

# **FUTURE IMPROVEMENTS TO GREAT LAKES INDICATORS**

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**A report submitted to the  
International Joint Commission by the  
Great Lakes Science Advisory Board  
Research Coordination Committee**

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## ACKNOWLEDGEMENTS

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## REPORT HIGHLIGHTS

The SAB-RCC, through contractors, thoroughly assessed Great Lakes indicators' data availability and accessibility and identified potential improvement for indicators used to report progress in meeting the Great Lakes Water Quality Agreement objectives.

The SAB-RCC recommends:

- Using source water instead of treated drinking water for the human health sub-indicators to measure the health of the Great Lakes as a source of drinking water.
- Adding total phosphorus, dissolved reactive phosphorus, and nitrate-nitrogen concentrations as indicator measures for Great Lakes nearshore zones.
- Adding loadings of total phosphorus and dissolved reactive phosphorus from the major Great Lakes tributaries.
- Adding nearshore predators' abundance and recruitment to better assess the health of food webs.
- Reporting on progress in Asian carp monitoring and prevention.
- Addressing data gaps for appropriate indicators that have only partial data or no data by establishing a long-term focused sampling program.
- Standardizing assessment methods and data sources used to increase consistency in assessing long-term trends and detecting changes in lake health status.
- Overhauling data management and sharing by collating data used in past assessments of progress in a centralized, publicly accessible location.

# 1 INTRODUCTION

## 1.1 Background

The Great Lakes Water Quality Agreement (GLWQA) committed the governments of Canada and the United States (the Parties) to restore and maintain “. . . the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem” (GLWQA 2012). In 2012, the GLWQA was amended by protocol. In this amendment, priority was placed on monitoring and scientific assessment to evaluate progress of Great Lakes programs. The amended Agreement charges the International Joint Commission (IJC) with the responsibility to assess and report on the progress of the Parties in their implementation of the Agreement. The IJC has charged its advisory boards to conduct several projects to help conduct this assessment. One of these projects was to select a list of key indicators that can be used to accurately evaluate progress on the general and specific objectives of the Agreement, including its annexes.

Ecosystem indicators are described in Annex 10 of the GLWQA, which states: “The Parties shall establish and maintain comprehensive, science-based ecosystem indicators to assess the state of the Great Lakes, to anticipate emerging threats and to measure progress in relation to achievement of the General and Specific Objectives of this Agreement. The indicators shall be periodically reviewed and updated as necessary.” Indicators have been part of the GLWQA since 1994 when they were first employed as part of the State of the Lakes Ecosystem Conference (SOLEC), which was a forum for exchanging information on the ecological condition of the Great Lakes and their watersheds. The conference, which was broadly attended by persons from all levels of government and corporate, educational, and not-for-profit sectors, generated a set of science-based indicators that became known as SOLEC Indicators. From 1994 until the adoption of the 2012 amended GLWQA, these indicators were refined and expanded to incorporate a large number of measures – comprehensive but difficult to assess because of their sheer number. The last SOLEC report included data through 2011 and consisted of a 555-page report with a broadly read 26-page Highlights report.

The complexity of the indicator process led to a series of IJC workshops to evaluate the role and number of indicators. With input from the Parties and a broad range of experts, the IJC published reports on Great Lakes Ecosystem (IJC 2014) and Human Health (HPAB 2014) indicators (Table 1). These reports proposed a reduced set of indicators: 21 indicators with 51 “measures” divided into two general types. The first type addresses GLWQA General Objectives 1-3 and primarily

focuses on monitoring factors that affect human health. The second type focuses on GLWQA General Objectives 4-9 and primarily measures the health of the Great Lakes ecosystem.

The majority of the indicators recommended by these IJC workshops were adopted by the Parties for the 2016 State of the Great Lakes (SOGL) Report. In this process, the term of SOLEC Indicators was replaced by SOGL Indicators to distinguish the more limited scope. The Parties did not adopt all of the recommended IJC Indicators because not all had sufficient data to create a report. The SOGL Indicators currently consist of a set of nine indicators, one for each general Objective of the GLWQA, with 44 sub-indicators (Table 1).

**Table 1. GLWQA general objectives, indicators and measures recommended by the IJC in 2014, and high level indicators and sub-indicators used in reporting by the Parties in 2016**

GLWQA General Objectives	IJC		The Parties	
	Indicators	Measures	High Level Indicators	Sub-Indicators
<b>Objective 1:</b> Be a source of safe, high-quality drinking water	Biological hazards of source water	E. coli	<b>HUMAN HEALTH</b>	Treated drinking water
		Nitrate		
		Turbidity		
	Chemical integrity of source water	Atrazine		
		Estrogenicity		
		Cyanotoxins		
<b>Objective 2:</b> Allow for swimming and other recreational use, unrestricted by environmental quality concerns	Illness risk at beaches	95th percentile of numbers of E. coli. per 100ml at beaches		Beach advisories
	Source of risk at beaches	Percent beaches with beach sanitary survey		
<b>Objective 3:</b> Allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants	Contaminant levels in edible fish species	concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of lake trout, walleye, yellow perch, whitefish, and smallmouth bass		Contaminants in edible fish
<b>Objective 4:</b> 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	PBT in biota	whole fish	<b>TOXIC CHEMICALS</b>	Toxic chemicals in whole fish
		Herring gull eggs and bald eagle		Toxic chemicals in whole fish and herring gull eggs
	Chemical of Mutual Concern in water	Chemical of Mutual Concern in water		Toxic chemical concentrations in open water
				Toxic chemicals in sediment
	Atmospheric deposition of toxic chemicals	atmospheric deposition of toxic chemicals		Atmospheric deposition of toxic chemicals
				Water quality in tributaries
	Abundance and distribution of fish-eating and colonial nesting birds	Population status		Fish eating and colonial nesting waterbirds
		Health status		

<b>Objective 5:</b> Support healthy and productive wetlands and other habitats to sustain resilient populations of native species	Coastal wetland extent, composition and quality	Macroinvertebrates	<b>HABITATS and SPECIES</b>	Coastal wetland invertebrates
		Fish		Coastal wetland fish
		Plants		Coastal wetland plants
		Amphibians		Coastal wetland amphibians
		Birds		Coastal wetland birds
		Area and extent		Coastal wetlands: extent and composition
	Shoreline alteration index	Physical shoreline indicator		Hardened shorelines
	Lower food web productivity and health	Phytoplankton biovolume	<b>FOOD WEB</b>	Phytoplankton (open water)
		Zooplankton (crustacean) and Mysis biomass		Zooplankton (open water)
		Benthos abundance		Benthos (open water)
				Diporeia (open water)
	Fish species of interest (recruitment and abundance)	Preyfish biomass and diversity index		Preyfish (open water)
		Cool water, offshore - lake trout and whitefish		Lake trout
		Cool water, near shore - walleye		Walleye
		Cool water, near shore, rivers, channels - lake sturgeon		Lake sturgeon
		Warm water, near shore – northern pike and/or smallmouth bass / largemouth bass		
<b>Objective 6:</b> Be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts 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	Phosphorus loads and in-lake concentrations	In-lake TP and DRP concentrations	<b>HARMFUL and NUISANCE ALGAE</b>	Nutrients in lakes (open water)
		Tributary TP and DRP loads		
	Harmful and nuisance algae	Harmful algal blooms		Harmful algal bloom
		Nuisance algal blooms		
		Excessive algal abundance		
				Cladophora
<b>Objective 7:</b> 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	Aquatic invasive species, invasion rates and impacts	Rates of invasion	<b>INVASIVE SPECIES</b>	Aquatic Invasive Species
		Status and impacts (e.g., sea lamprey, zooplankton, Asian carp, Dreissenid mussels, Round Goby, Ruffe)		Sea lamprey
				Dreissenid mussels
				Terrestrial invasive species

<b>Objective 8:</b> Be free from the harmful impact of contaminated groundwater	Contaminants in groundwater	Measure of chemical and physical parameters from agricultural and urban watersheds	<b>GROUNDWATER R</b>	Groundwater quality
<b>Objective 9:</b> 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	Water level	Water level variability	<b>CLIMATE CHANGE</b>	Water level
		Timing of min and max		
		Magnitude of seasonal rise and decline		
		Lake-to-lake differences		
	Water temperature	Summer average		Surface water temperature
		Stratification date		
		Turnover date		
		Maximum and average ice concentrations		Ice cover
				Precipitation events
				Baseflow due to groundwater
	Land cover and fragmentation status	Land conversion rate	<b>TRANSFORMING WATER-SHEDS</b>	Watershed stressors
		Land fragmentation measures		Forest cover
				Land cover
	Tributary physical integrity	Hydrologic alteration (flashiness index)		Tributary flashiness
		Tributary connectivity to Great Lakes		Habitat connectivity
		Sediment-turbidity measure		
				Human population

To fulfill its assessment and reporting responsibilities assigned by the GLWQA, the IJC recognizes the need for continuous improvement of indicators for future ‘assessments of progress’ reports beyond 2016. Since the 2016 SOGL report uses only indicators with available data, additional indicators and associated measures that currently have only partial or no data need to be re-examined to determine whether data are now available or whether operationalizing these indicators would better achieve future assessment and reporting responsibilities. Because data collection can be expensive and time consuming, the Great Lakes Science Advisory Board Research Coordination Committee (SAB-RCC) was charged with the responsibility to further review needed indicators and measures. The goal of the review was to identify those indicators and measures that provide the most useful information while considering the need to make the best use of available resources.

## **1.2 Purpose of this Report**

### **Scope:**

The purpose of this report is to identify which IJC indicators and measures have data, partial data, or no data and then assess the quality and quantity of that data for reporting on the health of the Great Lakes. This information was subsequently used to recommend improvements of Great Lakes indicators for use in future ‘assessments of progress’ reports on the Great Lakes ecosystem beyond 2016.

### **Objectives:**

- 1) Identify data availability and gaps for the IJC indicators and measures.
- 2) Identify future improvements in indicator data collection, synthesis, sharing and management to enhance indicator assessment efficiency and consistency in reporting on the health of the Great Lakes.
- 3) Assess what additional indicators and measures are needed in addition to the sub-indicators used in the 2016 State of the Great Lakes Report.



## **2 EVALUATION AND ASSESSMENT PROCESSES**

### **2.1 Objectives 1 and 2: Process for identifying data gaps in IJC indicators and improvements for data collection, synthesis, sharing and management**

To meet the objective of identifying indicator data gaps, the SAB-RCC contracted with faculty of the University of Michigan and Michigan State University (selected through an open competition process) to assess data accessibility and identify data gaps related to calculation of the indicators recommended by the IJC (Roth et al., 2015; Appendix A). Some of these indicators had full overlap with the SOGL indicators and sub-indicators so it was assumed that data to calculate these indicators/sub-indicators were generally available. At the time that this analysis was completed by the contract, full descriptions of all of the 2016 SOGL indicators and sub-indicators were not available.

To assess data availability (i.e., data spatial and temporal coverage, and data accessibility) for a given IJC indicator or measure, likely data holders as well as online databases and reports were identified through literature reviews, online research, and personal connections and communication with experts in the field. Whenever feasible, efforts were made to acquire data through downloading data directly from the internet, leveraging data collected by other research projects, and acquiring data directly from data holders. The goal of acquiring data was to assess data accessibility and evaluate if the data were sufficient for calculating individual indicators and their associated measures specified in the Great Lakes Ecosystem Indicator Project report (IJC 2014) and the Recommended Human Health Indicators for Assessment of Progress on the Great Lakes Water Quality Agreement (HPAB 2014). For most indicators these efforts were successful, which allowed data accessibility concerns and data gaps for most indicators to be identified and also provided metadata information in cases where data were available in raw forms or not shared.

Although more than 150 environmental and human health scientists and managers in the Great Lakes region were contacted during this process, the assessment of data availability for some indicators was still a rough estimate because some requests for data were not answered or data holders did not have time to provide detailed information. As a result, some data availability assessments are based on the 2011 State of the Lakes Ecosystem Conference report and the first draft of the SOGL report, while others are data holders' qualitative estimates; however, the majority of the data were assessed quantitatively.



## **2.2 Objective 3: Process for evaluating the need for additional IJC indicators and measures**

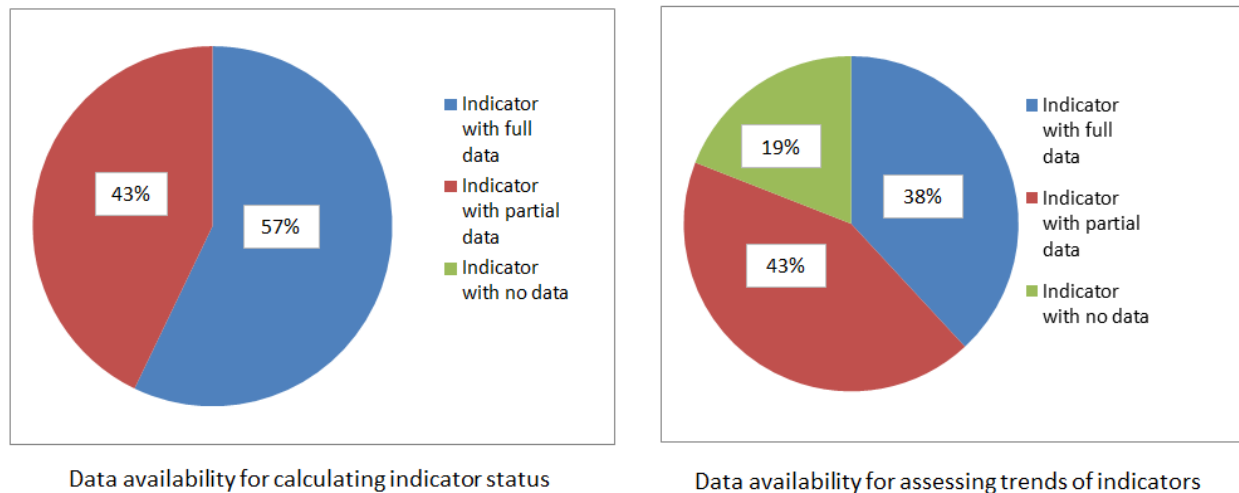
To assess whether additional indicators and measures are needed in addition to the sub-indicators used in the 2016 SOGL report, an Indicator Improvement Work Group was formed consisting of members of the IJC's Great Lakes Science Advisory Board, Water Quality Board, and Health Professionals Advisory Board. The Indicator Improvement Work Group developed a work plan to compare between the nine general objectives of the GLWQA with the 44 sub-indicators used in the SOGL report to identify issues/topics for potential improvement. With the assistance of a professional contractor selected by open competition, a binational expert consultation workshop was held in Ann Arbor, Michigan, in December 2015. The workshop was held to review the sub-indicators in the 2016 SOGL report and assess whether gaps exist that would limit 'assessment of progress' in achieving the GLWQA objectives and to identify if indicators recommended by IJC would fill any of those gaps (Sinha and Pettit, 2016; Appendix B). Additionally, the ability and ease of obtaining data for the recommended indicators were also assessed. Participants at the workshop included various stakeholders and experts who are familiar with the mandate of the GLWQA and have been involved in the process of indicator development by the Parties and by the IJC. Consistent with the practice of IJC, this work was carried out through a binational consensus-based process.

## 3 EVALUATION AND ASSESSMENT FINDINGS

### 3.1 Objective 1: Data availability for the IJC Great Lakes indicators

The availability of sufficient data to develop an indicator (and its associated measures) is a key aspect in determining if a particular indicator is functionally viable. Functional viability has two components: spatial and temporal availability of the data. A “full” data set consists of: (1) sufficient spatially-distributed data to represent the Great Lakes region, and (2) sufficient historical data to establish a baseline for detecting trends. Of the 16 ecosystem and five human health indicators identified by the IJC, 12 indicators have full data (57%), nine indicators have partial data (43%), and none of the indicators have no data at all for a one-time indicator status calculation (Table 2, Figure 1). Of these same indicators, only eight (38%) have sufficient long-term data to calculate trends. In addition, nine indicators (43%) have partial data for calculating trends, and four indicators (19%) have no data for assessing trends.

Figure 1. Percentages of IJC indicators that have full, partial and no data for indicator calculation and detecting trends



Because most IJC indicators consist of multiple measures, data availability was also evaluated for each measure. Among the 49 measures of the 16 ecosystem and five human health indicators, 34 measures have full data (69%), nine of which have partial data (18%), and six measures have no data (12%) for indicator status calculation. When analyzed for data to calculate trends, 25 measures have sufficient long-term data to calculate trends (51%), nine measures have partial data (18%), and 15 measures have no data (31%) for trend calculation (Table 2).

Table 2. Summary of data availability for indicator calculation and trend detection for the IJC ecosystem and human health indicators

	IJC indicator	IJC measures	Used in 2016 SOGL	Sufficient data for	
				Indicator calculation	Trend detection
Human health	Biological hazards of source water	<i>E. coli</i>	No	Likely exists at municipal level (for raw water at intakes)	No
		nitrate	No	May exist at municipal level	No
		turbidity	No	Partial, OH only (but could be estimated from remote sensing for trend detection on lake-wide scales)	No
	Chemical integrity of source water	Atrazine	No	May exist at municipal level	No
		estrogenicity	No	May exist at municipal level	No
		cyanotoxins	No	Partial, likely available from some municipalities and/or public health agencies resulting from sporadic drinking and recreational sources water quality monitoring, and from open-water monitoring by federal and state/provincial authorities	No
	Illness risk at beaches	95th% # of <i>E. coli</i> /colony-forming units of <i>E. coli</i> /100 ml	No	Partial, I (from state, provincial or municipal beach water quality monitoring programs)	Partial
	Source of risks at beaches	Percent of beaches with sanitary survey or environmental health and safety survey	No	Partial	Partial
Ecosystem Health	Contaminant levels in edible fish species	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of fishes	Yes	Full	Yes
	Shoreline alteration	Physical shoreline indicator	Yes	Full	No
	Coastal wetland	Invertebrates	Yes	Full	No
		Fish	Yes	Full	No
		Plants	Yes	Full	No
		Amphibians	Yes	Full	No
		Birds	Yes	Full	No
		Area and extent	Yes	Full	No
	Water level	Long-term water level variability	Yes	Full	Yes
		Timing of seasonal water level maximum and minimum	No	Full	Yes
		Magnitude of seasonal rise and decline	No	Full	Yes
		Lake-to-lake water level difference	No	Full	Yes
	Tributary	Hydrologic alteration (R-B Flashiness Index)	Yes	Full	Partial
		Sediment-turbidity measure	No	Full	Partial

		Tributary connectivity to Great Lakes	Yes		Full	Yes
	Water temperature	Annual average summer (July-September) surface temperature for each lake	Yes		Full	Yes
		Lake water thermal stratification date	No		Full	Yes
		Fall lake water turnover date	No		Full	Yes
		Maximum and average ice coverage	No		Full	Yes
	Air deposition of Chemical of Mutual Concern	Based on SOGL indicator - atmospheric deposition of toxic chemicals	Yes		Full	Yes
	Chemical of Mutual Concern in water	Based on Annex 3 recommendation	Yes		Full	Yes
	Contaminants in groundwater	Measure >10 chemicals from agricultural and urban watersheds	Yes		Partial	Partial
	PBT in biota	PBT chemicals in Great Lakes whole fish	Yes		Full	Yes
		PBT chemicals in Great Lakes herring gull eggs and in bald eagle	Yes		Full	Yes
	Phosphorus loading and in-lake concentration	In-lake TP and DRP concentrations	Yes		Full	Yes
		TP and DRP loading from tributaries	No		Partial	Partial
	Aquatic invasive species	Rate of invasion	Yes		Full	Yes
		Status and impacts	No		Partial	Partial
	Lower food web	Phytoplankton biovolume	Yes		Full	Yes
		Zooplankton and <i>Mysis</i> biomass	Yes		Full	Yes
		Benthos	Yes		Full	Yes
		Preyfish	Yes		Full	Yes
	Fish species of interest	Adult abundance	Yes		Full	Yes
		Recruitment	Yes		Partial	Yes
		Harmful algal blooms	Yes		Partial	Yes
	Harmful algal blooms	Nuisance algal bloom	No		No data (but could be estimated from remote sensing for trend detection at lakewide scales)	No
		Excessive algal abundance	No		No data (but could be estimated from remote sensing for trend detection at lakewide scales)	No
	Abundance and distribution of fish-eating and colonial nesting waterbirds	Population status	Yes		Full	Yes
		Health status	No		Full	Partial
	Land cover and fragmentation status	Conversion measures	No		Full	Partial
		Fragmentation measures	No		Full	Yes

### ***Human Health Indicators***

For the five human health indicators, contaminant levels in edible fish species is the only indicator that has sufficient data available for both indicator calculation and detecting trends (Table 2).

The biological hazards of source water and chemical integrity of source water indicators do not have available data for indicator calculation or trend detection, although data for these indicators may be available from individual municipal water supply providers. The 2016 SOGL report used treated water to assess status and trends of drinking water, which may not meet the requirement of assessing progress toward achieving the objective of “the waters of the Great Lakes should: be a source of safe, high-quality drinking water” as stated in GLWQA Article 3.1(a)(i).

The illness risk and source of risks at beaches human health indicators have data available but only from the US. The 2016 SOGL report used beach advisories to assess status and trends, which may not be adequate for assessing progress toward achieving the GLWQA objective because the criteria of beach advisories have not been standardized among Great Lakes states and between the USA and Canada.

