved reactive phosphorus (DRP) since 1975. Reduced loading of TP and DRP through 1995 is a sign that control programs were successful. Since that time, and especially in the last few years, there has been a reemergence of harmful algal blooms in Lake Erie. These blooms are thought to be attributed to DRP because loadings of TP levels have been stable while loadings of DRP have increased and because DRP is easier for algae to consume. Improved management controls for runoff, especially from agricultural lands, and associated monitoring of DRP are needed.

Importance for measuring progress toward objectives

Excessive phosphorus loading to waters in the nearshore has resulted in degraded water quality conditions and led to oxygen depletion and fish kills. Cyanobacteria that can form blooms containing dangerous natural toxins are increasing according to work conducted under the direction of the Lake Erie Lakewide Management Plan Management Committee (Lake Erie Nutrient Science Task Group 2008). The exudates (foam) that contain these toxins are a risk to both humans and wildlife. These cyanobacteria blooms are exacerbated with increased phosphorus concentrations in the water column (Downing et al. 2001). Benefits derived from controlling phosphorus loading from any one of the large array of nonpoint 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 nonpoint source agricultural nutrient problem arising a cost-effective manner. Such efforts will require suitable detailed data for nutrient load estimation.

Methods

The National Center for Water Quality Research (NCWQR) began monitoring nutrient levels in the major US tributaries to Lake Erie in 1975. The NWCWQR is a U.S. program and is part of the science departments of Heidelberg University, Ohio. 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 US Geological Survey (USGS). Samples for nutrient analyses are obtained at or near USGS gauging 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 US 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. The total phosphorus loads in the Maumee River appear to have been decreasing over the entire period of measurement (Fig. 1). However, this trend is not statistically significant and the loading is heavily influenced by frequency and intensity of stormwater events. We have examined the data with river flow as a covariate and have found that agricultural best management practices adoption has reduced particulate phosphorus loading (Richards et al. 2009). The annual discharge in the Maumee has increased, as have most other Lake Erie tributaries.

Dissolved reactive phosphorus (DRP) is 100% 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 frequency and intensity of stormwater events. 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.

Until recently, government support for control, monitoring and research of Lake Erie tributaries had dwindled in both Canada and the United States. In recent years however, Great Lakes Restoration Initiative (GLRI) investments have supported work on the U.S, side of the lake and in 2012 the Canadian Government committed to an investment of $16 million on the Canadian side. Presently, it is unclear as to if or how these funds will translate into long-term stable funding for current monitoring activities. Long-term monitoring is essential for forecasting threats to human and ecosystem health. Monitoring allows for the identification of factors and their relationships leading to harmful algal blooms (HARRNESS 2005). Managing nonpoint source TP and DRP exports to the nearshore waters of Lake Erie is a considerable challenge given that over 80% of the 6,500 square mile basin is agricultural, and intensive surface and subsurface drainage systems readily transport soluble nutrients into receiving waters.

Future use of indicator

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 subwatershed level.

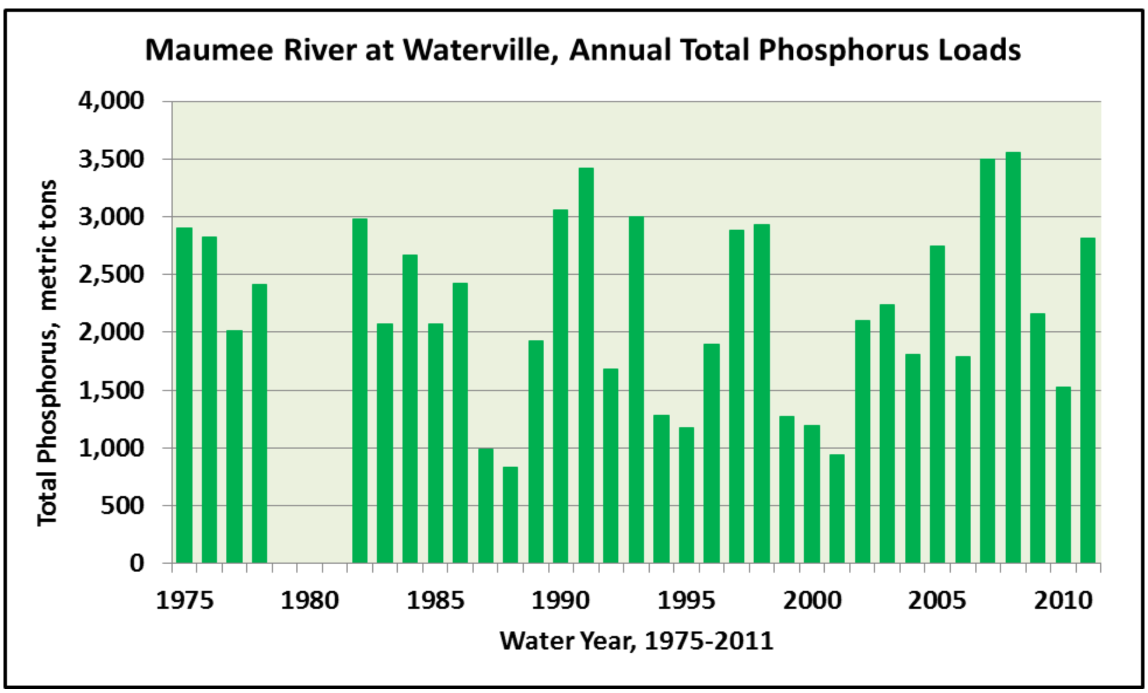

Figure 1. Maumee River total phosphorus loads 1975-2001 (metric tons). Water year is October 1 – September 30.

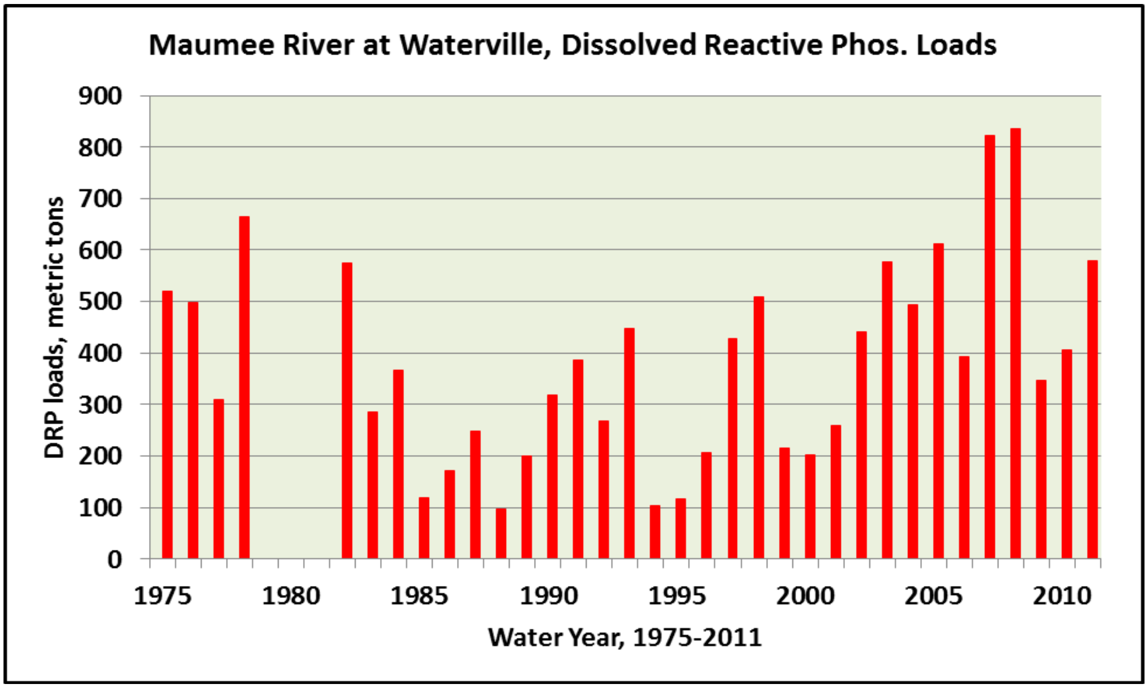

Figure 2. Maumee River dissolved reactive phosphorus loads 1975-2011 (metric tons). Water year is October 1 – September 30.

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2.7 Atmospheric Deposition of Toxic Contaminants

Author: Dave Dempsey, International Joint Commission.

Reviewers: Ronald Hites, Indiana University; Vic Serveiss, International Joint Commission .

Summary

Atmospheric deposition occurs when pollutants are transferred from the air to the Earth's surface. The amount of deposition of some persistent toxic chemicals in the Great Lakes basin, as measured by the US-Canada Integrated Atmospheric Deposition Network (IADN), has declined since the 1970s and 1980s, when several were banned in North America. For instance, deposition of PCBs has continued to decline and is now at about half the 1990 level, although the rate of decline has slowed significantly. Concentrations of some banned or restricted pesticides, such as lindane and DDT, decreased considerably. Concentrations of several alternative flame retardants are increasing.

Importance for measuring progress toward objectives

The Great Lakes Water Quality Agreement (1987 Agreement) defines the virtual elimination of persistent toxic substances as one of its specific objectives. Further, the general objective (d) of the 1987 Agreement states that the Great Lakes "should be free from materials entering the water as a result of human activity that will produce conditions that are toxic to human, animal or aquatic life."

The discovery of PCBs and DDT in fish in Siskiwit Lake on Lake Superior's 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

Siskiwit Lake and were thus 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 (USEPA 2011). Contaminants may also migrate from the Great Lakes to air when their fugacities are lower in air than in water. For example, after the banning of PCBs led to steep reductions in emissions and deposition in the lakes, PCBs at times volatized from the lakes into the air, according to USEPA's 1994-1995 Lake Michigan Mass Balance Study (USEPA 2009).

Methods

To measure the contribution of both local and long-range transport of chemical contaminants and their deposition in the Great Lakes basin, Canada and the United States have operated IADN since 1990. IADN was a specific commitment of Canada and the United States in Annex 15 of the 1987 Agreement. IADN was also called for in the 1990 Amendments to the Clean Air Act.

There are five master monitoring stations, one for each lake, and ten satellite stations (USEPA, 2011). The master stations are Eagle Harbor (Lake Superior), Sleeping Bear Dunes (Lake Michigan), Burnt Island (Lake Huron), Sturgeon Point (Lake Erie) and Point Petre (Lake Ontario). The satellite stations provide additional detail about levels of toxics in the air around the lakes. All of the Canadian satellite stations are precipitation-only except for Egbert, which monitors in the gas phase only. The US satellite stations, in Chicago on Lake Michigan and in Cleveland on Lake Erie, provide the same measurements as those performed at the master stations. Data are collected and reported on a station-by-station basis.

Gas phase and particulate phase samples are collected every 12 days for 24 hours while precipitation samples are collected on a monthly basis. Samples are analyzed for more than 150 pollutant concentrations deposited from the atmosphere in all three phases (airborne vapor, airborne particles and precipitation). Organic pollutants of particular interest include chlorinated pesticides, PCBs, several polycyclic aromatic hydrocarbons, and more recently, brominated and chlorinated flame retardants (Hites 2010). The list of monitored chemicals is continuously expanded to include new and emerging compounds. Examples of such compounds are decabromodiphenylethane (DBDPE), a replacement of BDE-209, and 1,2-*bis*(2,4,6-tribromophenoxy)ethane (TBE), a replacement of octa-BDE.

The Canadian Atmospheric Mercury Measurement Network and the US Mercury Deposition Network supplement IADN data.

Results

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 the estimated time to reach a 50% reduction based on recent concentration trends time is a relatively slow 17 ± 2 years (Venier and Hites, 2010). Increases were noted during the late 1990s at the remote sites and around 2007 at Chicago (Venier et al. 2012). 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 2000-2001, levels have declined at all of these sites. The Lake Erie monitoring site has recorded elevated gas-phase concentrations compared relative 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 and other hexachlorocyclohexanes and DDT have decreased more rapidly than PCBs since 1990, with halving times of five years (Venier and Hites, 2010). Other data reveal spatial and seasonal trends. Air concentrations of chlordane are about ten times higher at urban stations than at rural stations, possibly as a result of previous use of chlordane as a building termiticide (SOLEC, 2009 and 2012). Dieldrin is also elevated in urban areas. Endosulfan, still in agricultural use, shows seasonal increases during summer.

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. Results of the Mercury Deposition Network (MDN), which provides a long-term record of total mercury concentration and deposition in precipitation in Canada and the United States, showed that concentrations of mercury in wet deposition in the Great Lakes region were unchanged between 2002 and 2008 (Risch et al. 2011).

Flame retardants in the atmosphere around the Great Lakes show varying trends. Penta- and octa-PBDEs, whose production was voluntarily phased out by the only US manufacturer in 2004, are declining (Salamova and Hites, 2011a), but deca-DBE, which is still produced in the United States and accounts for about 25% of the total flame retardant concentrations, does not yet show a discernible trend (SOLEC 2012). Similarly, concentrations of decabromodiphenylethane (DBDPE), an alternative for deca-BDE, are not statistically changing over time, suggesting a continuing source of this compound.

Several alternative flame retardants have been detected in IADN samples. Some of these compounds are decreasing with time; for example, hexabromobenzene (HBB) and 1,2-bis(2,4,6-tribromophenoxy)ethane (TBE or BTBPE) show halving times on the order of ten years (Salamova and Hites, 2011a). Others are increasing with time, suggesting that they are still produced and used in commercial products. Dechlorane Plus, which was first discovered in IADN samples and then measured all around the world, shows an increasing trend in the atmosphere of the Great Lakes with a doubling time of approximately ten years (Salamova and Hites, 2011b). Similarly, 2-ethylhexyl-2,3,4,5-

tetrabromobenzoate (TBB) and bis(2-ethylhexyl)-2,3,4,5-tetrabromophthalate (TBPH), the two principal components of the commercial mixture that is the main replacement for penta-BDE used in furniture, show a doubling time of approximately two years (Ma et al. 2012).

Discussion

For almost all chemicals continuously monitored by IADN, since its inception in 1990, concentrations in air and precipitation have generally declined. This suggests that banning of organochlorine pesticides and PCBs, as well as in-basin source reduction activities such as collection and disposal of PCB-containing transformers and capacitors have had beneficial results. However, detection of alternative fire retardants underscores the need for ongoing monitoring and control efforts.

