GREAT LAKES ECOSYSTEM INDICATOR PROJECT REPORT

A Report of the IJC Priority
Assessment of Progress towards Restoring the Great Lakes

June 2014

INTERNATIONAL JOINT COMMISSION
Canada and United States

COMMISSION MIXTE INTERNATIONALE
Canada et États-Unis

(inside front cover)

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This report on ecosystem indicators is the product of a binational cooperative effort that involved over 100 experts from Canada and the United States. The International Joint Commission expresses its sincere appreciation to the many scientific experts from multiple government, academic, non-profit, and other organizations who contributed to this report. Their collaborative efforts provide the foundation for the Commission to recommend to the governments of Canada and the United States measures to effectively assess progress towards achieving the promise of the Great Lakes Water Quality Agreement. The workgroup's efforts will inform how the Commission will independently assess progress under the Agreement.

Contributing experts are listed in each indicator report. We note, however, that the findings and recommendations in this report are solely the responsibility of the Commission.

EXECUTIVE SUMMARY

The Great Lakes Water Quality Agreement charges the International Joint Commission (the Commission) with the responsibility for assessing and reporting upon the progress of the governments of Canada and the United States in their implementation of the Agreement. To meet this charge, the Commission established a three year priority (2012-2015) to develop approaches and tools for undertaking the assessment. This Commission report on ecosystem indicators is a synthesis of extensive scientific analysis and provides additional technical analysis building upon the work and recommendations of IJC's binational workgroup reports issued in 2013 titled: Great Lakes Ecosystem Indicators Summary Report: the Few That Tell Us the Most and Technical Report on Ecosystem Indicators.

The overall objective of the Assessment of Progress priority is to ensure that the Commission is well placed to fulfill its assessment and reporting responsibilities assigned by the Great Lakes Water Quality Agreement. The Commission believes that an assessment of progress under the Agreement should include the measurement and reporting of quantifiable indicators related to Agreement objectives. Scientifically sound indicators applied consistently over time are essential to track changes in Great Lakes water quality.

Identifying key ecosystem indicators that tell us the most about the Great Lakes is the first project under the Assessment of Progress priority. Targeted ecosystem indicators are important tools to inform the critical decisions for Great Lakes protection and restoration efforts to benefit the millions of people who depend on and enjoy the waters of the Great Lakes.

The Commission recommends 16 indicators composed of 41 measures to be the best indicators for assessing progress for the ecosystem under the new Agreement. The suite of 16 ecosystem indicators are the "few that tell us the most" and this report defines and discusses their relevance to Agreement objectives and ecosystem health conditions, their constituent measures and how the indicators should be interpreted. The ecosystem indicators provide good coverage of the Agreement Objectives and Annexes with the smallest number of indicators possible. Key gaps in the coverage, including indicators for human health and program effectiveness, will be addressed through separate projects also being conducted under the Commission's Assessment of Progress Priority.

The Commission recommends that the governments of Canada and the United States consider using the Commission's recommended ecosystem indicators in State of the Lakes Ecosystem Conference (SOLEC) reporting. As part of this process, the Commission also recommends that the governments review the indicators with respect to how easily they can be fully implemented and provide feedback to the Commission regarding their potential for operationalization.

A comparison of the Commission's ecosystem indicators and ecosystem indicators in the recent SOLEC report by the governments is also included in this report as an initial step in that assessment process. While the Commission did find some overlap; 23 out of the 41 measures of IJC ecosystem indicators are defined differently from SOLEC indicators.

The next steps for the Commission's Assessment of Progress Priority are to examine how best to use the indicators in this report for reporting on progress, raising awareness and encouraging action – the tasks key to the Commission's responsibilities under the Agreement. The Commission is also considering identifying a small set of apex indicators to guide Commission assessment and reporting activities and for communication with the public. Feedback from the governments regarding the operationalization of the recommended indicators will be important input as the Commission continues its work to develop tools and approaches to effectively assess progress of achieving the objectives of the Great Lakes Water Quality Agreement.

The Commission thanks the SOLEC representatives involved for their constructive engagement in the Commission's work on indicators to date. The Commission looks forward to further constructive engagement with the governments as the Assessment of Progress Priority work moves toward completion in 2015.

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Chapter 1: INTRODUCTION

1.1 Purpose of the Report

The purpose of this report is to present the Commission's work done to date on the first project of the Assessment of Progress priority. This report on ecosystem indicators from the Commission provides additional analysis and technical information and is intended to build upon the Commission Workgroup reports issued in June 2013: Great Lakes Ecosystem Indicators Summary Report: the Few That Tell Us the Most and Technical Report on Ecosystem Indicators (http://www.ijc.org/en_/AOP/Publications).

The report includes recommendations to the governments of Canada and the United States with respect to the ecosystem data they are collecting and providing to the Commission, and to the general public. Recommendations are aimed at facilitating the work of the Commission in assessing the progress of the governments of Canada and the United States in their implementation of the Great Lakes Water Quality Agreement (the Agreement) and increasing public awareness of the quality of the Waters.

Recommendations relate to the adoption and monitoring of a set of ecosystem indicators that are considered to be the key indicators in assessing the governments' progress in achieving the General and Specific Objectives of the Agreement. The report sets out the details of these recommended indicators, along with the binational process for their identification and development.

The report also aims to set this work on ecosystems indicators in the context of the Commission's Assessment of Progress Priority giving background and next steps for this area of work.

Although this report was prepared to provide advice to the governments of Canada and the United States regarding the collection and reporting of monitoring data for the Great Lakes. The findings and recommendations of the report will also be of interest to a broad audience of agencies, water users, residents, organizations and decision-makers concerned about water quality and the implementation of the Agreement.

1.2 Establishment of the Assessment of Progress Priority

In 2012, the Commission established the development of approaches and tools for the assessment of progress under the 2012 Great Lakes Water Quality Agreement as one of its Great Lakes priorities covering the 2012-2015 triennial cycle. The overall objective of the Assessment of Progress priority is to ensure that the Commission is well placed to fulfill its mandate under the Agreement to report to the Parties and to the State and Provincial Governments concerning progress toward the achievement of the General and Specific Objectives, including, as appropriate, matters related to Annexes to the Agreement.

The Commission believes that an assessment of progress under the Agreement should include the measurement and reporting of quantifiable indicators related to Agreement objectives.

This Commission report is the first issued under the Assessment of Progress Priority and it focuses on the key ecosystem indicators best suited to assess progress towards meeting the goals and objectives of the Great Lakes Water Quality Agreement. The Commission has spent much of the past two years developing a list of ecosystem indicators that can be termed as "the few that tell us the most". This report presents the outcome of the work to identify and define the best ecosystem indicators to gauge progress under the Great Lakes Water Quality Agreement.

The work on ecosystem indicators is only one aspect of this priority. Separate projects are on-going with respect to human health indicators and program effectiveness indicators. An ultimate aim of the priority is to combine these initiatives and, from them, recommend to the governments of Canada and the United States a smaller apex set of indicators for public communication. Work conducted under this priority is intended to complement the SOLEC process, by providing binational advice regarding the development, design and reporting on selected indicators, including their monitoring needs.

1.3 Background to the Report

The Commission is an independent binational organization created by Canada and the United States under the Boundary Waters Treaty of 1909. Under the Treaty, the two countries cooperate to prevent and resolve disputes relating to the use and quality of the many lakes and rivers along their shared border.

Canada and the United States have been working together closely for over 40 years to manage and protect the Great Lakes. The two countries committed in the Great Lakes Water Quality Agreement to restore and protect the physical, chemical, and biological integrity of the waters of the Great Lakes basin ecosystem. The Governments, private sector, and public have invested billions of dollars in pollution controls, restoration, and conservation work since the Agreement was signed in 1972 and significant improvements have been accomplished. However, there are many continuing concerns and questions about how the lakes are doing, whether we really are making progress and, if so, how much.

At the request of both governments, under the Great Lakes Water Quality Agreement, the Commission has a role in advising the two countries on restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes. Most notably in the context of this report, the Agreement gives the Commission the responsibility of providing to the governments of Canada and the United States an "Assessment of Progress Report" every three years. The Assessment of Progress Report is intended to assess the extent to which programs and other measures are achieving the General and Specific Objectives of the Agreement.
The Commission has had this responsibility to assess and report upon progress made under the Great Lakes Water Quality Agreement, since the Agreement was revised in 1978 and has issued

16 biennial reports between 1980 and 2013. The 2012 revised Agreement changed the timing of the reporting from biennial to triennial.

From 1978 to 1987, the Commission's biennial assessment of progress reports were produced by a network of specialized subcommittees that were part of the Commission's advisory boards. These boards included government officials who could collect the necessary data to support the assessment. With the requisite data available, the first four biennial reports were 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 Commission was transferred to the governments. Then it became a challenge for the Commission to obtain data that clearly reflected progress towards achieving the objectives of the 1987 Agreement. The difficulty in obtaining sufficient data led the Commission to change the focus of its biennial reporting. In 1990, starting with the Fifth Biennial Report, the aim of biennial reporting shifted and became "not to provide a comprehensive report of all subjects of importance to the Great Lakes, but rather highlight some issues needing urgent and focused attention" (IJC 1990).

The Commission has drawn attention to the need for comprehensive data from the Parties 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, to improve reporting particularly as it related to the achievement of Agreement objectives. The report advocated a smaller number of SOLEC indicators (relative to the about 80 SOLEC indicators at that time), such that each indicator retained directly related to the objectives of the Agreement and was adequately funded.

Scientifically sound indicators applied consistently over time are essential to track changes in Great Lakes water quality. The Commission has long advocated using indicators to measure progress toward Agreement objectives and has recommended criteria for selecting them (IJC 1991; IJC 1996; IJC 2000; IJC 2006b). The Commission also recognizes that resources are only available to monitor, compile, and present information on a limited set of indicators. Furthermore, conveying clear information to the public and to decision makers is best accomplished using a small set of scientifically sound indicators communicated in non-technical language.

In anticipation of the new GLWQA in 2011, the Commission initiated the return to a more comprehensive assessment of progress for its biennial report. The 16th Biennial Report, published in 2013, used seven indicators of chemical integrity, five indicators of biological integrity, two of physical integrity, and two performance indicators to assess progress under the Agreement since the Agreement was last revised in 1987. The 16 indicators used in the report were selected by Commission staff based on relevance to GLWQA objectives and availability of data. While the report was very useful and provided a retrospective analysis over the past 25 years, the amount and type of data available limited the extent of assessment that could be made. To the Commission it was clear that a set of core indicators related to Agreement objectives and useful for a concise assessment of progress was needed and that these core indicators should be consistently monitored over time.

With the renewal in September 2012 of the Great Lakes Water Quality Agreement, the Commission seized upon the occasion to reaffirm its commitment to fulfilling its responsibility under the Agreement of assessing and reporting upon the progress being made toward the achievement of the General and Specific Objectives of the renewed Agreement, including, as appropriate, matters related to its Annexes.

SOLEC

The Commission's work on indicators for assessing the physical, chemical, and biological integrity of the Great Lakes is reliant upon the excellent work by, and collaboration with, the State of the Lakes Ecosystem Conference (SOLEC). SOLEC is an initiative by the U.S. Environmental Protection Agency and Environment Canada on behalf of the two countries. It involves over 125 scientists and experts from Canada and the U.S. who assemble environmental information about the Great Lakes ecosystem through the SOLEC process. The conferences are intended to report on the state of the Great Lakes ecosystem and the major factors impacting it, and to provide a forum for exchange of this information amongst Great Lakes decision makers. The conference was held every two years between the first conference in 1994 and the conference in 2008. Conferences will be held every three years under the 2012 Agreement. The most recent conference was in 2011. A report on "The State of the Great Lakes" is issued after each conference.

Through SOLEC, the state of the Great Lakes is assessed using nearly 60 indicators, organized in a DPSIR (driver, pressure, state, impact, response) framework. The DPSIR framework is an underlying tool to aid in the selection, organization, and reporting on indicators, which allows decision makers to understand the linkages between the conditions of the ecosystem, pressures on the ecosystem, and how human activities are related to the condition of the system. SOLEC reports are very useful and provided much of the data for the Commission's 16th Biennial Report. However, these indicators could be improved for delivering clear and concise messaging regarding progress in the restoration and maintenance of the Great Lakes. The Commission also recognizes that prioritizing a core set of indicators could be used to prioritize the limited resources available for monitoring.

In looking to identify a subset of indicators for assessment and reporting, the Commission questioned whether the SOLEC ecosystem indicators included the best indicators possible for making the assessment of progress they desired.

Since the Commission began work on this priority in early 2012, SOLEC has continued to evolve, in particular in its reporting of the 2011 State of the Lakes Conference. These developments are discussed in Chapters 4 and 5 of this report.

1.4 Organization of the Report

The rest of this report is organized into the following four chapters and a reference section:

Chapter 2 presents the indicator development process.

Chapter 3 presents the descriptions for each of the 16 indicators.

Chapter 4 reviews the indicators relevance to the objectives of the GLWQA and the indicators presented in SOLEC 2011 reporting.

Chapter 5 presents the Commission's recommendations for the governments with respect to these ecological indicators as well as the Commission's own next steps in taking this work forward under the Assessment of Progress priority.

The report represents a synthesis of extensive scientific analysis. Readers wanting more detailed information, particularly on the indicator development process, are encouraged to review the original technical report and summary report prepared by the Work Group as part of the study.

Chapter 2: INDICATOR DEVELOPMENT PROCESS

To meet the objective of identifying a set of key indicators for the assessment of progress in this priority, an Ecosystem Indicator Work group was formed consisting of members of the Commission's Great Lakes Water Quality Board and Great Lakes Science Advisory Board. SOLEC representatives from Environment Canada and the U.S. Environmental Protection Agency consulted with the advisory boards in this process and provided assistance and feedback as the work progressed. Consistent with Commission practices, the indicators were to be identified through a binational consensus-based process.