***Ecosystem Indicators*** For the 16 ecosystem indicators, eight have sufficient data available for both indicator calculation and detecting trends: water level, water temperature, air deposition of chemicals of mutual concern, chemicals of mutual concern in water, PBT in biota, and lower food web (Table 2). The ecosystem indicators that have full data for both indicator calculation and trend detection have been largely sampled under long-term federally funded programs. For example, water levels and water temperature have been monitored using lake gauges and buoys mostly operated by the National Oceanic and Atmosphere Administration, Environment and Climate Change Canada, and universities. Toxic chemicals in air, water and biota have been sampled by the US Environmental Protection Agency and Environment and Climate Change Canada. Lower food web composition has been measured as part of the binational Cooperative Science and Monitoring Initiative and the US Great Lakes Open Water Monitoring Program. Those ecosystem indicators that have partially available data for indicator calculation and trend detection have been largely sampled by programs designed for purposes other than meeting GLWQA objectives. Hence, they are often incomplete (partial), inconsistent (temporally or spatially incomplete), and therefore difficult to integrate.

The coastal wetland indicator is an example of an indicator where data are of sufficient spatial coverage to calculate the majority of measures, namely the measures of wetland amphibians, birds, fish, invertebrates and plants; however, temporal data are not available to allow trend detection. The biotic data in support of the coastal wetland sub-indicators have been collected under a large US federally funded program – the Great Lakes Restoration Initiative (GLRI). The first five-year data collection effort (2011-2015) sampled almost all coastal wetlands **greater**

**than or equal to** 4 ha in area with a surface water connection to the Great Lakes (SOGLR 2016) and cost of \$10 million USD. Temporal trends cannot be assessed because the majority of the sampling locations were sampled only once over the five-year period. The next five-year data collection effort (2016-2020), with another \$10 million USD, is underway and will allow resampling of some wetlands. Other similar data is collected as part of shorter-term monitoring programs, for example by University of Minnesota Duluth's Great Lakes Environmental Indicator project also funded by GLRI and by Bird Studies Canada's Great Lakes Marsh Monitoring Program. However, it was worth noting that unlike the biotic measures under the coastal wetland indicators, concurrent data are not available for the associated measure, coastal wetland area and extent. The data on coastal wetland area and extent were generated in 2004 by the Great Lakes Coastal Wetlands Consortium. Hence, the current areal extent of coastal wetlands across the entire Great Lakes basin cannot be reported (SOGLR 2016) and no long-term coastal wetland indicator monitoring plan exists. With such costly sampling effort, it is apparent that improvements in data collection are required to ensure the sustainability of monitoring for the detection of trends in coastal wetlands.

The GLWQA requires the Parties and IJC to assess progress made toward achieving the objectives. Hence, the indicators selected for such an assessment must have adequate quantitative data for reporting progress consistently over time to enable tracking of changes in the health of the Great Lakes. The large portion of indicators and their measures having no data or only partial data would be a barrier for the Parties and IJC to meet such a requirement. Since collecting long-term data for all indicators and their measures is limited by resources and time, a strategy to further evaluate indicator measures and then devise a long-term focused sampling program to collect the appropriate indicator data is needed.

### **3.2 Objective 2: Accessibility and management of data in support of Great Lakes indicators**

The Parties' 2016 State of the Great Lakes report and the previous State of the Lakes Ecosystem Conference reports describe indicators calculated and synthesized by authors with subject expertise from government agencies, academia institutions, and nongovernment organizations. Those authors are either the data holders or they synthesize data from others who have access to the data needed for indicator calculation. After writing the reports, the data stay with the authors and are not stored or managed by a data system that can be accessed by other users or updated. Even in the preparation of this assessment, the contractors had to contact likely data holders and experts in the field, and search online databases and reports to assess data availability because a central depository for data used in past SOLEC or current SOGL reporting was not in place. This inaccessibility to data used previously for indicator calculation may hamper consistency in data

synthesis, summary and interpretation for future SOGL reporting if the same indicators are calculated by different authors among reporting years.

Data for more than half of the indicators are from federal programs; however, the data themselves as well as their management have not always been integrated. The open data system effort of the Government of Canada and the data harvesting portals of the US Geological Survey, the Illinois-Indiana Sea Grant, the Great Lakes Observing System, the Great Lakes Aquatic Habitat Framework, and the US Environmental Protection Agency Great Lakes Environmental Database are great efforts, but they are not integrated and sometimes overlap, and hence do not meet the needs to assess progress of the GLWQA objectives. A considerable portion of the critical data needed for indicator calculation comes from non-federal programs, such as the human health source of drinking water data collected by municipal, provincial or state programs, and require binational efforts to synthesize, integrate and harmonize the data to make it accessible and easily interpreted.

Overall, there is an urgent need to store and manage the data used for the State of the Great Lakes reporting at a centralized location that can be accessed by others in future. A binational effort is required to synthesize and harmonize the needed indicator data that have been and will be collected and to store it in a publicly accessible central location. These publicly accessible data will not only increase the efficiency, consistency and transparency of the assessment of progress, but also enhance the effectiveness of information delivery for public awareness and science based policy and management decision making.

### **3.3 Objective 3: Improvements to better meet the needs of reporting progress**

In consultation with Great Lakes regional indicator experts who are familiar with GLWQA implementation, the SAB-RCC noted that the sub-indicators used by the Parties generally well represent the nine GLWQA General Objectives (Table 1). Many of the IJC recommended measures are similar to the SOGL sub-indicators because many were already in use by the Parties, and the Parties adopted a few of the new IJC proposed measures for SOGL reporting. The SAB-RCC identified key areas for indicator improvement associated with four of the GLWQA general objectives. These recommendations could be implemented in the near future and are identified in Table 3 in blue font.



Table 3. IJC indicators and associated measures, with recommendations to the Parties identified in blue font

GLWQA General Objectives	IJC	
	Indicators	Measures
<b>Objective 1:</b> Be a source of safe, high-quality drinking water	Biological hazards of <b>source water</b>	E. coli
		Nitrate
		Turbidity
	Chemical integrity of <b>source water</b>	Atrazine
		Estrogenicity
		Cyanotoxins
<b>Objective 2:</b> Allow for swimming and other recreational use, unrestricted by environmental quality concerns	Illness risk at beaches	95th percentile of numbers of E. coli per 100 ml at beaches
	Source of risk at beaches	Percent of beaches with beach sanitary survey
<b>Objective 3:</b> Allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants	Contaminate levels in edible fish species	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of lake trout, walleye, yellow perch, whitefish, and smallmouth bass
<b>Objective 4:</b> 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	PBT in biota	PBT in whole fish PBT in herring gull eggs and bald eagle
	Chemical of Mutual Concern in water	Chemical of Mutual Concern in water
	Atmospheric deposition of toxic chemicals	Atmospheric deposition of toxic chemicals
	Abundance and distribution of fish-eating and colonial nesting birds population status and health status	Population status
		Health status
<b>Objective 5:</b> Support healthy and productive wetlands and other habitats to sustain resilient populations of native species	Coastal wetland extent, composition and quality	Coastal wetland invertebrates
		Coastal wetland fish
		Coastal wetland plants
		Coastal wetland amphibians
		Coastal wetland birds
		Coastal wetland area and extent
	Shoreline alteration index	Shoreline alteration index
	Lower food web productivity and health	Phytoplankton biovolume
		Zooplankton biomass; <b>Mysis biomass</b>
		Benthos abundance
		Preyfish biomass and diversity index
	Fish species of interest (recruitment and abundance)	Lake trout and whitefish
		Walleye
		Lake sturgeon
		<b>Nearshore predators (largemouth/smallmouth bass, northern pike)</b>
<b>Objective 6:</b> Be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria	Phosphorus loads and in-lake concentrations	In-lake Water TP and DRP concentrations
		<b>Nearshore water TP, DRP, and nitrate concentrations</b>
		<b>Tributary TP and DRP loadings</b>
	Harmful and nuisance algae	Harmful algal blooms

that interfere with aquatic ecosystem health, or human use of the ecosystem		Nuisance algal blooms
<b>Objective 7:</b> 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	Aquatic invasive species (invasion rates and impacts)	Rates of invasion Status and impacts of <b>invasive plankton, Asian carp, round goby, ruffe, sea lamprey, Dreissenid mussels</b>
<b>Objective 8:</b> Be free from the harmful impact of contaminated groundwater	Contaminants in groundwater	Measure of chemical and physical parameters from agricultural and urban watersheds
<b>Objective 9:</b> 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	Water level	Water level variability
		Timing of water level minimum and maximum
		Magnitude of seasonal rise and decline
	Water temperature	Summer average
		Stratification date
		Turnover date
		Maximum and average ice concentrations
	Land cover and fragmentation status	Land conversion rate Land fragmentation
	Tributary physical integrity	Hydrologic alteration (flashiness index) Tributary connectivity to Great Lakes Sediment-turbidity measure

**Drinking Water Indicator** - The GLWQA General Objective 1 states that the Great Lakes “be a source of safe, high-quality drinking water,” while the Parties used the sub-indicator of treated drinking water. **Because this objective specifies the Great Lakes to be a “source” of safe, high quality drinking water, the SAB-RCC recommends the Parties use the IJC indicators of biological hazards and chemical integrity of source water.** Since the purpose of the GLWQA is to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes, reporting progress on the condition of sources of drinking water, rather than treated drinking water, is more appropriate. Additionally, with the highly advanced technology and associated cost, even sewage water can be treated to reach drinkable standards. Hence, measuring treated drinking water does not measure progress in protection and restoration of the health of the Great Lakes.

**Food Web Indicators** - The GLWQA General Objective 5 states that the Great Lakes “support healthy and productive wetlands and other habitats to sustain resilient populations of native species.” Because this objective includes both physical and biological aspects of the ecosystem, this objective is associated with the largest number of indicators. Although preyfish is used to indicate the health of wetlands, and preyfish and predators are used to indicate food web health in the offshore area, certain aspects of the nearshore food web indicator are missing. **Hence, the SAB-RCC recommends the Parties adopt the IJC measure of recruitment and abundance of nearshore predators.** This is because the nearshore area is the most productive and ecologically diverse zone of the Great Lakes, and is the most vulnerable zone to anthropogenic

disturbances. The health of the food web in this area provides good signals of progress to restore and maintain the chemical, physical and biological integrity of the Great Lakes.

**The SAB-RCC also recommends the Parties add opossum shrimp (*Mysis*) as a sub-indicator because they have occupied some of the ecological niche formerly held by *Diporeia*.** Once the most abundant bottom-dwelling organism in cold, offshore regions of the Great Lakes, *Diporeia* served as an important pathway by which energy is passed up the food web. Presently, it is completely absent from large areas in each of these lakes and in its absence it would be useful to measure *Mysis* populations, which are a new food resource for species that relied on *Diporeia*.

**Harmful and Nuisance Algae Indicator** - The GLWQA General Objective 6 states that the Great Lakes “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.” In 2016 reporting, the Parties used the sub-indicator of nutrients in lakes, which includes concentrations of total phosphorus, dissolved reactive phosphorus, and nitrate in open water. **The SAB-RCC suggests the Parties explicitly add the sub-indicator concentrations of total phosphorus, dissolved reactive phosphorus, and nitrate in the in the nearshore area (in addition to the open water).** Due to the invasion of *Dreissenid* mussels, nutrient concentrations in four of the Great Lakes in offshore regions have been decreasing, which has been a concern of fisheries productivity (Hinderer et al. 2011). In contrast, nutrient concentrations in some nearshore areas have been increasing due to watershed and coastal human activities and are associated with harmful algal blooms and, in certain embayments, hypoxic conditions. Because of the differing ecological impacts of excessive nutrients on the nearshore versus offshore waters, the SAB-RCC suggests reporting on nutrient concentrations not only from offshore but also from nearshore areas. **In addition, because of the role that nitrogen may play in determining the composition of algal blooms, the SAB-RCC recommends including nitrogen forms as measures in the harmful and nuisance algae indicator.**

Because the major nutrient sources for the Great Lakes waters are from watersheds, reporting on the trend of nutrient loading from tributaries is critically important for developing effective management practices and policies to control land-based sources. The Parties report on the sub-indicator “water quality in tributaries” under Objective 4 but this indicator does not include nutrient loadings. **Hence, the SAB-RCC recommends adding an additional sub-indicator to report on loadings of total phosphorus and dissolved reactive phosphorus from the major Great Lakes tributaries.**

**Aquatic Invasive Species Indicator** – GLWQA General Objective 7 states that the Great Lakes shall “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.” The indicators used by the Parties include the sub-indicators “aquatic invasive species rate of invasion and status and impacts of Sea Lamprey and *Dreissenid* mussels.” **The SAB-RCC recommends using the IJC indicator of aquatic invasive species, which includes also reporting on invasion rates and impacts of Asian carp, invasive plankton such as the spiny water flea (*Bythotrephes*), round goby, and ruffe.** All of these invasive species may have the potential to make significant impacts on the Great Lakes ecosystem and economy. Reporting on progress in Asian carp monitoring and prevention is critically important since this species poses an unknown but potentially major threat to the annual \$7 billion fisheries of the Great Lakes.

## 4 RECOMMENDATIONS

The effort of identifying potential future improvements to Great Lakes indicators by the SAB-RCC reveals that the sub-indicators used by the Parties for the 2016 State of the Great Lakes report generally meet the requirement of the GLWQA. Built on many years of experience and considering the data available, the Parties have taken the best efforts to assess the status and trends of the health of the Great Lakes related to the GLWQA objectives. Recognizing the challenges in meeting the mandate of assessing progress toward achieving the objectives specified by the GLWQA for a system as complex and spatially extensive as the Great Lakes, the SAB-RCC proposes the following recommendations for the IJC and Parties to consider for future improvement in achieving the objectives of the GLWQA:

- The Parties further assess the proposed IJC measures with respect to data availability, cost and technological capability associated with implementing these measures. This evaluation may result in adding several existing SOGL sub-indicators with IJC measures to better measure progress in achieving the GLWQA general objectives.
  - Use source water instead of treated drinking water for the human health sub-indicators to measure the health of the Great Lakes as a source of drinking water under GLWQA Objective 1.
  - Add total phosphorus, dissolved reactive phosphorus, and nitrate-nitrogen concentrations as indicator measures for nearshore zones to better assess potential for harmful and nuisance algae under GLWQA Objective 6.
  - Add loadings of total phosphorus and dissolved reactive phosphorus from the major Great Lakes tributaries to better assess potential for harmful and nuisance algae under GLWQA Objective 6.
  - Add nearshore predators and opossum shrimp to better assess the health of food webs under GLWQA Objective 5.
  - Report on progress in Asian carp monitoring and prevention, which is critically important because of its potential to significantly impact the Great Lakes ecosystem and economy.
  - Add other invasive species, specifically round goby, ruffe, and the spiny water flea, to better address the full range of invasive species under Objective 7.
- Address data gaps for IJC measures that have only partial or no data. Among the 49 measures of the 16 IJC ecosystem and five human health indicators, 34 measures have full data, nine have partial data and six measures have no data for indicator status calculation. A long-term focused sampling program is likely needed for these and other selected measures.
- There is a need to overhaul data management and sharing. It is recommended that data used in past assessments be collated in a centralized publicly accessible location. This will help standardize the assessment methods and data sources used. In addition, there is a need to

establish a binational effort to harmonize the needed indicator data that will be collected in the future. Publicly accessible data will not only increase the efficiency, consistency and transparency of the assessment of progress, but also enhance the effectiveness of information delivery for public awareness and science based policy and management decision making.

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### Appendix A:

Great Lakes Indicator Data Accessibility and Data Gaps Analysis for Assessing Progress Toward Achieving the GLWQA Objectives. A Contractor Report Submitted to the International Joint Commission Science Advisory Board Research Coordination Committee. By Drs. Brian M. Roth, William W. Fetzer and Dana R. Infante, Michigan State University; Catherine M. Riseng and Beth L. Sparks-Jackson, University of Michigan. 111 pp, April 2016.

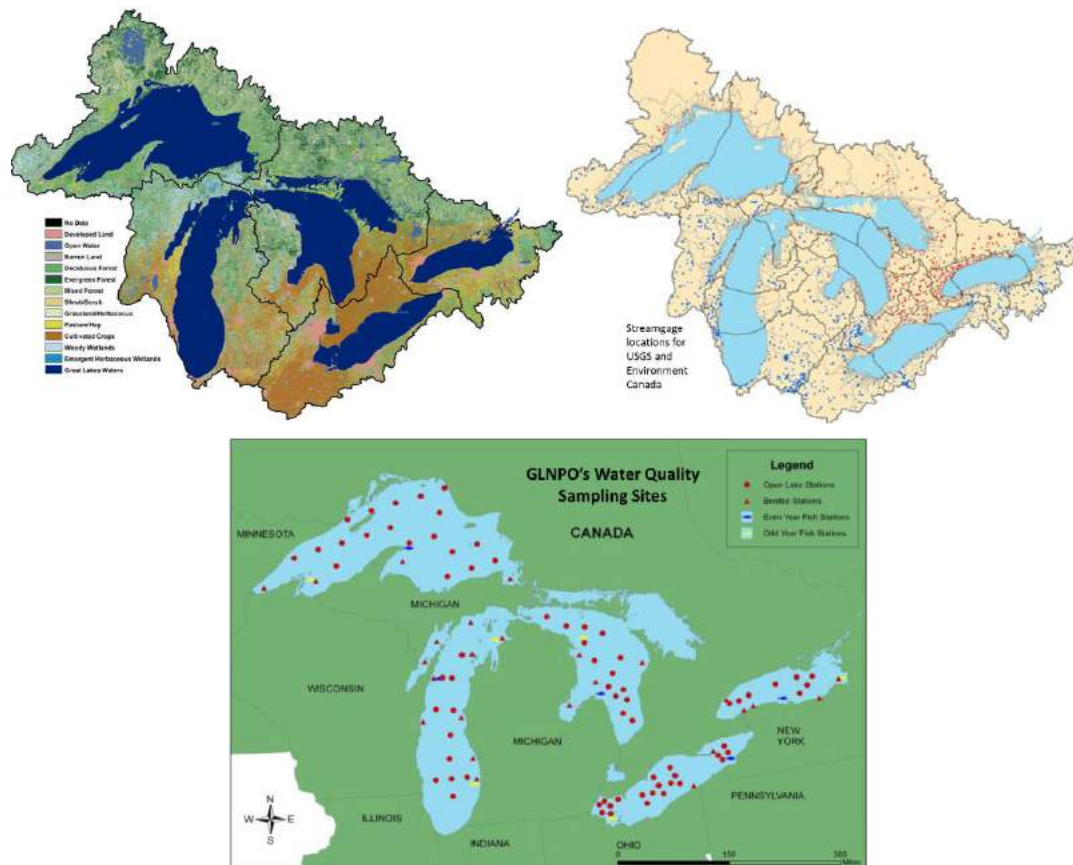
### Appendix B:

Identifying Future Improvements to Great Lakes Ecosystem and Human Health Indicators. A Contractor Report Submitted to the International Joint Commission Science Advisory Board Research Coordination Committee. By Sanjiv K. Sinha and Rob Pettit, Environmental Consulting & Technology Inc. 42 pp, April 2016.



# GREAT LAKES INDICATOR DATA ACCESSIBILITY AND DATA GAPS ANALYSIS FOR ASSESSING PROGRESS TOWARD ACHIEVING THE GLWQA OBJECTIVES

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April 10, 2016

*A Contractor Report Submitted to the International Joint Commission Science  
Advisory Board Research Coordination Committee*

By

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## Executive Summary

This report contains the results of an effort to assess data accessibility and identify data gaps in the needs of calculating the Great Lakes indicators that have been recommended to the Canada and U.S. governments by the International Joint Commission for assessing progress toward achieving the Great Lakes Water Quality Agreement (GLWQA). More than 150 scientists, managers, and human health experts in the Great Lakes Basin were contacted to, at the very least, identify what data were available on a given indicator measure, and whenever possible to obtain an access to the data to assess data accessibility. Additionally, the Great Lakes Aquatic Habitat Spatial Framework was used to integrate the accessible data we obtained to assess the spatial coverage of those indicators and their associated measures.

Our investigation revealed a substantial amount of data covering the vast majority of indicators and their associated measures. We evaluated a total of 60 measures across the 21 ecosystem and human health indicators. Forty of these measures have full coverage of the Great Lakes, and 12 measures had partial datasets, meaning that data were only collected over a portion of the Great Lakes. We were able to have access to 33 of these measures. For some measures, we were only able to have access to data for the U.S. side of the Great Lakes; others only for some U.S. states. We were unable to have access to data for 27 measures. Nine of these measures had full overlap with the State of the Great Lakes subindicators, for which we were unable to have access to the data at this time. The majority of the others were human health indicator measures, for which little data is available. Some of the data required for this project were developed through the Great Lakes Aquatic Habitat Spatial Framework (GLAHF) project. Additionally, many data and measures can be calculated and summarized according to GLAHF spatial units (e.g., by lakes, lake subbasins, or Great Lakes Hydrography Dataset watersheds). When applicable, these indicators and measures can also be presented as maps using the GLAHF spatial units. The data with no sharing restrictions in the GLAHF database are now available via the GLAHF website ([GLAHF.org](http://GLAHF.org)) for download. These include lake and lake subbasin spatial units, the Great Lakes Hydrography Dataset watersheds, harmonized shoreline classifications, and various measures of temperature and ice cover.

Although our goal was to identify accessibility of data and data gaps, we also identified indicators and indicator measures that need further clarification. The assessment of progress indicator authors in consultation with IJC staff are best equipped to further develop quantitative measures given their expertise in each field and their knowledge of existing datasets.