Future use of 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. A historical database can provide information not only on long-term trends of chemicals in the atmosphere but also on more subtle changes that could not be detected in shorter-term projects. These subtle changes can provide valuable information to regulators and administrators. The governments should sustain IADN at historic funding and staffing levels.

To help clarify the relative contribution of current in-basin and regional atmospheric sources, the IJC recommends that IADN data for selected nonlegacy contaminants be compared with emissions data from sources in the region. Emission databases include the US National Emissions Inventory and US Toxic Release Inventory and Canadian National Toxic Release Inventory. Consideration should also be given to adding newly emerging chemicals of concern to IADN monitoring in order to determine trends in atmospheric transport and resultant human health and aquatic exposures.

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Section 3. Indicators of Physical Integrity

3.1 Surface Water Temperature

Authors: Dave Dempsey, International Joint Commission.

Reviewers: Jay Austin, University of Minnesota-Duluth; Don Scavia, University of Michigan; Vic Serveiss, International Joint Commission.

Summary

Significant warming since the mid-1980s is evident in surface temperatures of several of the Great Lakes. 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. Warming is most pronounced in Lake Superior, the coldest and largest of the Great Lakes.

Importance for measuring progress toward objectives

Great Lakes surface water temperatures are important to the chemical, biological and physical integrity of the Great Lakes. For example, 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. Warmer surface water temperatures may also adversely impact native cool and coldwater fish species.

Methods

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; 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 US National Oceanic and Atmospheric Administration's National Data Buoy Center, the US National Weather Service, the US Great Lakes Environmental Research Laboratory, the US Environmental Protection Agency STORET, the US Environmental Protection Agency 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

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). Other studies looked at individual lakes and usually found similar trends.

Austin and Colman (2007) reviewed temperature changes in Lake Superior and noted rapid warming in summer (July-September). Surface water temperatures increased approximately 2.5 degrees C overall between 1979 and 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 from 1968 to 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.

In McCormick and Fahnensteil (1999), five of seven sites analyzed showed annual mean results that suggested a long-term warming trend. Two of the sites showed an increase of 14 days in the duration of summer stratification for Sault Ste. Marie and 18 days for Put-In-Bay, respectively.

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 nonnative 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. Blooms of cyanobacteria (blue-green algae), particularly toxin-producing species, are increasing in the Great Lakes. The most significant cyanobacteria bloom species in the Great Lakes, *Microcystis aeruginosa*, produces a toxin (microcystin) that has both chronic and acute effects (Carmichael 2001). *Microsystis* growth is stimulated with higher temperatures and increased sunlight (Liu et al. 2010).

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

Besides the influence of temperature on cyanobacteria, increased 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 (Wismer and Christie, 1987). Warmer water temperatures can move the southernmost range of cold water fish such as brook trout and lake trout to the north while permitting survivability of warm water fish not native to the Great Lakes in southern Great Lakes habitat (Chu et al. 2005).

Future use of indicator

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. Mary's River and Buffalo, are available as far back as 1906 (McCormack and Fahnensteil, 1999) and 1927 (NOAA 2011b), 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. The IJC recommends adding more monitoring buoys and analyzing the data collected to contribute to the understanding of trends.

Analysis of surface water temperatures should be made routine given the relatively low costs and easy data availability. Further, changes in temperature in the water column should be routinely monitored and analyzed (SOLEC 2011). Surface temperatures by themselves do not necessarily demonstrate the heat content of a lake, which is a more robust measure of a lake's thermal condition. But surface temperature can be a proxy, since in fresh water, on the date at which surface water temperature reaches its maximum density, the entire water column must be at the same temperature.

The IJC also recommends testing hypotheses for the trend of warming surface temperatures by modeling the contribution of different aspects of weather (timing of stratification, air temperature, solar radiation, wind) and aspects of the lake (albedo, depth of stratification).

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3.2 Ice Cover

Authors: Dave Dempsey and Vic Serveiss, International Joint Commission.
Reviewer: Raymond Assel.

Summary

The Great Lakes are typically covered by ice during part of the winter and early spring. The average amount of ice cover and the number of days that each lake is covered by ice have declined on all Great Lakes since 1987. One study found substantial declines of ice cover on all Great Lakes between 1973 and 2010, with the smallest decline of 37% on Lake St. Clair and the largest of 88% on Lake Ontario. Another study similarly found declines in ice cover on all the lakes, and found that Lakes Superior and Michigan averaged less than half the number of days of ice cover than they had in the mid-1970s.

Importance for measuring progress toward objectives

Ice cover is important to the physical integrity of the Great Lakes and also impacts biological integrity. Ice cover is critical in regulating water levels, wetland functions, aquatic species populations and downwind precipitation (NOAA 2012). Reduced ice cover can lead to loss of critical habitat and increased evaporation. Because of the influence of air temperatures on ice cover and the influence of ice cover on solar radiation reaching the lake, ice cover is also considered a potential indicator and driver of climate trends.

Reduced ice cover also affects socioeconomic concerns and leads to a longer shipping season, lower lake levels, increased dredging for navigation, lower ship cargo capacity and reduced winter recreational activities (US Environmental Protection Agency 2011). Ice cover affects navigation, coastal power plants and cooling water intakes, and shore structures.

Methods

IJC's Upper Great Lakes Study (IJC 2009) examined 1973-2008 data from several sources for all the lakes excluding Lake Ontario. IJC (2009) performed regression analyses of seasonal averages, and seasonal maximum ice cover to reveal trends in ice cover.

IJC's study included an evaporation analysis. Daily lake-averaged ice concentration for winters 2006 through 2008 were developed from data abstracted from the Canadian Ice Service and National Ice Center. Additional data used for the analysis included NOAA's Great Lakes Environmental Research Laboratory monthly lake evaporation and over-lake air temperature data and monthly average Great Lakes water levels.

A study of all five lakes used composite ice charts, which contain a blend of observations from different data sources (ships, shore, aircraft and satellite) that cover the entire area of the Great Lakes for a given date (Assel, 2003), A 30-winter (1973-2002) set of composite ice charts was digitized, and a multiwinter statistical analysis of the climatology of the ice cover concentration and duration was completed.

Assel (2004) focused another study on Lake Erie by using grids of daily ice cover concentration for winters 1973–2002. The daily ice concentration grids, nominal 2.5 km spatial resolution, were calculated by linear interpolation of ice concentration for each given grid cell between consecutive ice charts for a given winter season. No extrapolation was made prior to the first ice chart or after the last ice chart of each winter season.

Wang et al. (2012) analyzed weekly ice charts developed by Canadian Ice Service and National Ice Center from 1973-2010. The weekly and monthly mean values were subtracted from the individual week and month data to obtain weekly and monthly anomalies. Annual-averaged ice cover values were obtained by averaging data in the whole winter season (ice year).

Results

IJC (2009) found that trends for seasonal averages of ice cover duration decreased in all of the studied lakes over the 36-winter period (Figure 1). The percentage of ice cover on Lakes Superior and Michigan was less than half of what it was at the start of this period, based on the five year running seasonal average. An ice cover-evaporation analysis showed that the ice cover was negatively correlated with lake evaporation in January, February and March for both Lake Erie and Lake Huron. This supports the finding that monthly evaporation increased with decreasing ice cover concentration.

The shallowness of the western basin of Lake Erie favors ice formation (USEPA 2011). Western Lake Erie basin average ice cover for January through March was calculated from daily averages (Assel, 2004). The three-month average ice cover varied from approximately 5% to 90%. Two extremely mild winters, 1998 and 2002, set new record lows for average winter ice cover (Assel, 2005**)**. The western basin was virtually free of any significant ice cover in 1998. These findings are consistent with data collected by IJC (2009) which show a maximum value in the late 1970s followed by a general downward trend thereafter, based on the five-year running average of ice cover on the entire lake (Figure. 1).

Wang et al. (2012) found a negative trend in annual mean ice cover in all lakes from 1973-2010. The negative trends varied from lake to lake (from -1.0% in Lake St. Clair to - 2.3% per year in Lake Ontario), with overall reductions ranging from 37% in Lake St. Clair to 88% in Lake Ontario. Wang also reported that ice cover varies widely from year to year. The maximum ice cover was 95% in 1979 and the minimum was 11% in 2002.

Discussion

Reductions in average ice cover are evident for all the lakes, with varying potential impacts. For Lake Superior, mean surface water temperatures have warmed faster than air temperature (Austin and Colman, 2007), possibly because decreasing ice cover has led to increased heat input into the lake. Coincident increasing lake and winter air temperatures have resulted in the temperature gradient between air and water being reduced, destabilizing the atmospheric surface layer above the lake and resulting in higher over-lake winds (Desai et al. 2009). Average wind speeds on the lake have risen 5% per decade since 1985. The increased winds in turn may affect the ecology of the lake. Rapid warming of Lake Superior could promote changes in aquatic species composition.

Gradually decreasing ice cover over the last three decades, with annual fluctuations, is evident. Great Lakes ice cover is influenced heavily by natural climate patterns such as El Nino and global climate warming. Regardless of the causative factors, if ice cover on the Great Lakes continues to decrease this will undermine the physical integrity of the ecosystem by altering water levels and affecting species health.

Future use of indicator

Ice cover is an important measure of physical integrity and can affect biological integrity. Reduced ice cover alters shoreline wetland integrity and fish spawning habitat, both of which are adapted to historic ice cover (NOAA 2012). For example, ice cover in shallow whitefish spawning habitat protects their eggs from destructive wind and wave action. Stable ice also protects wetlands and the shoreline from erosion. Changes in ice-out can affect the timing and availability of fish prey resources such as plankton production, in turn affecting feeding rate and subsequent growth and survival of a fish’s early life stages (Casselman 2002). Further, ice cover affects several socioeconomic concerns including shipping and navigation. Given the duration and quality of the ice cover data set, its importance to physical and biological integrity and to socioeconomic concerns, its use as an indicator should continue.

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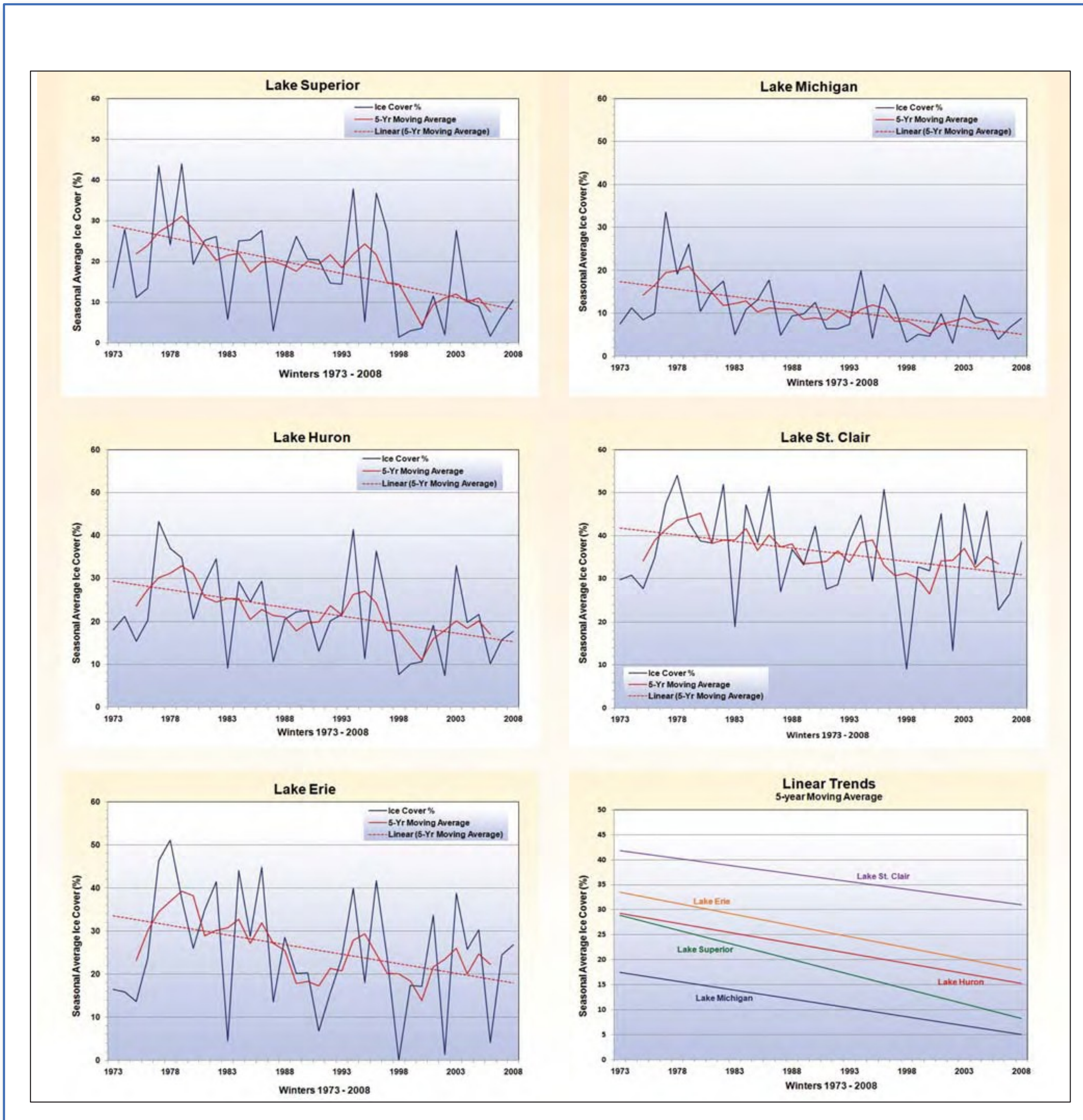

Figure 1. Seasonal ice cover 1973-2008. From *Impacts on Upper Great Lakes Water Levels: St. Clair River*, International Joint Commission, 2009.

Section 4. Indicators of Biological Integrity

4.1 Aquatic Invasive Species

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Reviewer: Mark Burrows, International Joint Commission.

Summary

Nonnative species have become established in the Great Lakes and have caused economic and ecological impacts. The number of established nonnative aquatic species in the Great Lakes increased steadily from 1900 until the late 1990s. In the latter portion of this period, established nonnative aquatic species were introduced mostly from unregulated ballast water discharges from transoceanic vessels. There were 34 nonnative species introduced since 1987 mostly from ballast water discharges. However, due partly to the implementation of stricter ballast water regulations by Transport Canada, U.S. Coast Guard and St. Lawrence Seaway Authorities, ballast water has not been the source of any invasions 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.