The Ecosystem Indicators Work Group developed a work plan that commenced with a literature search and a review of various national and international programs for assessing ecosystem health indicators used by the various programs, and criteria used for selection of indicators. The context and geographic framework for the selection of ecosystem indicators was defined by the renewed GLWQA. Reviewing and adopting the DPSIR framework, the Work Group decided that, for the purposes of this project, priority is given to state and possibly impact indicators which define the physical, chemical, and biological integrity of the Great Lakes ecosystem. This decision was based on the goal of identifying a small set of indicators to assess progress toward achieving the Objectives of the Agreement rather than identifying sources of impairments.

Based on the background work, the Work Group agreed upon a set of criteria to be used by an expert consultation workshop in selecting a set of indicators. The criteria were divided among four "themes", including usefulness, data quality, data availability, and practicality. Using these criteria, there was a bias towards existing indicators with existing data. However, the criteria did not prevent the identification of new indicators to fill the gaps of existing indicators.

A binational expert consultation workshop was held in Windsor, Ontario, in September 2012. The workshop was held with the primary objective of establishing a concise list of ecosystem indicators. Participants at the workshop included various stakeholders, experts on indicator development, and scientists with expertise in various disciplines and a diversity of affiliations. The workshop resulted in a prioritized list of 22 indicators. Through further efforts of the Ecosystem Indicator Work Group, these 22 indicators were combined into the set of 16 indicators presented in Chapter 3. Each of these indicators has 1-6 measures associated with its assessment.

The Ecosystem Indicators Work Group then identified experts (1-3 individuals) to draft detailed descriptions of the indicators and their measures based on input from the participants that attended the expert consultation workshop. These draft descriptions were subsequently reviewed by members of the Science Advisory Board, Water Quality Board, as well as the entire group of workshop participants to ensure alignment with discussions at the meeting. In the summer of 2013, the work-group produced a summary report and a technical report, which are available on the Commission's website (www.ijc.org/en_/AOP/Publications). These reports describe in detail the indicator selection process, their relevance to the GLWQA objectives and annexes, and provide initial descriptions of the indicators.

After the completion of the reports, the Ecosystem Indicators Work Group felt additional work was needed to finalize the measures that would be included in each indicator, describe how the measures would be calculated, and provide adequate information on spatial and temporal coverage of the measures. Sixteen Indicator Expert Teams (one for each indicator) were established by Commission staff. The Indicator Teams consisted of the authors of the initial indicator description, previous Workgroup co-chairs, regional experts of the indicators, and Commission staff. Each of the indicator teams was charged by the Commission to develop more details for each indicator to help determine what measures to use, which data are needed, and how to obtain, synthesize, analyze, and report the findings. Chapter 3 of this report presents the descriptions of the 16 ecosystem indicators that were refined by the Indicator Teams.

Chapter 3: DESCRIPTIONS OF ECOSYSTEM INDICATORS

3.1 Introduction

This Chapter presents the details of the 16 ecosystem indicators recommended for the Assessment of Progress under the Great Lakes Water Quality Agreement. It provides information on (1) the experts involved in the development of each indicator, (2) how each indicator is defined, (3) relevance of the indicators to Agreement objectives and ecosystem health conditions, (4) what measures each indicator includes and how each measure should be calculated, and (5) how the indicators should be interpreted and what caveats and cautions should be considered when using these indicators. The key measures of each indicator are listed and described under the heading Descriptions of Measures. The measures under the heading Other Indicators Considered are those measures that were discussed, but are not recommended to be used at this time.

Where the indicators are the same or similar to SOLEC indicators, the experts consulted were usually also involved in the SOLEC work. This is true for approximately half of the indicators. The value of these indicators descriptions relative to SOLEC is that the descriptions reinforce the value of some of the SOLEC indicators, propose useful adjustments to others or propose new additions to the SOLEC indicator suite. A chart comparing the two indicator sets is presented in Chapter 4.

The 16 indicators in this Chapter are organized into physical, chemical, and biological groups. Within each group, the indicators are presented in alphabetical order.

3.2 Physical Indicators

3.2.1 Coastal Habitat – Shoreline Alteration Index

Expert workgroup member:	Scudder Mackey
IJC staff:	Lizhu Wang

Definition

The indicator uses Shoreline Alteration Index (SAI) as a measure of human modified shoreline length that is physically and biologically unfavorable to the Great Lakes ecosystems. The physical and biological components used to calculate the SAI can be measured using conventional high-resolution aerial photography or satellite imagery at multiple scales. The physical component is the ratio of lineal length of armored and other "man-made" shoreline relative to total lineal length of the shoreline. The biological component is the lineal length of biologically incompatible shoreline structures relative to the total lineal length of human modified shoreline.

Indicator Relevance

This indicator is directly relevant to GLWQA Annex 7- Habitat and Species. Physical modifications to the shoreline have disrupted coastal and nearshore processes, flow and littoral circulatory patterns, altered or eliminated connectivity to coastal wetlands/dunes, and have altered nearshore and coastal habitat structure.

Description of Measures

SAI is a combination of the ratio of human modified shoreline length to total shoreline length and the proportion of human modified shoreline length that is biologically compatible (Livchak and Mackey, 2007).

1. *Physical shoreline indicator* is the ratio of the lineal length of human modified shoreline relative to total lineal length of the total shoreline length. More specifically, the P ratio equals human modified shoreline/total shoreline.

2. *Biological shoreline indicator* is the ratio of the lineal length of biologically incompatible structures (shore perpendicular structures, vertical sheet pile, concrete walls, and other "man-made" structures that cannot serve as biological habitat) relative to total lineal length of "man-made" shoreline (B ratio).

3. *SAI* is calculated by multiplying the physical and biological shoreline indicator values and subtracting the resulting value from one.

$$\text{SAI} = 1 - (\text{P ratio} \times \text{B ratio})$$

Other Measures Considered

None

Indicator Interpretation and Comments

The value of the physical shoreline measure ranges between 0-1. A value of zero (0) represents a natural shoreline and a value of one (1) represents a completely human modified shoreline.

The value of the biological shoreline measure ranges between 0-1. A value of zero (0) represents that the human modified shoreline has no adverse biological or ecological impact, and a value of one (1) represents 100% of human modified shoreline has significant adverse biological or ecological impacts.

The value of SAI also ranges from 0-1. A value of zero (0) represents that the shoreline is 100% biologically or ecologically impacted by shoreline modifications of human activities. A value of one (1) indicates the shoreline has no biological or ecological impacts even though a portion of the shoreline may have been modified by human activities.

The greater the SAI value, the more unaltered and biologically compatible the shoreline is. The SAI is scalable to any shoreline length, and can be applied to present and historical data for comparison and trend analyses. The advantage of this approach is that as structures are removed and/or modified to provide habitat enhancements, the indicator will shift toward a more unaltered or natural state. Conversely, if the number and extent of biologically incompatible shoreline structures increases, the indicator will shift toward a more altered state. The physical shoreline indicator, biological shoreline indicator, and SAI can also be used separately. An example of such narrative descriptions is listed below.

Indicator (Sub)	Poor	Fair	Good	Excellent
Physical	0.7 to 1.0	0.4 to 0.7	0.15 to 0.4	0.0 to 0.15
Biological	n/a	n/a	n/a	n/a
SAI	0.0 to 0.3	0.3 to 0.6	0.6 to 0.85	0.85o 1.0

3.2.2 Extent, Composition, and Quality of Coastal Wetlands

Expert workgroup members:	Don Uzarski, Dave Ulrich, Denny Albert, Patricia Chow-Fraser, Matt Cooper, Lucinda Johnson, Kurt Kowalski, Carl Ruetz, Doug Wilcox
IJC staff:	Lizhu Wang, John Wilson

Definition

This indicator tracks the trends of Great Lakes coastal wetland ecosystem health by measuring the composition and density of macroinvertebrates, fish, plants, amphibians, and birds. The Great Lakes Coastal Wetlands Consortium (GLCWC) developed indices of biological integrity (IBIs) for each of the groups in 2002 and protocols were finalized in 2008 (GLCWC, 2008). The five sub-indicators being used in the current monitoring project are existing individual SOLEC indicators. The continuation of this work addresses Objective 2.2 in the US EPA Strategic Plan of fiscal year 2014-2018. Individual IBIs are derived for each of the sub-indicators which can be used independently as a measure of Great Lakes coastal wetland ecosystem health. However, an overall view of wetland health can be derived by considering these sub-indicators in combination, because they function and indicate anthropogenic disturbance at different spatial and temporal scales and have varying resolution of detection.

Indicator Relevance

This indicator is directly relevant to Annex 7–Habitat and Species since coastal wetlands provide critical breeding and migratory habitat for wildlife such as birds, mammals, reptiles, and amphibians. These habitats are also critical spawning and nursery areas for many fish species of ecologic and economic importance. This indicator is indirectly relevant to the other annexes because coastal wetlands trap, process, and remove nutrients and sediment from Great Lakes nearshore waters; and recharge groundwater supplies. However, over half of all Great Lakes coastal wetlands have been destroyed by human activities and many remaining coastal wetlands suffer from anthropogenic stressors such as nutrient and sediment loading, fragmentation, invasive species, shoreline alteration, and water level control, as documented by a bi-national Great Lakes-wide mapping and attribution project (Albert and Simonson, 2004; Ingram and Potter, 2004). Therefore, conservation of remaining coastal wetlands and restoration of previously destroyed wetlands are vital components of restoring the Great Lakes ecosystem and this indicator can be used to report progress toward such an objective.

Description of Measures

1. *Macroinvertebrates*

   Macroinvertebrate samples should be collected annually from the dominant plant zones in each wetland (Uzarski et al., 2005 using dip nets in accordance with standard SOLEC protocols. Plant zones are defined as patches of vegetation in which a particular plant type or growth form dominates the plant community based on visual coverage estimates. Numerous replicate samples are collected from each plant zone within each wetland.

Sampling should begin in mid-June in the most southerly regions of the Great Lakes and continue into early September, moving north when emergent plants generally achieve maximum annual biomass. Macroinvertebrate abundance by taxon data is used to calculate an IBI score in accordance with GLCWC protocols.

2. *Fish*

   Fish should be sampled using three replicate fyke nets in each major plant zone (wet meadow, emergent vegetation, and submergent vegetation) in each wetland for one net-night (Uzarski et al., 2005). Sampling locations should correspond with those for macroinvertebrate and water quality sampling. The timing of sampling should correspond with the maturity of the vegetation in each system. Fish abundance by taxon is used to calculate the GLCWC (2008) IBI scores.

3. *Plants*

   Aquatic plants from each wetland is sampled from three transects perpendicular to depth contours crossing wetland vegetation zones during July and August. The number of vegetation zones will vary depending on each particular wetland. Operationally-defined vegetation zones are wet meadow, emergent vegetation, and submergent vegetation. Plant abundance by species data will be used to calculate wetland ecosystem health according to GLCWC (2008). The score derived for ecosystem health based on plants relies heavily on the Floristic Quality Index (FQI) and the occurrence of invasive species.

4. *Amphibian (Frogs and Toads)*

   Amphibian occurrence in each wetland is sampled by listening and counting frog and toad (anuran) vocalizations in accordance with SOLEC procedures. Sampling should occur during breeding season, which is generally in early April for southern region, but should be later in the northern regions. This measure is still in the developmental phase and it is not known if it can eventually be used alone as an indicator of ecosystem health. It is currently being used to indicate temporal variation in anuran communities.

5. *Birds*

   Birds are sampled by counting the number of species and individuals in each wetland. The bird counting points are generally the same locations used for the amphibians where both shoreline (i.e., approximate upland/wetland interface) and interior stations should be sampled. Wetlands should be surveyed twice per breeding season, with a minimum of 10 days between visits. One count should be in the morning and one count in the evening. This measure is still in the developmental phase and it is unknown if it can eventually be used alone as an indicator of ecosystem health. It is currently being used to indicate temporal variation in bird communities.

6. *Wetland Area and Extent*

   Wetland area and extent can only be assessed using remote sensing. Recurring remote sensing assessments should be used as a means to monitor wetland loss, hydrologic alterations, and changes to physical habitat condition. The timing of these measurements will be restricted by the availability of data at a given water level. An attempt to develop wetland area and extent metrics is currently underway using GLRI funds. In 2008, the GLCWC recommended a two-tiered wetland mapping system at 30-m and 1-m resolution be conducted every 5 years. Potential metrics may include gains and losses of wetland area, land cover/land use adjacent to each wetland, changes in land use/land cover across the basin, and area dominated by invasive vegetation.

Other Measures Considered

1. *Chemical/Physical*

   Basic chemical and physical data should be collected concurrently with invertebrate and fish samples in accordance with the GLCWC Monitoring Plan (GLCWC, 2008). Water quality is sampled from single composite samples from each vegetation zone and associated with invertebrate and/or fish sampling. The measurements include temperature, dissolved oxygen, pH, specific conductivity, transparency tube clarity, oxidation-reduction potential (redox), and in situ chlorophyll fluorescence. Alkalinity, turbidity, soluble reactive phosphorus (SRP), [nitrate+nitrite]-nitrogen, ammonium-nitrogen, chlorophyll-a, total nitrogen (TN), total phosphorus (TP), chloride, color, and sediment percent organic matter should be measured in the lab.

2. *Overall Index of Wetland Health*

   While the individual indices of biological integrity (IBIs) derived for each of the measures can be used independently to assess coastal wetland health, an overall index of wetland health can potentially be derived by combining these individual scores and realizing that the specific indicators represent disturbance within different portions of the individual wetland along a hydrologic gradient, and therefore, providing the most reliable and complete measure of the extent, composition and quality of coastal wetlands in the basin. An attempt to combine sub-indicators into an overall measure of wetland health is currently underway.