Overall, this analysis indicates that substantial amount of the data needed for assessing the progress toward achieving the the GLWQA objective is missing and needs to be assembled from state and academia data sources or new and redirected monitoring program to collect such data. This analysis also shows that accessing the available data is extremely challenging due to the lack of centralized binational database. However, it is critically import to make the said data publicly available for making management decision and policies and informing publics. This analysis also find that data from Canada are underrepresented and further collaboration and investigation are likely required to fully integrate data from Canada into the existing datasets.

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## Introduction

The Great Lakes Water Quality Agreement (amended in 1987) committed the United States and Canada to restore and maintain “...the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem” (IJC 2014). In 2012, the United States and Canada signed the amended Great Lakes Water Quality Protocol of 2012 (GLWQA). In this amendment, priority was placed on the assessment of progress of Great Lakes programs and monitoring. From this amendment, the International Joint Commission (IJC) identified several projects that were needed to accomplish goals set from this priority on ecosystem assessment. One of these projects was to select a list of key indicators that could be used to accurately assess progress on the GLWQA objectives, including the introduction and spread of non-native species, nutrient loading and its effect on water quality and human health, and the conservation of nearshore areas of the Great Lakes.

The need for a reduced set of indicators focused on the GLWQA Annex priorities was identified as needed to summarize and quantify the vast quantity of monitoring data present in the Great Lakes (*e.g.*, for fish, temperature, nutrient concentrations). The IJC Water Quality Board, Science Advisory Board, and Public Health Advisory Board, working with the other government and non-government technical experts, were tasked to identify a set of ecosystem and human health indicators for assessment of progress toward achieving the GLWQA objectives. The use of indicators is contingent on an ecosystem-based management approach (Cury and Christensen 2005), and as such should contain information on a number of individual measures that together provide a more holistic view of the issues at hand.

The IJC, through its boards and the Great Lakes regional experts, developed a list of 21 ecosystem and human health indicators. To meet the mandates of the 2012 GLWQA on assessing progress, the IJC has recommended these indicators to the governments of United States and Canada. The governments have accepted those indicators that have available data for the assessment of progress in 2017 State of the Great Lakes () report. These apex indicators are typically composed of several components (*i.e.* measures) that are combined into one indicator. Riseng and Sparks-Jackson (2013) identified individual datasets necessary for calculating each ecosystem indicator measure and evaluated approaches for calculating the measures. The identification of these datasets was a major step towards implementation of these indicators within the Great Lakes Water Quality Agreement framework. However, the next step of identifying accessibility, cross-walking, integrating, and compiling the existing data into a dataset that can be used for calculating each measure is needed in order to be able to assess the utility of the indicators and identify data gaps.

The purpose of this document is to report the findings of our investigation into the availability, extent (spatial and temporal), and quality of the data for calculation of the apex indicators. These methods essentially act as filters after which dataset cross-walking, integration, and compiling can occur. The inverse of these findings represent data gaps. Consequently, the methodology of inquiry is important for understanding our findings relative to available data.

## Methods

### Data inquiry, collection, and calculation procedures

We identified likely data holders through literature reviews, online research, and personal connections and communication with experts in the field. For most indicators, these efforts were successful. We were able to identify data quality concerns and data gaps for most indicators, provide summary metadata in cases where data exist but were not shared, and provide some combination of complete metadata, raw data, calculated indicators, and a coarse trend analysis for indicators where data were acquired.

For some indicators, we were unable to acquire the necessary data for three major reasons. First, four of the IJC indicators replicated indicators and data were not publicly available. These data will not be available until the report has been completed. Second, data collection was hampered due to lack of coordination and standardization of data collection across Great Lakes agencies and researchers. For these indicators, data were dispersed or nonexistent, and our data collection efforts were often unsuccessful. Third, some of our requests for data were not answered despite numerous requests, or the data provider did not have the time to prepare the data to share. Lastly, we were more successful in acquiring U.S. data than Canadian data. This was likely due to two reasons: 1) restricted data sharing policies for Canadian agencies and, 2) our own somewhat biased professional circles. We list the data gaps for all indicators in Tables 1-4.

Whenever feasible, we acquired data through several means. We downloaded data directly from the internet, leveraged data collected by other research projects, and acquired data directly from data holders. If data were acquired, our goal was to use the data to calculate individual measures described for each indicator as specified in the Great Lakes Ecosystem Indicator Project Report (IJC 2014a) or the Recommended Human Health Indicators for Assessment of Progress on the Great Lakes Water Quality Agreement (IJC 2014b). For some indicators, a lack of specificity in the measure descriptions limited our ability to calculate measures or to assess temporal trends in the measures. We used our best professional judgment in calculating measures and documented how we performed these calculations. For measures where we were able to automate the data download or measure calculations, we have included copies of processing scripts to facilitate repeatable calculations as monitoring and data generation continue.

### Database philosophy and structure:

Three of our goals in the design of the database were to 1) keep the database simple yet comprehensive, 2) as consistent as possible, and 3) accessible to anyone with modest computer experience. In addition to metadata summaries and the acquired data themselves, the database is also populated with support documents. The data are organized so they can be attached to the spatial framework we provided and the possible joins are described in the metadata for each indicator. For example, one measure in the Tributary Physical Condition indicator, the degree of river mainstem connectivity to the Great Lakes, can be summarized by watershed and therefore can be joined to the watershed feature coverage provided in the spatial framework. Alternatively, connectivity can also be summarized at larger spatial extents such as the lake sub-basin and lake basin, and can be joined to the lake sub-basin and lake basin feature classes.

The database is a series of nested folders and files. Each indicator has a unique folder. At minimum, this folder will always include a Microsoft Excel workbook titled with the indicator name and contain a README metadata worksheet that describes the data and data sources in detail. The indicator folder may also contain additional files, including important reference manuscripts or documents, processing scripts and detailed descriptions of how data were processed, raw data files, and any additional files that might be useful. The figure below provides an example of the hierarchical structure of folders within three physical indicators in the right column and the left column illustrates the contents of the water temperature folder including the primary Microsoft Excel workbook for the water temperature indicator.

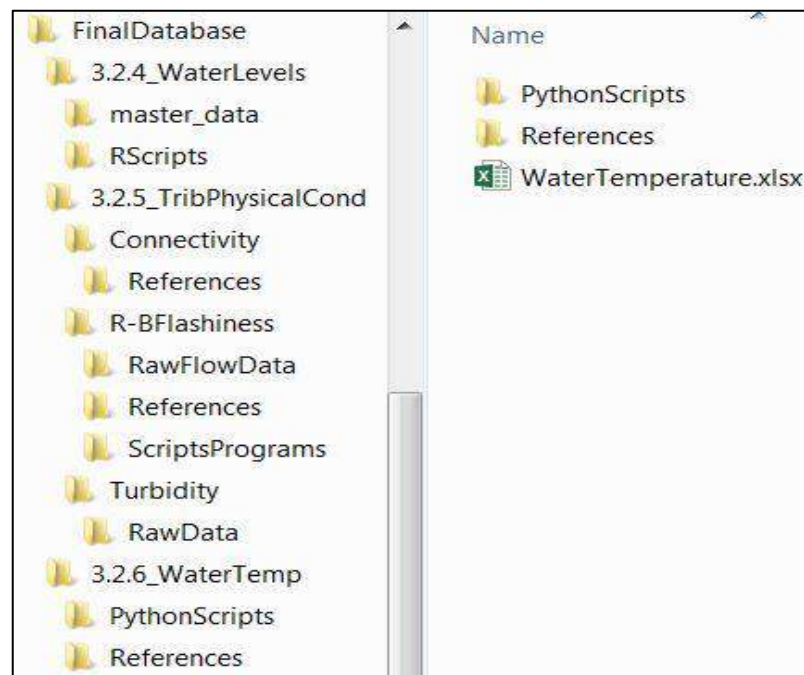


Figure 1: An example of the Database hierarchical file structure.

Across all indicators, we used a standardized structure within each indicator Excel Workbook. These workbooks took two basic configurations depending on data availability and indicator details.

- 1) If data could not be acquired or do not exist for an indicator, only the README metadata worksheet is included in the Excel file. The README metadata worksheet describes the indicator, data sources and contact information, temporal and spatial extent if known, any known data quality issues, and data gaps.
- 2) If data were available and acquired, and at least one indicator measure could be calculated, the README worksheet is followed by multiple worksheets. In this case the README metadata sheet includes descriptions of indicator and the file structure, data sources and contact information, temporal and spatial extent, how data were processed and indicators calculated, indicator interpretation, any known data quality issues, and data gaps as well as a description of the contents of each of the following worksheets.

Figure 2 shows a portion of the primary workbook for the Tributary Physical Integrity indicator. The measure descriptions on the README worksheet are excerpted from IJC Ecosystem Indicator or Human Health reports (IJC 2014a or 2014b) and the Excel tabs describe the content of each worksheet. Each

worksheet is labeled by the measure and a brief statement of content (e.g. M1 = Hydrologic alteration measure, M2=Connectivity to receiving waters, etc.).

	A	B	C	D
1	Indicator:	Tributary Physical Integrity		
2				
3	Indicator and file details:	Metrics:		
4			Metric 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 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 (see equation in cell to the right and Baker et al., 2004).
5			Metric 2:	Tributary connectivity to receiving waters Part 1: Tributary connectivity for an individual watershed = $(L_b/L_m) \times 100$ where $L_b$ is the distance between the Great Lakes and the first barrier on the main stem channel and $L_m$ is the total length of the main stem channel.
6				Tributary connectivity to receiving waters Part 2: Tributary Connectivity for multiple watersheds is calculated by summing the total length of main stem channels without barriers and then dividing by the total sum of main stem channel lengths.
7			Metric 3:	Sediment-turbidity measure Part 1: Turbidity Exceedance Time is the proportion of time that the turbidity threshold (T) is exceeded during the time series ( $t_e > T$ ) divided by the total time within the series (see equation in cell to the right). 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). In other words, days in the year that the mean daily turbidity value exceeded the threshold, divided by days of data in that year.
8				Sediment-turbidity measure Part 2: 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 ( $c_e > T$ ) divided by the turbidity threshold value (see equation in cell to the right). For example, a turbidity concentration ratio of 3.6 indicates that the magnitude of exceedance is 3.6 times greater than the turbidity threshold. In other words, of the days that the threshold was exceeded, find the average turbidity value across those exceedance days and divide it by the threshold value.
9		Excel tabs:	Metric 1:	M1_RBIndex_ByTrib: R-B Index values year and gage for US and CAN streams with flow data (includes all gages with flow data that have at least 364 days of valid ice-free flow measures)
10				M1_RBIndex_Trends: Trend in R-B Flashiness for all US and CAN gages with at least five R-B Flashiness calculations. This worksheet includes the number of R-B Flashiness calculations available, the oldest and most recent years with an R-B Flashiness calculated, the estimated slope and intercept of the trendline, the statistical significance of the slope of the trendline ( $p < 0.05$ highlighted in dark rose and $0.05 < p < 0.10$ highlighted in light rose), and whether the trend is for increasing flashiness, decreasing flashiness, or there is no trend (no change) in flashiness.
11			Metric 2:	M2_Connect_ByTrib: Connectivity of individual watersheds
12				M2_Connect_BySubbasin: Summary of connectivity within lake subbasins
13				M2_Connect_ByLake: Summary of connectivity within lake basins
14			Metric 3:	M3_Turbidity: Turbidity exceedance time and Turbidity concentration time for thresholds of 10, 25, and 50 NTUs.
15				
16				
17				
18				

Figure 2: An example of the README worksheet associated with each indicator and the labelling of worksheets containing data.

### Spatial Framework Overview:

Where applicable we have used the Great Lakes Aquatic Habitat Framework (GLAHF) spatial framework to summarize data at a specific spatial extent or over multiple spatial extents. The data in the Excel worksheets contain columns that link to spatial units such as watersheds (Figure 3), sub-basins (Figure 4), or line feature classes, such as shoreline in the GLAHF spatial framework (Wang et al. 2015). Data acquired include point feature classes, such as water quality monitoring stations identified by Latitude and Longitude (Figure 5) which can then be summarized by lake or lake subbasin. A more complete description of the spatial framework is provided in the Spatial Framework README Document. The spatial framework is provided in the form of an ArcGIS geodatabase.



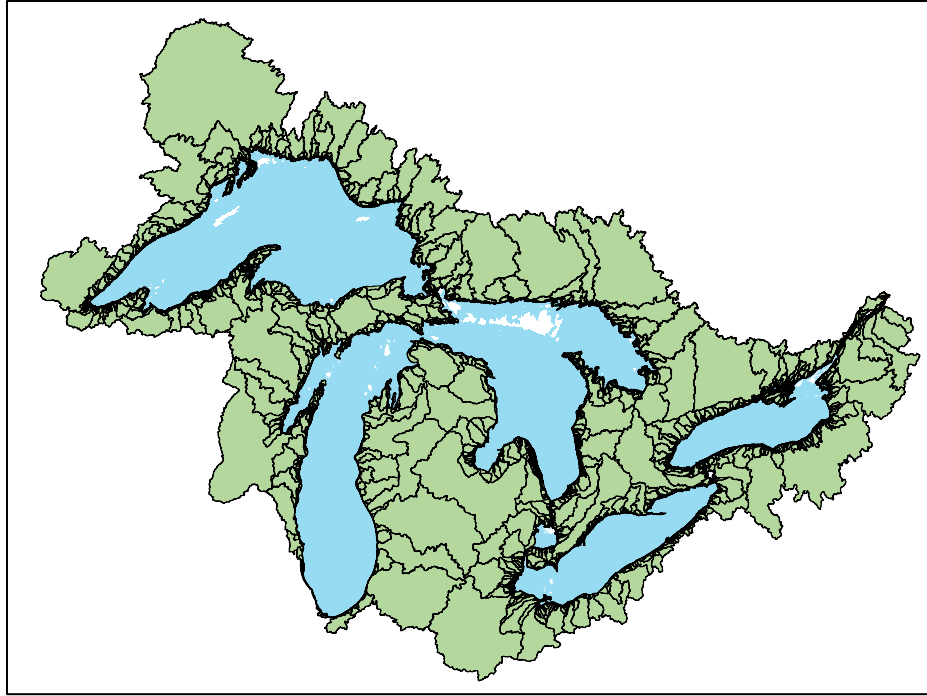


Figure 3: Mainland watershed boundaries from the Great Lakes Hydrography Dataset (Forsyth et al, 2015 in review), part of the GLAHF spatial framework.



Figure 4: Lake sub-basins in the GLAHF spatial framework.

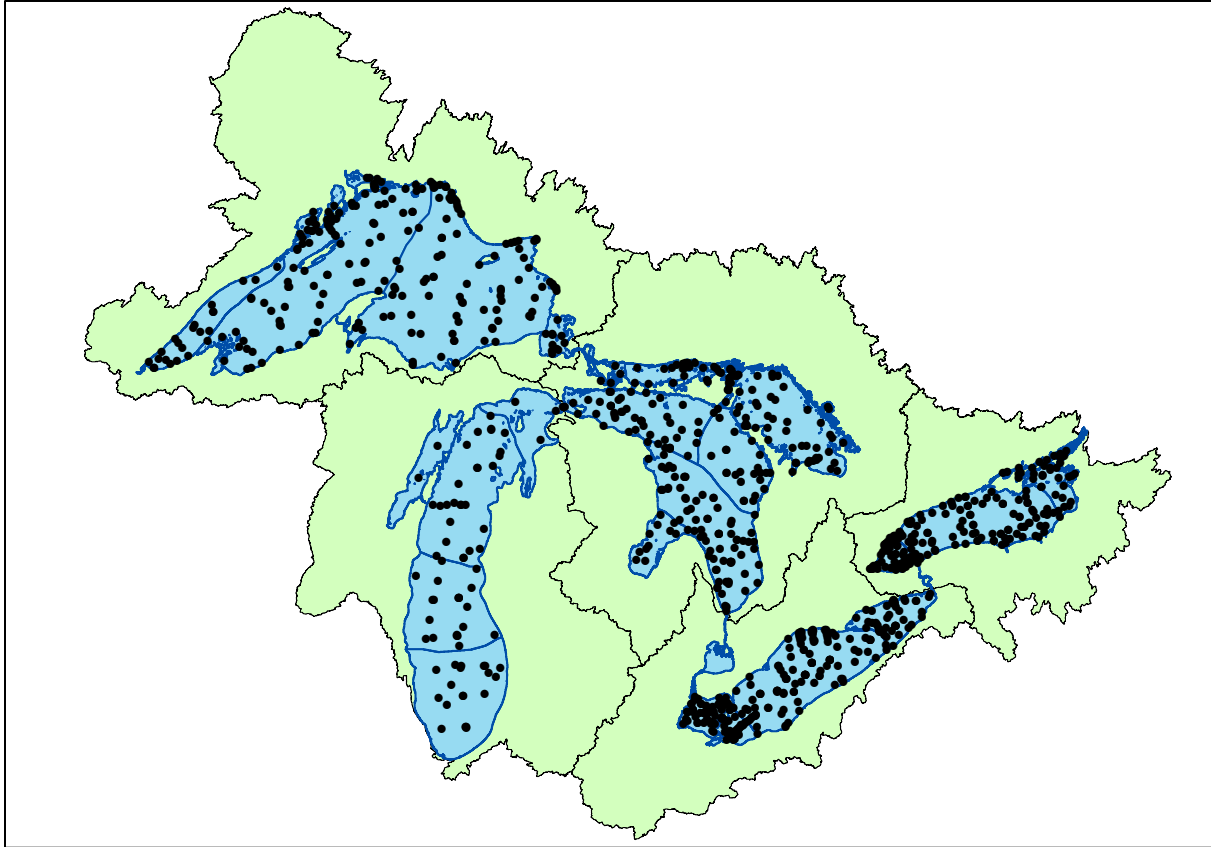


Figure 5: An example of a point feature class included in the GLAHF/IJC spatial framework. Water quality monitoring stations mapped by Latitude and Longitude and shown within lake subbasins (blue) and within lake basin drainages (light green).

## Summary Table of Datagap Analysis

The tables below provide an overview of the data gap analysis conducted as part of this project. In general, full data availability indicates that we are aware of data that would fully cover the Great Lakes whereas partial data availability indicates that data is only available for a portion of the Great Lakes. Information in the Notes column only reflects the spatial extent of the data we were able to obtain, if any. See each indicator report for specifics regarding data availability and sources.

Table 1. Human Health Indicators

IJC Indicator	IJC Measures	Data Availability	Data in Hand	Notes
Biological Hazards of Source Water	<i>E. coli</i>	Unknown	No	Data may exist at municipal level
	Nitrate	Unknown	No	Data may exist at municipal level
	Turbidity	Partial	No	OH only
Chemical Integrity of Source Water	Atrazine	Unknown	No	Data may exist at municipal level
	Estrogenicity	Unknown	No	Data may exist at municipal level
	Cyanotoxins	Partial	No	OH only
Illness Risk at GL Beaches	95th% # of <i>E. coli</i> /colony-forming units of <i>E. coli</i> /100 ml	Full	Yes	US only
Source of Risks at GL Beaches	% beaches with Beach Sanitary Survey or Environmental Health & Safety Survey in a given year	Full	Yes	US only
Contaminant Levels in GL Edible Fish Species	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of Lake Trout	Full	Yes	Some US states
	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of Walleye	Full	Yes	Some US states
	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of Yellow Perch	Full	Yes	Some US states
	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of Whitefish	Full	Yes	Some US states
	Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, mirex in edible portions of Smallmouth Bass	Full	Yes	Some US states

Table 2. Physical Indicators

<b>IJC Indicator</b>	<b>IJC Measures</b>	<b>Data Availability</b>	<b>Data in Hand</b>	<b>Notes</b>
Shoreline Alteration	Physical shoreline indicator	Full	Yes	
	Biological shoreline indicator	No data	No	
	SAI-Combined physical and biological index	Partial	Yes	Combined index includes physical component
Coastal Wetland	Invertebrates	Full	No	SOGL
	Fish	Full	No	SOGL
	Plants	Full	No	SOGL
	Amphibians	Full	No	SOGL
	Birds	Full	No	SOGL
	Area and extent	Full	No	SOGL
Water Level	Long-term water level variability	Full	Yes	
	Timing of seasonal water level maximum and minimum	Full	Yes	
	Magnitude of seasonal rise and decline	Full	Yes	
	Lake-to-lake water level difference	Full	Yes	
Tributary	Hydrologic Alteration (R-B Flashiness Index)	Full	Yes	
	Sediment-turbidity measure	Full	Yes	
	Tributary connectivity to GL	Full	Yes	
Water Temperature	Annual summer (July-September) surface average temperature for each lake	Full	Yes	
	Fall lake water turnover date	Full	Yes	
		Full	Yes	
	Maximum and average ice concentrations	Full	Yes	

Table 3. Chemical of Mutual Concern in Water Indicators

<b>IJC Indicator</b>	<b>IJC Measures</b>	<b>Data Availability</b>	<b>Data in Hand</b>	<b>Notes</b>
Air Deposition of CMC	Based on SOGL indicator Atmospheric Deposition of Toxic Chemicals	Full	No	SOGL
Chemical of Mutual Concern in Water	Based on Annex 3 recommendation	Full	No	SOGL
Contaminants in Groundwater	Measure >10 chemicals from ag and urban watersheds	Partial	Yes	
PBT in Biota	PBT chemicals in Great Lakes whole fish	Full	No	SOGL
	PBT chemicals in Great Lakes Herring Gull eggs	Full	No	SOGL
	PBT chemicals in Great Lakes Bald Eagles	Partial	No	MI waters
Phosphorus Loading and In- lake Concentration	In Lake TP and DRP concentrations	Full	Yes	
	TP and DRP loading from Tribes	Partial	Yes	

Table 4. Biological Indicators

IJC Indicator		IJC Measures	Data Availability	Data in Hand	Notes
Aquatic Invasive Species	Rate of Invasion	Plotting cumulative numbers of invasions versus time	Full	Yes	
	Status and Impacts	Plankton	Full	No	SOGL
		Asian Carps	No data	No	
		Round Goby	Partial	Yes	
		Ruffe	Partial	Yes	
		Sea Lamprey	Full	Yes	
		Dreissenid Mussels	Full	Yes	
Lower Foodweb		Phytoplankton biovolume	Full	No	SOGL
		Zooplankton biomass	Full	No	SOGL
		Benthos abundance	Full	No	SOGL
		Mysis biomass	Full	No	SOGL
		Preyfish biomass and diversity index	Full	Yes	
Fish Species of Interest		Recruitment and abundance of lake trout and whitefish	Full	Yes	
		Recruitment and abundance of walleye	Partial	Yes	Only for some locations
		Recruitment and abundance of lake sturgeon	Partial	Yes	Sparse data
		Recruitment and abundance of northern pike or yellow perch or smallmouth/largemouth bass	Partial	Yes	Sparse data
Harmful Algal Blooms		Harmful Algal Blooms	Partial	No	Mostly W. Lake Erie
		Nuisance Algal Bloom	No data	No	
		Excessive Algal Abundance	No data	No	

## Biological Hazard Index for Source Water

### Summary:

This indicator tracks the extent of biological hazards for Great Lakes source water from human and agricultural activities by monitoring the presences of *E. coli*, nitrates, and turbidity. The purpose of this indicator is to: 1) examine trends in the endemic, seasonal, and episodic presence of sewage and agricultural effluent and other contaminated runoff in the Great Lakes, 2) examine seasonal and geographic distribution of selected human pathogens, and 3) infer the effectiveness of management actions taken to reduce the impact of pathogens and nitrates in source waters. This indicator is calculated using data collected prior to treatment to assess changes in water quality within the Great Lakes, not changes in the efficiency of water treatment facilities.