Importance for measuring progress toward objectives

The introduction of nonnative aquatic species (NAS) is one of the most important issues affecting the biodiversity of lakes and coastal ecosystems. These species are a key threat to the biological integrity of the Great Lakes because they can 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 affected biological integrity. Furthermore, NAS have impaired several beneficial uses listed under Annex 2, 1 (c) of the Great Lakes Water Quality Agreement of 1987 (1987 Agreement), including fish and wildlife consumption and fish wildlife populations. The 2012 Agreement 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 Canada and the United States 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) and this occurred in the revised 2012 Agreement.

The Great Lakes basin is among the most highly invaded aquatic ecosystems 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). Since the opening of the St. Lawrence Seaway in 1959, 65% of all invasions in the Great Lakes have been attributed to ballast water releases (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 nonnatives cause adverse effects. Only thirteen nonnatives were reported as causing serious impacts (Mills et al. 1993) and considered as invasive species at the time. Since then 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 of invasive species.

The term aquatic invasive species (AIS) is subject to inconsistent usage (NOAA 2011), but we use it here to distinguish the subset of those NAS that are 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 as an NAS that 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, 2004). 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. US Department of Agriculture 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):

- the species appeared suddenly and had not been recorded in the basin previously
- it subsequently spreads within the basin
- its distribution in the basin is restricted compared with native species
- its global distribution is anomalously disjunct (i.e., contains widely scattered and isolated populations)
- its global distribution is associated with human vectors of dispersal
- 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

The National Oceanic and Atmospheric Administration (NOAA), reports 182 NAS (as of September 30, 2012), 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 attributed to the ballast water vector have been discovered since 2006. However, from the trade vector (aquarium/live food) the red swamp crayfish (*Procambarus clarkia)* have become established in the Chicago lagoons contiguous with Lake Michigan (~2011) and two additional NAS have been reported in Lake St. Clair in 2010 and 2011 (water hyacinth and water lettuce).

The rate of NAS discovery increased significantly after the opening of the modern St. Lawrence Seaway (Seaway) in 1959 (NOAA 2011). The change in invasion discovery rate between the pre- and post-Seaway opening periods is in concordance with changes in the vector; that is, a shift from invasions caused by fish stocking or accidental release to shipping-related invasions, as illustrated in Figure 2. 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 seven parasites/pathogens (40%), four sediment-associated organisms attributed to no-ballast-on-board (NOBOB) vessels (24%) and six 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).

Discussion

Ballast water management regulations were first introduced by the United States in 1993 requiring vessels to conduct mid-ocean ballast water exchange. Ballast water exchange 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, NOBOB vessels contain residual waters and sediments that can harbor 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 ballast water exchange regulations (Bailey et al. 2005b).

In 2006, Canada introduced regulations for mid-ocean Ballast Water exchange 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 Transport Canada, U.S. Coast Guard 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 (or equivalent treatment) of their ballast tanks before transiting the St. Lawrence Seaway, regardless of whether their destination is a Canadian or US port.

Prior to the implementation of the 2006 regulations, 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.

While ballast water continues to be a highly monitored vector for NAS introduction, the potential establishment of nonnative 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) or by unauthorized introduction, remains a major concern. Red swamp crayfish has recently become established in the Chicago lagoons contiguous with Lake Michigan. 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 and water lettuce were likely introduced via the pond trade into Lake St. Clair (Adebayo et al. 2011). Regulators in both Canada and the United States should consider formal assessments of the species involved in the home aquarium/pets/pond trades and the risk these species pose if introduced successfully to the Great Lakes.

Future 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 effects on the ecosystem, but only a limited number have undergone significant and rigorous research to characterize the type and extent of their impact. Estimates of the frequency at which introduced species become invasive vary widely from about 1/100 to 1/4. Williamson and Fritter (1996) estimated that about 10% of introduced species become established and about 10% of those (or about 1/100) become invasive). For freshwater fish, mammals and birds, Jeschke and Strayer (2005) found very high rates of establishment (50%) and invasiveness (50%), implying about 25% of introduced vertebrate species are invasive.

Given the difficulty in identifying which species will become pests, it is imperative to focus resources on prevention**.** Once NAS become established it is very difficult to eradicate them, and often very costly and difficult to limit or control their spread. Therefore the IJC, 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 lakewide area management plans, 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.

It is recommended that governments in both countries increase their systematic detection and monitoring efforts, use the best available technologies and continue to develop improved technologies for prevention, detection and monitoring. The IJC supports the adoption of the recommendation made by the National Academy of Sciences (2008) and that harmonized regulatory standards, consistent and shared procedures be adopted by both countries. At least with respect to the Seaway, both Canadian and US Seaway authorities are using the same techniques. 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.

The IJC supports the recommendations for risk-based monitoring that were made by two recent National Academy of Science panels (2008 on the Great Lakes; 2011 on ballast water standards) which recommended monitoring to detect new AIS and to understand the dose-risk relationship, respectively.

Finally, in cases where NAS successfully invade, the IJC recommends the implementation of rapid response protocols. These protocols require a rapid determination to be made if the species poses a risk of being invasive. This outcome can then guide whether an eradication attempt or other form of rapid response is undertaken.

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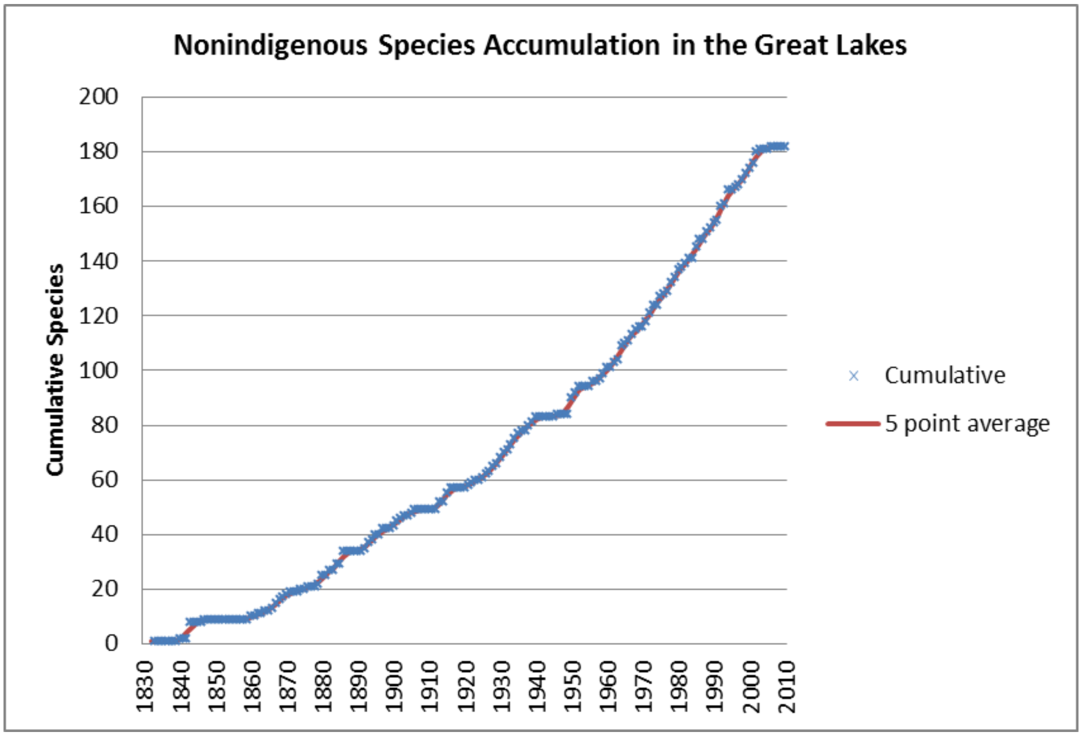

Figure 1. Cumulative number of nonnative aquatic species discovered in the Great Lakes basin since 1840.

Source: NOAA GLANSIS Program, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

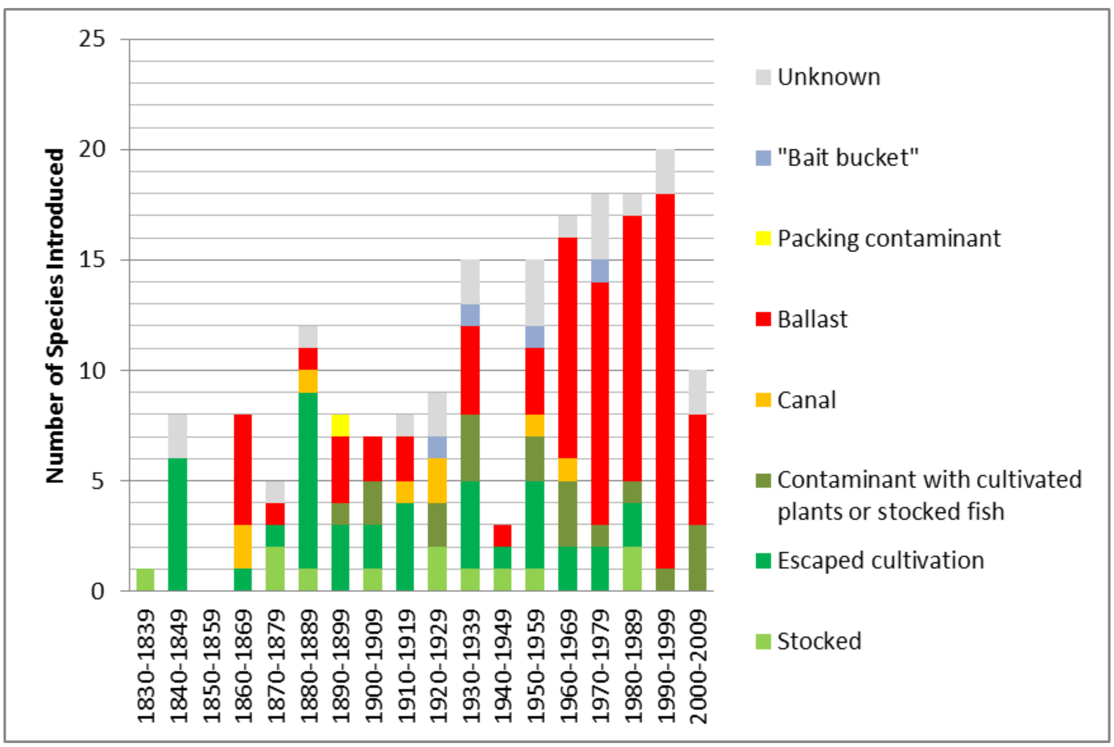

Figure 2. Distribution of nonnative aquatic species introduced to the Great Lakes by various vectors since 1840.

Source: NOAA GLANSIS Program, http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

4.2 Burrowing Mayfly Density

Authors: Vic Serveiss, International Joint Commission; Don W. Schloesser, US Geological Service, Great Lakes Science Center.

Summary

The burrowing mayfly, *Hexagenia*, is important to fish populations 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 from urban and industrial activities. High loads of nutrients triggered a series of events resulting in greater growth of algae, settlement of algae to the bottom substrates, and its decomposition causing low dissolved oxygen, which leads to losses of mayflies and other lake bottom dwellers.

In western Lake Erie, mayflies 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 pollution reduction is are likely to allow sustained "recovery" of mayflies in western Lake Erie and other shallow areas of the Great Lakes. Therefore, continued monitoring of *Hexagenia* is recommended because they are important to fish, reflect the status of water quality in shallow waters and are relatively efficient to sample.

Importance for measuring progress toward objectives

Great Lakes Water Quality Agreement

Hexagenia is relevant to several aspects of the Great Lakes Water Quality Agreement of 1987 (1987 Agreement). Article II of the 1987 amended Agreement states that its purpose 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 impair beneficial uses. Beneficial uses, listed in Annex 2, Section 1c., 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 impairments of beneficial use of fish wildlife populations (item iii) is discussed in the next section (Use by fish).

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 inputs lead to eutrophication, low dissolved oxygen (DO) and harm to *Hexagenia*, phosphorus controls linked to the 1987 Agreement are relevant. Annex I, Section 3 states that phosphorus concentrations should be limited to the extent necessary to prevent nuisance growths of algae. Annex 3, "Control of Phosphorus," devotes six 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 because they are excellent indicators of the quality of fish and wildlife habitat which is one of the 14 beneficial use impairments. The relevance to the impairment of habitat and eutrophication is discussed in the section "Use as habitat and eutrophication indicator".

Use by fish

Hexagenia are known to help maintain large populations of native fish species, such as yellow perch *(Perca flavescens)*, which support 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, bays and nearshore waters of the Great Lakes (Figure 1a). *Hexagenia* disappeared from many of these waters in the 1950s, and their use as a high-quality source of food for fishes was eliminated (Daiber 1952; 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 that occurred in 67% of all fish. However, by 1983 no mayflies were found in Lake Erie fish diets (Hayward and Margraf, 1987).

Use as habitat and eutrophication indicator

Burrowing mayflies are not only a valuable prey item for fishes but they are also excellent indicators of habitat quality and mesotrophic (moderately productive) waters. Mayflies typically live in mesotrophic waters which can easily become eutrophic (excessive production) as a result of pollution and once conditions become eutrophic, burrowing mayflies typically disappear (Britt 1955; Fremling 1964; Hiltunen and Schloesser, 1983; Rasmussen 1988; Schloesser 1988; Reynoldson et al. 1989).

There are two main characteristics that make *Hexagenia* a useful bioindicator of eutrophic conditions in nearshore habitats. First, *Hexagenia* is sensitive to low concentrations of DO, typical of eutrophic waters and, second, *Hexagenia* prefers to inhabit soft-deposition 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).

In deep waters, low DO is typically caused when waters thermally stratify and accumulated organic materials decompose, using available DO during stratification. Therefore, measurement of DO in deep waters is a good indicator of the trophic status of a lake. However, this is not the case in shallow waters where mixing of water typically prevents use of DO concentrations to determine the trophic state. In these shallow waters, detection of eutrophication is more complex, difficult and costly. Hence, the need to have a sensitive indicator, such as *Hexagenia* nymphs, that are sensitive to low DO and are common in shallow waters with soft sediments.