Indicator Interpretation and Comments

This indicator consists of the composition and density of macroinvertebrates, fish, plants, amphibians, birds, and water quality measures. Currently, about 200 wetlands are sampled annually since 2011, which is funded by GLRI through 2015 (about $2 million per year). Upon completion of the fifth year, the coastal wetlands greater than 4 hectares with a surface water connection to the Great Lakes will be sampled and a baseline will be established. The five measures that comprise this indicator are existing individual SOLEC indicators. Individual IBIs are derived for each of the measures and can be used independently as a measure of coastal wetland health, based on a percentage of points possible reflected as 'reference conditions' to 'extremely degraded'. However, an overall view of wetland health can be derived by considering these sub-indicators in combination, because they function and indicate anthropogenic disturbance at different spatial and temporal scales and have varying resolution of detection. For example, the vegetation sub-indicator tends to indicate coarse scale regional variation of the dryer portions of the wetland while invertebrates detect much more local disturbance of the lakeward portion of the wetland within regions. Fish tend to detect disturbance somewhere between the local and regional scale. The geographic scale of disturbance for birds and amphibians is not yet determined, nor is the resolution for detecting ecosystem health. Landscape measures are used to determine loss, transformation and restoration of wetland types experiencing varying degrees of anthropogenic disturbance. However, landscape measures have been challenging due to data gaps and because coastal wetlands are extremely dynamic systems; they migrate, disappear, and appear with changing water levels not necessarily related to anthropogenic disturbance.

3.2.3 Land Cover and Fragmentation Status

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IJC staff:	Lizhu Wang, Vic Serveiss

Definition

This indicator assesses the rate and extent of change to, and the fragmentation of, natural land cover within the Great Lakes watersheds. This landscape scale indicator will inform inferences about the major proximate causes of changes and trends in other biological communities, physical habitat, and water quality indicators that are more directly reflective of the health of the Great Lakes ecosystem.

Indicator Relevance

This indicator is relevant to GLWQA Annex 4-Nutrients that manages phosphorus and other nutrient concentration and loading from watersheds to the lakes. It is also relevant to Annex 2-LAMPs, Annex 7-Habitat and Species, and Annex 8-Groundwater, since the changes in this indicator directly affect trends in other physiochemical and biological indicators that are more directly reflective of the health of the Great Lakes ecosystem.

Description of Measures

This indicator includes land cover conversion measures and fragmentation measures.

1. *Conversion measures*:
    - Natural land cover type unchanged (%).
    - Major change in natural land cover types (%).
    - Major change to anthropogenic non-urban or industrial land use (restorable) (%).
    - Major change to urban or industrial land use ("Unrestorable") (%).

- Changed to water (%).

A change matrix will be developed so that each 1 km pixel in the analyses is given a "rating of change". For example, a change from wetland to urban would receive the most negative value (e.g. -2), no change would receive a neutral value (e.g., 0) whereas restoration of a non-natural type to natural habitat would receive a positive value (e.g. 2). The pixels in the analysis would be classified this way to give a visual representation of change in addition to the tabular data.

2. *Fragmentation measures*:
   - Average number of patches for each natural land-cover class, which can be measured using Fragstat software at 1 ha scale.
   - Average patch size for each natural land cover class.

Other Measures Considered

1. The five land conversion and the two fragmentation measures can be potentially aggregated into an overall index. However, the aggregation approach is yet to be determined.

2. The Forest Spatial Integrity Index is developed for evaluation of forest fragmentation. Forest Spatial Integrity Index is calculated based on forest patch size, spatially weighted forest cover density, and connectivity using LANDFIRE Refreshed Existing Vegetation Type data. Presently, the LANDFIRE data is available only for U.S. side of the Great Lakes. It is possible to crosswalk LANDFIRE data to related Canadian ecological data systems, but development of analogous data, while extremely valuable, would be expensive.

Indicator Interpretation and Comments

As natural lands convert to agricultural or urban use, the ecosystem products and services provided by those cover types such as timber, water storage and purification, wildlife habitat, carbon storage, recreation, and aesthetic beauty, etc. are changed. The loss of natural habitat, particularly forest, can also have profound economic impact on communities that rely on the forest for food and economic development. Furthermore, conversion of natural land cover to urban and agricultural lands leads to increased runoff and associated increased inputs of sediments, nutrients, and contaminants to inland waters and the Great Lakes (Seilheimer et al., 2013; Wolter et al., 2006). High rates of land conversion place stress on the natural ecosystem. Growth in human population and resource consumption are drivers for more development, which displace both agricultural and natural lands. Other things being constant, high conversion rates are associated with rapid rates of development. The spatial pattern of land use conversion affects wildlife habitat and associated wildlife populations and communities. For example, fragmentation of natural or semi-natural lands can create migration barriers or inhospitable habitats for wildlife and interfere with other ecological processes. Forest interior breeding birds in the Great Lakes and other ecoregions have been shown to have higher breeding success in relatively unfragmented landscapes than fragmented landscapes (Robinson et al., 1995). The size and number of natural habitat patches has been shown to have a significant influence on a variety of wildlife populations, including populations in the Great Lakes region (Saunders et al., 2002). Finally, small ownership parcels found in fragmented landscapes complicate management and cooperation at landscape and watershed scales due to the increased number of stakeholders that must be involved in land management decisions (Pijanowski and Robinson, 2011).

*There are coarser-scale land cover and use data available for Canada, e.g., "NACP Forest Age Maps at 1-km Resolution for Canada (2004) and the U.S.A. (2006)" (http://daac.ornl.gov/NACP/guides/NA_Tree_Age.html)

3.2.4 Seasonal and Long-Term Fluctuations in Great Lakes Water Levels

Expert workgroup members:	Drew Gronewold, Norm Grannemann, John Allis, Glen Benoy, Jacob Bruxer, David Fay, Mike Shantz, Al Steinman
IJC staff:	Lizhu Wang, Glenn Benoy, Vic Serveiss

Definition

This indicator tracks seasonal, inter-annual, and long-term (i.e. decadal) trends in lakewide-average water levels across each of the Great Lakes. The set of measures associated with this indicator are calculated from existing estimates of lake-wide average water levels based on gage measurements since 1918. This formal network of gages for each lake was established and has served as the basis for an internationally-coordinated set of monthly-average water level measurements. Lake-wide average water levels based on gage measurements is also available dated back to 1860, the year in which at least one gage ("master gage") was installed along the shoreline of each of the Great Lakes. The measures proposed below are based on monthly average water level records from gage data collected between 1918 and present. It is suggested to not use the data before 1918 because of the concern that glacial isostatic adjustment may bias the measures.

Indicator Relevance

This indicator is directly relevant to GLWQA Annex 9-Climate Change Impacts, since water level characteristics could be strongly influenced by climate change. This indicator is also relevant to Annex 7-Habitat and Species because water level change has strong influences on Great Lakes habitat and biological communities associated with them. Impacts of alterations in the water level fluctuations of the Great Lakes on shoreline ecosystems (particularly coastal wetlands) are widely-documented, and underscore important additional (but less apparent) relationships between ecosystem response and both human intervention (such as implementation of outflow regulations on Lakes Superior and Ontario) and climate change (Wilcox et al., 2002; Hartmann, 1990). In general, water level fluctuations have both direct and indirect connections to nearly every aspect of ecosystem and coastal water quality (whether through connections to the magnitude and timing of tributary inflows, or interrelationships between evaporation, ice cover, water temperature, and water quality). This suite of relationships is particularly relevant given the current period of persistent low water levels on Lakes Michigan and Huron

(Gronewold et al., 2013), including the record low monthly average levels set on the Lake Michigan-Huron system in December 2012 and January 2013, the record monthly lows set on Lake Superior for the months of August and September (both in 2007), and the record monthly high water level set in 1986 for Lake Michigan. Notably, the monthly average water level recorded on Lake Michigan-Huron in January 2013 is the lowest monthly average water level ever recorded for the Michigan-Huron system. These recent phenomena underscore the need for explicit identification of water level measures that provide a suitable context within which to assess and understand drivers behind, and implications of, observed extreme low (and high) water levels and shifts in the natural seasonal cycle (Lenters, 2004).

Description of Measures

This indicator includes four measures:

1. *Long-term water level variability*

   This measure is derived by assessing trends in the "rolling" 5- and 30-year standard deviation of monthly mean water levels over the period of record for each of the Great Lakes. Water level variability across different time scales can serve as indices of significant changes in regional meteorology and climate and a reflection of anthropogenic influence (including regulation of outflows from Lakes Superior and Ontario), and an important indicator of potential impacts on coastal ecosystems, hydropower capacity, and other socioeconomic factors.

2. *Timing of seasonal water level maximum and minimum*

   This measure is based on assessing changes over time in the month in which the seasonal water level maximum and minimum occur. Water levels on each of the Great Lakes follow a strong seasonal pattern (Lenters, 2004) in which water levels tend to rise in the spring (as a result of increasing precipitation, melting of snow from the previous winter, and decreasing over-lake evaporation) until a peak is reached in mid-summer. Water levels then typically decline through the fall months (primarily through increased evaporation rates and reduced runoff), reaching a typical seasonal low in early winter. Persistent shifts in the timing of either the seasonal maximum or minimum may reflect shifts in the regional water budget (including changes in the timing and magnitude of precipitation, tributary flows, and evaporation) and provide insight into potential impacts on aquatic plants and fish spawning habitats, and other sensitive aspects of the coastal ecosystem.

3. *Magnitude of seasonal rise and decline*

   This measure is based on assessing trends over time in the magnitude of spring rise, and the magnitude of fall decline. A persistent increase in the magnitude of spring rise might, for example, reflect increasing "flashiness" in tributary inflows, while periods of decreased declines in the fall may reflect cooler water temperatures and diminished evaporation rates. These regional drivers of climate have important implications for the magnitude of seasonal rises and declines, and impacts on the coastal ecosystem. Long-term changes in Great Lakes water levels often occur through persistent above- or below-average water level changes in the spring and fall. For example, systematic increases in long-term water levels are often a consequence of consistent above-average runoff rates in the spring and below-average evaporation rates in the fall. In addition, the magnitude of seasonal rise and decline (within a given year) has important implications for coastal recreational activities and the design of coastal infrastructure. It also has implications for vegetative phenology and sediment-water nutrient exchange.

4. *Lake-to-lake water level difference*

   This measure is based on assessing long-term trends in the difference between the monthly mean water level for each lake and the monthly mean water level for the downstream lake. Differences between the water levels of each of the lakes may follow a relatively consistent and predictable pattern; anomalies in these differences may suggest an imbalance in the regional water budget, physical changes in the channels that connect the lakes, or the apparent and physical impacts of glacial isostatic adjustment on recorded water levels (International Upper Great Lakes Study, 2009).

Other Measures Considered

1. *Dangerously low water levels*

   A chart-referenced low water datum (LWD) elevation is established for each of the Great Lakes, and indicates an elevation below which water levels are not expected to decline frequently. The frequency with which water level depths exceed the LWD is important because, unlike long term average water levels (which are continuously calculated as new data become available), the LWD does not change over time. This measure is based on assessing the number of months, within each historical calendar year, for which the water level is below LWD.

2. *Seasonal water level cycle anomalies*

   This measure provides information similar to seasonal measures identified above, but is based on calculating (and assessing trends in) the difference between each monthly average water level and the average water level for that particular month.

3. *Frequency of extremes*

   Extreme high and low water levels can have significant impacts on the regional economy and on ecosystem health. Tracking the frequency of these extremes can shed light into whether or not the Great Lakes system is entering a new (or staying within a given) hydrologic regime. This measure, then, is based on documenting years in which a monthly (or all-time) water level maximum or minimum was recorded, and assessing the distribution of time intervals between those extremes.

Indicator Interpretation and Comments

Maintenance and operation of the Great Lakes water level monitoring network is critical to understanding the Great Lakes regional water budget, and is currently a central regional mission of both the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOAA-NOS), and the Fisheries and Oceans Canada - Canadian Hydrographic Survey (CHS). Synthesizing and communicating lakewide-average water level data is coordinated through a regional partnership led by the United States Army Corps of Engineers (USACE) Detroit District, and Environment Canada. Understanding changes in the proposed water level measures should continue to leverage this unique and long-standing regional partnership.

The measures proposed provide an indication of water level trends over different time scales, and there are dozens (if not hundreds) of important connections to regional climate trends, commerce (such as commercial shipping and hydropower capacity), and ecosystem and human health (Millerd, 2005). These connections are likely more clearly identified within other ecosystem indicators (including, for example, shoreline integrity, coastal wetlands, and ice cover), and should continue to emphasized in future iterations of this effort.

3.2.5 Tributary Physical Integrity

Expert workgroup member:	Scudder Mackey
IJC staff:	Lizhu Wang

Definition

This indicator includes three measures. The Hydrologic Alteration (R-B Flashiness Index) quantifies the hydrologic responsiveness (i.e. flashiness) of a Great Lakes tributary to temporal changes in precipitation and runoff. The Tributary Connectivity quantifies the percent of mainstem channel length that is naturally accessible and is connected to the Great Lakes. This measure can be calculated for a single tributary or multiple tributaries. The Tributary Sediment-Turbidity quantifies changes in the magnitude and duration of turbidity referenced to a turbidity threshold. When calibrated properly, turbidity may be used as a surrogate for changes in suspended sediment load.

Indicator Relevance

This indicator is directly relevant to the GLWQA Annex 7-Habitat and Species objectives by (1) measuring progress made in reducing river flashiness and increasing in connectivity between the Great Lakes and their tributaries; (2) quantifying the longitudinal connectivity between the Great Lakes and their tributaries necessary to meet the life history requirements of anadromous fish and other aquatic species, including access to critical spawning and nursery habitats; and (3) assessing sediment-turbidity changes in the tributaries as an important water quality parameter that directly impacts aquatic vegetation and tributary fish and benthic communities.