### Measures:

The IJC Human Health Indicators Report (IJC 2014b) provides recommendations for implementing this indicator, including 1) monitor for *E. coli*, nitrate, and turbidity at intakes to water treatment plants with standardized methodologies with daily frequency, 2) conduct trend analyses on extremes and exceedances of measurement beyond the provisional baseline rather than averages, 3) consider steps to include smaller municipalities and regions with lower population densities, and 4) establish provisional baselines for these measures in source water. Development and implementation of these procedures will allow calculation of three measures that track spatial and temporal trends in *E. coli*, nitrates, and turbidity from source water at utilities plants in the United States and Canada. Provisional baselines have not been established.

Measure	Description
1	Trend analyses on extremes and exceedances of measurements beyond provisional baselines for <i>E. coli</i>
2	Trend analyses on extremes and exceedances of measurements beyond provisional baselines for Nitrate
3	Trend analyses on extremes and exceedances of measurements beyond provisional baselines for turbidity

### Data sources:

We have identified no data sources in Canada or the United States that can be used to calculate this indicator. Throughout our data gap assessment, we reached out to individuals at federal, state, provincial, and local levels but were unable to obtain any data on water prior to its entry into water treatment facilities. Current monitoring and reporting by utilities to government agencies are focused on water quality post-treatment to ensure that water delivered to the general public is safe for drinking. In our data gap analyses, we were consistently informed that there are no regulations requiring that utilities monitor or report source water quality prior to treatment; therefore, these data are not available in a centralized location that can be easily accessed and integrated within the IJC indicator project. However, pre-treatment water quality data are likely collected by individual treatment facilities to increase efficiency of water treatment, but we were unable to access this information despite contacting several water treatment plants. Additionally, the State of Minnesota does collect some source water data prior to treatment but we were unable to obtain the data prior to completion of the final report. Assessing the extent of data collected by water treatment facilities would require a more

detailed project, focused on identifying water treatment facilities across the basin, determining contacts for these locations, and then working with state and federal agencies to develop the relationships necessary for data sharing to occur.

**Steve Robertson**, Drinking Water Protection Section, Minnesota Department of Health,  
651.201.4648, [steve.robertson@state.mn.us](mailto:steve.robertson@state.mn.us)

*Spatial Extent:*

If available, data will be associated with a specific water treatment facility. There could be multiple water intake locations per facility; however, the specific location of intakes is not available and is apparently a matter of national security.

*Temporal extent:*

If available, data will likely be collected daily or at similar frequencies. The duration of data is unclear and will likely depend on the specific measure of interest. For instance, turbidity data will likely have the longest record because it is easy to measure.

**Summary of findings:**

Data to calculate this indicator are not readily available and are likely diffuse across the Great Lakes basin and maintained by individual water treatment facilities, if available. Additional time and resources will need to be made available to conclusively determine data availability and gaps for this indicator through a focused effort and coordination with water treatment facilities and state/federal agency contacts.

**Data gaps and recommendations:**

We were unable to locate any data to calculate this indicator for the reasons outlined in the *Data sources* and *Summary of findings* sections above. Federal mandates for monitoring and reporting of source water quality prior to treatment would increase the availability of data for this indicator, as is required for post-treatment water quality.

## **Chemical Integrity for Source Water**

**Summary:**

This indicator tracks the chemical integrity of Great Lakes source water from agricultural and industrial activities, point source contamination by wastewater treatment facilities and uncontained landfills, and industrial population-induced sprawl by monitoring the presences of pesticides (atrazine), endocrine disrupting compounds (estrogenicity assay), and harmful algal blooms (cyanotoxin levels). The purpose of this indicator is to: 1) examine trends in seasonal and geographic variability or targeted chemical compounds in waters used as sources for regional drinking water supply, 2) assess the level of hazard and infer the impact of chemical contaminants in the drinking water sources on the health of the human population in the Great Lakes, 3) infer the effectiveness of management actions taken to reduce the overall levels of pesticides, nutrients, and endocrine disrupting chemicals in the Great Lake source water for drinking, and 4) examine indications for possible improvements to potable and waste water treatment. This indicator is calculated using data collected prior to treatment to assess changes in water quality within the Great Lakes, not changes in the efficiency of water treatment facilities. Data collection should be performed by the utilities.



**Measures:**

The IJC Human Health Indicators Report (IJC 2014b) provides recommendations for implementing this indicator, including 1) monitoring the levels of atrazine, estrogenicity, and microcystin-LR at intakes to drinking water treatment plants with weekly frequency and standardized methodologies, and 2) establishing provisional baselines for these measures in source water. Development and implementation of these procedures will allow calculation of three measures that track spatial and temporal trends in atrazine, endocrine disrupting compounds, and cyanotoxin levels from source water at utilities plants in the United States and Canada. Provisional baselines have not been established.

Measure	Description
1	Trend analyses on extremes and exceedances of measurements beyond provisional baselines for atrazine
2	Trend analyses on extremes and exceedances of measurements beyond provisional baselines for endocrine disrupting compounds
3	Trend analyses on extremes and exceedances of measurements beyond provisional baselines for cyanotoxins

**Data sources:**

We have identified virtually no data sources in Canada or the United States that can be used to calculate this indicator. Throughout our data gap assessment, we reached out to individuals at federal, state, provincial, and local levels but were only able to collect data from water treatment facilities prior to treatment in Ohio. Current monitoring and reporting by utilities to government agencies are focused on water quality post-treatment to ensure that water delivered to the general public is safe for drinking. In our data gap analyses, we were consistently informed that there are no regulations requiring that utilities monitor or report source water quality prior to treatment; therefore, these data are not available in a centralized location that can be easily accessed and integrated within the IJC indicator project. However, pre-treatment water quality data are likely collected by individual treatment facilities to increase efficiency of water treatment, but we were unable to access this information despite contacting several water treatment plants. Additionally, the state of Minnesota does collect some source water data prior to treatment but we were unable to obtain the data prior to completion of the final report. Assessing the extent of data collected by water treatment facilities would require a more detailed project, focused on identifying water treatment facilities across the basin, determining contacts for these locations, and then working with state and federal agencies to develop the relationships necessary for data sharing to occur.

**Steve Robertson**, Drinking Water Protection Section, Minnesota Department of Health,  
651.201.4648, [steve.robertson@state.mn.us](mailto:steve.robertson@state.mn.us)

**Barb Lubberger**, Supervisor, Source Water Protection Program, Ohio EPA, Division of Drinking  
and Ground Waters, 614.644.2863, [barb.lubberger@epa.state.oh.us](mailto:barb.lubberger@epa.state.oh.us)

***Spatial Extent:***

If available, data will be associated with a specific water treatment facility. There could be multiple water intake locations per facility; however, the specific location of intakes is not available and is a matter of national security.

***Temporal extent:***

If available, data will likely be collected daily, weekly, or at similar frequencies. The duration of data is unclear and will likely depend on the specific measure of interest. For the Ohio dataset, the duration is 2010 through present.

#### **Summary of findings:**

Data to calculate this indicator are not readily available and are likely diffuse across the Great Lakes basin and maintained by individual water treatment facilities, if available. Additional time and resources will need to be made available to conclusively determine data availability and gaps for this indicator through a focused effort and coordination with water treatment facilities and state agency contacts. Though we have collected some data for Ohio, provisional baselines and clear guidance on measure calculation will need to be developed before indicator trends can be reported.

#### **Data gaps and recommendations:**

We were unable to locate any data to calculate this indicator for the reasons outlined in the *Data sources* and *Summary of findings* sections above. Federal mandates for monitoring and reporting of source water quality prior to treatment would increase the availability of data for this indicator, as is required for post-treatment water quality.

## **Illness Risk at Great Lakes Beaches**

#### **Summary:**

This indicator uses *E. coli* levels to assess risk of illness to people using Great Lakes beaches. Its purpose is to infer potential harm to human health at routinely monitored beaches through use of fecal indicator organisms as surrogates for pathogens, to describe temporal and spatial trends in recreational water quality throughout the Great Lakes, and to allow comparisons of recreational water quality across jurisdictions using a common methodology.

#### **Measures:**

This indicator consists of the 95<sup>th</sup> percentile numbers of *E. coli* (i.e., 95% of the sample measurements taken must lie below a specific value in order to meet the standard) measured as the most probable number (MPN)/colony-forming units (CFU) per 100 ml of Great Lakes beaches to determine change over time. There are many uncertainties remaining about the actual protocol that should be used to calculate this indicator. The indicator description does not provide guidelines for the spatial and temporal scale that should be used to summarize trends in this measure over time. For instance, the value of the 95<sup>th</sup> percentile will vary depending on if it is calculated for each beach, subbasin, lake, or basin. Further it is unclear if the value of the 95<sup>th</sup> percentile is the indicator or if the number of measurements exceeding the 95<sup>th</sup> percentile is the indicator. This difference affects whether the 95<sup>th</sup> percentile is calculated annually at a given spatial scale, or if a 95<sup>th</sup> percentile is established for the entire data time series and then used to assess the number of times it is exceeded.

Measure	Description
1	95th percentile of numbers of <i>E. coli</i> measured as the most probable number (MPN)/colony forming units (CFU) of <i>E. coli</i> per 100 ml at Great Lakes beaches to determine change over time

#### **Data sources:**

**Beach Advisory and Closing Online Notification System (BEACON)**, US EPA database of pollution occurrences for coastal recreational waters, data are available by state from 2003 through present, data available through website, <http://watersgeo.epa.gov/beacon2/>

**Bill Kramer**, National Beach Program, US EPA, 202.566.0385, [kramer.bill@epa.gov](mailto:kramer.bill@epa.gov), primary contact for access United States data through the BEACON.

**Gregory Matheny**, Special Projects Manager, Illinois Department of Public Health, 217.782.5830, [gregory.matheny@illinois.gov](mailto:gregory.matheny@illinois.gov), provided access to more detailed information for beach data from Illinois Great Lakes beaches.

**Ray Copes**, Chief, Environmental and Occupational Health, Public Health Ontario, 647.260.7491, [ray.copes@oahpp.ca](mailto:ray.copes@oahpp.ca), provided contact information for specific labs that conduct beach water quality testing in Ontario.

**Tim Fletcher**, Manager, Water Standards Section, Standards Development Branch, Ministry of the Environment and Climate Change, 416.327.5002, [tim.fletcher@ontario.ca](mailto:tim.fletcher@ontario.ca), previously worked to integrate beach monitoring data from 19 public health units in Ontario. May be possible to share this information but would be limited to 2 years of study and would not allow temporal analyses.

**Sandy Edelsward**, Program Coordinator, Drinking Water Testing, Public Health Ontario, 519.455.9310 ext. 2557, [Sandra.Edelsward@oahpp.ca](mailto:Sandra.Edelsward@oahpp.ca), connected to Ontario water testing lab and has insights into Canadian contacts.

**Tony Amalfa**, Manager, Environmental Health Policy and Programs, Ministry of Health and Long-Term Care, 416.327.7624, [Tony.Amalfa@ontario.ca](mailto:Tony.Amalfa@ontario.ca), potential contact for beach data available through Ontario Public Health Units.

**Shawn Telford**, Public Health Coordinator, Ontario Parks, Ministry of Natural Resources and Forestry, 705.755.1716, [Shawn.Telford@ontario.ca](mailto:Shawn.Telford@ontario.ca), potential contact for beach data available through Ontario parks.

#### ***Spatial Extent:***

E. coli data are collected at individual beaches across the Great Lakes basin and spatially referenced to a specific latitude and longitude. Data from individual beaches can be integrated to summarize trends at larger spatial scales. Canadian data are not stored within a centralized database but maintained by individual public health units. Discussions with Tim Fletcher indicated that gathering E. coli data from beaches across Ontario will require a significant investment of time and is beyond the resources of this project. However, some data may be available through Sandy Edelsward at the lab where testing is conducted.

#### ***Temporal extent:***

The duration and frequency of beach monitoring varies across beaches. Some beaches are measured very frequently (*i.e.*, multiple times per week) and have records dating back to 2003. These beaches tend to be located near population centers, have high numbers of visitors, and/or are located near areas where beach closings have been a problem in the past. In general, the number of beach sampling events within a year has increased across the basin. We are currently unable to assess the duration and frequency of beach monitoring in Canada.

#### **Summary of findings:**

Data exist to assess this indicator within the United States and are likely available in Canada but collating this information into a usable format would require a significant investment of time and resources. However, further details need to be provided to guide how this indicator is actually

calculated (see above). For instance, is the indicator the number of days that exceed a 95<sup>th</sup> percentile threshold (and if so, how are data across space and time integrated to calculate this threshold), or is the indicator the value of the 95<sup>th</sup> percentile within a beach for a specific year, or is the indicator some combination of this information? The current measure description refers to the World Health Organization's guidelines (World Health Organization, 2003), but this document does not provide sufficient information to interpret how the authors of the indicator envisioned assessing the illness risks at Great Lakes beaches across space and time, and how this information should be effectively communicated.

#### **Data gaps and recommendations:**

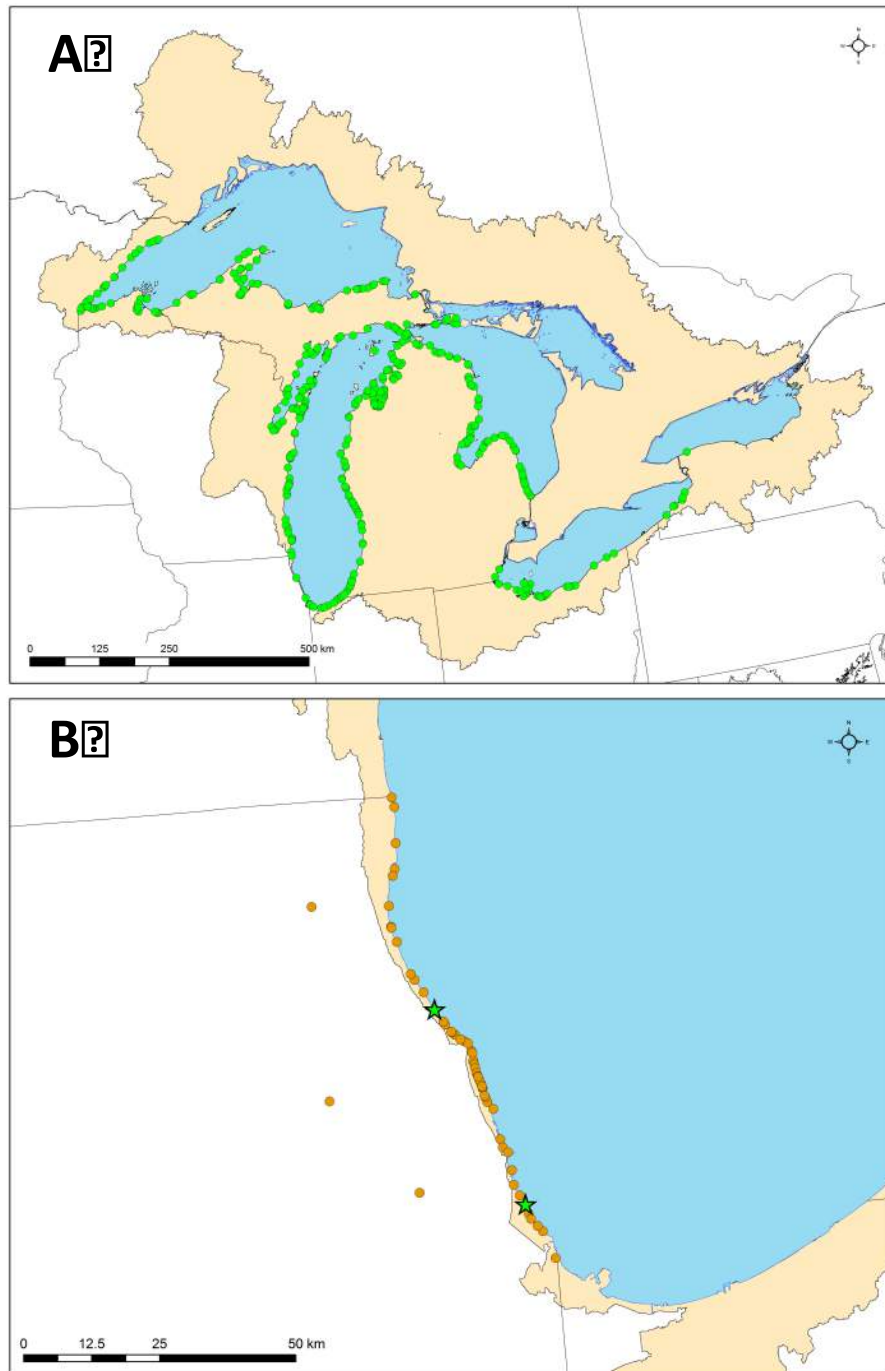
The primary data gap is the availability of data from Canada (Figure 6). These data likely exist but will require significant effort to collate these data from the individual public health units in Ontario where it is stored. Tim Fletcher attempted this for the data from 2007-2008 and found that it required hiring a full time employee who worked exclusively on this task. It is also unclear at this point if archived data are maintained, and if so, what challenges will be encountered while trying to integrate this information into a single database. There are also issues within the United States dataset that suggest the BEACON website may not contain all available data (Table 5). The Illinois Department of Public Health provided over 39,000 sampling events from 56 beaches located along Lake Michigan in Illinois (Table 5), while the BEACON website contained only 800 sampling events from only 2 beaches (Figure 6). Though not evaluated in any other states, the results from Illinois suggest there are likely additional beach monitoring data available across the basin that are not contained with the BEACON database (*e.g.*, New York state). Beach attribute data (Beach ID, Beach Name, Beach Length, Start/End Latitude/Longitude) are not available for some beaches where *E. coli* data are available.

Future efforts should attempt to clarify how this indicator is calculated by answering the questions highlighted above. Additionally, effort should be made to collate Canadian data into the BEACON database structure and encourage future measurements be submitted by the individual agencies to this centralized database, similarly to how this is done within the United States. Within the United States, effort should be made to assess whether additional data are available across the basin that are not included within the BEACON database.

**Table 5.** Summary of sampling events available through the US Environmental Protection Agency Beach Advisory and Closing Online Notification system and the Illinois Department of Public Health.

State	1996	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Illinois							6	64	107	131	80	109	147	143
Illinois*	2	21				6	5880	4249	4667	4731	3980	4486	4421	4406
Indiana						1506	968	1447	2020	2111	2363	2493	2455	2600
Michigan				92	2617	2639	4067	2067	7701	8356	15312	15578	11366	5693
Minnesota			598	920	1038	923	776	838	815	168	724	746	727	699
New York			432	582	495	479	433	543	490	711	725	836	961	1013
Ohio			1094	1584	1437	1725	1762		2578	2747	2820	2709	2582	2561
Wisconsin				3886	3864	2236	2962	4338	4107	4499	4340	4531	3496	3444

\*Sampling frequency of data provided by the Illinois Department of Public Health.



**Figure 6.** (A) Location of beaches within the Great Lakes where *E. coli* data are currently available through the US Environmental Protection Agency Beach Advisory and Closing Online Notification system (BEACON). (B) Locations of beaches within Illinois waters of Lake Michigan where data are available from the BEACON system (green stars) and the Illinois Department of Public Health (orange circles).

## Source of Risks at Great Lakes Beaches

### Summary:

This indicator characterizes sources of risk at Great Lakes beaches by identifying the main pollution sources and measuring the percentage of beaches that employ Beach Sanitary Surveys (USA) and Environmental Health and Safety Surveys (Canada) in a given year. Data are available to calculate the percentages of beaches in the USA that employ Beach Sanitary Surveys but are not available in Canada. Identifying pollution sources at individual beaches in the Great Lakes is not currently possible for the United State or Canada, though this could be possible with greater sharing of monitoring results to the regional beach coordinators and the establishment of a centralized database for beach monitoring data in Canada.