Hexagenia is also an excellent indicator because this taxon only inhabit soft-deposition substrates in nearshore waters. For this reason, mayflies are believed to have once been abundant in most harbors and river mouths of the Great Lakes prior to the 1950s. Such habitats include many rivers and harbors of the Great Lakes (including 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), portions of the interconnecting channels such as the St. Mary's River and 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 1) (SOLEC 2009, Schloesser et al. 2000; unpublished).

These factors make burrowing mayfly nymphs excellent surrogate indicators for measurements of DO and pollutants in nearshore waters where stratification rarely occurs and continuous monitoring of oxygen and chemical input is impractical.

As a result of the importance of *Hexagenia* to native fish, the economic value of fish and the sensitivity of *Hexagenia* to eutrophication, mayfly populations of this taxon have become 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; and Krieger et al. (2007); Schloesser et al. (2000); 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 mid- to late 1990s (Reyndolson et al. 1989; Ohio Lake Erie Commission, 1998).

This widely used indicator has excellent applicability to the regions of less than 30 m depth with soft subtrates where mayflies existed in the past and could return. As discussed previously, these areas include the nearshore areas of several bays and basins in four of the five lakes along with interconnecting channels (Figure 1a). The indicator is not appropriate in deeper waters and in areas with hard substrates.

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 device for this purpose (Schloesser and Nalepa, 2002). The Ponar collects 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 obtain deeper and wider samples of sediments than other samplers. In addition, the screen top of a Ponar reduces hydraulic shock waves that can proceed the sampler on decent to the bottom.

Nymphs are the best life stage to monitor *Hexagenia* because this stage lasts about 23 months, whereas other stages (i.e., flying sub adults and adults) last about two days in the Great Lakes (Schloesser et al. 1984). *Hexagenia* typically hatch from eggs in August and spend almost two years as nymphs burrowed in the lake bed at sediment depths up to 5 to 10 cm in water that is usually less than 30 m deep (Charbonneau and Hare, 1998). Nymphs emerge from the water in late- June and early-July, swim to the surface, molt to become a sub-imago and fly to land. After resting one to three days, sub-imagoes molt to become adults, mate while in flight, deposit eggs and then die. Therefore, samples should be taken in April or May before nymphs leave the substrate (USEPA 2009).

Results and discussion

Compilation of all available information of the abundance of *Hexagenia* in Lake Erie (1929-2009) indicate *Hexagenia* was: 1) abundant before 1954; 2) absent in 1955; 3) at minimal to nonexistent abundances between 1955 and the early-1990s; 4) found at low abundance in 1993; and 5) present at relatively high abundances between 1993 and 2009 (Figure 2). In 1997, basin-wide densities of nymphs approached pre-1950 levels.

In the early-1990s, anecdotal observations of adults along shores indicate *Hexagenia* began to recolonize several areas of the Great Lakes, particularly Lake Erie, after being absent for about 40 years. Two likely factors that may have facilitated *Hexagenia* recovery are: 1) four decades of pollution-abatement programs that lowered production of algae and other aquatic plants which would decompose and cause low DO; and 2) colonization of zebra mussels, which filter water and remove sediments, phytoplankton and zooplankton, and deposit these materials on substrates and provide food and energy to benthic populations, including *Hexagenia* (MacIsaac 1996). However, a sustained recovery of mayflies has only been documented in western Lake Erie even though dreissenid mussels have invaded and colonized many nearshore waters of the Great Lakes (Krieger et al. 2007; Schloesser et al. 2000).

Recovery of mayflies in western Lake Erie suggests the basin has returned to a moderately-productive 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, nymphs nearly disappeared from the south shore again in 2001-2004, suggesting one or more factors limits survival of mayfly populations where they temporarily colonized in the late-1990s. Krieger et al. (2007) speculated predation by round gobies (*Negobius melanostomous*) may have limited the abundance of *Hexagenia* nymphs and our ability to detect them where they had become established between 1997 and 2000. Another hypothesis for the absence of *Hexagenia* in some areas is that suitable conditions exist but the reproductive threshold of *Hexagenia* has not been adequately reached and sustained to allow reestablishment (Jerry Kaster, University of Wisconsin at Milwaukee, personal communication).

Although the sustained recovery of *Hexagenia* is well documented, there were large fluctuations in mayfly abundance between 1997 and 2009 (Figure 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; Bridgeman et al. 2006). 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 and these conditions could contribute to hypoxia and reduced mayfly recruitment (Bridgeman et al. 2006). Another possibility is the existence of an unknown interaction between *Hexagenia* and nuisance algae blooms (e.g., *Microsystis*) which began to occur in the mid- to late-1900s. In the Mississippi River, changes in abundance may have possible links to large-scale sediment shifting (e.g., from mud to sand) and natural fluctuations in year-class strength (Jerry Kaster, University of Wisconsin at Milwaukee, personal communication).

Future use of 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 USEPA Guardian cruises do this in deep waters but it 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 regular monitoring regime. Areas where intermittent sampling could be added include historic habitats of the Bay of Quinte in Lake Ontario, Presque Isle Bay in Lake Erie, Saginaw Bay, the St. Marys River in Lakes Superior and Huron, along with Green Bay in Lake Michigan and the south shore of Lake Michigan. We have anecdotal reports that all these places along with several river mouths once supported mayflies. In addition, monitoring efforts could benefit from in situ studies to determine if conditions can support *Hexagenia.* Periodic data collection in these habitats will provide support for ecosystem trend analysis in the future.

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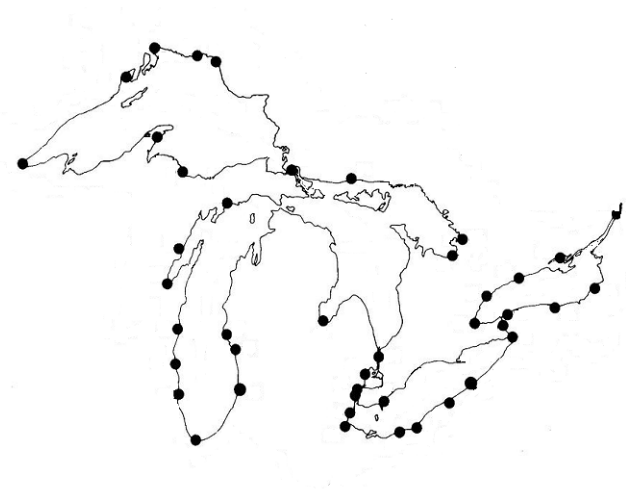
(a)



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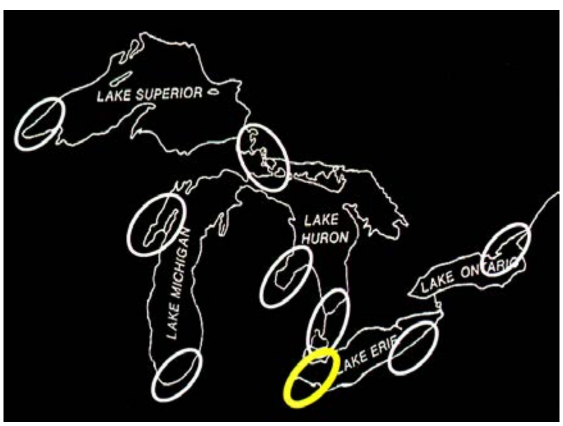

Figure 1. River mouths and harbors (areas of concern) where it is believed habitat would have been suitable for colonization by mayfly nymphs of the genus *Hexagenia* (a), and nearshore areas where *Hexagenia* were known to be abundant prior to 1950s (b) (Schloesser et al. 2000; unpublished).

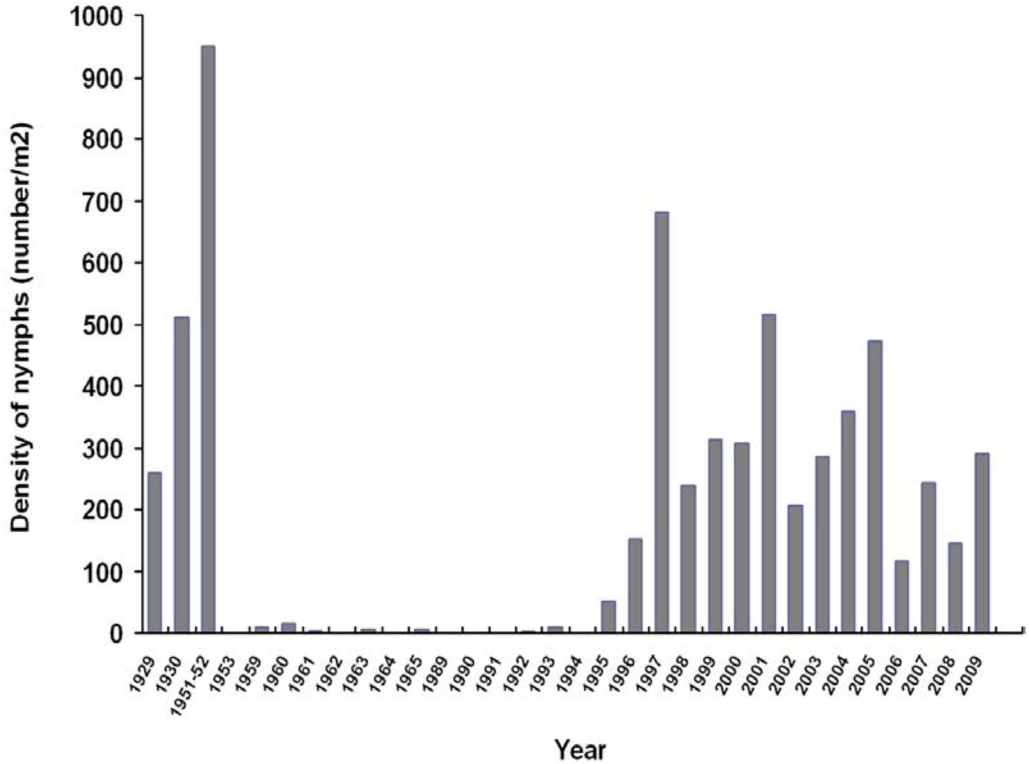

Figure 2. Density of *Hexagenia* nymphs in western Lake Erie 1929-2009 (Schloesser et al. 2000; unpublished, K. Krieger, Heidelberg College, Tiffin, Ohio).

4.3 Diporeia

Authors: Tom Nalepa, National Oceanic and Atmospheric Administration (emeritus) and Graham Environmental Sustainability Institute, University of Michigan; Vic Serveiss, International Joint Commission.

Summary

The bottom-dwelling amphipod (shrimp-like invertebrate) *Diporeia* is a native glacial relict that was once the most abundant bottom-dwelling organism in cold, offshore regions of the Great Lakes. *Diporeia*, with a maximum size of 10 mm, 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 passed up 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.

Importance for measuring progress toward objectives

Because of its abundance, wide distribution and important role in the food web, *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* are rich in calories because of its high lipid content and was readily available as prey for many species of Great Lakes (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 quantities of phytoplankton and hence greater amounts of food settling to the bottom. Short-term changes in abundances have mostly been attributed to shifts in the number 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 it is now insignificant as a food source for fish (Mohr and Nalepa, 2005; Nalepa et al. 2009).

Diporeia are important in maintaining the biological integrity of the Great Lakes because they are a source of food for many fish species, and they cycle energy to the preyfish community and some commercial species (lake whitefish). Furthermore, decreased abundances of *Diporeia* impacts some of the beneficial uses outlined in the 1987 Agreement (see Annex 2, Section 1c.; especially item iii) because *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 washed through a screen (or net mesh) with 0.5 mm openings. Since the minimum size of young *Diporeia* is about 1 mm, most 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

Beginning in the early 1990s, *Diporeia* populations declined dramatically in Lakes Michigan (Nalepa et al. 2009), Huron (Nalepa et al. 2007a) and Ontario (Watkins et al. 2007), and appear to have 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).

Even where *Diporeia* are still present in Lakes Ontario, Huron and Michigan, large declines are evident. At depths of 30-90 m, mean densities in Lake Michigan declined from 6,300/m^2 in 1994/95 to 49/m^2 in 2010; densities in Lake Ontario declined from 5,167/m^2 in 1994 to 7/m^2 in 2008; and densities in Lake Huron declined from 1,397/m^2 in 2000 to 93/m^2 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/m^2. Spatial patterns of decline in Lake Michigan between the mid-1990s and 2010 are provided in Figure 2.

Discussion

The loss of *Diporeia* became apparent soon after zebra and quagga mussels became established. The exact mechanism for the negative response of *Diporeia* to these nonnative mussels is not entirely clear, but it may a result of various stressors, including a decline in available food from the filtering activity of mussels (Nalepa et al. 2006).

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 (*Alosa pseudoharengus*), sculpin (Cottidae family) and bloater (*Coregonus hoyi)* 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 effect 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 declining (Barbiero et al. 2009; Pothoven et al. 2010). 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.

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 is no longer able to support the level of fish resources found in the past.

Future use of 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.

Until quagga mussel populations stabilize, the frequency and intensity of monitoring *Diporeia* populations could be decreased and more emphasis placed on understanding the causes of decline and potential remedies. The decline of *Diporeia* means that preyfish such as alewives must rely on alternate food sources. One potential replacement food source would be *Mysis diluviana*, the opposum shrimp. Like *Diporeia*, it is a glacial relict and could be a valuable additional indicator to supplement the historical record of *Diporeia*. Also, higher trophic levels, especially top predator fish species, may integrate the effects of the lower food web and could be another indicator.

Several federal agencies are currently monitoring populations of both *Diporeia* and mussels, and in combination, 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.