Description of Measures

1. *Hydrologic Alteration (R-B Flashiness Index)*

This measure describes the hydrologic response of a river to changes in precipitation/runoff events. The R-B Index is calculated using USGS mean daily flows on an annual basis (N=365) by dividing the sum of the absolute values of day-to-day changes in mean daily flow by the total discharge over that time interval (Baker et al., 2004).

$$\text{R-B Index} = \frac{\sum_{n=1}^{N} \left| q_n - q_{n-1} \right|}{\sum_{n=1}^{N} q_n}$$

The R-B Index is best used to track changing hydrologic responses of streams through time by calculating the relative change in the R-B Index over time on a watershed-by-watershed basis across the Great Lakes basin. These calculations should be updated every three to five years.

2. *Tributary Connectivity to Receiving Waters*

Tributary Connectivity is the percent of mainstem channel length (naturally accessible) that is connected to the Great Lakes. It can be calculated by individual watershed or by multiple watersheds.

$$\text{Tributary Connectivity for an individual watershed} = \left(\frac{L_b}{L_m}\right) \times 100$$

L_b is the distance between the Great Lakes and the first barrier on the mainstem channel; L_m is the total length of the mainstem channel.

For multiple watersheds/tributaries, the connectivity to the Great Lakes is calculated by summing the total length of mainstem channels without barriers and then dividing by the total sum of mainstem channel lengths (N = total number of mainstem channels).

$$\text{Tributary Connectivity for multiple watersheds} = \frac{\sum_{n=1}^{N} L_{b_n}}{\sum_{n=1}^{N} L_{m_n}} \text{ x } 100$$

Changes in watershed connectivity through time can be calculated using historical maps, aerial photographs, and other data. These calculations should be updated every five years (due to ongoing dam construction and/or removals).

3. *Sediment-turbidity measure*

This measure is quantified using Turbidity Exceedance Time and Turbidity Concentration Ratio**.**

Turbidity Exceedance Time is the proportion of time that the turbidity threshold (T) is exceeded during the time series ($t_n > T$) divided by the total time within the series. For example, a turbidity exceedance value of 0.50 indicates that the turbidity threshold was exceeded 50% of the time on an annual basis (N=365).

$$\text{Turbidity Exceedance Time} = \frac{\sum_{n=1}^{N} (t_n > T)}{\sum_{n=1}^{N} t_n}$$

Turbidity Concentration Ratio is the magnitude of exceedance above the turbidity threshold expressed as the ratio of the mean turbidity value that exceeds the turbidity threshold ($c_n > T$) divided by the turbidity threshold value. For example, a turbidity concentration ratio of 3.6 indicates that the magnitude of exceedance is 3.6 times greater than the turbidity threshold.

$$\text{Turbidity Concentration Ratio} = \frac{\sum_{n=1}^{N} (c_n > T)/N}{T}$$

Turbidity measurements may be used as a surrogate for suspended sediment load *only* when calibration studies have been performed to generate relationships between nephelometric turbidity units (NTU) and suspended sediment concentrations (mg/l) for individual watersheds. Once calibrated, these indicators may be used to track changes and longer-term trends in turbidity and suspended sediment loads within individual watersheds through time.

Other Measures Considered

None

Indicator Interpretation and Comments

Hydrologic Alteration (R-B Flashiness Index) - River flashiness is an important component of the hydrologic regime as it reflects the frequency and rapidity of short term changes in river flow to which aquatic ecosystems are adapted. Increasing or decreasing trends in flashiness may result in increased stress at lake areas that are influenced by river flows and may influence aquatic organisms that use rivers in part of their lives.

Possible range of values for the R-B Index is from 0 to 2. Typical values are from 0.05 (very stable) to about 1.2 (very flashy). The Index integrates all flow data rather than specific percentile data. The R-B Index is relatively stable from year to year and is a reliable indicator of longer-term trends (Baker et al., 2004). Overall, the R-B Index is positively correlated with increasing frequency and magnitude of storm events, and negatively correlated with baseflow and watershed area.

It should be noted that small streams tend to be flashier than large rivers, and this is reflected in generally higher R-B Index values for small streams. For small streams or streams with steep gradients, the hydrologic response may be too rapid to be resolved by daily flow data. For such systems, a version of the R-B Index based on hourly flow data can be used. However, Index comparisons between daily and hourly flow data are generally not meaningful. It is therefore critical that consideration be given to the type of flow data (daily or hourly) be used to calculate R-B Index values when making year-to-year comparisons or watershed-to-watershed comparisons.

Trend data would be reported on a watershed-by-watershed basis across the Great Lakes basin every three to five years. In almost all cases, reductions in the R-B Index would be considered desirable. Conversely, increases in the R-B Index would be considered undesirable. The following trend categories are suggested for the R-B Index:

Excellent	decreasing trend in flashiness (negative values - > 20% change in Index value)
Good	decreasing trend in flashiness (negative values - < 20% change in Index value)
Neutral	no trend in flashiness (zero change values)
Poor	increasing trend in flashiness (positive change values)

Absolute values of the R-B Index are not indicative of either good or bad conditions, especially if comparisons are made between watersheds of different types or sizes. However, when considering watersheds with similar flow regimes (e.g. event, variable, stable, or super stable) may be possible characterize a statistically appropriate range of R-B Index values by watershed type or ecoregion (Baker et al., 2004). Additional analyses are needed to develop appropriate criteria and measures to assess differences between absolute values of the R-B Index within similar watershed types.

The R-B Index is easy to calculate from widely available data. For each gauged river, changes in the R-B Index can be displayed graphically to illustrate trend or mapped geospatially to show geographic changes in the distribution of flashiness. Streams with long flow records (20 years plus) flowing across a diverse range of landscapes and watersheds would be desirable.

Tributary Connectivity to Receiving Waters - Values range from 0 to 100. A value of 0.0 represents a main stem channel that is not connected to the receiving water body (no connectivity) and a value of 100 represents a main stem channel with unimpaired connectivity.

In almost all cases, increases in watershed connectivity would be considered desirable (impediments to sea lamprey infestation are the exception). Conversely, decreases in watershed connectivity would be considered undesirable. The following ranking categories are suggested for the watershed connectivity indicator:

Excellent	90% to 100% (unimpaired connectivity)
Good	70% to 90%
Fair	50% to 70%
Poor	Less than 50% (impaired connectivity)

Using GIS tools, tributary main stem lengths and dam locations can be easily measured. The data are readily available for the entire Great Lakes Basin. A critical requirement will be periodic updates and validation of the dam inventory database.

Sediment/Turbidity - The possible range of values for turbidity exceedance time is from 0 to 1. Typical values will vary based on the established value of the turbidity threshold. Several States and Provinces have identified threshold NTU limits for turbidity (10, 25, or 50 NTU) and acceptable exceedance ranges (generally +10% of background or threshold values) (e.g. U S EPA, 1988; Marquis, 2005; Trebitz et al., 2007). Extended periods of high turbidity (> 50 NTU threshold) may result in increased ecosystem stress.

Using a threshold value of 50 NTU, typical turbidity exceedance time values may range from 0.3 to 0.7 depending on local hydrologic and geologic conditions. The possible range of values for the turbidity concentration ratio range from 0 to infinity, but typically will range from 0 to 20. Acceptable values of the turbidity concentration ratio would be 0.1 or less where acceptable exceedance ranges are +10% of threshold levels.

Sensitivity analyses indicate that comparisons between daily and hourly turbidity data are generally not meaningful (except perhaps for small streams). Hourly data can be used to calculate daily means which then can be used to calculate values for the turbidity indicators. Currently, these measures are only useful for trend comparisons within an individual watershed.

Turbidity measurements can be used as a surrogate for suspended sediment loads only if appropriate statistical relationships between turbidity (NTU) and suspended sediment concentrations (mg/l) are developed for individual watersheds. Additional studies will be needed to assess the reliability of watershed-by-watershed comparisons under varying geological conditions. These calculations should be updated every three to five years.

In almost all cases, low turbidity exceedance time values are considered to be more desirable than high exceedance time values. Similarly, low turbidity concentration ratios are considered to be more desirable than high concentration ratios. The following are general characterizations that may be useful when evaluating the trends of these measures.

Excellent	decreasing trend in turbidity (>20% change in duration and/or magnitude)
Good	decreasing trend in turbidity (< 20% change in duration and/or magnitude)
Neutral	no trend in turbidity (zero change in duration and magnitude)
Poor	increasing trend in duration and magnitude

3.2.6 Water Temperature

Expert workgroup members:	Norm Granneman, Eric J Anderson, Jay Austin, Ed Rutherford, Chris Spence, Jia Wang, and Ram Yerubandi
IJC staff:	Lizhu Wang, Glenn Benoy

Definition

This indicator tracks the trends in water temperature and extent of winter ice cover for each of the five Great Lakes by measuring changes in duration and spatial extent of water temperature and ice cover using long term data. This indicator measures the thermal properties of the Great

Lakes that affects the ecosystems' function and influences water evaporation from the lakes that affects lake's water level.

Indicator Relevance

This indicator is relevant to the General Objectives of the GLWQA and Annex 9-Climate Change Impacts in coordinating effort to identify, quantify, and understand, and predict climate change impacts on the quantity of the waters of the Great Lakes. This indicator is also relevant to the other Annexes since higher water temperatures and less ice cover may be related to more and earlier algae blooms which damage water quality and habitat; less ice cover exposes the shoreline to waves generated by winter storms that accelerates erosion; and higher temperatures may also be related to the spread of some invasive species.

Description of Measures

This indicator includes three measures:

1. *Annual summer (July-September) surface average temperature for each lake*.
   This measure applies to all the five lakes.

2. *Lake water thermal stratification date*.
   This measure applies to all the five lakes.

3. *Fall lake water turnover date*.
   This measure applies only to lakes with data (currently, Lakes Superior, Michigan, Erie, and Ontario have available data and Lake Huron does not have any data).

4. *Maximum and average ice concentrations* (use the definition by Assel, 2005).

Other Measures Considered

1. Measures that are important for fish: dates of the first reported ice, date of the last reported ice; and ice duration for each winter.

Indicator Interpretation and Comments

According to Assel (2005), the daily spatial average ice cover for each Great Lake was calculated from daily grids. Daily grids were generated by linear interpolation of observed ice cover grids between adjacent dates for a given winter season from the date of first ice chart to date of last ice chart (Assel and Norton, 2001). Lake-averaged ice cover prior to date of first ice chart and after date of last ice chart was assumed to be zero. The daily lake-averaged ice cover on each Great Lake is used to calculate the seasonal average ice cover. The seasonal average ice cover is the sum of the daily lake-averaged ice cover over a winter divided by 182 (the number of days between 1 December to the following 31 May). The seasonal average ice cover is calculated for days when the lake-averaged ice cover was greater than or equal to 5%.

The seasonal average ice cover is an index of the severity of an annual ice cycle. Ancillary ice cycle variables calculated for each winter are the Julian dates that the first and last observed lake-averaged ice cover was greater than or equal to 5% and the duration of the ice cover, that is, the difference between dates of last and first ice.

3.3 Chemical Indicators

3.3.1 Atmospheric Deposition of Chemicals of Mutual Concern

Expert workgroup member:	Todd Nettesheim
IJC staff:	Jennifer Boehme, Antonette Arvai

Definition

This indicator will report on spatial patterns and temporal trends of concentration of chemicals of mutual concern in the atmosphere and precipitation of the Great Lakes region. The indicator will be used to infer potential impacts of toxic chemicals from atmospheric deposition loadings on the Great Lakes aquatic ecosystem, as well as to infer the progress of various programs toward virtual elimination of toxics from the Great Lakes.

Indicator Relevance

This indicator is relevant to the General Objective of the GLWQA that the waters of the Great Lakes are free from pollutants in quantities or concentrations that that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain. This indicator is also relevant to Annex 3-Chemicals of Mutual Concern of the GLWQA, the purpose of which is to "reduce the anthropogenic release of chemicals of mutual concern, recognizing: (i) that chemicals of mutual concern released into the air, water, land, sediment, and biota should not result in impairment to the quality of the Waters of the Great Lakes; and (ii) the need to manage chemicals of mutual concern including, as appropriate, by implementing measures to achieve virtual elimination and zero discharge of these chemicals." The Annex 3 further calls for the Parties to (i) monitor and evaluate the progress and effectiveness of pollution prevention and control measures; (ii) exchange, on a regular basis, information on monitoring, surveillance…; (iii) identify and assess the occurrence, sources, transport, and impact of chemicals of mutual concern, including spatial and temporal trends in the atmosphere…; and (iv) identify and assess loadings … from the atmosphere.

Description of Measures

It is proposed that the Atmospheric Deposition indicator be largely based on the well-established SOLEC indicator Atmospheric Deposition of Toxic Chemicals (Nettesheim et al., 2014). The atmosphere is a key source of many persistent, bioaccumulative, and toxic chemicals to the Great Lakes and hence into Great Lakes fishes. The atmosphere was first recognized as an important source in the 1980s and later confirmed with data from the Integrated Atmospheric Deposition Network (IADN) and Lake Michigan Mass Balance study. Recent IADN and Mercury Deposition Network (MDN) data and publications indicate that the atmosphere remains an important source of PBT. Chemicals of mutual concern in the atmosphere and precipitation will be measured at IADN and MDN stations, using the protocols established by the binational IADN network and MDN respectively. Additional chemicals of mutual concern may be added as they are selected by the GLWQA Annex 3 sub-committee.

IADN and MDN are well-established international monitoring programs with protocols for sampling frequency, site selection, and sampling and analytical methods, with stations in the Great Lakes region that could be utilized for this indicator. For example, IADN has established one master station on each of the five Great Lakes: Eagle Harbor (USA) on Lake Superior, Sleeping Bear Dunes (USA) on Lake Michigan, Burnt Island (Canada) on Lake Huron, Sturgeon Point (USA) on Lake Erie and Pt. Petre (Canada) on Lake Ontario. Additional satellite stations increase the resolution capability of IADN, which could be incorporated into the geographic scope of this indicator.