### Measures:

This indicator consists of two measures. Measure one identifies the main pollution sources identified at beaches that employ Beach Sanitary Surveys or Environmental Health and Safety Surveys. Measure two measures the percentage of beaches that employ Beach Sanitary Surveys or Environmental Health and Safety Surveys to provide context for how many beaches are providing data for this indicator.

Measure	Description
1	Main pollution sources identified at beaches that employ Beach Sanitary Survey or Environmental Health and Safety Survey
2	Percentage of beaches that employ Beach Sanitary Survey or Environmental Health and Safety Survey in a given year

### Data sources:

**Holiday Wirick**, Regional Beach Program Coordinator, United States EPA, 312.353.6704, [wirick.holiday@epa.gov](mailto:wirick.holiday@epa.gov), primary contact for information on the number of beaches using Beach Sanitary Surveys.

**Tim Fletcher**, Manager, Water Standards Section, Standards Development Branch, Ministry of the Environment and Climate Change, 416.327.5002, [tim.fletcher@ontario.ca](mailto:tim.fletcher@ontario.ca), previously worked to integrate beach monitoring data from 19 public health units in Ontario. May be possible to share this information but would be limited to 2 years of study and would not allow temporal analyses.

**Sandy Edelsward**, Program Coordinator, Drinking Water Testing, Public Health Ontario, 519.455.9310 ext. 2557, [Sandra.Edelsward@oahpp.ca](mailto:Sandra.Edelsward@oahpp.ca), connected to Ontario water testing lab and has insights into Canadian contacts.

**Tony Amalfa**, Manager, Environmental Health Policy and Programs, Ministry of Health and Long-Term Care, 416.327.7624. [Tony.Amalfa@ontario.ca](mailto:Tony.Amalfa@ontario.ca), potential contact for beach data available through Ontario Public Health Units.

**Shawn Telford**, Public Health Coordinator, Ontario Parks, Ministry of Natural Resources and Forestry, 705.755.1716, [Shawn.Telford@ontario.ca](mailto:Shawn.Telford@ontario.ca), potential contact for beach data available through Ontario parks.

### *Spatial Extent:*

Presence/absence of Beach Sanitary Surveys in the United States is conducted at the level of individual beaches and can be scaled up to individual states, lakes, or the whole basin (Table 6). Some beaches do not have latitudes and longitudes, but all include the county where the beach is located.

*Temporal extent:*

Data provided for this indicator only indicate if a Beach Sanitary Survey has been conducted at least once. No information is available to assess the first year a survey was conducted or if a survey is conducted within each year.

**Summary of findings:**

Data exist to assess this indicator within the United States and are likely available in Canada, but would require a significant investment of time and resources to collate this information into a usable format. Currently, approximately 50 percent of beaches within the United States use Beach Sanitary Surveys. This percentage is higher at Tier 1 beaches (*e.g.*, large, near population centers, high annual attendance). The current data do not allow identification of the major sources of pollution at individual beaches because the regional beach coordination program does not collect this information. Some beaches have additional information provided that discusses specific mitigation efforts to assess individual pollution sources, but this information is uncommon and rarely easy to discern from the database.

**Data gaps and recommendations:**

The primary data gap is the availability of data from Canada. These data exist but will require significant effort to collate these data from the individual public health units in Ontario where it is stored. Tim Fletcher attempted a similar effort in 2007-2008 to collect *E. coli* data and found that it required hiring a full time employee who worked exclusively on this task. It is likely that determining the number of beaches that use Environmental Health and Safety Surveys will also be challenging and require an individual to reach out to individual public health units or even individual beach employees.

Within the United States dataset there are a number of data limitations that prevent complete calculation of this indicator. There is no temporal information available to determine temporal trends in the percentage of beaches conducting Beach Sanitary Surveys. There is no information within the database about the sources of pollution identified by the Beach Sanitary Surveys, preventing us from determining the main sources of pollution across beaches. Geo-referencing many of the beaches is difficult since 60 percent of beaches within the database do not include latitudes and longitudes. This information is likely available and can be linked through the data gathered for the indicator, "Risk of Illness from Great Lake Beaches". However, the lack of this information in the Beach Sanitary Survey database highlights the need for a formalized database structure within the United States to keep track of all the information collected through basin-wide monitoring. Canadian data could be incorporated into this database and allow simple calculation of the most significant risks at Great Lakes beaches.

**Table 6.** Summary of beaches in the United States’ waters of the Great Lakes conducting Beach Sanitary Surveys.

<b>State/Lake</b>	<b>Number of Beaches</b>	<b>Number with Beach Sanitary Survey</b>	<b>% of Beaches</b>
Illinois	58	39	67.2
Indiana	29	29	100.0
Michigan	586	255	43.5
Minnesota	90	2	2.2
Ohio	62	64	103.2
Pennsylvania	13	4	30.8
New York	62	28	45.2
Wisconsin	227	131	57.7
Lake Erie	97	84	86.6
Lake Huron	176	109	61.9
Lake Michigan	540	292	54.1
Lake Ontario	43	11	25.6
Lake Superior	271	56	20.7
<b>Total</b>	<b>1127</b>	<b>552</b>	<b>49.0</b>

## Contaminants Levels in Great Lakes Edible Fish Species

### Summary:

This indicator uses contaminants data from edible portions of Great Lakes fish species to develop a basin-wide fish consumption indicator. However, jurisdictional differences in methods for collection and analysis need to be overcome before this indicator can be developed. Currently, there are no guidelines outlined for how to proceed with calculation of this indicator and the human health indicator report recommends the IJC and governments should provide: 1) the resources needed to analyze time trends, 2) the necessary coordination via workshops and teleconferences to refine the edible fish indicator while recognizing differences among jurisdictions, and 3) further investigation of exposure pathways, beyond fish, including spatial and temporal analyses of biomonitoring data as well as morbidity outcomes specifically due to Great Lakes fish consumption.

### Measures:

No guidelines are provided to calculate this indicator; therefore, we have focused our time on collating data from different agencies across the Great Lakes basin into a common location. Further effort will be required to integrate these data into a shared database. Efforts were focused on obtaining contaminants (e.g., PCBs, DDT, mercury, chlordanes, toxaphanes, and mirex) in tissues of key fish species (e.g., Lake Trout, Lake Whitefish, Walleye, Yellow Perch, and Smallmouth Bass) to be included in this indicator.

### Data sources:

State and provincial agencies across the Great Lakes basin monitor trends in fish contaminants across a variety of species; however, the duration and sampling frequencies differ across agencies and



species (Table 1). We have been able to collect data for Illinois, Minnesota, Michigan, New York, Ohio, and Wisconsin, and have confirmed that similar data exist for Great Lakes tribes, Indiana, Pennsylvania, and Ontario.

**Patricia McCann**, Research Scientist, Minnesota Department of Health, 651.201.4915, provided fish contaminants data from Minnesota waters of the Great Lakes.

**Joseph Bohr**, Water Resource Division, Michigan Department of Environmental Quality, 517.284.5525, bohrj@michigan.gov, provided fish contaminants data from Michigan waters of the Great Lakes.

**Tom Hornshaw**, Illinois Environmental Protection Agency, 217.785.0832, thomas.hornshaw@illinois.gov, provided fish contaminants data from Illinois waters of the Great Lakes.

**Gary Klase**, Ohio EPA, Division of Surface Water, 614.644.2865, gary.klase@epa.ohio.gov, provided fish contaminants data from Ohio waters of Great Lakes.

**James Grazio**, Great Lakes Biologist, Pennsylvania Department of Environmental Protection, 814.217.9636, jagrazio@pa.gov, unable to coordinate a time when we were able to meet but likely has access to Pennsylvania data.

**Wayne Richter**, New York State Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, 518.402.8974, wayne.richter@dec.ny.gov, provided digital fish contaminants data from New York waters of the Great Lakes. Indicated that additional data are likely available but in hard copy.

**Jim Stahl**, Senior Environmental Manager, Indiana Department of Environmental Management, 317.308.3187, jstahl@idem.IN.gov, I was directed to Jim Stahl by Dr. Charles Santerre (Purdue University) in late August but was not able to set up a conversation in time to include in the report.

**Candy Schrank**, Toxicologist, Wisconsin Department of Natural Resources, 608.267.7614, candy.schrank@wisconsin.gov, currently working on putting together contaminants data from Wisconsin. Unclear if it will be done in time to add to report.

**Mark Dellinger**, Research Scientist, Medical College of Wisconsin, 414.955.4954, mdellinger@mcw.edu, currently discussing with his tribal contacts the potential to share data with this project, has some concern because they are working on publishing results.

**Satyendra Bhavsar**, Ontario Ministry of the Environment, 416.946.3506, satyendra.bhavsar@ontario.ca, received manuscripts that discuss patterns of contaminants in Canadian waters of the Great Lakes. I requested summary information of trends presented in manuscripts but have not received a response. Manuscripts focus on dioxins, furans, PCBs, and mercury for Lake Trout and Walleye.

#### *Spatial Extent:*

Contaminants data are collected across the Great Lakes basin at irregular spatial scales (Figure 7). Some jurisdictions have set locations sampled at set frequencies (e.g., annually, biannually), while other jurisdictions do not have set sampling locations or schedules. Across jurisdictions, data are primarily organized by specific latitudes and longitudes (though some are spatially referenced to broader locations), and can be scaled up to larger geographic scales.

#### *Temporal extent:*

Jurisdictions differ in sampling duration and frequency, though most agencies have been collecting data since the 1970's on an annual to biannual basis. Sampling often rotates to cover a broader spatial scale, though in general, most sites are sampled multiple times and tend to be associated with a specific geographical region but may not be sampled in all years or on a regular schedule.

## Summary of findings:

Data are present across the basin; however, combining data from different agencies will require collaboration from experts across the basin. These individuals are familiar with their monitoring programs and have expertise on the difficulties associated with integrating data from diverse sources. This effort will prove challenging; however, the work done by Bhavsar and others (2007, 2008, 2010) highlight the insights that can be learned by taking broad, comparative approaches that highlight the complexity of fish contaminant changes across space and time.

## Data gaps and recommendations:

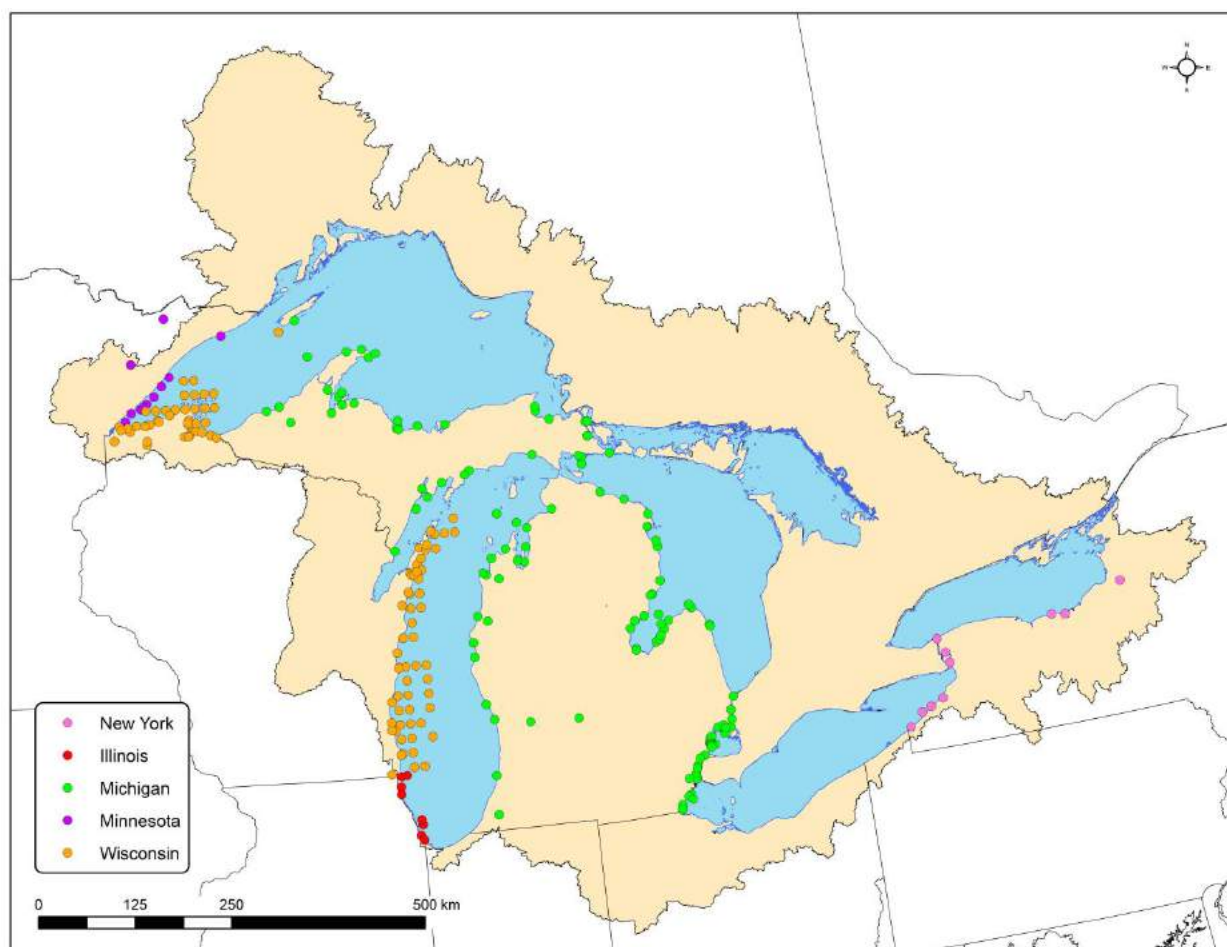
Data exist for this indicator across the basin. Current gaps in the information we have collected are because we have been unable to obtain the data from Indiana, Pennsylvania, and Canada. In the United States, this inability was primarily driven by the busy schedules of our contacts within individual states and the short timeline of this project. In the future, this information will likely be available. Much of the Canadian data has been summarized for Walleye and Lake Trout by Bhavsar and others (2007, 2008, 2010) and is likely to be made available with additional time.

The most significant data gap will be the challenges associated with integrating data from a variety of agencies and jurisdictions. This will require that similar species, size classes, and sexes are used to ensure fair comparisons across space and time and to eliminate artifacts of experimental design. Further integration will also require that analytic methods are identical or appropriate calibration methods exist to all comparison.

An additional challenge to calculate this indicator is that states are not required to report fish contaminants data to a basin-wide data suppository. Though some states do report a portion of their monitoring to the EPA, this is not required, resulting in substantial variation in the amount of information shared across the different states. Further development of this database could help to aid future analyses to provide a holistic view of spatial and temporal differences in the risk of fish contaminants to human health across the basin.

**Table 7.** Summary of contaminant measurements obtained from state agencies in United States.

State	Number of samples	Duration	Species (# of measurements)
Illinois	138	1985-2014	Smallmouth Bass (15), Lake Trout (71), Yellow Perch (52)
Minnesota	815	1970-2010	Alewife (12), Brook Trout (2), Bloater (9), Burbot (41), Chinook Salmon (157), Coho Salmon (78), Lake Herring (83), Lake Sturgeon (1), Lake Trout (198), Lake Whitefish (17), Longnose Sucker (10), Mottled Sculpin (30), Pink Salmon (26), Rainbow Trout (32), Rainbow Smelt (24), Siscowet Lake Trout (70), Walleye (16), White Sucker (9)
Michigan	5882	1983-2013	Black Bullhead (10), Black Crappie (18), Bluegill (58), Brown Bullhead (2), Brown Trout (162), Bullhead (10), Burbot (33), Carp (576), Channel Catfish (251), Chinook Salmon (833), Bloater (2), Coho Salmon (712), Freshwater Drum (112), Lake Herring (31), Lake Trout (565), Lake Whitefish (315), Largemouth Bass (76), Longnose Sucker (41), Muskellunge (18), Northern Pike (128), Pumpkinseed (48), Rainbow Trout (153), Redhorse Sucker (57), Rock Bass (100), Siscowet Lake Trout (148), Smallmouth Bass (187), Splake (7), Walleye (608), White Bass (114), White Perch (38), White Sucker (87), Yellow Perch (382)
New York	594	2010-2012	Brown Bullhead (10), Brown Trout (10), Carp (42), Channel Catfish (26), Chinook Salmon (30), Coho Salmon (48), Freshwater Drum (45), Golden Redhorse (1), Largemouth Bass (28), Lake Trout (113), Rock Bass (51), Rainbow Trout (45), Smallmouth Bass (63), White Perch (50), Walleye (15), White Sucker (15)
Ohio	770	1970-2014	Lake Trout (24), Lake Whitefish (35), Smallmouth Bass (175), Walleye (319), Yellow Perch (217)
Wisconsin	4030	1971-2014	Alewife (49), Black Bullhead (1), Black Crappie (1), Bloater (383), Bluegill (2), Brook Trout (48), Brown Bullhead (7), Brown Trout (292), Burbot (57), Channel Catfish (1), Chinook Salmon (841), Coho Salmon (301), Carp (25), Deepwater Sculpin (12), Freshwater Clam (9), Gizzard Shad (1), Green Sunfish (1), Lake Herring (111), Lake Sturgeon (29), Lake Trout (791), Lake Whitefish (158), Largemouth Bass (1), Longnose Sucker (24), Muskellunge (1), Northern Pike (14), Pink Salmon (3), Pumpkinseed (1), Rainbow Smelt (47), Rainbow Trout (157), Rock Bass (4), Round Whitefish (14), Sculpins (4), Silver Redhorse (2), Siscowet Lake Trout (203), Shorthead Redhorse (6), Slimy Sculpin (10), Smallmouth Bass (10), Splake (6), Spottail Shiner (1), Walleye (142), White Sucker (50), Yellow Perch (210)



**Figure 7.** Sampling locations where contaminant measurements have been collected by state agencies in the United States. Note: Ohio data were not received in time to incorporate into map. Some sampling events target Great Lakes fish within tributaries.

## Coastal Habitat- Shoreline Alteration Index (SAI)

### Summary

The Shoreline Alteration Index (SAI) is a measure of the length of human modified shoreline that is physically and biologically unfavorable to Great Lakes ecosystems. The physical component is the ratio of the lineal length of armored and other “human-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. SAI is a combined measure of protected shoreline length that is physically and biologically unfavorable. The resulting SAI would range from zero (0) representing a highly altered, biologically incompatible shoreline to one (1) representing a biologically compatible shoreline (even though it may be modified by human activities).

### Measures:

Measure	Description
1	Physical component: Ratio of the lineal length of armored shoreline relative to total lineal length of the shoreline (i.e. the ratio x 100 = percent of armored shoreline). More specifically, the P Ratio equals human modified shoreline/total shoreline. The P Ratio is also assigned scores of "poor" (0.7 to 1.0), "fair" (0.4 to 0.7), "good" (0.15 to 0.4), and "excellent" (<0.15).
2	Biological component: The ratio of the lineal length of biologically incompatible structures (shore perpendicular structures, vertical sheet pile, concrete walls, and other "human-made" structures that cannot serve as biological habitat) relative to total lineal length of "human-modified" shoreline (B Ratio).
3	$SAI = 1 - (P \text{ Ratio} \times B \text{ Ratio})$

### **Data sources**

The SAI requires calculated ratios of lengths of modified shoreline and biologically incompatible shoreline. Calculation of the SAI required the integration of multiple data sources, primarily maps developed at various times by several agencies. However, there is negligible data available for the biological portion of the indicator. The physical portion of the indicator, the P Ratio in measure 1, requires historical and current shoreline maps with measured line segments attributed with shoreline types/classes that can be reclassified into 'modified' or 'not modified'. Coarse-scale (i.e. usually larger than 1 km segments of shoreline) basin-wide historical data (pre 1990s) are available as shoreline maps originally developed for oil spill response (e.g. Canadian Environmental Sensitivity Atlas (ESA) and American Environmental Sensitivity Index (ESI)). Two additional shoreline maps provide more recent shoreline maps for comparison: 1) A map of the Lake Ontario shoreline developed for the International Joint Commission (IJC) and 2) A recent shoreline map of the entire US Great Lakes shoreline developed by the United States Army Corps of Engineers (USACE). Each shoreline map is discussed in more detail below.

Using the four shoreline maps available, we developed three comparisons of shorelines to assess change in P Ratio over time: 1) The circa 1990s ESI versus the circa 2012 USACE shorelines for much of the US Great Lakes shoreline, 2) The circa 1990s ESI and ESA and the circa 2002 IJC shorelines for all Lake Ontario shoreline, and 3) The circa 1990s ESI, 2002 IJC, and 2012 USACE shoreline for the US shoreline along Lake Ontario (Figure 8). All shoreline maps required moderate alteration before the physical shoreline indicator could be calculated in order to match spatial extent and intensity of mapping. For example, we excluded extensive mapping of rivers mouths, bays and embayments, and islands if these areas were not mapped in all the shorelines being compared.

Shoreline classes defined in the four shoreline maps were largely inadequate to identify biologically compatible shoreline. Additionally, there is a need to develop consensus on impacts of shoreline modifications on nearshore and coastal biological systems before the biological component of the SAI can be included. Thus, we were unable to calculate the biological shoreline measure (Measure 2) nor were we able to integrate the physical and biological components as required for Measure 3.

### **Environmental Sensitivity Atlas (ESA):**

Canadian shoreline map created by Environment Canada. ESA data characterize coastal environments and wildlife by their sensitivity to spilled oil. Maps represents shoreline condition in the 1980s-1990s. Spatial resolution is approximately 1:24,000 and reach lengths are variable, generally larger than 1 km in length. Maps are available in print and digitized format.