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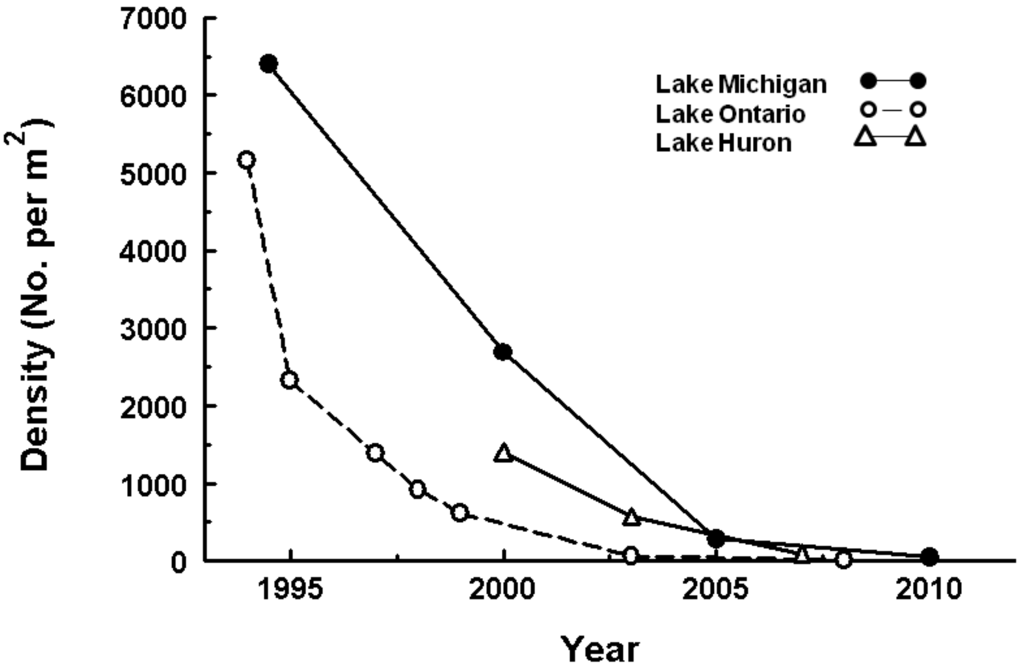

Figure 1. Mean density (no. per m^2) of *Diporeia* spp. at 30-90 m in Lakes Michigan, Ontario and Huron. Data derived from Nalepa et al. 2007a, 2007b, 2009; Watkins et al. 2007; Nalepa unpublished; Lozano unpublished).

4.4 Lake Sturgeon Abundance

Authors: Nancy Auer, Michigan Technological University; Dave Dempsey, International Joint Commission.

Reviewer: Vic Serveiss, International Joint Commission.

Summary

Lake sturgeon abundance, which fell to 1% of historical levels by the mid-1950s, 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 successful restoration of habitat or creation of artificial habitat by multiple levels of government and organizations. However, the species is still listed as threatened or endangered throughout much of the Great Lakes basin, making recovery uncertain. Continued monitoring, habitat restoration and water quality improvements will be necessary to the survival of the species in the basin.

Importance for measuring progress toward objectives

Annex 2 of the 1987 Great Lakes Water Quality Agreement (1987 Agreement) provides for areas of concern where impaired beneficial uses, such as degradation of fish and wildlife populations, are to be remedied. Several historic lake sturgeon habitats, including the Detroit River, are within areas of concern. Remediation of these areas will, to the extent that sturgeon populations are suppressed by contaminants and loss of habitat, assist in restoring this beneficial use.

Lake sturgeon (*Acipenser fulvescens*) 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 one of the few species sensitive to 3-trifluoromethyl-4-nitrophenol treatments (Johnson et al. 1999), which are used to suppress sea lamprey

(*Petromyzon marinus*) spawning, so their absence can be used as an indicator of chemical contamination. As adults, due to their great physical strength and numerous sensory receptors on the head and barbels, sturgeon detect and avoid unpleasant stimuli before other less sensory-equipped families of freshwater fish.

Second, lake sturgeon are also sensitive to low dissolved oxygen (DO) levels. Because sturgeon are benthic-feeding fish, the lower oxygen concentrations and higher concentrations of metals and organic debris of the benthos will affect sturgeon more than fish feeding higher in the water column.

Third, they accumulate contaminants. Sturgeon live to great age, often over 100 years (Harkness and Dymond, 1961) and this long lifespan leaves sturgeon vulnerable to the buildup of contaminants.

Fourth, the increased presence of sturgeon in nearshore waters can indicate health of systems. The fish's ability to return to natal streams via imprinting indicates good river health and connectivity. Lake sturgeon utilize a diverse habitat throughout their life. Sturgeon begin as eggs 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. 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. Rivers with unperturbed, large wetlands are known to support the largest stocks of sturgeon, so sturgeon abundance is one of several indicators of wetland health (Cookman 2001).

Finally, lake sturgeon are increasingly an iconic fish species for the public, symbolic of the health and recovery of the Great Lakes.

Methods

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, state departments of natural resources, US 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

The State of the Lakes Ecosystem Conference (SOLEC 2009) reported that sturgeon reproduction continues in at least 10 of 22 historical tributary locations in Lake Superior, where populations are believed highest among the five Great Lakes. In the Sturgeon River, a tributary of Lake Superior, the annual spawning run increased by approximately 100 adults in the mid-1980s to a total of 350 to 400 in 2004 (Auer 1996a,1996b).

The Lake Michigan population was estimated at less than 10,000, but the abundance of spawners appears to have increased in several tributaries.

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 have been documented in the Menominee, Manistee, Oconto and Peshtigo Rivers (Elliott 2008).

Populations in the Peshtigo River, Wisconsin, part of the Lake Michigan drainage basin, grew over a 20-year period (US 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). Caroffino et al. (2010) suggested populations in the river could be further increased through management actions designed to reduce early life stage mortality.

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 absence of statistically valid sampling and data, studies of specific spawning locations and subpopulations contribute to understanding of trends. In the St. Clair River, (Thomas and Haas, 2004) found consistent recruitment during the 1970s and 1980s, but low recruitment prior to 1973 and after 1994, based on age of sturgeon captured which were mostly adult fish at spawning time. 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 was at more than 29,000 fish in 1999 and about 5,000 fish in 2000.

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 (US Fish and Wildlife Service 2009).

Discussion

While recent spawning success in the Detroit River and other traditional spawning habitats is encouraging, recovery cannot be assumed. Some unpublished data collected by Michigan Technological University are beginning to suggest that increased variability in the 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. Although some efforts have begun to rehabilitate stocks in the Great Lakes region, more variable climate patterns may add additional challenges to recovery efforts. The IJC recommends sustained, long-term monitoring of Great Lakes lake sturgeon populations, which 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 hydroelectric dams prevent lake sturgeon from migrating up the river from Lake Michigan to get to their prime spawning and rearing habitat. Removal of the two lowermost dams would increase juvenile lake sturgeon habitat from 212 to 1,610 acres (Daugherty 2006; Daugherty et al. 2007). The US 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 an impediment on many other spawning streams.

Future use of 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.

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4.5 Lake Trout Abundance

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Reviewers: John Dettmers, Great Lakes Fishery Commission; Vic Serveiss, International Joint Commission .

Summary

Since the mid-1980s, the number of lake trout in four of the five Great Lakes has been stable overall, largely because of stocking. Self-sustaining populations 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 Lake 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, nonnative alewives preying on fry and thiamine deficiency induced by using alewives as a food source, resulting in early mortality syndrome (EMS). Dioxin-like substances may be inhibiting reproduction in the lower lakes.

Importance for measuring progress toward objectives

Article II of the 1987 Great Lakes Water Quality Agreement (Agreement) states its purpose is "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.

Specific Objectives Supplement to Annex 1, Subsection 3(a) of the 1987 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

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 whole population or some area of interest. Measures of relevant abundance vary by lake. In US waters of Lake Superior, 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 US 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. 2008a; 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 nonnative predators such as coho and chinook salmon. These targets are based on what is necessary to achieve sufficient spawning stock biomass for successful natural reproduction. Measured abundance is then compared with the targets.

Results

Lake trout population trends have differed among the lakes. Lakes Superior and Huron populations have fluctuated year by year but remain at levels comparable to those of the mid-1980s. Lake Superior populations are fully restored based on comparing current measures of abundance and natural reproduction with historical measures. 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.

The low reproduction rates in Lakes Ontario, Michigan and Erie are thought to be due to high mortality from sea lamprey predation on adults and alewife predation on young (SOLEC 2012) and reproductive failure due to thiamin deficiency (Fitzsimons et al. 2009).

Discussion

Lake trout has historically been the top salmonine predator in Lakes Superior, Huron, Erie and Michigan and has shared this position with Atlantic salmon in Lake Ontario. It has been a key source of sustenance for Native Americans. Ecologically, the lake trout represents the endemic salmonine atop the food chain and has been the 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, lake trout are an excellent indicator of ecosystem health (Edwards et al. 1990).

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, limited fishing and 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 in Lake Superior and stocking for rehabilitation has been discontinued. Lake Superior provides high quality habitat for lake trout because of its cold water temperatures, largely undisturbed physical habitat, low contaminant levels and few invasive species. Lake trout in all other Great Lakes face pressures from high adult and excessive fry mortality from alewife predation, 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 nonnative alewives, a species harboring high thiaminase activity, and has been linked to egg and fry mortality 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 this 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 likely be necessary to restore self-sustaining lake trout populations.

Halogenated aromatic hydrocarbons, including PCBs, polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), are dioxin-like substances and persistent bioaccumulative toxic chemicals. Bioaccumulation of these hydrocarbons is potentially one of many factors causing low lake trout reproduction rates in the lower Great Lakes in 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.

Future use of indicator

The biological significance of lake trout as a native top predator fish makes it ideal as an indicator of Great Lakes biological health. For this reason, fisheries management agencies have devoted considerable effort to lake trout rehabilitation for the past several decades. Continued use of the indicator is advisable.

The value of the indicator would be enhanced if standard metrics were established for all of the lakes. Until then, the indicator is valuable as a measure of lake-by-lake trends in relative lake trout abundance but not a strong measure of comparable populations among the lakes.

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Section 5. Indicators of Performance

5.1 Removal of Beneficial Use Impairments and Restoration of Areas of Concern

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Reviewers: John Perrecone, United States Environmental Protection Agency; Jon Gee, Environment Canada.

Summary

Based on Annex 2 of the 1987 Great Lakes Water Quality Agreement (1987 Agreement), Canada and the United States identified 43 areas of concern (AOCs), including 26 in the United States, 12 in Canada and five in shared waters, and called for the federal governments to restore them. The requirement to restore them continues in the 2012 Agreement. The designated areas had suffered serious bacterial or chemical degradation and were likely to have compromised the area's ability to support aquatic life. At the outset, each of the 43 AOCs had at least one and as many as 14 beneficial use impairments (BUIs). Examples of BUIs include loss of fish habitat or contaminants in fish serious enough to prompt consumption warnings. There were a total of 409 BUIs spread across the 43 AOCs. In the past quarter century, four of the AOCs have been restored and three of them improved enough to be considered Areas in recovery. In the United States, 33 of 255 BUIs have been removed, and in Canada, 54 of 154 are removed.

Importance for measuring progress toward objectives

Annex 2 of the 1987 Agreement directs Canada and the United States, working with state and provincial governments, to designate geographic areas of concern and develop remedial action plans (RAPs) to restore beneficial ecosystem health and human uses such as fish and benthos health, drinking water, fish consumption and swimming at beaches. The designated geographic areas with such use impairments are known as areas of concern (AOCs). The federal governments identified 43 AOCs, including 26 in the United States, 12 in Canada and five in shared waters (Figure 1). AOCs in shared waters require restoration efforts by both governments.

AOCs are designated if an area does not meet one or more of 14 beneficial uses. The so-called beneficial use impairments (BUIs) are listed in Annex 2 of the 1987 Agreement and in Annex 1 of the 2012 Agreement and are shown in the Methods section. Examples of BUIs include loss of fish habitat or contaminants in fish serious enough to prompt consumption warnings. Each country may designate different BUIs for each of the shared AOCs. AOCs are generally delisted when all of the BUIs are removed and reflect direct measures of progress made by the Parties toward restoring degraded conditions. Removal of BUIs from AOCs that have not been delisted provides an important, useful and easily understood yardstick for measuring progress (USPC 2001).

Most of the indicators in this 16th Biennial Report measure environmental conditions or stressors that reflect progress toward objectives for chemical, physical and biological integrity. AOC delistings and BUI removals are also a direct measure of restoration made by the governments and they directly measure progress toward an objective of an Annex to the Agreement.

Methods

Environment Canada (EC 2010) and the United States Policy Committee (USPC 2001) describe the process for delisting an AOC via the RAP process in compliance with Annex 2 of the 1987 Agreement. Each AOC has developed a RAP that guides restoration and protection efforts. All RAPs must proceed through three stages. Stage one is to determine the severity and underlying causes of environmental degradation that make the location an AOC. An AOC could be degraded for a variety of reasons, such as excess nutrients in the water, bacteria or chemical contaminants in the environment, or loss of fish and wildlife habitat. Stage two is to identify goals and recommend actions that will lead to the restoration and protection of ecosystem health. Stage three is to implement recommended actions and measure progress of restoration and protection efforts in the AOC to ensure the local goals have been met.

Under the revised 2012 Agreement, an AOC will be delisted when the restoration objectives (delisting criteria) in the RAP have been achieved. The decision to delist is made by the governments of Canada and the United States. Decisions to delist are made in consultation with the provinces or affected states, local stakeholders and RAP participants, and with the advice of the IJC. For the binational AOCs, delisting decisions include consultation among both federal governments.

Listed below are the 14 beneficial use impairments from Annex 2:

- restrictions on fish and wildlife consumption
- tainting of fish and wildlife flavor
- degraded fish and wildlife populations
- fish tumors or other deformities
- bird or animal deformities or reproductive problems
- degradation of benthos
- restrictions on dredging activities
- eutrophication or undesirable algae
- restrictions on drinking water consumption or taste and odor problems
- beach closings
- degradation of aesthetics
- added costs to agriculture or industry
- degradation of phytoplankton and zooplankton populations
- loss of fish and wildlife habitat

Each AOC has a RAP team that has developed its own restoration targets with measurable environmental conditions for each BUI. The IJC has compiled a list of the remaining BUIs, which includes current examples of delisting targets (IJC 2011). The targets provided by the IJC are intended to assist RAP groups that have not yet established targets for some beneficial uses and may relate to state and provincial standards. For example, the BUI delisting criterion for the Detroit River Canadian AOC is: “ When consumption advisories for indicator fish species given for the sensitive population in the AOC are similar to upstream and downstream non-AOC Great Lakes reference areas”.

restoration target for fish contaminants for the Detroit River Canadian AOC requires levels of contaminants such as PCBs and mercury in fish tissue to be less than state and provincial action levels.

Targets should be locally derived and should include the minimum requirements specified in Annex 2 along with meeting regulations, objectives, guidelines and standards set by the federal, state and local agencies with jurisdiction over the AOC (USEPA 2001).