Other Measures Considered

None

Indicator Interpretation and Comments

Air (vapor and particle) samples are collected for 24 hours every 12 days. Precipitation samples are integrated over each month. Annual average concentrations will be calculated and reported using these measurements. Spatial and temporal trend analyses will be performed on the IADN data using a variety of statistical tools (Venier et al., 2012; Venier and Hites, 2010a; Venier and Hites, 2010b).

Weekly composite precipitation samples will be collected and analyzed for mercury across the Great Lakes basin at MDN stations, using the same strict sampling and analytical protocols established under the network. Annual mercury concentrations, precipitation depths, and wet deposition will be calculated and reported using this data. Spatial and temporal trend analyses will be performed on the MDN data using a variety of statistical tools (Risch et al., 2012; Prestbo and Gay, 2009).

Air concentrations respond rapidly to changes in emissions, but it is not known how rapidly the lakes and the fishes in them will respond (“environmental hysteresis”). This makes atmospheric measurements a very useful tool for tracking progress as a result of management actions.

3.3.2 Chemicals of Mutual Concern in Water

Expert workgroup members:	Michael Murray, Deborah Swackhamer, Gail Krantzberg, and Conrad DeBarros, Gary Klecka
IJC staff:	Jennifer Boehme

Definition

This indicator addresses total concentrations of selected legacy toxic chemicals and chemicals of emerging concern in water that are determined at selected offshore and nearshore sites in each lake on a two-to-three-year basis. The specific chemicals of mutual concern, including legacy and emerging chemicals, will be selected by the Great Lakes Executive Committee as per Annex 3 of the GLWQA. The purpose of the indicator is to assess the magnitude and direction of trends of chemicals of mutual concern (CMCs) in Great Lakes surface water, the potential for human or ecological impacts, and progress toward virtual elimination of toxic substances in the Great Lakes basin (Dove, 2011).

Indicator Relevance

An aqueous concentration indicator is directly relevant to the General Objective of the GLWQA, specifically that the Lakes be "free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain…" The indicator is also relevant to the Article 3 Specific Objective that substance objectives (or numeric targets) be developed "to manage the level of a substance or combination of substances to reduce threats to human health and the environment in the Great Lakes Basin Ecosystem."

Description of Measures

The indicator would be obtained through integrating data from direct measurements of aqueous concentrations of various CMCs selected from those listed pursuant to Annex 3 of the renewed GLWQA.

Currently, the GLWQA Annex 3 Subcommittee is forming a task team to evaluate the first list of CMC candidates put forward by Environment Canada and the USEPA, with their reports and recommendations on the first list of CMCs due to the Annex 3 Subcommittee by October 2014. The first recommended CMCs and supporting documentation based on the task team reports will then be submitted by the Annex 3 Subcommittee to the Great Lakes Executive Committee for approval by December 2014. As part of this process, the Annex 3 Subcommittee will develop an approach for preparing bi-national strategies for CMCs which may include research, monitoring, surveillance and pollution prevention and control provisions.

The selected CMC concentrations should be measured from data collected every two-three years, and at selected offshore and some nearshore sites, during the spring isothermal period. Site selection should represent the diversity of aquatic habitats in each lake (i.e., nearshore sites at different distances from major tributary mouths, offshore sites in different basins), building off current efforts used through SOLEC. SOLEC Indicator 118 Toxic Chemical Concentrations in Offshore Waters incorporates multiple chemical components including mercury and organochlorine compounds, which could provide partial overlap with CMCs identified in the future through the Annex 3 Subcommittee process described above. However, its focus on offshore sampling locations restricts its geographic scope relative to the scope of sampling locations proposed here.

Other Measures Considered

None

Indicator Interpretation and Comments

For future consideration, it is recommended that managers also consider the potential additional monitoring value of passive techniques, such as semipermeable membrane devices (for semivolatile organic compounds, e.g. Alvarez, 2010) and the polar organic chemical integrative sampler (POCIS) technique for more polar compounds (e.g. Li et al., 2010). Such techniques are already in use in selected areas, and could be phased into existing monitoring programs for toxic chemicals in the Great Lakes more broadly following a method development and evaluation phase. Resulting data could assist in determining local and regional differences in CMCs as well as further monitoring and management actions that might be pursued concerning CMCs in the Lakes.

Additional factors to consider in identifying measurement parameters for the CMC indicator include consideration of ongoing sensitivity issues (including as legacy chemical concentrations continue to decline); spatial and temporal considerations (e.g. number and locations of sites in nearshore vs. offshore areas, sampling frequency); changes in ancillary factors, such as food webs and climate (e.g. Carlson et al., 2010); and issues of statistical power and trend detection (e.g. Chang et al., 2012).

3.3.3 Contaminants in Groundwater

Expert workgroup members:	Norm Granneman, Gary Bowen, Emil Frind, Dale VanStempvoort, Al Kehew, Bill Alley
IJC staff:	Antonette Arvai, Lizhu Wang

Definition

Groundwater is an important component of the hydrologic cycle and, therefore, groundwater quality is an important factor in determining the overall quality of water in the Lakes. Groundwater is important to ecosystems in the Great Lakes Region because it is, in effect, a large, subsurface reservoir from which water is released slowly to provide a reliable minimum level of water flow to streams, lakes, and wetlands. Groundwater discharge to streams generally provides good quality water that, in turn, promotes habitat for aquatic animals and sustains aquatic plants during periods of low precipitation. The major groundwater resources issues in the Great Lakes Region revolve around 1) the quantity of groundwater, 2) groundwater and surface-water interaction, 3) changes in groundwater quality as development expands, and 4) ecosystem health in relation to quantity and quality of water. This indicator includes the quality and quantity of the groundwater in the Great Lakes region, and its interaction with the surface water in the Great Lakes basin.

Indicator Relevance

This indicator is relevant to the General Objective of the GLWQA in measuring progress toward protecting the waters of the Great Lakes from the harmful impacts of contaminated groundwater.

This indicator is also relevant to Annex 8-Groundwater, which contributes to the achievement of the objectives of the Agreement.

Description of Measures

This indicator will measure physical and chemical parameters from various river watersheds where they have direct influence on each of the 5 Great Lakes.

1. *River Watersheds*

   The recommended rivers include those that have a good baseflow component and in watersheds that are representative of

   1) Agricultural;
   2) Urban; and
   3) Forest areas

Lake	River	Dominant Watershed Type
Lake Ontario	Humber River (ON)	Urban
	Ganaraska River (ON)	Agriculture/Rural
	Duffins Creek (ON	Agriculture/Rural
	Genesee River (NY)	Forest/Agriculture/Urban mix
	Oak Orchard Creek (NY)	Agriculture
	Eighteenmile Creek (NY)	Agriculture
	Salmon Creek (NY)	Forest
	Black River (NY)	Forest
Lake Erie	Big Creek (ON)	Agriculture
	Kettle Creek (ON)	Agriculture
	Grand River (ON)	Urban
	Maumee River (OH)	Agriculture/some urban
	Sandusky River (OH)	Agriculture/some urban
Lake Huron	Thunder Bay River (MI)	Forest
	Au Sable (MI)	Forest
	Saugeen River (ON)	Agriculture
	Spanish River (ON)	Mining
	Pine River (ON)	Agriculture
	Nottawasaga River (ON)	Forest/Rural
Lake Superior	St. Louis River (MN)	Forest/Rural
Lake	Manitowoc River (WI)	Agriculture

Michigan	Muskegon River (MI)	Forest/Agriculture mix

2. *Chemical and Physical Parameters*

The parameters for measure include those that are common to all river watersheds in addition to parameters specific to urban and agricultural watersheds.

Common to all river watersheds	Location, water level and/or flow, temperature, pH, TDS, nitrate, chloride, sulfate, calcium, magnesium, sodium, potassium, carbonate, bicarbonate
Additional Urban Parameters	Total chlorinated compounds, BTEX (benzene, toluene, ethylbenzene, xylenes), arsenic, cadmium, zinc
Additional Agriculture Parameters	Phosphorus, triazine herbicides

Other Measures Considered

None

Indicator Interpretation and Comments

Groundwater discharge is a long-term, persistent component that results from the part of precipitation that infiltrates into the soil, percolates into an aquifer, and then flows to a stream, lake, or wetland. Most groundwater/surface-water interaction in the Great Lakes basin takes place in the near surface unconsolidated glacial-deposit aquifers. Because groundwater is so highly distributed in the Great Lakes basin, representative locations to conduct measurements of changes in groundwater quality that demonstrate the state of the groundwater resource as it relates to Great Lakes issues are needed.

Measures focus on groundwater as a transmitter / vector of contaminants and nutrients to the Great Lakes mostly as it impacts the quality of water in streams flowing into the Great Lakes. It also impacts the ecology / habitats of streams that are interconnected with ecology of the Great Lakes such as fish spawning and migration, wetland health, tributary physical integrity, and water temperature.

Groundwater data will be obtained from water from selected wells and stream reaches unaffected by waste water discharge during baseflow conditions. Groundwater data will be summarized from existing data collected by federal, state, provincial, regional and local authorities at locations that illustrate the effects of human-induced changes to groundwater quality from urban and agricultural development. Some of this representative data can focus on water quality in water from streams under baseflow conditions and other data will be for water from wells that will be used in conjunction with the streamflow data. Because of the slow movement of groundwater, the effects of surface activities on groundwater flow and quality can take years to manifest themselves.

3.3.4 Persistent, Bioaccumulating, Toxic (PBT) in Biota

Expert workgroup members:	Jeff Ridal, Michael Murray, Conrad deBarros, Gary Klecka
IJC staff:	Vic Serveiss, Lizhu Wang

Definition

The persistent, bioaccumulating, toxic substances (PBTs) in biota indicator is an assessment of the trends in the concentrations of PBTs in whole fish and fish-eating birds. It can be used to describe temporal and spatial trends of bioavailable contaminants in representative biota throughout the Great Lakes; to infer the impact of contaminants on the health of fish and bird populations; to infer the effectiveness of remedial actions related to the management of critical pollutants; and to document and describe the trends of chemicals of emerging concern.

Indicator Relevance

This indicator is relevant to the General Objectives of the GLWQA in measuring progress made in allowing for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants and being free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain. This indicator is also relevant to the GLWQA objectives of Annex 1-Areas of Concern, Annex 2-Lakewide Management, Annex 3-Chemicals of Mutual Concern, and Annex 10-Science.

Description of Measures

This indicator will measure:

1. *PBT chemicals in Great Lakes whole fish*, specifically the top predators Lake Trout (*Salvelinus namaycush*), Walleye (*Sander vitreus*) and the forage fish, Rainbow Smelt (*Osmerus mordax*). Other species of forage fish could also be considered (e.g., yellow perch, spottail shiners).

2. *PBT chemicals in Great Lakes Herring Gull (Larus argentatus) eggs and in Bald Eagles*.

3. The PBT chemicals to be measured include PCBs, organochlorine pesticides, dioxins and furans, and trace metals including mercury. Additional chemicals of mutual concern with PBT properties can be added as they are selected by the GLWQA Annex 3 Subcommittee.

Other Indicators Considered

None

Indicator Interpretation and Comments

This indicator is largely based on two well-established SOLEC indicators: (1) contaminants in whole fish and (2) contaminants in fish-eating colonial waterbirds, as well as the newly developed SOLEC indicator for Bald Eagles. The whole fish indicator assesses the temporal and geographic trends in the chemical contaminant levels in Lake Trout from Lakes Ontario, Huron, Michigan and Superior, and Walleye from Lake Erie. Environment Canada and the USEPA both contribute data to this indicator, although different methodologies limit the statistical analyses that can be performed (McGoldrick et al., 2014). Environment Canada also provides data on Rainbow Smelt, a common forage species. Samples are collected and analyzed at least every two years at 10 established sites (2 in each of the 5 Great Lakes) by a USEPA program and annually at 12 sites established by Environment Canada in Superior, Huron, Erie and Ontario. It is recommended that sampling be conducted at a minimum at 2 sites per lake, and at a frequency of at least every two years. In addition, consideration should be given to including a warmwater fish species (e.g. largemouth bass) to greater represent the whole fish community. Criteria for selection could include significance as a food source, relevance of the species to the whole lake community, and ease of monitoring (e.g., via existing contaminant monitoring in state and provincial programs, assuming a similar protocol is adopted).

Through existing USEPA and Environment Canada monitoring programs, contaminant analyses in whole fish reported include legacy PBTs such as PCBs, organochlorine pesticides, dioxins and furans, mercury and other trace metals, and also contaminants of emerging concern such as polybrominated diethyl ethers (PBDEs), fluorinated chemicals and synthetic musks. Trends through time are assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines. Concentrations are also compared to applicable benchmarks for concentrations in whole fish. It is recommended that this chemical suite and trend analysis approach be continued.

Regarding the second indicator component, Herring Gull eggs are collected annually by Environment Canada at 15 sites representative of all 5 Great Lakes. Contaminants analyzed include PCBs, organochlorine pesticides, dioxins and furans, mercury and other trace metals, and (since 2000) PBDEs. An archival database of sample extracts has been established and should be maintained for retrospective analysis. In addition, it is recommended that sampling and analysis continue on an annual basis. Concentrations of PBT chemicals should also be assessed in Bald Eagles; such information will be collected as a component of a Bald Eagle indicator being developed for the SOLEC program for 2014.

Several factors affect the annual concentrations of PBTs in biota. These include changing food webs, prey availability, growth rates, and climatic variability; therefore, ancillary data is required for detailed interpretation of the whole fish trend data. The Herring Gull and Contaminants in Whole Fish monitoring programs have established ancillary data collections that include fish age, length, weight, sex, and lipid content of the fish collected. Egg moisture and lipid contents, and a gull diet index based on stable isotopes, trophic position, and diet fatty acid content are collected for the Herring Gull egg program. Additional physiological measures are conducted on the colonies from which the eggs are collected (Weseloh and Moore, 2014). Detailed data on sample size, location and the complete suite of ancillary measurements can be sourced from the program leads for the Contaminants in Whole Fish and Contaminants in Fish-eating Colonial Waterbirds programs.