### **Environmental Sensitivity Index (ESI):**

US shoreline map created by National Oceanic and Atmospheric Administration (NOAA), Office of Ocean Resources Conservation and Assessment. ESI data characterize coastal environments and wildlife by their sensitivity to spilled oil. ESI represents shoreline condition in the 1980s-1990s. Spatial resolution is approximately 1:24,000, and reach lengths are variable, generally larger than 1 km in length. The digital version of the ESI is missing Lake Erie and a large section of Lake Michigan.

#### IJC-Lake Ontario:

The updated dataset was developed in 2001 and 2002 to support the International Joint Commission's (IJC's) International Lake Ontario – St. Lawrence River Regulation Study. This map is considered representative of shoreline condition in late 1990s, although the imagery used to create the map is from a much broader timespan. A consistent methodology was utilized to classify the full U.S. and Canadian Lake Ontario shoreline based on the type and extent of shoreline hardening (see Stewart 2002) with the results summarized in the Flood and Erosion Prediction System (FEPS) database (see Baird 2005). The spatial resolution is 1:24,000 to 1:250,000 and reach lengths are 1 km in length.

#### USACE:

The 2012 USACE Oblique photos were used to determine all of the shoreline classification constraints, including the shoreline material type. The oblique images were taken over 1000 feet off of the ground so the classification of the shoreline material type is on a coarse scale. The primary shoreline material covers the majority of the immediate shoreline and human-modified shoreline is simply classified as "Artificial". Spatial resolution is approximately 1:24,000 and reach lengths are 1 km in length.

#### *Spatial coverage:*

The ESA and ESI provide a nearly complete basin line map of circa 1990s shorelines (missing Lake Erie and part of Lake Michigan). The IJC shoreline only includes Lake Ontario and the USACE shoreline includes all US shoreline in the Great Lakes Basin. Figure 1 shows the specific spatial extent of each shoreline comparison.

#### *Temporal coverage:*

Historical/baseline shoreline maps (ESA and ESI) represent conditions from 1980 to the early 1990s, the IJC shoreline represents conditions as of 2002, and the USACE shoreline from 2012 represents "current" conditions.

#### **Summary of Findings:**

The trends summarized here should be interpreted with caution and an analysis of the effect of differences in mapping approaches on trends may be warranted. There is uncertainty in undertaking direct comparison between the various shoreline datasets. Categorization of shoreline is based on shoreline mapping efforts that use reaches of different lengths and different definitions of shoreline classes. The ESA and ESI datasets use shoreline reaches of variable length whereas the Lake Ontario IJC and USACE shoreline maps use fixed 1 km shoreline reaches. It is possible that an increase in human-modified shoreline reflects a general reduction in reach length (due to the inclusion of smaller-scale shoreline modifications) and not an overall increase in modified shoreline. In addition, despite some modification of the shoreline maps to ameliorate this issue, the overall shoreline lengths vary between datasets due to the resolution of the base shoreline mapping used in the classifications. Because the indicator is based on a relative difference in the percent of shoreline within various categories, it is still possible to make some comparisons. However, it should be recognized that direct comparisons between datasets will be highly uncertain without using a common baseline shoreline delineation and

comparable reach lengths. Efforts to update existing datasets should use similar classification methodologies and standardized reach delineations.

#### Comparison 1:

For US shoreline summarized at the basin level, the Great Lakes remain stable with regards to its P Ratio. The P Ratio did increase slightly from the 1990s to 2012, from 0.151 to 0.167 (Table 8). However, substantial shoreline modification must occur for the score to change categories from 'Good' to 'Fair'. At the whole-lake level, Lake Superior and Lake Huron received 'Excellent' scores in the 1990s, but Lake Huron experienced enough hardening to decrease its score from 'Excellent' to 'Good' in 2012 (Table 8). Whereas Lake Michigan and Lake Ontario both received 'Good' scores in the 1990s, Lake Ontario fell into the 'Fair' category in 2012. Lakes Superior, Huron, and Ontario all experienced an increase in shoreline modification, whereas Lake Michigan experienced a small decline.

The general trend of increasing shoreline modification was also observed at the subbasin level. Overall, 11 of the 15 subbasins we evaluated experienced an increase in shoreline modification (Table 9). Southern Lake Michigan, Central Lake Ontario, and Whitefish Bay all had their P Ratio increase by more than 0.12. Of the 11 subbasins that increased in hardening, five declined in rating. Not all locations are experiencing shoreline modification, however. The St. Mary's River, Green Bay, Central Lake Superior, and Northern Lake Huron all saw declines in their P Ratio. However, none of these areas increased in rating, as all but Green Bay are in the 'Excellent' category as of 2012.

#### Comparison 2:

When comparing the 1990s ESI/ESA data, to the IJC shoreline data from 2002 for Lake Ontario, the shoreline appears to be undergoing a rapid increase in hardening. At the whole lake level Lake Ontario has experienced a nearly 100% increase in the proportion of modified shoreline (Table 10). Further, all Lake Ontario basins have also declined in shoreline ratings, with only Eastern Lake Ontario retaining a 'Good' rating as of 2002. However, it should be noted that these two datasets vary in shoreline reach resolution, and because of the limited spatial extent (i.e. Lake Ontario), trends may be influenced by differences in mapping and should be interpreted with caution.

#### Comparison 3:

For this three time step comparisons (i.e. circa 1990s, 2002, 2012) limited to a smallest section of shoreline in Lake Ontario, the P Ratio increases from 0.450 to 0.596 and then decreased to 0.336. It is very likely this calculated decrease is the result of a change in how shoreline is classed in the USACE shoreline map, rather than actual changes in the degree of human modification of the shoreline itself. This provides an excellent example of why it is necessary to investigate the effects of differences in mapping as well as trends in shoreline modification.

#### Data gaps and Recommendations

With the possible exception of some extremely detailed shoreline maps developed by the Ohio DNR for Lake Erie we were not able to acquire, data do not currently exist to calculate the biological shoreline indicator (Measure 2) and thus also the SAI (Measure 3). The primary limitation is that in both the ESA and ESI, classes for human-modified shoreline include structures that contains both favorable and non-favorable structure types and the USACE 2012 shoreline map simply designates "artificial" shoreline with no ability to discern biological compatibility.

Because armoring is rarely removed, combined use of the ESA and the ESI maps are sufficient to establish a baseline, or "best case" scenario for the physical shoreline indicator. Lake Erie and missing portions of the Lake Michigan shoreline have been mapped in the ESI, but have not been digitized. If

these mapped areas in the ESI can be digitized, a baseline map of the entire Great Lakes shoreline can be developed.

Because of advances in mapping and the wide spread availability of high resolution imagery, NOAA/USACE has no plans to revisit km-by-km shoreline mapping along Great Lakes shorelines. No updates to the ESA/ESI shorelines are planned either. Instead, updated shoreline maps have been developed in limited areas around the Great Lakes (e.g. portions of Lake Michigan and Southern Georgian Bay). More recent shoreline maps could be developed using new and recurring high-resolution aerial photography and/or satellite imagery. This data exists for much of the U.S. shoreline (see NOAA's Digital Coast viewer). Computers could be trained to classify imagery data into shoreline types/structures. A map of spatially referenced points for all visible man-made structures along Great Lakes shorelines (derived from direct interpretation of aerial photos), may be of great assistance during such training.

As described in the "Summary of Findings" section above, there is uncertainty in undertaking direct comparison between the various shoreline datasets, as well as some specific issues with the datasets themselves. With the exception of Lake Ontario, this indicator cannot be calculated with existing maps of Canadian shoreline. The only map of the complete Canadian shoreline is the circa 1990s ESA and an updated map is not available. The digitized 1990s shoreline map for the US (ESI) does not include Lake Erie and a large portion of the eastern shore of Lake Michigan. Although the IJC Lake Ontario dataset was compiled in 2002, these data are based on imagery from as early as 1950 to as late as 1999. Therefore, this dataset may not actually represent a true representation of shoreline condition in in the early 2000s

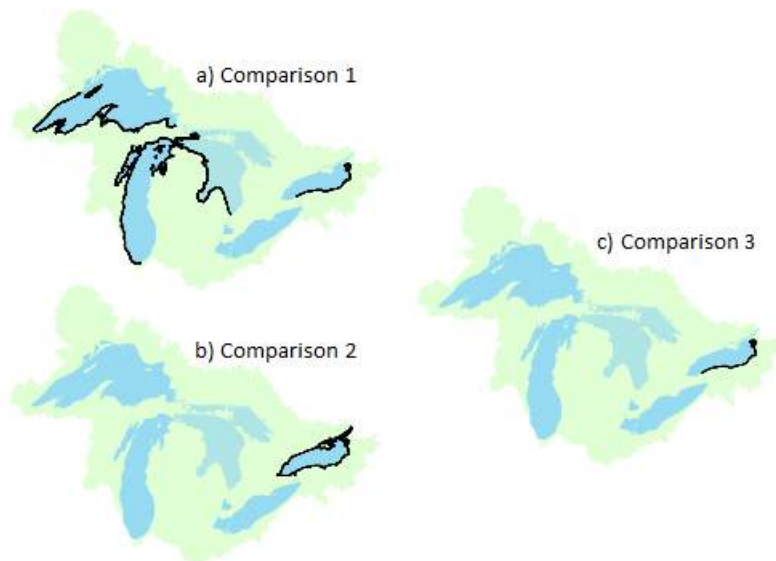


Figure 8. Spatial extents of the three shoreline comparisons as shown by black highlighted shorelines: a) The circa 1990s ESI and the circa 2012 USACE shorelines, b) the circa 1990s ESI and ESA and the circa 2002 IJC shorelines, and c) the circa 1990s ESI, 2002 IJC, and 2012 USACE shorelines.

Table 8. Change in human modification of shoreline for the ESI (circa 1990s) versus USACE (circa 2012) summarized at the whole basin (GLB) and whole lake scale. A positive change in the P ratio and/or a decline in score suggests the amount of human modified shoreline has increased from the 1990s to 2012.

Spatial Extent	Spatial Unit	1990s ESI		2012 USACE		Change in P-Ratio	Change in Score
		P-Ratio	Score	P-Ratio	Score		
GLB:	GLB	0.151	Good	0.167	Good	0.016	None
Lake:	Huron	0.141	Excellent	0.161	Good	0.021	Decline
	Michigan	0.215	Good	0.203	Good	-0.013	None
	Ontario	0.318	Good	0.427	Fair	0.109	Decline
	Superior	0.063	Excellent	0.075	Excellent	0.012	None

Table 9. Change in human modification of shoreline for the ESI (circa 1990s) versus USACE (circa 2012) summarized at the subbasin scale. A positive change in the P ratio and/or a decline in score suggests the amount of human modified shoreline has increased from the 1990s to 2012.

Spatial Unit	1990s ESI		2012 USACE		Change in P-Ratio	Change in Score
	P-Ratio	Score	P-Ratio	Score		
Northern Lake Michigan	0.077	Excellent	0.078	Excellent	0.001	None
North Central Lake Michigan	0.073	Excellent	0.075	Excellent	0.002	None
Central Lake Michigan	0.351	Good	0.386	Good	0.035	None
Southern Lake Michigan	0.696	Fair	0.833	Poor	0.136	Decline
Green Bay	0.218	Good	0.161	Good	-0.058	None
Western Lake Superior	0.062	Excellent	0.066	Excellent	0.005	None
Central Lake Superior	0.048	Excellent	0.046	Excellent	-0.002	None
Eastern Lake Superior	0.085	Excellent	0.114	Excellent	0.029	None
Whitefish Bay	0.076	Excellent	0.197	Good	0.122	Decline
Central Lake Ontario	0.358	Good	0.491	Fair	0.133	Decline
Eastern Lake Ontario	0.318	Good	0.416	Fair	0.098	Decline
Northern Lake Huron	0.083	Excellent	0.051	Excellent	-0.032	None
Central Lake Huron	0.129	Excellent	0.215	Good	0.086	Decline
Saginaw Bay	0.247	Good	0.366	Good	0.120	None
St. Marys River	0.072	Excellent	0.028	Excellent	-0.044	None



Table 10. Change in human modification of shoreline for the ESI and ESA (circa 1990s) versus IJC Shoreline (circa 2002) for Lake Ontario summarized by the entire lake and by lake subbasin spatial extents.

Spatial Extent	Spatial Unit	1990s ESI/ESA		2002 IJC		Change?	
		P-Ratio	Score	P-Ratio	Score	Change in P-Ratio	Change in Score
Lake	Ontario	0.230	Good	0.441	Fair	0.211	Decline
Subbasin:	E. Lake Ontario	0.122	Excellent	0.368	Good	0.246	Decline
	C. Lake Ontario	0.320	Good	0.484	Fair	0.164	Decline
	W. Lake Ontario	0.704	Poor	0.763	Poor	0.060	None

## Extent, Composition, and Quality of Coastal Wetlands

### Summary:

This indicator tracks trends in Great Lakes coastal wetland ecosystem health by measuring wetland area and extent, monitoring water quality, and calculating condition indices for vegetation, macroinvertebrates, fish, plants, amphibians, and birds. Data exist for this indicator but there have been delays in database development and we are unable to include the data in this database. Don Uzarski has agreed to share the data with both SOGL and the IJC when they become available. Assessing trends in this indicator may be difficult as there is minimal older data to which indicator status based on current sampling efforts can be compared.

### Measures:

Measure	Description
1	Macroinvertebrate Index of Biotic Integrity (IBI) scores
2	Fish IBI scores
3	Measure of wetland ecosystem health based heavily on the Floristic Quality Index (FQI) and the occurrence of invasive species
4	Some measure of amphibian (frogs and toads) health (measure in development)
5	Some measure of bird health (measure in development)
6	Wetland Area and Extent: Change measured through recurring remote sensing (calculation every 5 years is suggested)

### Data sources

#### Measures 1-5:

Data are from sampling and summarization efforts led by the Great Lakes Coastal Wetland Consortium (GLCWC). Don Uzarski (uzars1dg@cmich.edu) and Matt Cooper (uzars1dg@cmich.edu) are the lead authors we have contacted.

#### Measure 6:

Don Uzarski and Laura Bourgeu-Chavez are the primary data holders.

*Temporal extent:*

Measures 1-5:

Sampling began in earnest in 2011 and by the end of 2015 the GLCWC hopes to have all wetlands greater than 4 hectares with a Great Lakes connection sampled at least once.

Measure 6:

Indicator suggests a 5 year cycle. Imagery (mostly from 2010) was used to develop the wetland map created by Laura Bourgeau-Chavez at MTRI.

*Spatial extent:*

Measures 1-5:

Individual wetlands on all Great Lakes identified by the GLCWC. A map of these wetlands is included as a shapefile in the GLAHF/IJC spatial framework. For measures 1-5, some measures are for specific vegetation zones within a wetland. How the data will be “scaled-up” to an entire wetland and then to larger spatial units such as subbasins and lakes is unknown.

Measure 6:

Unknown.

**Summary of Findings**

Data do exist for this indicator and are collected and processed by the Great Lakes Coastal Wetlands Consortium (GLCWC). There have been delays in database development and we have yet to receive the actual data for this indicator. Don Uzarski, PI of the GLCWC, has agreed to share the data with both SOGL and the IJC when they are available.

**Data gaps and recommendations:**

We cannot fully address specific data issues or analyze data gaps for most of the indicator measures, as the data is held by the GLCWC and is still in development. For measures 1-5, sampling locations are selected by vegetation zone within a wetland. It is unclear how to scale-up calculations on individual vegetation zones within a wetland to an entire wetland and then from a wetland to larger spatial units such as subbasins and lakes. This topic has been a matter of debate within the GLCWC. It is also unclear how the different measures will be integrated into a single measure of wetland condition. In addition, we are aware of substantial delays in the calculation of Measure 6 because wetland boundaries occur at different spatial scales. Calculations for this measure are apparently very time-consuming and there is no clear plan for calculating this measure.

Sampling for the GLCWC began in 2011 and by 2015 all Great Lakes coastal wetlands were expected to have been sampled. The GLCWC sampling plan was to sample a different set of wetlands every year for five years but include annual sampling at a subset of sites. The GLCWC likely represents the baseline condition for Great Lakes coastal wetlands to which future data can be compared. Comparable data may exist, especially with the Great Lakes Environmental Indicators project, however this data was not available and only includes a subset of the Great Lakes coastal wetlands. Don Uzarski and the GLCWC is the best resource for ultimately addressing these currently unresolved issues.

## **Water levels**

**Summary**

The water level indicator tracks trends in the average, timing, and variability of lake water levels. This indicator includes measures of the maximum and minimum water levels observed on each lake per year, including temporal magnitude and extent of the rise and fall of water levels. Long-term data are available for calculation of all measures.

**Measures:**

Measure	Description
1	Long-term water level variability (as measured by the rolling standard deviation of monthly mean water levels over the period of record for each of the Great Lakes).
2	Timing of seasonal water level maximum and minimum (as measured by changes in the month in which the seasonal water level maximum and minimum occur).
3	Magnitude of seasonal rise and decline (as measured by the magnitude of spring rise and fall decline).
4	Lake-to lake water level difference (as measured by 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.)

**Data sources**

Monthly Lake-Wide Average Water Level data for January 1860 to December 2013 were provided by Drew Gronewold. Data can also be downloaded from the Great Lakes Water Level Dashboard. The Great Lakes Water Level Dashboard is sponsored by the Great Lakes Restoration Initiative (GLRI), the Cooperative Institute for Limnology and Ecosystems Research (CILER), and the Great Lakes Environmental Research Laboratory (GLERL), part of the National Oceanic and Atmospheric Administration (NOAA). Water levels are currently recorded at 53 monitoring stations in the U.S. (NOAA) and 33 stations in Canada (Canadian Hydrographic Service) through a binational partnership. However, only a few of these monitoring stations contribute to the monthly average values used for this indicator, and the specific stations used vary with data year. In 1992, the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data approved a set of gauges (U.S. and Canadian) for each lake that water resource professionals believe give the most accurate reflection of the lake's overall water level when averaged. These 10 gauges are used to calculate monthly averages for the period of record from 1918 to 2013. Lakes Michigan and Huron are treated as a single, hydraulically connected lake (hereafter referred to as Lake Michigan-Huron). From 1860 to 1917, monthly water levels were estimated from a single gauge per lake which was then adjusted for isostatic rebound for Lakes Superior and Erie. More details on the specific gauges used to calculate the monthly lake-wide averages and isostatic rebound adjustments are available at <http://www.glerl.noaa.gov/data/dashboard/info/opLevels.html>. Measures 1-3 were calculated using R scripts provided by NOAA GLER and modified to produce output tables as needed.

*Spatial coverage:*

Water level indicators are recorded at the whole-lake scale. Michigan and Huron are treated as one hydraulically connected lake referred to as Michigan-Huron.

*Temporal coverage:*

All measure calculations are based on monthly lake-wide average water level data from January 1860 thru December 2013.

**Summary of Findings:**

Note: The R script that Drew Gronewold at NOAA GLERL provided calculates many of the measures and produces a series of complex figures for exploring trends in measures 1-3 of this indicator. These figures are provided as a pdf in the database and portions of some are included in this report. We have also included two simplified figures we developed for measure 1 and figures for measure 4, lake-to-lake water level difference, which are not included in the NOAA GLERL figures.

*Measure 1:*

Lake levels were inherently variable for the first 150 years of the dataset. Both Lake Michigan-Huron and Lake Erie water levels appeared to decline until the 1930s, and then appeared to increase until the 1980s. All lakes appear to be declining since the 1980s (Figure 9). When raw lake levels are computed as a deviation from the long-term mean, recent lake levels appear to either hover around the mean or increase (Figure 10).

*Measure 2:*

The month of minimum water levels has remained relatively consistent since 1860 for Lakes Superior and Michigan-Huron and Superior, but has substantially increased (moved earlier in the year) for Lakes Erie and Ontario (Figure 11). Although each lake shows some fluctuations of timing of water level maximums over the period of record, there do not appear to be any major shifts in the timing of water level maximum in the Great Lakes since 1860 (Figure 12).

*Measure 3:*

Given the complexity of this measure, we prefer to leave the interpretation of trends in the timing and magnitude of the seasonal rise and decline to water level experts.

*Measure 4:*

All lakes show trends in lake-to-lake water level differences over the period of record (Figure 13). As compared to the long-term average difference in lake levels, water levels in Lake Michigan-Huron from 1860 to 1900 were comparatively higher than in Lake Superior, while from 1930 to 1970 water levels in Lake Superior were comparatively higher. As compared to the long-term average difference in water levels in Lakes Michigan-Huron, the general trend since 1860 is a shift to relatively higher levels in Lake Erie. As compared to the long-term average difference in lake levels, water levels in Lake Ontario from 1920 to 1960 were relatively higher than in Lake Erie, while from 1860 to 1900 and 1970 to 2000 water levels in Lake Erie were comparatively higher.

**Data gaps and Recommendations**

There are no known data gaps and there are internationally approved buoys that are used to calculate water levels for all lakes. Pre-1918 levels may not be comparable to data after 1918. The decision to use pre-1918 data needs to be resolved by experts in the field. We also recommend that that a full analysis of water levels trends be conducted by Great Lakes hydrology experts who are knowledgeable about trends in precipitation, evaporation, tributary flows, and barriers, and who can best interpret causes of observable trends in water levels.