The United States Policy Committee (USPC 2001) describes the scenarios under which a BUI can be removed:

- A delisting target has been met through remedial actions that confirm that the BUI has been restored.
- It can be demonstrated that the BUI is due to natural causes.
- It can be demonstrated that the BUI is typical of lake-, region-, or area-wide conditions.
- The impairment is caused by sources outside the AOC. In this case the impairment can be removed or changed to “impaired not due to local sources.” Responsibility for addressing the source is given to another party (e.g., lakewide area management plan) and the AOC can be delisted with a BUI categorized in this manner.

USEPA (2012a) and EC (2010) records which of the 43 AOCs have been delisted or reclassified as areas of recovery over time and also track the status of BUIs at each AOC.

Results

AOC delistings or reclassifications

Of the 43 original AOCs, 4 have been restored and delisted (Figure 1). In Canada, 3 out of the 12 Canadian AOCs have been delisted: Severn Sound, Collingwood Harbour and Wheatley Harbour. Spanish Harbour and Jackfish Bay are considered areas of concern in recovery.

On the US side, only 1 of 26 AOCs have been delisted—the Oswego River—while Presque Isle Bay is considered an area of recovery. None of the five binational AOCs have been delisted and all still have most of their BUIs on both sides of the border.

BUI removals

In Canada, as of May 2011, 54 out of 154 BUIs have been removed and 100 BUIs remain (Table 1).

In the United States, there were originally 255 BUIs, and 33 of them have been removed (Table 2). The pace of removal has been quicker with the advent of the Great Lakes Restoration Initiative, and 20 BUIs were removed in the last three years.

Environment Canada tracks restoration progress and BUI removals at each of the 17 Canadian and binational AOCs (Table 1). EC (2010) provides a description of each AOC and also discusses the RAP and restoration activities. This report also provides an update on the status of beneficial use impairments in Canadian AOCs as of September 2010 and also includes a description of the actions completed and remaining to restore the beneficial use.

USEPA (2102a) provides information about each AOC that discloses the BUIs, delisting targets, along with RAP history and status.

Discussion

In Canada there has been good progress, with over one-third of Canadian BUIs removed. In the United States there has been much recent success using Great Lakes Restoration Initiative funding. Many sediment and habitat restoration projects are underway in both countries that are expected to lead to more BUI removals and AOC delistings. While headway has been made in both countries, after 25 years, most AOCs and BUIs are still listed and more work is needed.

Many annexes of the 1987 and 2012 Agreements require the governments to report on the progress of programs and measures used to achieve objectives. As discussed elsewhere in this report, for many other indicators such reports have not been provided. The Canadian and US governments are commended for reporting AOC delistings, listing each AOCs BUIs and BUI removals, and providing other information about each AOC.

Furthermore, the Commission lauds the government for making progress on BUI removals as indicators of performance. For instance, in Canada, BUI status and progress is an indicator in the suite of Canadian Environmental Sustainability Indicators (EC 2012). On the US side, BUI removal is included as an indicator in both the US Environmental Protection Agency Office of Water Performance measures for the Great Lakes (USEPA 2012b) and the Great Lakes Restoration Initiative Accountability System (USEPA 2011).

However, further improvements can be made. IJC (2003) produced a report to inform the public on how much had been done towards restoring BUIs. Below, the IJC reiterates some recommendation from that report and adds a few more:

While current website reporting provides much useful information, the governments of Canada and the United States should ensure annual updates of their respective websites to inform the public about the:

- number or remaining BUIs
- degree to which each BUI in each AOC has been restored
- government's investments and achievements to date
- schedule for developing restoration targets, and priorities for restoring BUIs
- rationale for priority decisions and designating AOCs in recovery stage

Future use of indicator

This indicator directly measures restoration progress made by the governments. Since removing or restoring beneficial use impairments and reducing the number of listed areas of concern will continue to be an objective under the 2012 Agreement, this indicator should continue to be tracked and reported. The work is wide-ranging, costly and has numerous participants, and the IJC recommends that adequate resources be made available for restoration activities by both federal governments. In addition, accountability and responsibility should be assigned to specific agencies to accelerate progress towards BUI removals and AOC delistings.

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Figure 1. Location and status of the 43 Great Lakes areas of concern.

Source of data: Environment Canada, 2010. Canadian Great Lakes Areas of Concern: Status of Beneficial Use Impairments Overview.

Table 1. Status of beneficial use impairments in the Canadian areas of concern.

AREA OF CONCERN	1. Restrictions on fish and wildlife consumption	2. Tainting of fish and wildlife flavour	3. Degradation of fish and wildlife populations	4. Fish tumours or other deformities	5. Bird or animal deformities or reproduction problems	6. Degradation of benthos	7. Restrictions on dredging activities	8. Eutrophication or undesirable algae	9. Restrictions on drinking water consumption, or taste and odour problems	10. Beach closings	11. Degradation of aesthetics	12. Added costs to agriculture or industry	13. Degradation of phytoplankton or zooplankton populations	14. Loss of fish and wildlife habitat
Thunder Bay	Yellow	Grey	Red	Yellow	Yellow	Red	Red	Grey	Grey	Yellow	Red	Green	Yellow	Red
Nipigon Bay	Grey	Green	Green	Green	Grey	Red	Green	Green	Grey	Grey	Red	Grey	Grey	Red
Jackfish Bay	Yellow	Grey	Red	Green	Green	Red	Green	Grey	Grey	Grey	Yellow	Grey	Grey	Red
Peninsula Harbour	Red	Grey	Red	Green	Grey	Red	Red	Grey	Grey	Grey	Grey	Grey	Grey	Red
St. Marys River	Red	Green	Red	Red	Yellow	Red	Red	Red	Grey	Red	Red	Grey	Grey	Red
Spanish Harbour	Red	Grey	Green	Grey	Green	Red	Red	Grey	Grey	Green	Grey	Green	Green	Green
Severn Sound (blue)	Green	Grey	Green	Grey	Grey	Green	Grey	Green	Grey	Green	Green	Grey	Green	Green
Collingwood (blue)	Green	Grey	Grey	Grey	Grey	Grey	Green	Green	Grey	Grey	Grey	Grey	Grey	Green
St. Clair River	Red	Green	Yellow	Yellow	Yellow	Red	Red	Grey	Red	Red	Red	Red	Grey	Red
Detroit River	Red	Yellow	Red	Red	Red	Red	Red	Grey	Green	Red	Red	Green	Yellow	Red
Wheatley Harbour (blue)	Green	Grey	Green	Grey	Grey	Green	Green	Green	Grey	Grey	Grey	Grey	Grey	Green
Niagara River	Red	Grey	Red	Green	Green	Red	Green	Red	Grey	Red	Grey	Grey	Yellow	Red
Hamilton Harbour	Red	Grey	Red	Yellow	Yellow	Red	Red	Red	Grey	Red	Red	Grey	Yellow	Red
Toronto and Region	Red	Grey	Red	Green	Yellow	Red	Red	Red	Grey	Red	Red	Grey	Yellow	Red
Port Hope	Grey	Grey	Grey	Grey	Grey	Grey	Red	Grey	Grey	Grey	Grey	Grey	Grey	Grey
Bay of Quinte	Red	Grey	Red	Yellow	Grey	Red	Green	Red	Red	Red	Red	Grey	Red	Red
St. Lawrence River	Red	Green	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green	Green	Red

KEY	
Red	Impaired
Yellow	Requires Further Asse
Green	Not Impaired (restored
Grey	Never Impaired
Blue	**Delisted Area of Con**

Source of data: Environment Canada, 2010. Canadian Great Lakes Areas of Concern: Status of Beneficial Use Impairments Overview.

Table 2. Status of US areas of concern and BUI removal progress.

Area of Concern	Lake	State	Maximum # of BUIs	# BUIs Removed	# BUIs Impaired
Ashtabula River	Erie	OH	6	-	6
Black River	Erie	OH	9	-	9
Buffalo River	Erie	NY	9	-	9
Clinton River	Erie	MI	8	-	8
Cuyahoga River	Erie	OH	9	-	9
Deer Lake	Superior	MI	3	2	1
Detroit River	Erie	MI	11	1	10
Eighteen Mile Creek	Ontario	NY	5	-	5
Fox River / Lower Green Bay	Michigan	WI	11	-	11
Grand Calumet River	Michigan	IN	14	2	12
Kalamazoo River	Michigan	MI	8	2	6
Lower Menominee River	Michigan	WI/MI	6	1	5
Manistique River	Michigan	MI	5	3	2
Maumee River	Erie	OH	10	-	10
Milwaukee Estuary	Michigan	WI	11	-	11
Muskegon Lake	Michigan	MI	9	1	8
Niagara River	Ontario	NY/ON	7	-	7
Oswego River	Ontario	NY	6	6	0
Presque Isle Bay	Erie	PA	2	1	1
River Raisin	Erie	MI	9	1	8
Rochester Embayment	Ontario	NY	14	2	12
Rouge River	Erie	MI	9	-	9
Saginaw Bay	Huron	MI	12	2	10
Sheboygan River	Michigan	WI	9	-	9
St. Lawrence River	Ontario	NY/ON	7	-	7
St. Louis River	Superior	MN/WI	9	-	9
St. Mary's River	Superior	ON/MI	10	-	10
St. Clair River	Erie	MI/ON	10	4	6
Torch Lake	Superior	MI	3	1	2
Waukegan Harbor	Michigan	IL	6	1	5
White Lake	Michigan	MI	8	3	5
TOTAL US			255	33	222

Source of data: USEPA 2012a. Great Lakes Areas of Concern: Overview. http://www.epa.gov/greatlakes/aoc/

5.2 Beach Closings and Advisories

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Reviewers: Vic Serveiss, International Joint Commission; Holiday Wirick, US Environmental Protection Agency.

Summary

The number of Great Lakes beach closings and advisories remained fairly constant between 1998 and 2006-2007. The percentage of all US Great Lakes beaches closed more than 10% of days during beach season ranged from 12% in 1998 to 9% in 2006-2007. The comparable Ontario figure was 54% in 1998 and 42% in 2006-2007. These data need to be interpreted with caution because of changes in the number and set of beaches that were analyzed over time and because different states and Ontario use different criteria for closures.

Disease occurrences related to swimming at Great Lakes beaches are likely underreported. 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 occurrences registry are recommended.

Importance for measuring progress toward objectives

A specific objective of the 1987 Great Lakes Water Quality 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 on Great Lakes beaches are an indicator of local water quality, help shape public perceptions of the health of the Great Lakes ecosystem and may be linked to human health.

The number of beach closings 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 *Escherichia coli* as the standard basis for beach closings. Until new standardized measures are developed and data generated under them are reported and compiled, this indicator will continue to be the only indicator of fecal contamination of water with a historical record.

Methods

The State of the Lakes Ecosystem Conference (SOLEC 2009) used beach closing data collected and reported by US 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 US BEACH Act, the number of Great Lakes beaches covered by reporting rose from 303 in 1998 to 1,445 in 2007. An increased 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 possible presence of fecal pathogens that can affect human health.

A new metric was used beginning in the 2008 swimming season which SOLEC (2011) used for reporting The 1998-2007 figures included nonmonitored US beaches. The nonmonitored beaches were listed as open and safe for swimming for 100% of the beach season because the lack of monitoring resulted in no postings. From 2008 forward only data from the monitored beaches were counted. The change in metric precludes trend analysis for the entire 1998-2010 period.

Results

Between1998 and 2007, the average number of days that Great Lakes beaches were closed 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. Variations in the number and set of beaches monitored may also influence the results.

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

The percentage of US beaches closed more than 10% of the time ranged from 12% in 1998-1999 to 9% in 2006-2007. The comparable Ontario figures were 54% in 1998-1999 and 42% in 2006-2007.

Discussion

One limitation of the SOLEC data is that year-to-year fluctuations in beach closings are largely attributable to the number and intensity of rainfall events. Heavy rainfall causes combined sewage overflows as well as agricultural and urban runoff, which lead to bacterial contamination loadings into recreational waters (IJC 2009).

Another limitation in the use of beach closings as 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.

The SOLEC metric has been changed as of 2008 and is now the percentage of days of the beach season that monitored Great Lakes beaches are open and safe for swimming. This makes trend analysis challenging. Since most beach closures 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. Because human health impacts have been associated with swimming at Great Lakes beaches in two studies (Wade et al. 2006; Wade et al. 2008), better data on swimming-related disease occurrences should be collected and reported. Wildlife droppings may also be a contributor to many closures (Environment Canada 2012), and this vector should be further explored.

Future use of indicator

Closings associated with Great Lakes bathing beaches affect public health and public perception of ecosystem health, which supports future use of this indicator, with qualifications. To improve this 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 and waterborne disease resulting from swimming at public beaches. Disease occurrences related to use of recreational waters should be reported to the registry and made available to the public and to researchers.

- Develop binational, standardized basinwide surveillance and monitoring protocols in conjunction with preventive risk management strategies, and adopt binational standardized criteria for beach closings.
- Continue to improve monitoring methods to support real-time assessments of beach water quality and support timely closings to protect beach users. For instance, Wade et al. (2008), 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.

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Section 6. Conclusions and Recommendations

The Great Lakes Water Quality Agreements of 1987 and 2012 mandate that the IJC assess the extent to which programs and other measures are achieving the Agreement's objectives, and to provide advice and recommendations on matters related to the Agreement. These responsibilities form the basis of the IJC's advice to the governments of Canada and the United States. The findings from the previous indicator chapters are summarized below for each aspect of integrity and each individual indicator. Finally, the chapter presents IJC's recommendations for improving the assessment and reporting of progress under the 2012 Agreement.

6.1 Conclusions from Indicator Reports and Recommendations for Managers and Scientists

The indicators tell a mixed story about the attainment of 1987 Great Lakes Water Quality Agreement objectives and yield conclusions that support the IJC's recommendations for monitoring and program management actions. Many government policies have had favorable results. For instance, banning persistent bioaccumulative toxicants (PBTs), like PCBs and DDT, has led to reductions in chemical concentration and increases in colonial waterbird and raptor populations. Conclusions about indicators and accompanying recommendations are sorted by the Agreement's overarching objective of restoring and maintaining the chemical, physical and biological integrity of Great Lakes waters. Some of the recommendations reiterate recommendations that the IJC made in its 15th Biennial Report on Great Lakes Water Quality (IJC 2011).