3.3.5 Phosphorus Loads and In-Lake Concentrations

Expert workgroup member:	Joe DePinto
IJC staff:	Mark Burrows, Raj Bejankiwar

Definition

This indicator tracks the trends in phosphorus loading to each of the Great Lakes, including specification of loading to major embayments/sub-basins of the lakes. The loads of both total phosphorus (TP) and dissolved reactive phosphorus (DRP) should be tracked from the major watersheds of each lake. A second component of the indicator is to track the spatial and temporal trends of TP and DRP concentrations in the nearshore and offshore areas of each lake in response to the external loads.

Indicator Relevance

This indicator is directly relevant to the GLWQA Annex 4-Nutrients to manage phosphorus concentrations and loadings in the Waters of the Great Lakes. Excessive phosphorus concentrations in specific lakes or specific lake areas and excessive amount of phosphorus loading from tributaries continue to be the primary stressor leading to excessive harmful and nuisance algal conditions.

Description of Measures

1. *Phosphorus Loads*
   TP and DRP loadings should be calculated from the major tributaries of each basin using method in Dolan and Chapra (2012). The major tributaries are those that taken together contribute >80% of the TP load to the system of concern. Daily flow measurement by USGS gage station with at least between 12 and 24 TP and DRP concentration measurements annually (depending on flashiness of the tributary) with an emphasis of the concentration sampling (~2/3 of samples) on high-flow events in late fall and spring.

2. *In-lake Concentration*
   Continuation of the spring (pre-stratification) and summer stratification monitoring by the Parties, but revisit the placement of stations and the depth resolution of sampling to better capture nearshore-offshore gradients in the system and improve the accuracy of basin-wide average concentrations of both TP and DRP.

Other Measures Considered

None

Indicator Interpretation and Comments

Watershed phosphorus load control continues to be the primary management action that can be taken to address the eutrophication and excessive amount of nuisance and harmful algae issues. But two factors primarily impact the understanding and establishment of target phosphorus loads necessary to achieve eutrophication-related targets in the lakes:

- The relationship between the loading of phosphorus and in-lake concentrations has greatly changed in the Great Lakes due to changes in how the lake ecosystem processes those loads (e.g., Dreissenids and Cladophora);
- The increases in the fraction of algal-available phosphorus in the external loads as a result of various activities in the lake's watershed (e.g., recent trends in DRP loading in Maumee and Sandusky Rivers).

Hence, while phosphorus loads and in-lake concentrations are still a critical indicator of Great Lakes ecological health, there is a need to change the way we measure that indicator to support more informed phosphorus/eutrophication management decisions.

On a five-year rotating basis in association with the Great Lakes Cooperative Science and Monitoring Initiative (CSMI), conduct an intensive, external load and lake-wide monitoring program for both TP and DRP that would permit development of a phosphorus mass balance model that can serve as an indicator of how each lake is processing phosphorus to develop a quantitative understanding of the nearshore-offshore gradients and phosphorus retention relationships that are observed in the system. This is important to better understand and manage the nearshore eutrophication-offshore oligotrophication that seems to be resulting from ecosystem changes in the lakes. Also, it can be inserted into the CSMI process with virtually no additional expense in additional data collection and relatively little additional expense for model application. A pilot study, perhaps for the data collected in Lake Huron during 2012 by making some revisions to the existing TP model (Chapra and Dolan, 2012), could help better define the required sampling resolution for such a program.

Monitoring programs need to account for the fact that nearshore P concentrations are highly variable in both time and space. To get a sampling value that can be confidently interpreted in terms of inter-annual trends for a given location will require very intense monitoring.

3.4 Biological Indicators

3.4.1 Aquatic Invasive Species: Invasion Rates and Impacts

Expert workgroup members:	Bill Taylor, Gavin Christie
IJC staff:	Lizhu Wang, Mark Burrows, Vic Serveiss

Definition

This indicator measures the rate of invasion and status and impact. The rate of invasion is the number of new aquatic invasive species (AIS) arriving in the Great Lakes since the last assessment (3 year window), a retrospective analysis to identify the likely pathway by which the species arrived, and an evaluation of the longer record to quantify any trend in the rate of invasion.

The status and impact is to measure the detrimental effects of aquatic invasive species on the Great Lakes. It specifically excludes species that are benign or perceived to be desirable species. Status measures the relative abundance of AIS to native species of equivalent trophic position, while impact measures how AIS affects the other ecosystem components

Indicator Relevance

This is directly relevant to the GLWQA General Objective related to preventing impacts from aquatic invasive species and to Annex 6 – Aquatic Invasive Species objectives. It measures the success of management actions to reduce the rate of new species arriving in the Great Lakes; quantifies the extent to which Great Lakes are populated by AIS; and evaluates the detrimental impact and the success of mitigation measures.

Description of Measures

1. *Rate of Invasion* - plotting cumulative numbers of invasions versus time;
    - Recommend using binational standardized data, such as GLANSIS (Great Lakes Aquatic Non-Indigenous Species Information System) and identifying the subset of those non-natives that Are invasive
    - This is preferably done by lake, but if it is too difficult, then do all the 5 lakes together.

2. *Status and impacts* - several or all the following measures can be used:
    - Sea Lamprey - relative lakewide abundance versus target established by the Great Lakes Commission by lake (Lake Erie may be an exception);
    - Plankton – invasive zooplankton biomass relative to entire zooplankton community biomass by lake;
    - Asian Carp – occurrence, abundance (number or biomass), and potentially reproduction;
    - Dreissenid mussels – abundance on nearshore zone hard substrate and on offshore zone soft bottom by lake;
    - Round Goby – relative abundance (biomass or number) compared to all benthic fishes abundance in nearshore and tributaries;
    - Ruffe - relative abundance (biomass or number) compared to all benthic fishes abundance in nearshore and tributaries.

Other Measures Considered

1. *Phragmites* – relative abundance and occurrence. This measure overlaps with the Costal Wetland Indicator.

2. *Molecular methods* - It may also be possible to integrate molecular methods (e.g., eDNA) into monitoring for AIS relative abundance in the future.

Indicator Interpretation and Comments

The rate of invasion measure of this indicator depends on the timely detection of new AIS. To support rapid response programs being planned and implemented, sites that are high risk invasion points (harbours, marinas, city waterfronts, city parks connected to Great Lakes) should be selected and monitored. The selection of sites and the type of monitoring to be conducted at those sites should be based on risk assessment. A pilot program that is widely considered to be state of the art has been implemented at Duluth (USGS, 2007; Dupré, 2011). The current state of AIS monitoring activity in the Great Lakes was reviewed by Dupré (2011), and data on AIS are currently maintained at the Great Lakes Aquatic Non-Indigenous Species Information System (GLANSIS). A challenge with this measure is that invasions are low frequency, stochastic events. Therefore, it is hard to detect signal from noise.

The status and impacts measures of this indicator will generally measure AIS relative abundance to native species of equivalent trophic position (e.g., zooplankton, planktivorous fishes) and measure anything that may prevent the achievement of any of the General Objectives of the GLWQA, or that contributes to a Beneficial Use Impairment (Annex 1, GLWQA). These measures require broad-spectrum biological sampling, including plankton sampling, benthic sampling (nearshore and offshore), wetland sampling for plants and fauna, zooplankton sampling, and trawling for fish. Therefore, operational definition of this indicator should build on monitoring activities put in place for other reasons, rather than require new and redundant sampling efforts.

3.4.2 Abundance and Distribution of Fish-Eating and Colonial Nesting Birds

Expert workgroup members:	Bill Bowerman, Latice Fuentes, Pamela Martin, Robert Letcher, Doug Crump, Kim Fernie, Michael Gilbertson, James Ludwig, Shane DeSolla, Jeff Ridal
IJC staff:	Glenn Benoy, Lizhu Wang

Definition

This indicator measures ecological integrity using population measures that are tied to the health of individuals, colonies, and populations of fish-eating birds at multiple geographic scales; and links biological integrity to both chemical integrity and physical integrity, which are measurable stressors (causes) to biological integrity (effects).

Indicator Relevance

This indicator is indirectly relevant to GLWQA Annex 3-Chemicals of Mutual Concern by directly measuring the chemical pollution of the aquatic food-web, and the health of their populations are directly impacted by, and reflective of, the health of the biological (fish populations), physical (habitat quality), and chemical (pollutant) integrity of the Great Lakes ecosystem. Fish-eating birds are at the top of the Great Lakes aquatic food web and are represented here by Herring Gulls and Bald Eagles. The abundance and health of these birds and their ability to reproduce indicates the effects of chemical, physical, and ecological stressors within the Great Lakes ecosystem. They are distributed across all 5 Great Lakes, the connecting channels, and the St. Lawrence River. The effects of environmental pollutants on wildlife are clearly understood by the public, utilizing the illustration of the egg-shell thinning effects to bald eagles.

Description of Measures

1. *Population Status*
   a. Nest counts of Bald Eagles, Double-crested Cormorants, Herring Gulls, other colonial water birds (e.g. Common Tern) across the lakes at relevant temporal and spatial scales
      i. Annual: Bald Eagle, Herring Gull, Double-crested Cormorant
      ii. 10-year: Other colonial water birds

   b. Number of adult and number of young individuals at relevant spatial scales
      i. Bald Eagle Measure: Number of nestlings produced annually along Michigan, Wisconsin, Ohio, and New York shorelines
      ii. Colonial water bird Index: Number of nestlings produced and number of returning adults of Double-crested Cormorants, Herring Gulls, and other species within Great Lakes sub-regions
2. *Health Status*
   a. Reproduction—Individual level
      i. Bald Eagle Productivity: (number of nestlings produced/number of occupied nesting territories)
      ii. Hatch rates for Double-crested Cormorants, Herring Gulls, and Others

   b. Deformities—Tissue level
      jj. *In situ* surveys for Bald Eagle, Double-crested Cormorants, Herring Gulls, and Others

Other Measures Considered

1. *Cellular/Molecular Level*
   a. Immune tests for Herring Gulls.
   b. Biomarkers. It may not be cost efficient at this time based on current technology, but still considered.

2. *Rate of developmental deformities* - Bald Eagle, Herring Gull, Colonial waterbird.

Indicator Interpretation and Comments

This indicator measures biological, physical, and chemical integrities of fish eating and colonial waterbirds. Herring gull eggs have been collected annually on all 5 lakes and connecting channels since 1973 (Weseloh and Moore, 2014). The locations and sizes of colonies for all species of colonial waterbirds are documented every 10 years along all Great Lakes and connecting channels. Fish-eating birds are indicators in many of the AOCs, and are used for delisting criteria. While Herring Gull eggs provide a consistent, annual trend of contaminant trends, they fail to assess direct biological effects.

Bald Eagle population surveys have been conducted along most Great Lakes shorelines and interior areas since 1961. These surveys continue along the US shorelines of all 5 lakes, and along Lakes Erie and Ontario in Canada, and statewide in Michigan and New York. All Great Lakes shoreline habitat was quantified in 1992 (Bowerman et al., 2005). Blood, feathers, eggs and tissues are collected annually (Stromberg et al., 2007; Best and Wilke, 2009; Route et al., 2011).

Sampling of Herring Gull eggs should occur annually at the 15 CWS locations and 5 MDEQ locations. Colonial waterbird surveys should continue every 10 years. Bald Eagle productivity data should continue annually in current areas. Great Lakes habitat should be assessed every 10 years.

Relationships for contaminant concentrations among species and among tissues allow us to utilize the guild of fish-eating birds as the indicator (Weseloh and Moore 2014). Cause-effect relationships between biological outcomes and chemical, biological, and physical stressors for each species allow for direct comparison of health across spatial and temporal scales.

3.4.3 Lower Food Web Productivity and Health

Expert workgroup members:	Bill Taylor, Jan Ciborowski, Veronique Hiriart-Baer, Ora Johannsson, Tim Johnson, Chuck Madenjian, Euan Reavie, Lars Rudstam, Hank Vanderploeg, Sue Watson
IJC staff:	Lizhu Wang, Vic Serveiss

Definition

This indicator focuses on the efficiency with which energy is transmitted from primary producers to different levels of consumers. The indicator mainly measures phytoplankton and zooplankton community structures and biomasses, benthos abundance and diversity, and prey fish abundance and diversity. These measures are selected based on their inherent importance in energy transfer and their measurability.

Indicator Relevance

This indicator is directly relevant to GLWQA Annex 4-Nutrients to maintain trophic states with relative algal biomass and composition consistent with a healthy aquatic ecosystem in open waters of the Great Lakes. This indicator is indirectly relevant to Annex 6-Aquatic Invasive Species and Annex 7-Habitat and Species. This indicator reflects the principle that pelagic communities, on average, have approximately equal biomass in exponentially widening size classes (Sheldon et al., 1972). Material and energy flow up this size spectrum from bacteria and phytoplankton via zooplankton to fish with varying efficiency (Borgmann, 1987). Some of this production sinks from the surface euphotic zone to nourish the benthos. It may flow efficiently, with high productivity across the size-spectrum, or it may accumulate as algae, negatively affecting water quality while little energy reaches top predators. The purpose of this indicator is to measure the trophic efficiency of the food web at transferring algal production to fish.

Measure Description

This indicator includes measures of phytoplankton, zooplankton, benthos, and prey fishes. Data for these measures need to take into account spatial coverage, including nearshore and offshore for all measures, and hard and soft substrates for benthos. Sampling method for each measure should be standardized at least within each lake, and if possible across lakes.

1. *Phytoplankton*

   Total biovolume of phytoplankton (volume/volume) and taxonomic composition for spring and late summer. Taxonomic identification should be to the best detail possible (e.g., species) to identify atypical or non-native taxa. Abundances of taxa (e.g., blue-green algae or large diatom blooms) will reflect conditions relative to known historical condition within a lake. Sampling should be standardized across all lakes.