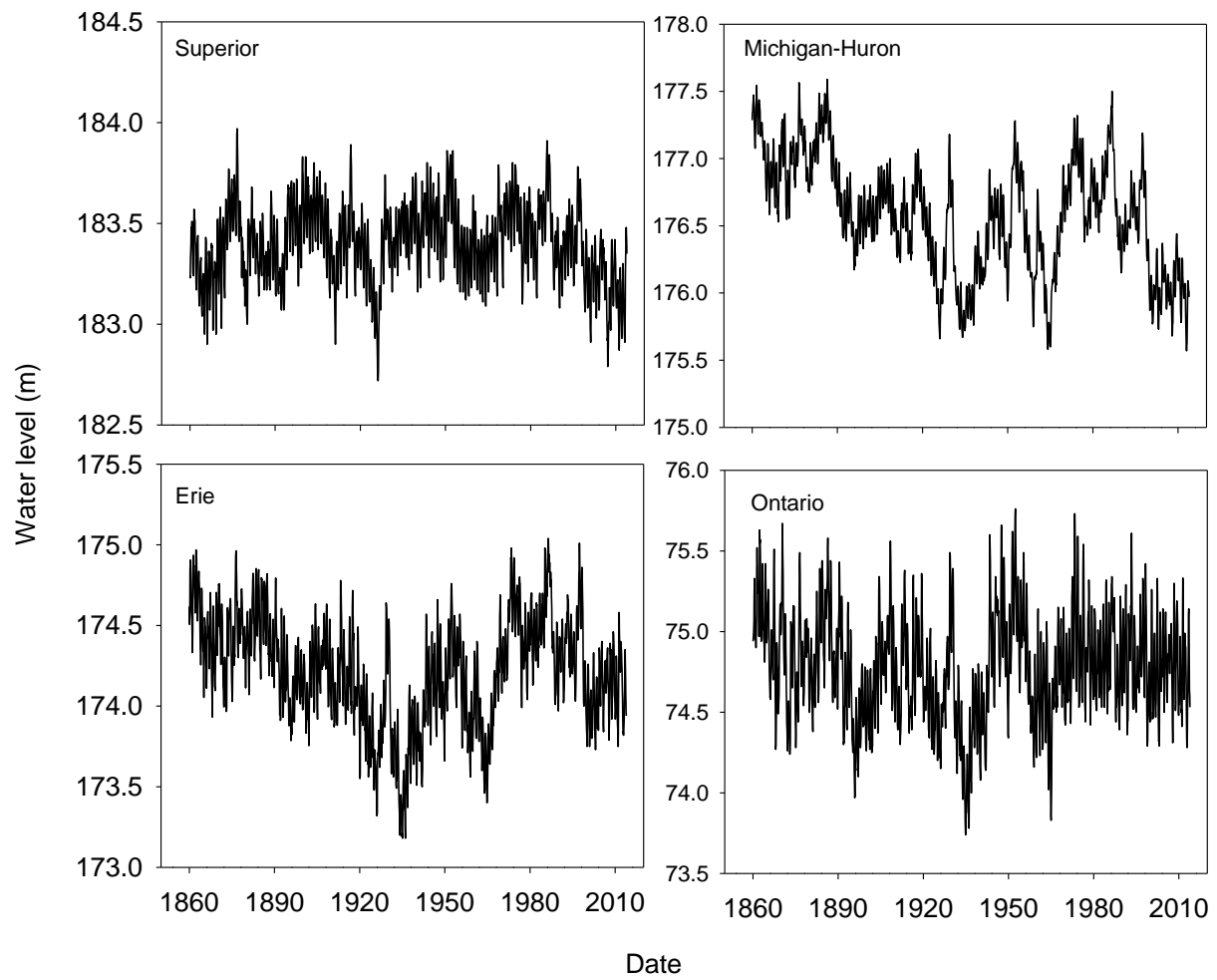


Figure 9. Great Lakes monthly average water levels 1860-2013.

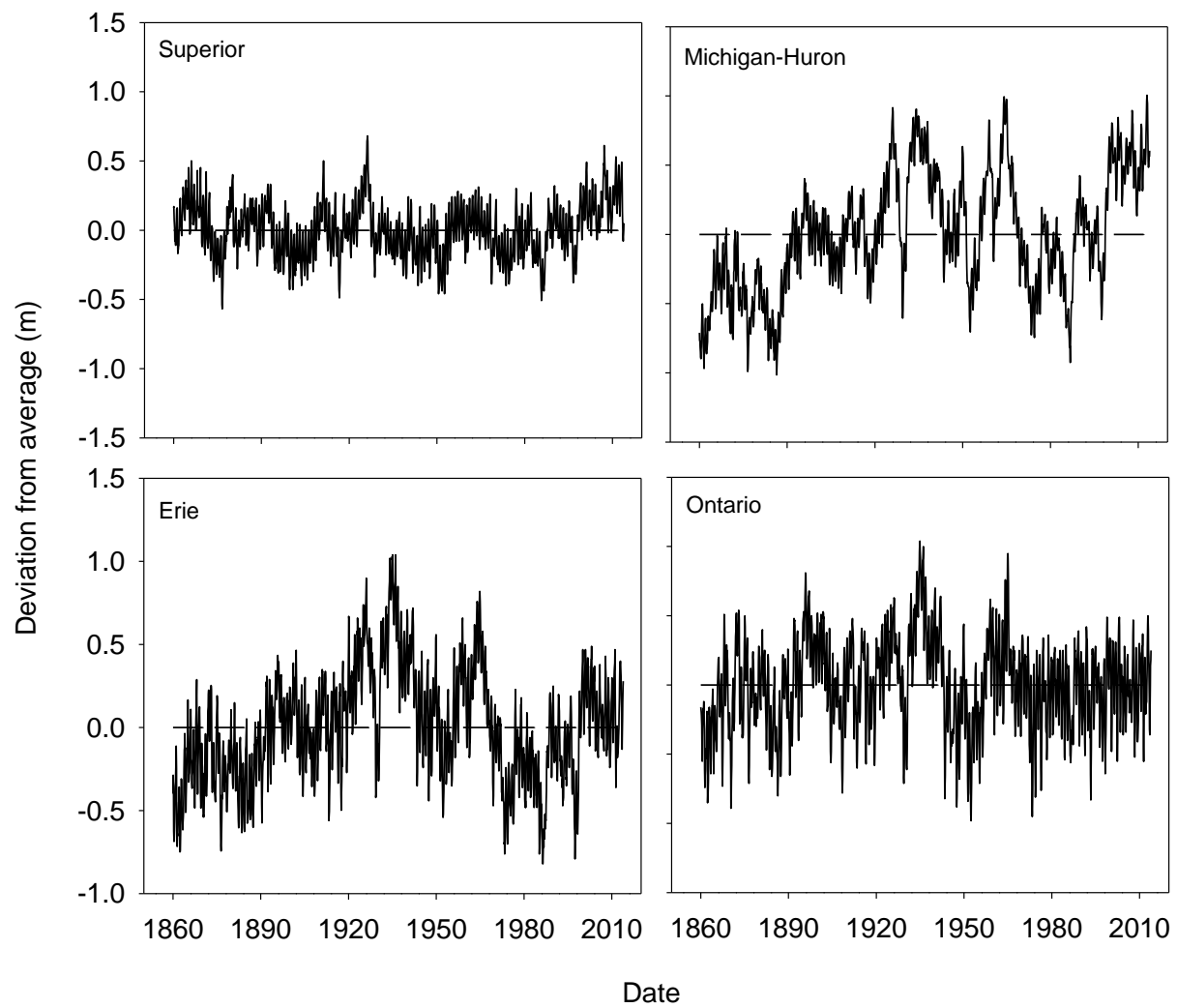


Figure 10. Great Lakes water monthly average water levels in deviation from the long-term average 0 (shown by the reference line).

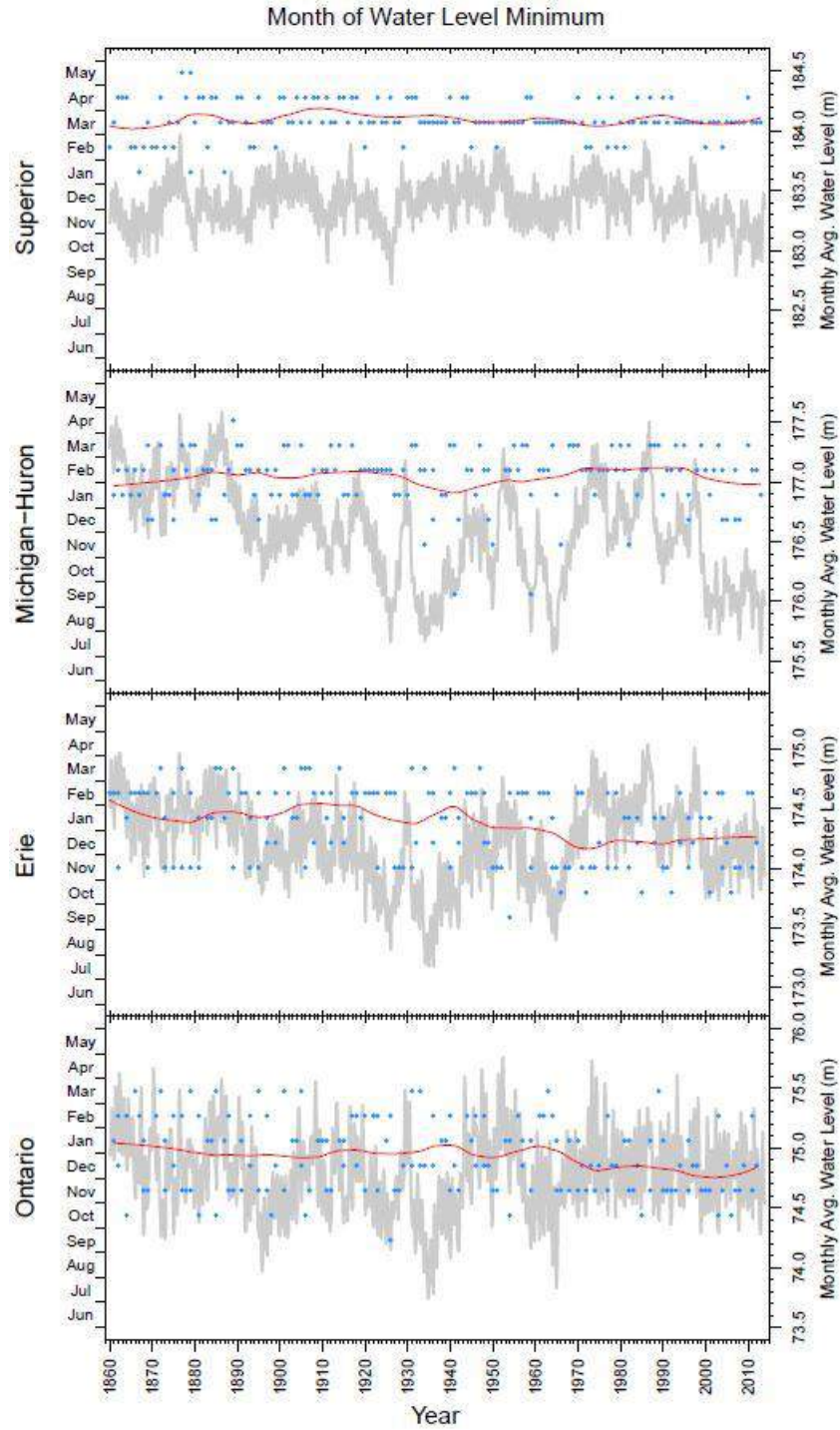


Figure 11. Month of water level minimum in the Great Lakes (1860-2013). This figure was provided by Drew Gronewold. The gray lines represent the average monthly lake levels, the blue dots represent the month of water level minimum, and the red line is a loess curve (produced by) to explore trends in timing of water level minimums.

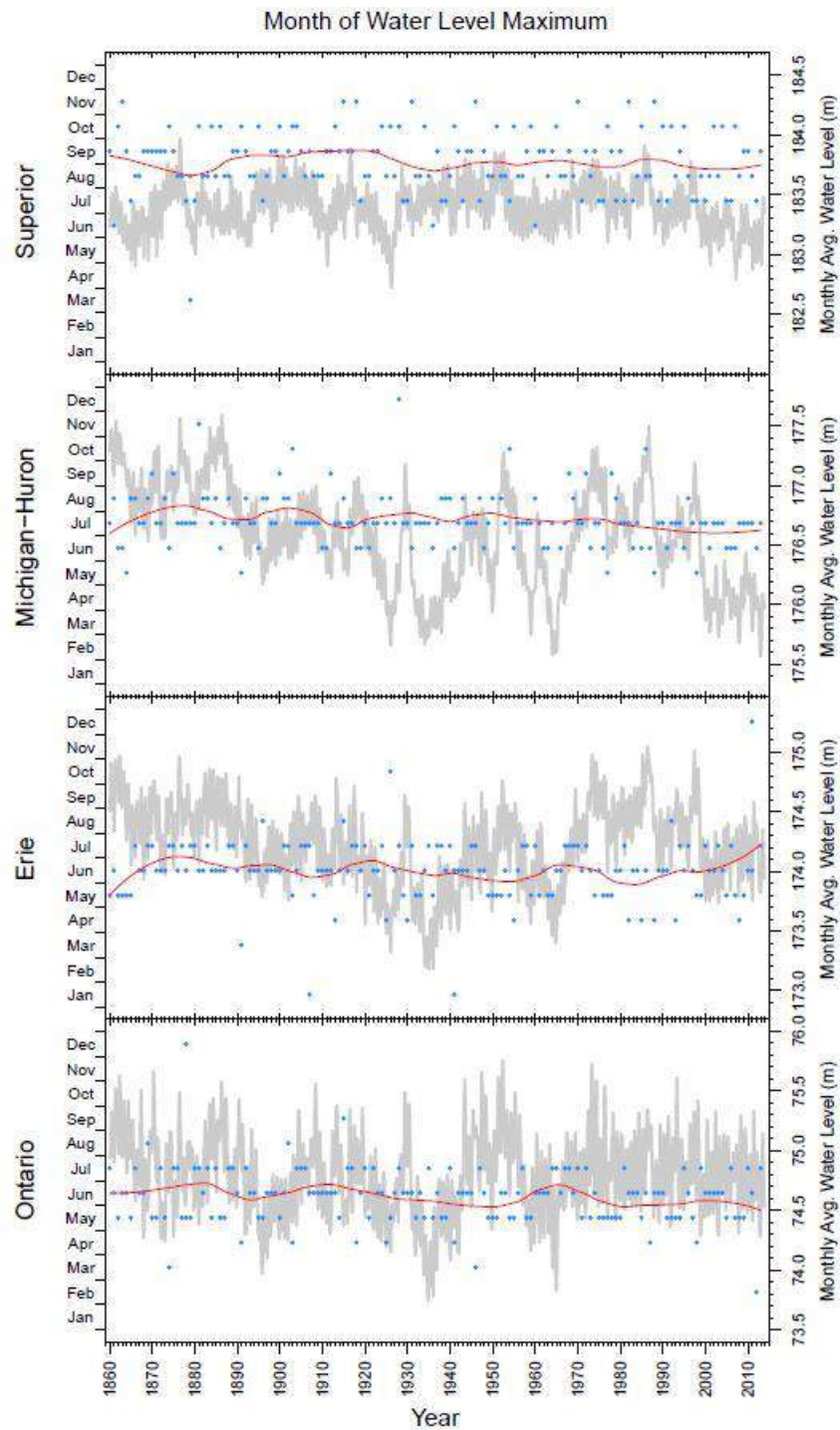


Figure 12. Month of water level maximum in the Great Lakes (1860-2013). This figure was provided by Drew Gronewold. The gray lines represent the average monthly lake levels, the blue dots represent the month of water level maximum, and the red line is a loess curve (produced by locally weighted scatterplot smoothing) to explore trends in timing of water level maximums.



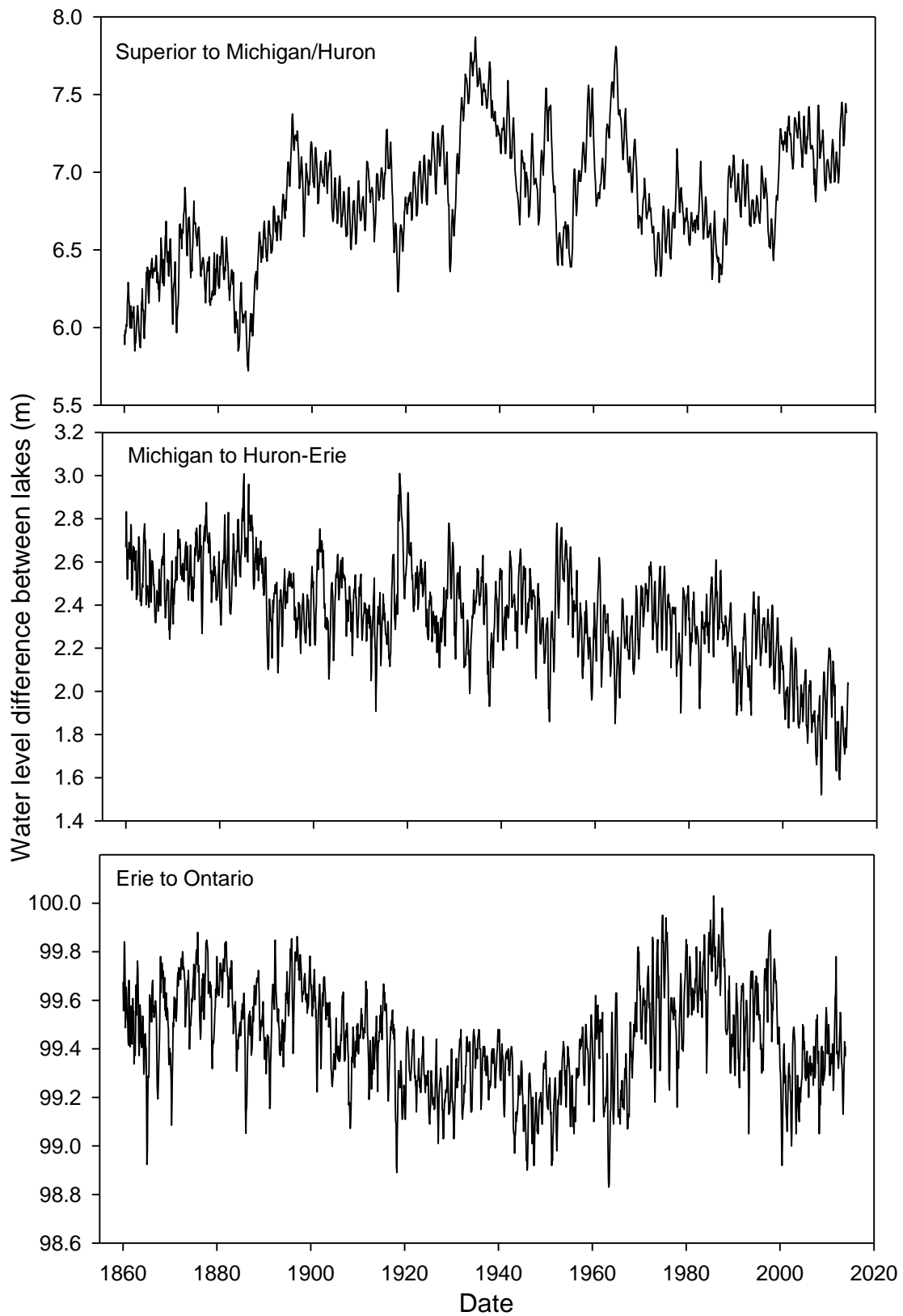


Figure 13. Lake-to-lake Water level differences for upstream to downstream lakes for monthly mean water level from 1860 to2013.

## Tributary Physical Integrity

### Summary:

The Tributary Physical Integrity indicator consists of three components, a measure of hydrologic alteration that requires daily discharge measurements, a measure of connectivity to receiving waters that requires locations of the first barriers on main stems of tributaries and their distances to the Great Lakes as well as total main stem lengths, and a measure of turbidity in relation to a turbidity threshold that requires daily turbidity measurements. Data are available for all three components with some limitations. First, barriers defined within the dataset focus on large dams, and ignore most small structures within the basin. Second, turbidity data are limited to relatively few stations with uneven spatial coverage. This may limit the use of the turbidity measures in the Tributary Physical Integrity indicator.

### Measures:

Measure	Description
1	<p>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 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 (see Baker et al. 2004).</p> $\text{R-B Index} = \frac{\sum_{n=1}^N  q_n - q_{n-1} }{\sum_{n=1}^N q_n}$
2a	<p>Tributary connectivity to receiving waters: Tributary connectivity for an individual watershed = (Lb/Lm) × 100 where Lb is the distance between the Great Lakes and the first barrier on the main stem channel and Lm is the total length of the main stem channel.</p>
2b	<p>Tributary connectivity to receiving waters: Tributary Connectivity for multiple watersheds is calculated by summing the total length of main stem channels without barriers and then dividing by the total sum of main stem channel lengths.</p>
3a	<p>Sediment-turbidity measure: Turbidity Exceedance Time is the proportion of time that the turbidity threshold (T) is exceeded during the time series (t<sub>n</sub> &gt; T) divided by the total time within the series (see equation in cell to the right). 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). In other words, days in the year that the mean daily turbidity value exceeded the threshold, divided by days of data in that year.</p> $\text{Turbidity Exceedance Time} = \frac{\sum_{n=1}^N (t_n > T)}{\sum_{n=1}^N t_n}$
3b	<p>Sediment-turbidity measure: 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<sub>n</sub> &gt; 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. In other words, of the days that the threshold was</p>

exceeded, find the average turbidity value across those exceedance days and divide it by the threshold value.