Chemical integrity

In general, all seven indicators of chemical integrity showed mostly favorable or stable results since 1987. The levels of many PBTs entering 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. More reductions and more intense declines occurred in the 1987-2000 period than more recently. It is clear that declines of chemical concentrations in biota have slowed since 2000 , and, for a small number of these chemicals, increases may have taken place in the most recent years. Finally, while progress was achieved in reductions of persistent toxic chemicals, concentrations of some chemicals of emerging concern have increased since 1987. The conclusions drawn from each of the chemical integrity indicator chapters and the subsequent IJC recommendations are provided below.

Contaminants in herring gull eggs

This indicator reveals large declines of several contaminants since 1987. However, in recent years declines have slowed and mercury levels have remained stable. Despite the reductions, herring gulls in polluted areas are experiencing more abnormalities than herring gulls in cleaner habitat. Since herring gulls are primarily fish-eaters, they reflect chemical concentrations and the condition of the fish they consume.

Herring gull egg indicator data are useful for tracking long-term trends in contaminants across different trophic levels in each of the Great Lakes. As a result, the IJC recommends:

- Governments should protect the herring gull egg monitoring and assessment program from budget cuts and it should continue as an indicator of Great Lakes chemical integrity. The program should be supplemented with monitoring of levels of chemicals of emerging concern. Other research activities should be incorporated into routine monitoring, including evaluation of the avian immune system.

Fish consumption restrictions

This indicator shows that the levels of several PBTs in Great Lakes fish declined between the 1970s and 1987 and for a few years thereafter. Since about 1990, the levels of these contaminants have either declined at a slower rate or have stabilized and, in the case of some emerging PBTs, have increased. Numerous restrictive fish consumption advisories aimed at protecting human health from contaminant exposure remain in place. The IJC recommends:

- State and provincial governments should include chemicals of emerging concern in their monitoring, reporting and decision making with respect to issuing fish consumption advisories

Contaminants in whole fish

This indicator shows similarly declining contaminant levels. However, many legacy chemicals may be impacting fish health. In order to best protect fish, the IJC recommends:

- Governments should continue monitoring PBTs and improve and seek ways to reduce their exposure pathways to fish.
- Governments should support programs to improve the understanding of how multiple variables (e.g., invasive species, loss of native species and global climate change) affect exposure pathways.
- Governments should support collaborative programs to improve and share understanding of the potential negative ecosystem health effects from exposure to PBTs.

Contaminants in mussels

This indicator shows that levels of many metals and legacy organic contaminants are decreasing basinwide. The IJC recommends:

- Governments intensify future monitoring by adding offshore sites (open water) to complement the data from nearshore sites. The two data sets combined will provide a better assessment of the extent of chemical contamination within the Great Lakes basin. The open water samples would add little additional cost because they would be collected as part of other ongoing offshore monitoring.

Contaminants in sediment cores

Although this indicator shows contaminant levels have declined, the IJC believes further work should be done to evaluate temporal trends. The IJC recommends:

- Governments should continue to examine changes in contaminant concentrations at the surface and at various depths of sediment cores collected from each of the lakes. This work needs to be maintained to assess changes in loading, identify and track sources of contaminants, and explore opportunities to accelerate the elimination of contaminants. Identification of contaminated sediment hotspots should warrant investigation to pinpoint possible local or subregional sources.

Phosphorus loading

This indicator underscores the contribution phosphorus makes to increased frequency and severity of harmful algal blooms in Lake Erie. Because the data are largely derived from agriculture-intensive tributary watersheds, the IJC believes the indicator chapter demonstrates the importance of addressing the contribution of runoff from land, particularly from agricultural activities. Reduced loadings and concentrations of available phosphorus, especially dissolved reactive phosphorus, are essential to controlling algal blooms. Without reductions in sources of phosphorus from agricultural runoff into tributaries such as the Maumee and Sandusky Rivers, western Lake Erie will continue to suffer the serious economic and environmental consequences of harmful algal blooms.

Most pollution reduction under the US Clean Water Act has been accomplished through pollution discharge limits imposed via permits for individual facilities or “point sources” such as factories and wastewater treatment plants. While effective in reducing a significant proportion of pollution to Great Lakes tributaries and open lakes, this approach does not address most nonpoint sources such as pollution runoff from land, including agricultural land. In the United States, the Clean Water Act provides a mechanism for addressing both point and nonpoint sources of pollution for a given water body. The total maximum daily load (TMDL) process involves development of an inventory of sources of a given pollutant for an individual water body, an allocation of the contribution of that pollutant from various point and nonpoint sources to the water body, and a plan to reduce pollution from these sources in order to meet Clean Water Act water quality standards.

Unfortunately, the TMDL process has not been sufficiently implemented in some areas of the Great Lakes that are impacted by nonpoint source pollution. The state of Ohio has not developed and implemented a phosphorus TMDL for western Lake Erie. Other states have also not developed and implemented phosphorus-loading TMDLs for some Great Lakes tributaries. As a result, the IJC recommends:

- Federal, state, and provincial governments should continue to develop and implement best or beneficial management practices to reduce DRP runoff from agricultural lands and to develop and enforce measures to decrease loadings in high risk watersheds.
- Governments should support and encourage farmers to be aware of recommended phosphorus levels for the crops they are growing, to test soil regularly, and to apply fertilizer or manure to soil only when phosphorus is needed.
- Governments should support and encourage development and use of related technologies such as using manure digesters and transporting manure to areas needing fertilizer.
- Governments should develop improved models to more accurately estimate phosphorous loadings to western Lake Erie and to other basins experiencing problems associated with excess phosphorus.
- Governments should collaborate to develop, maintain and share an inventory of effective management actions that are used to better retain nutrients and sediments on the land, especially in watersheds yielding high phosphorus loadings. Examples of management actions include: 1) nutrient-use planning for croplands and livestock operations; and 2) implementing outreach to waterfront residents on better

construction and maintenance of septic systems and 3) establishing requirements that septic systems be inspected at time of house sale and upgraded when necessary.

The states of Ohio, Michigan and Wisconsin should work with USEPA to complete phosphorus TMDLs for the respective water bodies of western Lake Erie, Saginaw Bay and Green Bay. Atmospheric deposition of toxic contaminants

This indicator shows that the amount of deposition of key persistent toxic chemicals has declined since the 1970s and 1980s, when many were banned in North America. However, emerging contaminants such as persistent compounds in flame retardants are of concern. The IJC recommends:

- The governments should sustain the Integrated Atmospheric Deposition Network (IADN) at historic funding levels. As a long-lived, statistically valid measure of atmospheric deposition of toxic chemicals, IADN and reporting of its data are important to measuring the chemical integrity of the Great Lakes.
- The governments should support research to help identify the origin of contaminants in order to target remediation and prevention actions.

Other chemical integrity recommendations

Although indicators used in this report show that significant progress has been made since 1987 in reducing a number of the historic chemical contaminants, further actions need to be aggressively pursued in order to invest public funds most efficiently. The IJC reiterates chemical policy recommendations from its 15th biennial report (IJC 2011):

- Federal governments should develop and implement a process to identify chemicals that are a priority for binational action consistent with national chemical management programs.
- Governments should supplement existing chemical monitoring programs with biological exposure and effects monitoring to better assess risks of chemicals and chemical mixtures to humans and the environment and to enable assessment of

management strategies.

- Governments should continue to invest in research to better understand human health and ecological effects of mixtures of chemicals, including chemicals of emerging concern.
- Governments should increase investments in scientific research to better understand causation of stable or increasing mercury levels in Great Lakes biota and sustain related monitoring and data analysis.
- Governments should continue implementation of standards reducing mercury emissions from coal-fired power plants, the leading domestic sources of anthropogenic mercury.
- Federal, provincial and state governments should invest in communication efforts that educate consumers and provide incentives that encourage them to purchase more environmentally friendly products and services, and practice safer disposal of products (e.g., take-back programs) that contain chemicals of emerging concern.
- Governments should increase investment in wastewater treatment technologies that improve the detection, control, removal and destruction of chemicals of emerging concern.
- Federal governments should work with provincial and state governments through targeted monitoring to identify and track down local sources of pollution for those chemicals whose distribution in the ambient environment suggests local or subregional 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 discharge of toxic substances to the Great Lakes.

Physical integrity

The IJC commends the Parties for beginning to undertake improved monitoring and analysis of physical indicators such as land cover, fish habitat and coastal wetland landscape extent and composition and for reporting results through SOLEC. Physical indicators are essential to determining progress toward 1987 and 2012 Agreement objectives. The conclusions drawn from each of the physical integrity indicator reports and the subsequent management recommendations from the Commission are provided below.

Lake surface temperature and ice cover

The data show increasing temperatures and dramatic reductions in ice cover, reflecting a warming trend that could impair native fish populations and have other undesirable impacts. The consensus among scientists is that these observations reflect global climate change. Some jurisdictions have taken actions to mitigate greenhouse gas releases such as the Ontario Green Energy Act and state climate change action plans. However, management actions in the Great Lakes basin can have only limited impacts on this worldwide global phenomenon. Therefore, program managers should seek to understand impacts and implications, and make adaptations to address climate change. The IJC recommends:

> Governments should adopt climate change adaptation strategies and mechanisms that would assist program managers

To enhance the value of the surface water temperature indicator, the IJC recommends:

- The Parties should routinely conduct analysis of long-term, geographically distributed surface water temperature data with additional monitoring buoys to contribute to the understanding of trends.

Biological integrity

Biological indicators yielded mixed trends. From 1987 to 2006, 34 nonnative species were introduced into the Great Lakes. Populations of the burrowing mayfly have started to recover, but lake trout populations are consistent with 1987 levels. *Diporeia*, a key part of the aquatic food web and a food source for many fish, has almost disappeared.

Nonnative Aquatic species

This indicator notes the continued introduction of such species over the past 25 years, with success in preventing any establishments from ballast water discharges since 2006. However, recently species have become established from other pathways. The potential for the spreading of such species and new introductions continues to exist, and aquatic invasive species pose a risk of causing further severe economic and aquatic food web impacts. As a result, further government research, control and response actions are warranted.

The IJC recommends that the governments institute these actions to address aquatic invasive species:

- Prevention: The governments should provide incentives for private industry to implement ballast water treatment technologies that further reduce the likelihood of introductions from this pathway. Public education and outreach programs should be expanded to increase awareness of AIS and reduce the spread from live trade and recreational boating. Control measures and legislation are needed to address hull fouling, anti-fouling paints and species sold in live trade.
- Early detection: Governments should sustain a long-term, binational, basinwide AIS early detection program. The program should include research on monitoring techniques and provide training for citizen volunteer monitoring. Risk assessments are needed to assess risk by vector and pathway and direct resources toward particular species and locations.
- Rapid response: Governments should develop and implement a cooperative, binational Great Lakes AIS rapid response plan with harmonized response actions. Each nation should officially designate a lead agency to assure appropriate action is taken in collaboration with the other nation to act without delay when an emergency arises.
- Control: Sustained control actions to prevent the spread of AIS are needed. For instance, continued application of lampricide to control sea lamprey should be conducted. More research on interlake transport of ballast water and ways to address

those movements are also needed.

Burrowing mayfly density

This indicator shows that burrowing mayflies (*Hexagenia*) in western Lake Erie, 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. The IJC recommends that:

- Governments support continued monitoring for Hexagenia where they are now found to help document density trends.
- Governments should monitor dissolved oxygen (DO) levels in suitable habitat to identify areas where Hexagenia return is anticipated and could be stimulated.

Diporeia abundance

This indicator shows that *Diporeia* (a bottom-dwelling amphipod) 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 IJC recommends that:

- Until quagga mussel populations decline, governments should decrease the frequency and intensity of monitoring *Diporeia* populations, and more emphasis should be placed on understanding the causes of decline and potential remedies such as monitoring and restoring an alternate species such as *Mysis*.

Lake sturgeon abundance

This indicator shows that sturgeon populations, which fell to one percent of historical levels in the mid-1950, are beginning to increase in some locations within the Great

Lakes. Since the mid-1980s, there has been spawning success in several traditional habitats, including the Detroit River, where spawning had not taken place in decades. The IJC recommends:

- Continued habitat restoration and water quality improvements, which will be necessary for the survival of the species in the basin.
- Governments should conduct sustained, long-term monitoring of Great Lakes lake sturgeon populations. 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.

Lake trout abundance

This indicator shows that since the mid-1980s, populations in four of the five Great Lakes have been stable overall, largely because of stocking; Lake Superior is the exception and now has a self-sustaining population. In Lake Huron there is a trend toward recovery with substantial reproduction in most areas. The IJC recommends:

- Because lake trout is a native top predator fish in four of the Great Lakes - Superior, Michigan, Huron, and Ontario, measuring its abundance serves as an indicator of biological health of those lakes. Continued use of lake trout abundance as an indicator is advisable in the four lakes. For Lake Erie, walleye abundance or harvest data should be the top predator fish indicator.

Indicators of performance

Areas of concern and beneficial use impairments

One of the program performance indicators is the restoration of beneficial use impairments (BUIs) at Great Lakes areas of concern (AOCs). AOCs were designated by the governments because the areas were degraded for a variety of reasons, including bacteriological pollution, chemical contaminants in fish or habitat loss. Of the 43 original AOCs, four have been restored and two are now considered areas in recovery. Each of the 43 AOCs had at least several beneficial use impairments. In the United States, 33 of 255 BUIs were restored. In Canada, 54 of 154 were restored. The governments have made progress implementing restoration actions to delist AOCs and remove BUIs, but this work needs to be accelerated. The governments have done an excellent job reporting on this indicator, and the results presented in this report are available from Environment Canada and US Environmental Protection Agency websites. The IJC recommends:

- Governments should make resources available for continuing and accelerating progress towards BUI removals and AOC delistings.
- Governments should continue to track and report on this indicator, since removing beneficial use impairments and delisting areas of concern is an objective under the 2012 Agreement.

Beach closings and advisories

This indicator suggests Great Lakes waters are swimmable with significant qualifications. Beach closings based on the presence of indicator bacteria have remained fairly stable over the reporting period of the last 14 years. Although most monitored beaches are open for swimming throughout the summer season, closures are still too common. The IJC recommends that governments take the following measures to enhance public health protection for Great Lakes recreational swimming:

- Develop binational, standardized, basinwide 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 to protect beach users.
- Continue research on microbial source tracking, which helps distinguish among the

various bacterial sources impacting recreation waters. The findings would help direct source intervention measures.