2. *Zooplankton*

   Crustacean biomass, including *Daphnia retrocurva*, *D. galeata*, Cyclopoida, *Limnocalanus*, and other Calanoida. This should be measured in a standard fashion, such as vertical tow from bottom-2 m or top 100 m, whichever is less, with a metered 0.5-m net with 153-µm mesh, during August or September.

3. *Mysis* biomass

   It should be measured once a year in a standard fashion with a coarse (0.5 or 1 mm-mesh) 1-m diameter net towed vertically from the bottom to the surface. Sampling needs to be done at night, at least 1 hour after sunset to 1 hour before sun rise, under red light (ship's deck lights off). The sampling design should incorporate spatial coverage of both deep (>120 m) and shallow (50 to 75 m) depth zones. Nighttime acoustic monitoring is showing great promise in measuring mysid biomass and could be used in conjunction with fewer net hauls (methods are presently being developed by Rudstam et al. (2008). Date of sampling should coincide with time period of higher numbers of larger mysids in the population.

4. *Benthos*

   Abundance of dreissenid mussels, *Diporeia*, *Hexagenia*, *Gammarus*, *Chironomidae* (individuals/m^2), and Oligochaete Trophic Index (EC and USEPA). Separate indices are needed for nearshore vs. offshore and hard vs soft substrate. Soft substrate should be sampled by ponar or petit ponar grab, and hard substrate needs to be sampled by airlift using divers.

5. *Prey fishes*

   Prey fish biomass per unit effort for all lakes and prey fish diversity (Shannon–Wiener Index).

Other Measures Considered

1. *Phytoplankton composition by size class*

   Divide algae assemblage to greater than 30 µm and smaller than 30 µm, approximating edible vs non-edible by grazing plankton. The expert group considered that major taxa contained more useful information.

2. *Integrated measures*

   It is interesting, but none of the proposed have any history and all need some development.

Indicator Interpretation and Comments

Phytoplankton composition is an important indicator of water quality, particularly the relative abundance of cyanobacteria versus diatoms and flagellates. The USEPA has an active program for phytoplankton collection and analysis in the pelagic regions of all Great Lakes in spring and summer. While counting phytoplankton is time-consuming, limiting the number of samples that can be processed, fluorometry also offers the promise to determine plankton composition *in situ* with a probe (Ghadouani and Smith, 2005) although there may still be issues with calibration to Great Lakes conditions (Twiss, 2011). Phytoplankton counting potentially can be restricted to the number of samples required to calibrate the fluorometer and to investigate blooms.

Zooplankton mean size directly assesses the balance between forage fishes and zooplankton through the well-known effect of planktivory by fishes on zooplankton size-distribution, although it may be problematical or need recalibration for lakes with *Mysis* (Mills and Schiavone, 1982). It has been used in and around the Great Lakes (Taylor and Carter, 1997).

Mysis is a key link between the pelagic and benthic systems in the offshore of the Great Lakes, transferring nutrients and contaminants between these systems and moving energy from these systems to both benthic and pelagic fish. Of the two large, native macroinvertebrates in the offshore of the Great Lakes which transferred lower food web production to fish, only *Mysis* remains abundant.

Preyfish are sampled using trawl surveys, although acoustic surveys are gaining in importance. The SOLEC indicator "Preyfish Populations and Communities" has endpoints for prey fish biomass taken from Fish Community Goals and Objectives for each lake. SOLEC indicator "Zooplankton populations" uses mean length of zooplankton sampled with a specific net size (153 µm) as an index of the balance between forage fish and their zooplankton food.

In the Cooperative Science Monitoring Initiative intensive field years, plankton and benthos samples should be collected from at least 5 offshore stations with long-term records, monthly from May through October. This level of sampling intensity is also recommended for lakes of current concern; Erie and Huron. Otherwise, multiple offshore stations should be sampled at least three times per year.

3.4.4 Fish Species of Interest

Expert workgroup members:	Gavin Christie, Roger Knight, James Boase, Chuck Bronte, Mark Ebener, Jixiang He, Kevin Kayle, Jana Lantry, Charles Madenjian, Tom Pratt
IJC staff:	Lizhu Wang, Vic Serveiss

Definition

This indicator measures status and trends in population abundance and recruitment for several key fish species that are representative of healthy fish communities in major habitats of the Great Lakes. It includes species that support valuable fisheries in the Great Lakes and that reflect ecosystem health through their roles in the aquatic food web.

Indicator Relevance

The indicator is directly relevant to the GLWQA Annex 7 – Habitat and Species and is indirectly relevant to the GLWQA General Objectives to support healthy and productive wetlands and other habitats to sustain resilient populations of native species. This indicator is also relevant to the other objectives that affect the food web and ultimately fishes, including being free from pollutants in quantities or concentrations that could be harmful to aquatic organisms, through direct exposure or indirect exposure through the food chain; being free from the introduction and spread of aquatic invasive species that adversely impact the quality of the waters of the Great Lakes.

Measure Description

This indicator consists of standardized scoring of lake-specific *adult abundance* and *recruitment* for several fish species that represent various thermal and spatial habitats:

1. Cold water, off shore - Lake Trout and Lake Whitefish.
2. Cool water, near shore – Walleye.
3. Cool water, near shore, rivers, and connecting channels - Lake Sturgeon.
4. Warm water, near shore – Northern Pike and/or Smallmouth Bass/Largemouth Bass.

Data availability (quantity and quality) may limit complete spatial coverage of each lake and may only reflect area ranges of defined fish stocks in each lake. Information from a specific area representing ideal habitats for the species in that lake is considered appropriate for the purpose of this indicator.

The standard scoring of each fish species at each lake/location should be developed by fisheries experts in the inter-jurisdictional Lake Technical Committees of the Great Lakes Fishery

Commission. The following hierarchy of data sources will be used for calculating adult abundance and recruitment scores:

1. Model-generated estimates of abundance at age for defined fish stocks under inter-jurisdictional fisheries management.
2. Catch per unit effort from fishery-independent survey gears.
3. Catch per unit effort from commercial and angler fisheries.

Other Measures Considered

None

Indicator Interpretation and Comments

A number of fish species are selected as indicator species because they belong to different communities occupying different habitats within the lakes, which are affected by different stresses. The “oligotrophic” fish community is associated with cold, clear, less productive, off shore waters. The “mesotrophic” cool-water fish community is associated with more productive waters in nearshore areas. And the “eutrophic” warm-water fish community is found in the most productive nearshore and embayment areas of the lakes. These three broad communities are found to varying degrees in all five of the Great Lakes with Lake Superior dominated by oligotrophic habitat and Lake Erie mostly mesotrophic habitat. The selected fish species represent the fish communities in each of these different ecosystems.

Native fish species are selected as indicators because they represent the original fish communities in the different habitats, they have value to the ecosystem and to fisheries, and they are the focus of fisheries management and restoration efforts. Being co-evolved with the rest of the fish community and the natural ecosystem of the Great Lakes, these native represent the natural biodiversity of the lakes. Many are of high economic value and have been affected by fishing, often to the point of extirpation. They have been subjected to the full slate of other environmental effects resulted from human disruption of the Great Lakes including habitat loss, nutrient pollution, and persistent toxic pollutants. These species are the focus of active fisheries management and of restoration efforts. While restoration efforts like stocking can complicate interpretation of their status, the successes of these species are indicative of progress toward the goals of the GLWQA.

Native species of interest selected include top predators and large benthivores (fish feeding on benthic organisms). The Lake Trout is the native top predator in deeper, open waters of all of the Great Lakes. The Lake Whitefish is the top benthivore of those same waters. The Walleye is the top predator in the cool near-shore waters of all the Great Lakes. The iconic Lake Sturgeon is the longest lived and largest of all Great Lake fishes, and an indicator of the connectivity of tributaries. The Lake Sturgeon inhabits near shore and river habitats in all the Great Lakes, connecting channels, and St. Lawrence River. Lake trout, sturgeon, and walleye are SOLEC indicators (Bronte et al., 2014; Elliott, 2014; Kayle, 2009). The Northern Pike and basses are top predators in near-shore waters and embayments.

3.4.5 Harmful and Nuisance Algae

Expert workgroup members:	Sue Watson, Greg Boyer
IJC staff:	Glenn Benoy, Lizhu Wang

Definition

Harmful algae or harmful algal blooms refer to blooms that are documented to contain toxins or are composed of species with the genetic potential to produce toxins that affect human health, livestock, pets, and other organisms. In the Great Lakes and most other freshwaters, harmful algae toxins are exclusively produced by certain species of cyanobacteria which may not always express their toxin genes to the fullest extent. Nuisance algae or nuisance algal blooms refer to a broader subset of algae and cyanobacteria species that form blooms which are nontoxic to humans but cause ecological and socioeconomic harm. Collectively, they are referred to as harmful and nuisance algae (HNA). Excessive algal blooms refer to those blooms where information on their composition and ecosystem effects is generally lacking. Most commonly, this will encompass bloom events detected by remote sensing where identification of the cyanobacterial taxa, toxicity, or ecosystem effects has not been confirmed by ground based measurements.

Indicator Relevance

This indicator is directly relevant to the GLWQA General Objectives in measuring whether the Great Lakes water is drinkable, swimmable, and fishable. HNA blooms are one of the most visible indicators of impaired water quality and receive widespread attention at all levels of society. This indicator also is relevant to most of the listed Area of Concern Beneficial Use Impairments. HNA blooms are a result of and exacerbation of impaired water quality. Because HNA responds rapidly to changes in nutrients and environmental stressors, this indicator can track long and short-term management actions towards nutrient reduction and improvement of other environmental factors.

Measure Description

This indicator consists of three measures and each measure can yield one of the three ratings:

- 1=good;
- 2=moderate; and
- 3=severe.

The overall lake indicator score is determined by the maximum score of any of the three measures.

1. *Harmful Algal Blooms* (adapted from Watson and Boyer 2014)

Severe	The occurrence of one or more observations has Microcystin-LR concentrations > 10ug/L (pelagic) or >300 ug/gram dry weight (benthic) OR The occurrence of one or more observations have chlorophyll-a > 30 ug/L for pelagic samples or >50% coverage for benthic samples, *and* dominance (> ~80%) of the biota by potentially toxic (*Microcystis*, *Anabaena*, *Planktothrix*, *Oscillatoria*, *Lyngbya*) cyanobacterial species.
Moderate	Toxicity or cyanobacterial abundance is observed, but the magnitude of the harmful algal bloom does not reach the threshold necessary to rate as "Severe".
Good	Lakes do not display any significant cyanobacteria dominated blooms or Microcystin-LR concentrations < 1 ug/L or <30 ug per gram dry weight.

2. *Nuisance Algal Bloom*

Severe	The occurrence of chlorophyll-a > 30 ug/L and levels of common algal odour compounds (e.g., geosmin, 2-MIB, b-cyclocitral, decadienal) are greater than human odour threshold concentrations (Watson, 2003) or malodour or taste unacceptable to sensory screening (sniff tests or standardized Flavour Profile Analysis; e.g. Dietrich, 2004). OR The occurrence of a significant number of beach posting or closure is due to excess algal material.
Moderate	Significant nuisance algal abundance is observed, but the magnitude of the nuisance algal bloom does not reach the threshold necessary to rate as "Severe".
Good	Lakes do not display any significant nuisance algal blooms that may impair ecosystem functions.

3. *Excessive Algal Abundance*

Severe	The occurrence of high levels of % coverage of nearshore (up to 15m depth) of nuisance algae at high risk sites and reference sites, sampled from quadrants; or % coastline with > 50% coverage or 50g dwt/m2 (Auer et al., 2010). OR The occurrence of an extensive pelagic bloom as measured by timing, intensity (average chlorophyll-a concentration), duration, aerial extent (e.g., Binding et al., 2011) using remote sensing techniques.
Moderate	Significant excessive algal abundance is observed, but the magnitude of the event does not reach the threshold necessary to be "Severe".
Good	Lakes do not display any significant excessive algal abundance events based on proxy measurements.

Other Measures Considered

None

Indicator Interpretation and Comments

The harmful algae and nuisance algae measures can use data from biweekly samples (or more frequently during high risk periods if feasible) taken at high risk and reference monitoring sites from discreet surface (0.5-1m) samples, or euphotic zone integrated samples, and/or benthic mats from June-November. The sampling period should be adapted to local conditions and previous records of harmful and nuisance algae seasonality, and may include winter (under ice) sampling if warranted. This indicator also includes a third category excessive algal abundance that includes blooms detected by remote sensing where ground or water based measurements are not available to evaluate their toxicity or ecosystem effects.

Cost effective and feasible measures ensure long-term continuity of monitoring program to evaluate trends and stochasticity. Differences in sampling regimes and analytical protocols affect data compatibility and the resolution of long term trends, and sampling regimes can miss spatial and temporal peaks. Most focus is on shoreline mats of attached algae or surface scums of buoyancy-regulating cyanobacteria. These can appear/disappear rapidly with changes in mixing, currents, and wind, and can produce significant spatial/temporal variance in biomass and toxins which is difficult to sample, quantify or predict and is 'smoothed out' by seasonal means. Beach and shoreline sampling requires multiple sites to capture this variance in risk and impairment.

Chapter 4: ECOSYSTEM INDICATOR RELEVANCE TO THE AGREEMENT OBJECTIVES AND A COMPARISON WITH SOLEC INDICATORS

4.1 Ecosystem Indicator Relevance to the Agreement Objectives

A key objective for this project was to make recommendations related to the adoption and monitoring of a set of ecosystem indicators that are considered to be the key indicators in assessing governments' progress in achieving the General and Specific Objectives of the Agreement. Therefore, the objectives of the Agreement have been a guiding principle in the process of indicator nomination, selection, and definition.

The following table provides a general comparison regarding the alignment of the measurements of the ecosystem indicators and the objectives of the Agreement.

COMPARISON OF GLWQA OBJECTIVES AND COMMISSION ECOSYSTEM INDICATORS

GLWQA General Objectives	Ecosystem Indicator Alignment Check
(i) be a source of safe, high-quality drinking water;	*
(ii) allow for swimming and other recreational use, unrestricted by environmental quality concerns;	* Harmful and Nuisance Algae
(iii) allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants;	PBTs in predators fish (walleye and lake trout) PBTs in prey fishes (Rainbow Smelt, yellow perch) PBTs in herring gull eggs PBTs in bald eagles
(iv) be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain;	Chemicals of Mutual Concern in Water PBTs in predators fish (walleye and lake trout) PBTs in prey fishes (Rainbow Smelt, yellow perch) PBTs in herring gull eggs PBTs in bald eagles Atmospheric Deposition
v) support healthy and productive wetlands and other habitats to sustain resilient populations of native species;	Coastal Wetland Macroinvertebrate Abundance Coastal Wetland Amphibians Occurrence Coastal Wetland Plants Health Index Coastal Wetland Fish Index Coastal Wetland Bird Abundance Composition/quality of wetlands Coastal Habitat Index Land Cover and Fragmentation Tributary Physical Integrity
(vi) be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem;	Harmful and Nuisance Algae Nutrient concentrations and loadings
(vii) be free from the introduction and spread of aquatic invasive species and free from the introduction and spread of terrestrial invasive species that adversely impact the quality of the Waters of the Great Lakes;	Status and Impact Aquatic Invasive Species (abundance and distribution) Rate of Invasion of Aquatic Invasive Species
(viii) be free from the harmful impact of contaminated groundwater;	Contaminants in Groundwater

(ix) be free from other substances, materials or conditions that may negatively impact the chemical, physical or biological integrity of the Waters of the Great Lakes;	Chemical of Mutual Concern in Water Water Level Ice Cover Surface Water Temperature Fish Species of Interest Abundance of Fish Eating and Colonial Nesting Birds

ANNEXES	ALIGNMENT CHECK
1. Areas of Concern	• Many indicators listed in the table apply to this objective
2. Lakewide Management	• Many indicators listed in the table apply to this objective
3. Chemicals of Mutual Concern	• Chemicals of Mutual Concern in Water • PBTs in predators fish (walleye and lake trout) • PBTs in prey fishes (Rainbow Smelt, yellow perch) • PBTs in herring gull eggs • PBTs in bald eagles • Atmospheric Deposition
4. Nutrients	• Nutrient concentrations and loadings
5. Discharges from Vessels	• Status and Impact Aquatic Invasive Species • Rate of Invasion of Aquatic Nuisance Species
6. Aquatic Invasive Species	• Status and Impact Aquatic Invasive Species • Rate of Invasion of Aquatic Nuisance Species
7. Habitat and Species	• Abundance of Fish Eating and Colonial Nesting Birds • Coastal Habitat Index • Fish Species of Interest • Land Cover and Fragmentation • Lower Food Web Productivity and Health • Tributary Physical Integrity • Composition/quality of wetlands
8. Groundwater	• Contaminants in Groundwater
9. Climate Change Impacts	• Water Level • Surface Water Temperature • Ice Cover
10. Science D. Ecosystem Indicators	• Addressed by all ecosystem indicators listed above

Note: * indicates gaps in the coverage of the Commission indicator set

This comparison indicates that almost all the progresses toward achieving the objectives of the Agreement can be measured generally using the ecosystem indicators developed by the Commission. Two gaps in the coverage relate to the objectives of drinkability and swimmability. Indicators for the assessment of progress relative to these objectives are being explored through a project aimed at identifying indicators related to human health, also under the Assessment of Progress priority. Human health indicators may also be relevant to other objectives and annexes, most notably the objective of fishability (Objective iii). An ultimate aim of the priority is to achieve a good coverage of the Agreement objectives through compilation of the indicators generated through the ecosystems indicator project and the human health indicator project. A third project on program effectiveness indicators also been launched by the Commission to understand the potential contribution of this type of indicator in assessing progress under the Agreement.

4.2 Comparison of Commission Ecosystem Indicators and SOLEC Indicators

While the Commission was working on its indicator descriptions, the governments were working on revising their draft 2011 State of the Lakes Ecosystem Conference (SOLEC) reports. In September 2013, SOLEC released a State of the Great Lakes Highlights report and in March 2014, SOLEC released its final 2011 technical report. This section provides a comparison between the ecosystem indicators recommended by the Commission in this report and the indicators used in the 2011 SOLEC reports.

The IJC's ecosystem indicators work selected 16 indicators to measure progress towards GLWQA ecosystem objectives. Each indicator consists of 1-6 measures and all the 16 indicators together have 41 measures. The SOLEC 2011 Highlights report presented 17 ecosystem indicators. The SOLEC 2011 full report used 46 ecosystem indicators along with other indicators related to programs, energy use, and drinking water. The table below indicates where SOLEC indicators are similar in definition to the Commission ecosystem indicators. For example, in Indicator #16, the two SOLEC measures, Contaminants in Whole Fish and Contaminants in Water Birds are identical to the IJC measures for the PBTs in Biota indicator. Some other IJC indicators, such as #3 Land Cover and Fragmentation Status, use different measures than the SOLEC indicators.

IJC Ecosystem Indicators ***and Measures***	**Indicators in 2011 SOLEC Report**
1. Coastal Habitat – Shoreline Alteration Index 1) *Physical shoreline indicator + Biological shoreline indicator**	1. Hardened Shorelines*
2. Extent, Composition, and Quality of Coastal Wetlands 2) *Macroinvertebrates* 3) *Fish* 4) *Plants* 5) *Amphibian (Frogs and Toads)* 6) *Birds* 7) *Wetland Area and Extent**	2. **Wetland Amphibians** 3. **Wetland Birds** 4. Wetland Fish 5. Wetland Invertebrates 6. **Wetland Plants** 7. Wetland Extent and Composition*
3. Land Cover and Fragmentation Status* 8) *Conversion measures** 9) *Fragmentation measures**	8. Land Cover*
4. Seasonal and Long-Term Fluctuations in Great Lakes Water Levels 10) *Long-term water level variability** 11) *Timing of seasonal water level maximum and minimum** 12) *Magnitude of seasonal rise and decline** 13) *Lake-to-lake water level difference**	9. Water Levels (deviation from long term mean)*
5. Tributary Physical Integrity 14) *Hydrologic Alteration (R-B Flashiness Index)* 15) *Tributary Connectivity to Receiving Waters* 16) *Sediment-turbidity measure**	10. **Tributary Flashiness** 11. **Aquatic Habitat Connectivity**
6. Water Temperature 17) *Annual summer (July-September) surface average temperature** 18) *Lake water thermal stratification date* 19) *Fall lake water turnover date** 20) *Maximum and average ice concentrations*	12. Surface Water Temperature (date of the onset summer stratification)* 13. Ice Duration
7. Atmospheric Deposition of Chemicals of Mutual Concern *21)* SOLEC indicator Atmospheric Deposition of Toxic Chemicals	14. Atmospheric Deposition

8. Chemicals of Mutual Concern in Water *22)* Annex 3 subcommittee recommendation	15. **Toxic Chemicals in Offshore Waters**
9. Contaminants in Groundwater *23) Urban, agriculture, and industrial contaminants**	
10. Persistent, Bioaccumulating, Toxic (PBT) in Biota *24) PBT chemicals in whole fishes* *25) PBT chemicals in Herring Gull eggs and in Bald Eagles*	16. **Contaminants in Whole Fish** 17. **Contaminants in Waterbirds**
11. Phosphorus Loads and In-Lake Concentrations *26) Phosphorus Loads of TP and DRP** *27) In-lake concentrations of TP and DRP*	18. Nutrients in Lakes* 19. **TP concentration of offshore***
12. Aquatic Invasive Species: Invasion Rates and Impacts *28) Rate of Invasion** *29) Status and impacts**	20. Aquatic Non-Native Species* 21. Sea Lamprey* 22. Dreissenid Mussels*
13. Abundance and Distribution of Fish-Eating and Colonial Nesting Birds *30) Population Status** *31) Health Status**	
14. Lower Food Web Productivity and Health *32) Phytoplankton* *33) ZooplanktonMysis biomass** *34) Benthos** *35) Prey fishes**	23. **Diporeia*** 24. Zooplankton biomass* 25. **Preyfish biomass-9 species***
15. Fish Species of Interest *37) Adult abundance* *38) Recruitment**	26. **Lake Sturgeon abundance*** 27. **Lake Trout abundance*** 28. **Walleye abundance***
16. Harmful and Nuisance Algae *39) Harmful Algal Blooms* *40) Nuisance Algal Bloom** *41) Excessive Algal Abundance**	29. Harmful Algal Blooms offshore* 30. Harmful Algal Blooms nearshore*

	31. **Benthos as trophic indicator** 32. **Forest land in tributary buffer** 33. **Forest land in watershed** 34. Air temperature 35. Baseflow due to groundwater discharge 36. Botulism outbreaks 37. Cladophora 38. Contaminants in sediment cores 39. Extreme precipitation events 40. Human population 41. Inland water quality index 42. Phytoplankton 43. Terrestrial non-native species 44. Water chemistry (conductivity. pH, chloride, alkalinity, turbidity, etc.) 45. Water clarity 46. Watershed stressor index

Note: 1. Shaded boxes indicate matches between IJC and SOLEC indicators
2. SOLEC indicators listed in **bold** text are indicators used in SOLEC Highlight Report
3. * indicates that the indicator has a different definition than the corresponding indicator in the other column.

Overall, two of the IJC indicators are not covered at all by the SOLEC indicator suite. Three of the Commission indicators have almost exact matches in the SOLEC suite (shown as shaded boxes), and the other 11 IJC indicators are similar to SOLEC indicators but are not exact matches. Twenty three out of the 41 measures of IJC indicators are defined differently from SOLEC indicators.

The Commission does not have the mandate or capacity to collect data for the proposed indicators across the Great Lakes. The table indicates where work would be needed by the governments to refine or augment the current SOLEC indicator set, and associated monitoring and data collection activities, if these recommended indicators are to be operationalized.

Chapter 5: DISCUSSION AND RECOMMENDATIONS

5.1 The Ecosystem Indicators

This ecosystem indicator work was undertaken as a first step toward ensuring that the Commission is well placed to fulfill its mandate under the Great Lakes Water Quality Agreement to report to the Parties and to the State and Provincial Governments concerning progress toward the achievement of the General and Specific Objectives, including, as appropriate, matters related to Annexes to the Agreement. It is the Commission's belief that an assessment of progress under the Agreement should include the measurement and reporting of quantifiable indicators related to Agreement objectives. As such, this report has set out key ecosystem indicators that the Commission sees as being vital to that mission. The report on each indicator includes the definition of the indicator, the relevance of the indicator to the Great Lakes Water Quality Agreement and description of its constituent measures and notes on its interpretation. For these indicators to be operational, they must be adopted by the governments, appropriate data must be collected through monitoring and findings must be reported to the Commission and the general public.

The Commission recommends:

- The governments of Canada and the United States review the indicators with respect to how easily they can be fully implemented and provide feedback to the Commission regarding their potential for operationalization, in the near term or over a longer time frame.

- The governments of Canada and the United States consider adopting the proposed indicators and prioritise them for the necessary monitoring and for inclusion in SOLEC reporting.

5.2 State of the Great Lakes 2011 reporting by SOLEC

The State of the Great Lakes 2011 Highlights Report released through SOLEC in 2013 reflects a number of positive changes that have addressed many of the recommendations made regarding SOLEC in the Commission's 16th Biennial Report. For instance, as recommended by the Commission, the SOLEC Highlights report now uses a small set (17) of core indicators to characterize the physical, chemical, and biological integrity of the lakes and an additional 3 indicators to measure how the ecosystem affects human health.

Another SOLEC accomplishment is telling the stories that answer key questions such as "What problems are invasives causing" and "Why are there fewer sports fish". The story telling approach used in the technical report (released in 2014) is an outstanding way to integrate the complex and integrated scientific indicators into descriptions that the general public can understand. The Commission recognizes the technical complexity of the Great Lakes ecosystem and the interconnectivity of many abiotic and biotic factors. Therefore, the scientific write-ups in the larger 500+ page technical report and associated peer reviewed science are necessary to support and justify the stories that are told. The Commission also applauds the lake by lake story telling that is the final part of the Highlights report. This detailed binational data collection and reporting provides vital input for the work of the Commission and the work of individuals and organizations across the basin that relates to specific technical aspects of the State of the Lakes.

As its next steps on indicators under this priority, the Commission will be looking more closely at the SOLEC reports and aiming to develop its work in a way that complements or enhances SOLEC work and avoids duplicating efforts.

The Commission has been very appreciative of the constructive engagement of SOLEC representatives in the Commission's work on indicators to date.

The Commission recommends that:

- The governments continue to collaborate with the Commission to improve effectiveness and reduce redundancy between the Commission's independent binational assessment and the government's State of the Lake (SOLEC) report.

5.3 Next Steps for the Commission

A primary aim of the Assessment of Progress priority is to identify a small set of apex indicators to clearly and concisely report on the progress of the parties in their implementation of the Agreement. The ecosystem indicator project has been very useful in identifying and defining key ecosystem indicators needed to assess progress. However when combined with the other projects under this priority, including projects to identify human health and program effectiveness indicators, the Assessment of Progress Priority has become an effort that is more comprehensive than concise. As a next step, the Commission is considering how to use the ecosystem indicators for reporting on progress, raising awareness and encouraging action – the tasks key to the Commission's responsibilities under the Agreement. To further this effort, the Commission is considering forming an apex set of indicators to focus Commission assessment and reporting activities and for communication with the public. As the Commission continues this work, it will value the requested feedback from the governments regarding indicator operationalization and continued collaboration with the SOLEC process.

5.4 Reporting on the Assessment of Progress Priority

The Commission intends to issue its final report for the Assessment of Progress Priority in 2015 for comment prior to finalization. The final Assessment of Progress Priority report will bring together work from all projects being conducted on this priority, including the results of the "next steps" for the Commission on ecosystem indicators, as outlined above.

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