- Develop a central Great Lakes registry for closings and waterborne disease resulting from swimming at public beaches. Disease occurrences related to use of recreational waters should be reported to the registry. In addition, investigations of the cause of major occurrences should be conducted and reported to the public and to researchers.

6.2 Conclusions Regarding Indicators and Reporting Progress

For the past 25 years, the IJC has issued reports that discuss the importance of indicators for assessing progress under the 1987 Agreement. The assessment of progress made in this report used on data and indicators that covered all, or most of the 1987-2012 period. Looking forward, under the 2012 Agreement, the IJC would like to better assess progress under the revised Agreement and improve communication of findings to the public. Ideally, future assessment of progress reports would include discussion and stakeholder buy-in for all the indicators used by IJC, along with clarification of how the data would be collected, analyzed and reported. With these goals in mind, this section sets out the Commission's recommendations for improvements to the reporting of progress made by the governments towards achieving the objectives of the 2012 Agreement.

Selecting a core set of indicators

The IJC recommends that the governments develop their Progress Report of the Parties using a core set of indicators related to the objectives of the 2012 Agreement. The governments have made progress since 1994 in refining indicators and moving toward selection of a core set through the State of the Lakes Ecosystem Conference (SOLEC) process. SOLEC 2011 presented approximately 80 indicators. Although there is research and management value in having many indicators, having a core set provides a focus for monitoring, analysis and public communications. Such core indicators provide the public and policy makers with scientifically sound information to make better monitoring, restoration, and prevention decisions.

These core indicators should be monitored and reported on regularly to enable tracking of progress for the lifetime of the updated Agreement. The governments also need to provide the resources for the prevention and remediation actions that are necessary to achieve the objectives measured by these indicators. . Targets, goals or standards should be developed for each of the core indicators and resources should be provided for protection and restoration actions to achieve the goals.

Environmental monitoring

Evaluating progress toward meeting 2012 Agreement objectives depends on a robust, long-term environmental monitoring program that is linked to core indicators. But monitoring has been insufficient for some core indicators related to critical Great Lakes conditions. Some of the data sets maintained by government agencies and discussed in this report lack spatial or temporal coverage. Phosphorus loading data for western Lake Erie is available only for some tributaries. Other data sets do not extend back to 1987, making it difficult to discern trends over the last 25 years. For example, beach closing data used in SOLEC reports reach back only to 1998.

There are also important gaps in what is routinely measured by governments, academic researchers and others, including human health as affected by the integrity of the Great Lakes. One of the most vital concerns of the public is the safety or risk to human health of exposure to Great Lakes contaminants through fish consumption, drinking water and swimming. Developing indicators of disease resulting from Great Lakes environmental exposures that reflect the best science and communicate meaningful information to the public is an important task for the governments.

Perhaps the most conspicuous example of a monitoring gap is the absence of comprehensive lakewide, long-term monitoring of phosphorus loadings to Lake Erie, which has complicated the choice of prevention and remediation measures. Heidelberg University's National Center for Water Quality Research in Ohio has maintained the only long-term sustained phosphorus monitoring of Lake Erie tributaries, with data reaching back to 1974 (NCWQR 2012). But the governments discontinued monitoring of Lake Erie phosphorus loadings in the mid-1990s, and, due to funding constraints, the Heidelberg program monitors only several tributaries. To fully understand the role of various sources of phosphorus to Lake Erie and to develop and implement effective management strategies, the governments must conduct long-term Lake Erie tributary monitoring of loadings. The monitoring must measure total phosphorus, dissolved reactive phosphorus, and also monitor phosphorus concentrations in the open lake.

Both governments have recognized this need and are currently directing additional resources towards phosphorus studies in the Lake Erie basin. Environment Canada's, Lakes Nutrient Initiative will help establish current nutrient loadings from Great Lakes tributaries, including tributaries of Lake Erie, and combat the recurrence of toxic algae. The U.S. Great Lakes Restoration Initiative is also funding Lake Erie nutrient monitoring. However, given the history of this particular issue and the possibility that funding may be reduced or eliminated in the future, governments should identify further means to support long-term monitoring of phosphorus in basins experiencing eutrophication issues (e.g., western Lake Erie, Saginaw Bay, Green Bay).

Sound monitoring data provide information to help protect environmental resources worth billions of dollars. Monitoring and assessment efforts along with peer-reviewed science are needed to make wiser management decisions and target limited resources for restoration and protection of Great Lakes water quality. In addition, monitoring and assessment of resulting data helps the public understand whether the integrity of the Great Lakes basin is improving or deteriorating. The IJC recommends:

- Even in a time of budget austerity, the governments should allocate sufficient resources to monitor a core set of indicators, enable scientific diagnosis of causes of adverse trends and undertake remediation and prevention actions that are needed to achieve objectives.

6.3 Reporting to the public

Development of a core set of Great Lakes ecological indicators is important to serve the public's information needs about the health of the ecosystem. Accurate data analysis and effective communication of results promotes public awareness of challenges to the ecological integrity of the Great Lakes and helps the public understand the importance of effective programs designed to address those challenges. Indicators that are understandable and responsive to public concerns also foster informed public participation in Great Lakes policy development (Schiller et al. 2001).

The governments should establish a user-friendly, basinwide system for ecosystem status information for scientists, managers, governments, policy makers and the public. The Great Lakes Observing System shows promise for answering this need (GLOS 2012). The observing system seeks to integrate chemical, biological, physical and hydrologic data; modeling tools; and monitoring programs for maritime, environmental, industry and governmental partners. SOLEC information can be even more useful with additional sorting and by improving the web-based delivery system. The IJC recommends:

- Federal, provincial, state, municipal and other public agencies and Canadian and US academic institutions should develop a common data access system, including a portal that is easy for scientists, managers, and the technically versed public to use. The system should provide electronic access to detailed data sets and tools to enable online searching.
- The governments should improve the organization of the SOLEC reports. Using a web-based delivery system, SOLEC information could be organized in such a manner to link its indicator reports to 2012 Agreement objectives. Also, indicator reports should be sorted temporally, spatially, or by topic to better meet particular needs of resource managers.
- The governments should create a useful reporting and communication system in a "report card" format, providing to the public plain-language descriptions of core indicators and discussion of trends.

The IJC believes the updated 2012 Great Lakes Water Quality Agreement provides an opportunity for the governments to make these two improvements in order to inform and engage the public. In addition, these three recommendations will strengthen accountability, helping to achieve a central goal of the new Agreement. Providing this information to the public is of particular interest to the IJC due to its responsibilities for consulting with the public about issues related to the quality of the waters of the Great Lakes and engaging with the public to increase awareness of the inherent value of the waters.

Section 7. Moving Forward under the 2012 Agreement

The recommendations in this report have been aimed at improvements in Great Lakes management, monitoring and reporting by the governments related to fulfilling the objectives of the 2012 Agreement. However, the IJC has also been working to address some of these issues, on its own or in collaboration with the governments.

The current view of IJC is that most of these indicators should have historical data, some should address nearshore and open water conditions, a few of them should reflect human health, and at least one should consider atmospheric deposition. Members of IJC's advisory boards are working on a project in consultation with the governments to identify a recommended set of core indicators.

The IJC has made the assessment of progress toward restoring the Great Lakes one of its priorities for 2012-2015. The Commission is examining how it can best fulfill its responsibility for assessing progress under the 2012 Agreement and assessing the extent to which programs and other measures are achieving the Agreement objectives. The IJC has establishing a working group of IJC advisory board members to assist in making recommendations to governments regarding specific indicators to be included in a limited set of core indicators for assessing progress toward Agreement objectives. This work is being undertaken with input from SOLEC representatives with the aim of producing a small set of environmental indicators that will draw from, augment and complement the wider set of SOLEC indicators.

The IJC established a second working group composed primarily of members of its Health Professionals Advisory Board to identify a set of core human health indicators to recommend to Governments. The IJC has welcomed the input of government representatives in both of these groups and hopes that this cooperation will lead to recommendations that are useful to all the progress reports. In this respect, the governments are already addressing the Commission's recommendation that they work with the IJC to identify a limited set of core indicators which measure the environmental conditions most relevant to 2012 Agreement objectives. The IJC will also review current monitoring programs and make recommendations regarding monitoring to support the proposed indicators.

This selection of core indicators is not intended to replace SOLEC as it is valuable to have additional indicators, beyond the core set for research and resource management purposes. Provided resources are available for addressing the needs of the core indicators, resources could be allocated for monitoring of additional indicators beyond the core set. These too should have targets and governments should undertake the necessary actions to achieve the targets. The Commission's 2012-2015 priority work on Lake Erie will also help to address the recommendations on phosphorus loading. The Commission has undertaken a three-year initiative to develop science-based advice to governments on reducing dissolved reactive phosphorus loads to Lake Erie.

To help address the issue of nonnative aquatic species, the IJC has taken action to develop a pilot binational aquatic invasive species rapid response plan with input from representatives of affected U.S. and Canadian jurisdictions. Great Lakes Restoration Initiative funding provided by the USEPA enabled the IJC to take this important step, which provides a foundation for further planning and binational response coordination under Annex 6 of the 2012 Agreement. While the IJC recognizes that prevention is a top priority, it also sees rapid response planning as a necessary backup.

On the topic of physical integrity, the 2012 Agreement cites linkages between water quality and water quantity and identifies the need to identify, quantify, understand, and predict the climate change impacts on the quality of the Waters of the Great Lakes. The need for these linkages is exemplified by the indicators for water temperature and ice cover. The IJC is acutely aware of the challenges presented by the current low water levels in the Great Lakes. In this regard, it is considering the recommendation of the International Upper Great Lakes Study that governments implement an adaptive management framework supported by strengthened hydroclimatic modeling and monitoring and that the IJC has a key role to play in this process.

Concluding comments

The 16 indicators selected for this report do not tell the entire story of Great Lakes ecosystem health, but offer valuable insights into trends and changes since the 1987 update of the Great Lakes Water Quality Agreement. The IJC believes the data and analysis supporting the indicators also suggest directions for the governments as they implement the 2012 Agreement. The IJC is encouraged and pleased to see that many of the management recommendations put forward in the report either could be, or will specifically be addressed by the Parties under the new 2012 Agreement that was signed as this report was being finalized. For example, all of the recommendations on Aquatic Invasive Species made in this report could be addressed by the governments under Annex 5 and 6, and some of the recommendations, such as those surrounding Rapid Response, constitute a major part of Annex 6. The IJC looks forward to reviewing the outputs from these new and continuing initiatives.

In particular, the IJC finds that sustained monitoring of a core set of indicators is essential and consistent with the ecosystem indicators called for in Annex 10 of the 2012 Agreement. Policymakers and program managers can best make informed and cost-effective judgments when sound scientific information about Great Lakes ecosystem health is available.

While indicators can track and communicate environmental improvements, they will be most useful if goals, targets or standards are established for each core indicator. Governments have the responsibility to ensure that adequate resources are made available to implement management actions needed to achieve the established objectives for each core indicator.

Additional indicators beyond the core set will be useful for research and resource management. Since the core indicators will be linked to the objectives of the Agreement,

achieving the targets of the indicators will help achieve the objectives of the 2012 Agreement.
Equally important, sustained monitoring and effective communication of a core set of indicators enables the public to understand Great Lakes ecosystem health. This in turn fosters informed decision making by citizens about both individual actions and the effectiveness of government programs and other measures to restore the health of the Great Lakes ecosystem. The IJC hopes that this report will contribute to the governments ongoing efforts to improve the application and communication of Great Lakes indicators, leading to fulfillment of the objectives of the 2012 Agreement.

At this point, IJC believes that a comprehensive assessment since the previous amendments in 1987 will provide important information and guidance to help inform the first review cycle of the 2012 protocol amending the Agreement, which was signed in September 2012 as this report was in its final stage of development. In addition, the IJC would like this report to encourage the governments to focus on using a limited set of core indicators for reporting progress towards achieving the objectives of the revised Agreement. The IJC is working on further recommendations in this regard with input from government indicator experts.

Looking forward to implementation of a newly revised Great Lakes Water Quality Agreement, the IJC hopes this report will offer guidance for an even stronger, more inclusive and collaborative binational commitment to the protection and restoration of the Great Lakes and improvements to the reporting and assessment of progress.

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Section 8. 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 the organisms 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, mammals 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. 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 nonnative 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: A discharge of untreated wastewater from a combined sewer system at a point prior to the headworks of a publicly owned treatment works. Combined sewer overflows 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 nonindigenous species of fish now found in Lakes Superior and 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 occur 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 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.

Nonindigenous species: 1) 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; 2) Those species that are found beyond their natural ranges or natural zone of potential dispersal. Also referred to as exotic species.

Nonpoint 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 stormwater. Common nonpoint 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, low in turbidity and often has very clear water. Relatively low amounts of nutrients (phosphorus and nitrogen) are found in the water column.

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, 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 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 1900s. 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, i.e., 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 important 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, including 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.

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Signed this 15th day of April, 2013 as the 16th Biennial Report on Great Lakes Water Quality and Accompanying Technical Report: Assessment on Progress Made on Restoring and Maintaining Great Lakes Water Quality Since 1987 Pursuant to the Great Lakes Water Quality Agreement of 1978

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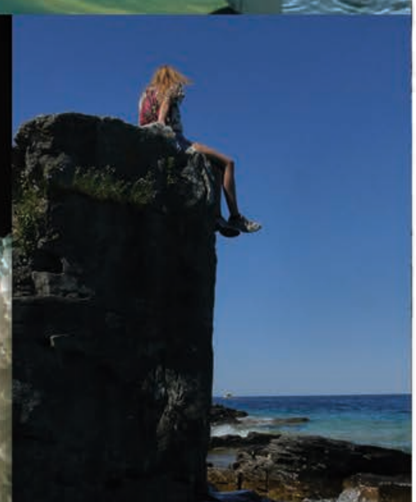

Top inset photo Aerial photo of harmful algae bloom, Kelly's Island, Ohio, Lake Erie.
Lower left photo Microphotograph of benthic organism food for fish — a freshwater worm (*lumbriculidae*) and an amphipod (*diporeia*) swimming at the sediment surface. **Lower right photo** A Great Lakes tourist.
Front cover photo Present-day Port Stanley, Ontario, a center of commercial fishing.