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

---

#### **Data sources:**

##### **Measure 1:**

Data collected from stream flow gages managed by USGS (for rivers in the US) and HYDAT (for rivers in Canada) were used to calculate mean daily flows for tributaries in the Great Lakes Basin. All gage stations with flow data are included. These may include multiple gages within the same Great Lakes Hydrography Dataset watershed (GLHD watersheds) and gages no longer in operation.

##### **Measure 2:**

We used the Great Lakes Hydrography Dataset, the watershed package integrated with GLAHF, for the river flowlines, the National Anthropogenic Barrier Dataset (NABD) for the US barriers, and the Ontario Provincial Dam Inventory (PDI) for Canadian barriers. The NABD was developed by Michigan State University and spatially linked the point dataset of the 2009 National Inventory of Dams (NID) created by the U.S. Army Corps of Engineers (USACE) to the NHDPlusV1 (Cooper et al. In Press). The NID consists of dams meeting at least one of the following criteria: 1) High hazard classification - loss of one human life is likely if the dam fails, 2) significant hazard classification - possible loss of human life and likely significant property or environmental destruction, 3) equal or exceed 25 feet in height and exceed 15 acre-feet in storage, or 4) equal or exceed 50 acre-feet storage and exceed 6 feet in height. Besides their spatial locations, dams included in NABD were modified based on 1) dam removals that occurred after development of the 2009 NID and 2) identification of duplicate dam records along state boundaries (cases where more than one state reported the same dam). The Ontario Dam Inventory (ODI) is a point based (x, y location) inventory of medium and large dams throughout Ontario. The ODI does not contain small dams, small water control structures, beaver dams, water crossings, or culverts. Between 2003 and 2009 the Lands & Waters Branch of the MNR worked in association with Conservation Ontario and MNR districts to produce the Provincial Dam Inventory (PDI). PDI data for medium and large size dams that passed quality control processes have been incorporated into the ODI. As part of GLAHF, the dams in Ontario were spatially linked to the river network and some dam locations were corrected or adjusted to better reflect actual dam locations with respect to mapped river flowlines.

##### **Measure 3:**

In 2009 the USGS began a trial continuous turbidity monitoring program at selected river monitoring stations. This program was expanded to additional sites in 2010 and 2011. The submersible turbidity device USGS uses measures turbidity with a single detector at 90 degrees to the incident beam, an infrared, monochromatic beam with a typical output in 780-900 nm range. Measurement is in Formazin Nephelometric Units (FNU). We chose to use the mean daily turbidity values for the calculations, although maximum daily turbidity data are also available if desired for indicator calculation. We calculated Turbidity Exceedance Time and Turbidity Concentration Ratio using three common turbidity thresholds, 10, 25, and 50 FNUs.

#### ***Spatial extent:***

##### **Measure 1:**

R-B Flashiness was calculated at stream gages throughout the Great Lakes Basin. A total of 239 streams gages had adequate data for calculation of the flashiness index. Lake Michigan contained the largest number of streams (72) whereas Lake Ontario (19) and Lake St. Clair (7) contained the fewest.

#### Measure 2:

R-B Flashiness was calculated for watersheds throughout the Great Lakes Basin. We quantified connectivity for a total of 2,268 watersheds across the Great Lakes Basin. Lake Superior contained the largest number of watersheds (665), whereas Lake Michigan contained the fewest (290).

#### Measure 3:

We calculated turbidity measures for 23 monitoring stations located throughout the Great Lakes Basin. However, most of stations are near Milwaukee, Wisconsin in the Lake Michigan basin (Figure 14).

#### *Temporal extent:*

#### Measure 1:

We have some records as far back as 1900 up to 2014, although this varies with the specific stream gage.

#### Measure 2:

Data exists for circa 2010 based on barriers existing at that time. No time series exist.

#### Measure 3:

Data exists for this measure from 2009-2014, depending on the station. Most of the stations with the longer records are around Milwaukee, Wisconsin.

### **Summary of Findings**

#### *Measure 1:*

We conducted simple linear regressions to quantify general trends in flashiness (i.e. no change, increasing, decreasing) across Great Lakes streams at gaged stations. Results of this analysis indicate that more streams at gaged locations across the Great Lakes demonstrate no change in flashiness compared to either increasing or decreasing (Figure 15). Across lakes, between 42-65% of all gaged locations are not changing in flashiness. Lake Ontario has the highest percent of locations that are increasing in flashiness (42%), whereas Lake Superior has the lowest percent (11.5%). Other lakes are between 14% and 24% (Figure 15). However, more streams at gaged locations are decreasing in flashiness than increasing. On most lakes, between 25-30% of all gaged locations are decreasing in flashiness. However, Lake Ontario has the fewest locations that are decreasing in flashiness (16%).

#### *Measure 2:*

Evaluated at the Great Lakes Basin extent across all river lengths, connectivity is 68%. In contrast connectivity is only 35.1% for the 100 largest streams (tributaries of >100 km in length). Overall, Lake Superior has the highest watershed connectivity (75%), whereas Lake Michigan has the lowest (55%) (Figure 16). At the subbasin level, there is substantial variation in connectivity. The two subbasins with the highest watershed connectivity are Whitefish Bay (97%) and St. Mary's River (95%). Subbasins with the lowest watershed connectivity are Southern Lake Michigan (41%) the North Channel and Georgian Bay (47%), and the Central Lake Michigan (51%) (Figure 17).

### *Measure 3:*

We did not calculate trends in turbidity measures because of the short time series for these data (<5yrs for most monitoring stations).

### **Data gaps and Recommendations**

There are no known data gaps for either Measure 1 (Flashiness) or Measure 2 (Connectivity), although both have substantial issues regarding either spatial or temporal extent. For Measure 1 we did not review gage station descriptions to assess whether a gage station's flow was extensively regulated by upstream impoundments (as suggested in Baker et al. 2004), nor did we choose between multiple gages within a watershed (all gages with sufficient data are included). We also included all gages with at least 5 years of R-B Flashiness estimates in the trends analyses. We did not explore how use of daily or hourly flow data affected the R-B flashiness index. Finally, although we used the slope of the best fit line to quantify trends in the R-B Flashiness of a watershed over time, more finessed trends analyses that can account for non-linearities in trends are possible. One substantial issue with the dataset we collected is that some gages in the trends worksheet are no longer in service. Thus, our analysis may be biased in that we were unable to compare only streams that had a continuous record. Further, streams that do have continuous records likely have inconsistent time series start dates, thus complicating the analysis further. Significant effort is likely required to develop a balanced measure that can incorporate inconsistent gage data into a measure that is representative of actual trends.

For Measure 2, connectivity of tributaries to the Great Lakes is likely overestimated because small dams and other barriers to fish movement are not included in either the US-based National Anthropogenic Barrier Dataset (NABD) dataset or the Ontario Provincial Dam Inventory (PDI). Another concern is whether dams included in the NABD dataset are equivalent in size to dams included in the PDI. The NABD data for US rivers is dominated by large dams, and mid-sized dams are inconsistently represented. In contrast, the PDI includes medium and large dams. There are efforts underway in the Great Lakes basin to address these issues and create a more complete dam and barrier dataset. Having such a dataset would be an important improvement over current barrier datasets.

Another concern is that summaries of connectivity condition at the watershed spatial extent can be very misleading. Because connectivity is proposed as a unitless measure for this indicator, a very small stream with 100% connectivity will be considered equally connected as a very large river with 100% connectivity. However, the potential ecological effect of connectivity of the two rivers is likely quite dissimilar. We recommend including river size in any discussion of connectivity at the watershed spatial extent. One potential improvement might be to include actual river miles connected to the Great Lakes as a complimentary indicator.

Measure 3 contains several data gaps. A test monitoring program began in 2009 at select gage stations in the US and expanded to additional stations in 2010 and 2011. Only 23 stations have sufficient data to calculate the turbidity measures, and of these, only three stations have the full six year record. Seven stations only have a single year of sufficient data. There are no equivalent programs monitoring turbidity in Canadian rivers. However, Environment Canada's Water Survey (HYDAT database) does include suspended sediment concentration estimates (in mg/L) on Great Lakes tributaries. Without calibration of the USGS turbidity data, these two data sets are not comparable. As such, only the USGS gauges are used for the calculations in this report. As seen in Figure 14 (which indicates monitored locations with the number of years of currently available data), turbidity sampling efforts are also unevenly distributed across the Basin.

### **References:**

Cooper, A. R., D. M. Infante, K. Wehrly, L. Wang, and T. Brenden. In press. Understanding large-scale dam influences on fishes: Identifying indicators and quantifying effects. *Ecological Indicators*.



Figure 14: Turbidity monitoring stations. Basin wide map and inset of area around Milwaukee, Wisconsin with stations marked by the number of years of continuous turbidity measurements.

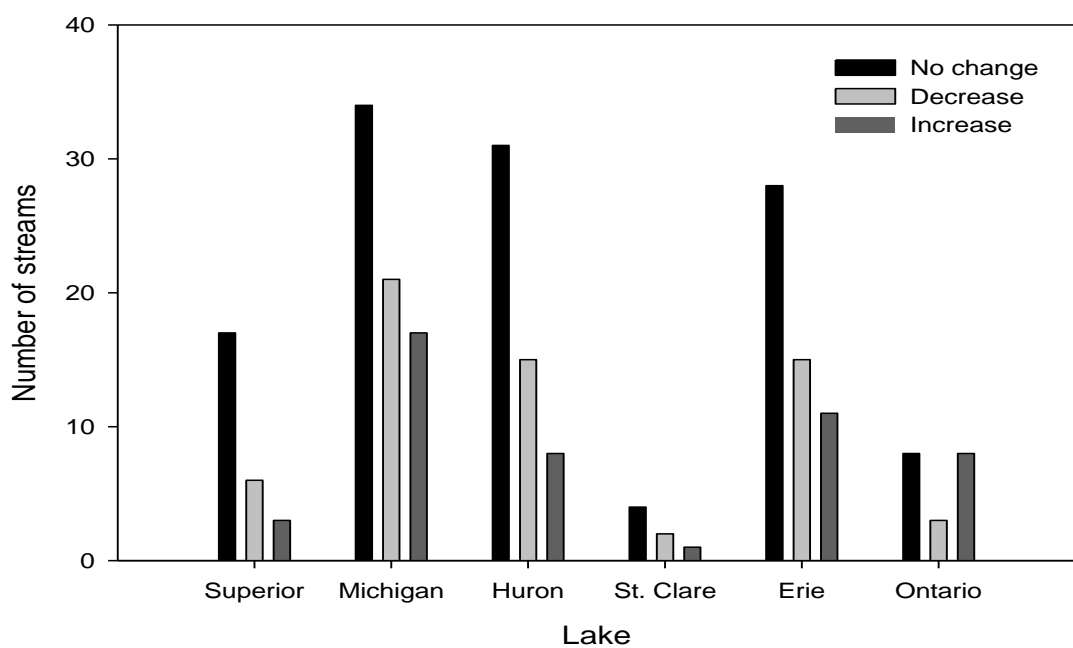


Figure 15. Number of gaged sites in each of the Great Lakes demonstrating No change, decreases, or increases in flashiness. Dates associated with the data vary by stream. See the Tributary Physical Integrity dataset for details. Decreases and increases are statistically-significant at the  $p < 0.05$  level.

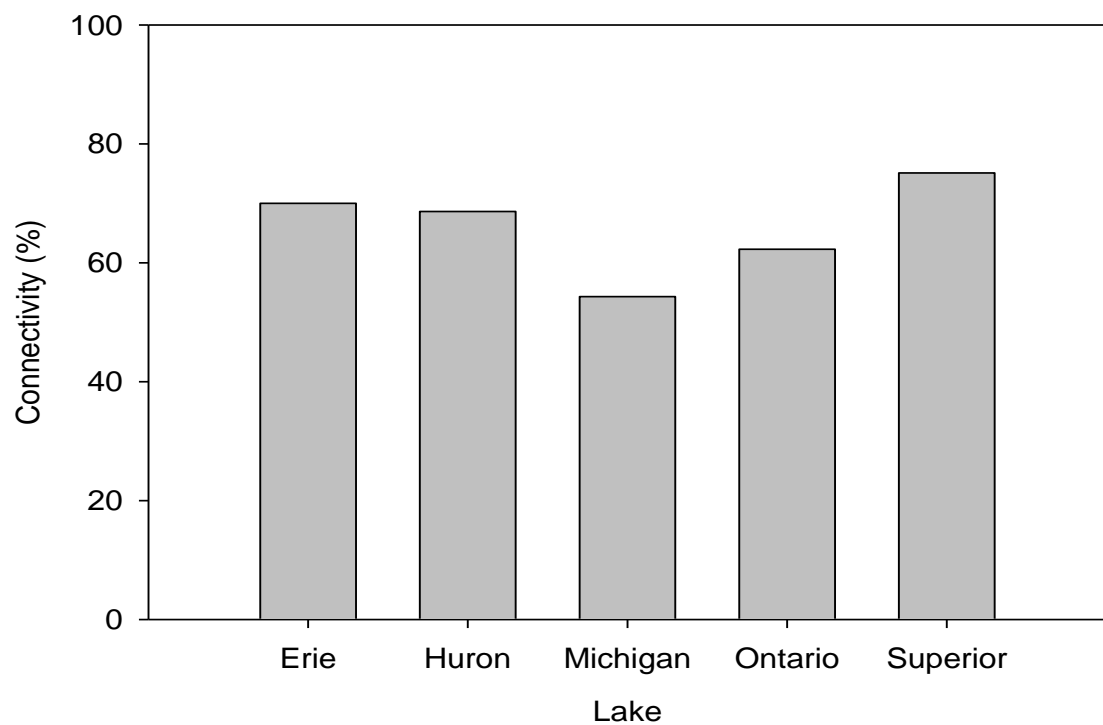


Figure 16. Connectivity (in % of mainstem length connected to receiving waters) by lake.

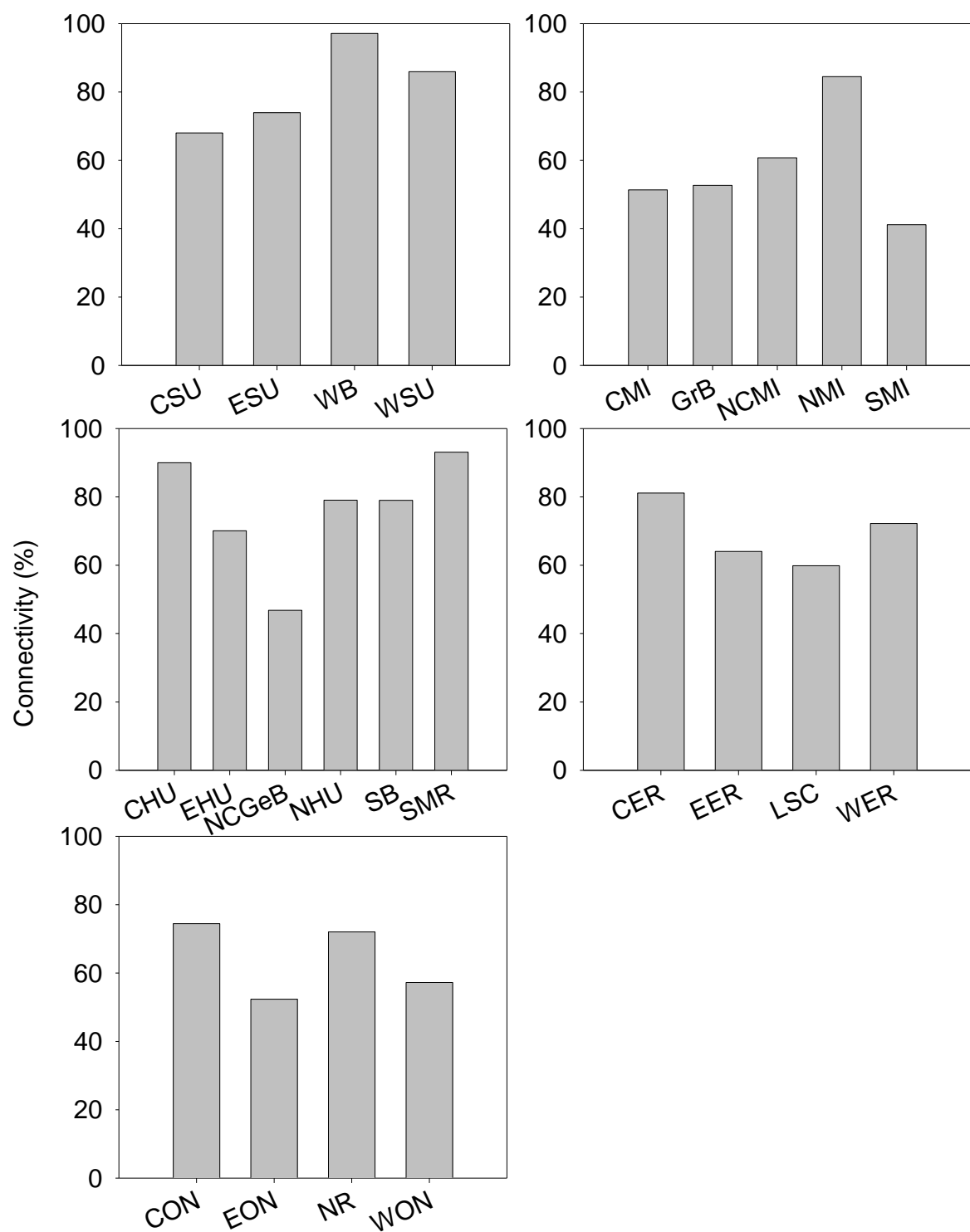


Figure 17. Connectivity of watersheds (in % of mainstem length connected to receiving waters) by subbasins in each lake. Subbasin acronym definitions are provided in the Metadata.



## Water Temperature

### Summary

The water temperature indicator tracks trends in average summer water temperature and ice cover measures, as well as the timing of spring stratification and fall turnover. The average temperature and timing of spring stratification measures have been calculated with both satellite-derived models and through buoy measurements. The strengths and limitations of each data source (e.g. differences in spatial resolution, temporal extent, data type) and the spatial unit of analysis (e.g. lake, subbasin, individual buoys) should be considered when using these data to describe trends in the water temperature measures.

### Measures:

Measure	Description
1	Annual summer surface average surface temperature (SAST) (July 1st - September 31st)
2	Stratification date (STD)
3	Fall turnover date (TOD)
4	Maximum and Average ice concentrations (MIC and AIC respectively)

### Data sources

As noted above, data for measures 1 & 2 are available from two sources and GLSEA-sourced data for all four measures can be computed at the lake or subbasin extent.

### Measures 1,2, and 3:

The Great Lakes Surface Environmental Analysis (GLSEA and GLSEA2) are digital maps of the Great Lakes surface water temperature and ice cover which is produced daily (year round or during ice season only). These are produced at the NOAA Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan through the NOAA CoastWatch program. The lake surface temperatures are derived from the NOAA-12 and NOAA-14 polar orbiter satellite Advanced Very High Resolution Radiometer (AVHRR) instruments with a measurement attempt approximately every six hours (actually frequency of measurement depends on cloud cover). Lake surface temperatures are updated daily with information from the cloud-free portions of the previous day's satellite imagery. If no imagery is available, a smoothing algorithm is applied to the previous day's map. Satellite and NOAA weather buoys sourced data are highly correlated. However, Schwab et al. 1992 found the satellite-derived temperatures were consistently 1-1.5 degrees Celsius cooler than buoy temperatures, Schwab et al. (1999) found that the mean temperature difference between buoys and the GLSEA analysis averaged over a 5-year period was on the order of 0.5 degrees Celsius or less, and Li et al. (2001) found similar results for a comparison of AVHRR-buoy data on the Great Lakes during a 3-month period in 1997. Measures 1 and 2: National Buoy systems: The NDBC (<http://www.ndbc.noaa.gov/faq.shtml>) and DFO (<http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm>) maintain a number of meteorological buoys in the Great Lakes. The sensor payloads on each buoy measure and log physical data every hour, with some data records beginning in 1980. As such, an automated analysis is highly preferable for summarizing these data sets. Buoys are deployed in the spring and retrieved in the fall with timing depending on ice cover and weather conditions, thus deployment and removal dates for buoys differs with location and year. The data buoys are equipped with a water temperature sensor on the bottom of their hull approximately 1 m below the surface. It appears that buoys are generally removed prior to fall turnover, thus buoy data are not used to calculate TOD.

#### Measure 4:

Composite ice charts, a blend of observations from different data sources (ships, shore, air craft, and satellite) that cover the entire area of the Great Lakes for a given date, and which may contain some estimated ice cover data, were produced starting in the 1970s. A 30-winter (1973-2002) set of composite ice charts was digitized and daily Great Lakes ice cover grid time series were created for each winter season by interpolating between observed ice chart grids for each winter season. The time series for each winter always begins Dec 1, and is 182 days, so it ends May 31 on non-leap years and May 30th on leap years.

#### Temporal extent

Temporal coverage varies by data source but generally includes at least 20 years of data. The GLSEA source includes data from 1995 through 2014, the Buoy datasets begin in 1979 or 1980 depending on the lake and individual buoy. The exception to this generality is Lake Ontario, for which buoy data begins in 1991 and 2002 for its two buoys. Ice measures begin in 1973 and go through 2013.

#### Spatial extent

Spatial coverage is defined in the metadata, and depends on the data source and specific measure. The majority of measure calculations occur at the lake or subbasin level.

### **Summary of findings**

#### Measure 1:

Trend analysis revealed that all lakes are increasing in summer average surface temperature, albeit slowly since 1995 (Figure 18). All regression slopes associated with SAST calculations at the Lake, Subbasin, and Buoy spatial scales revealed non-significant positive increases, with the exception of subbasin and buoy temperatures from Western Lake Ontario, which declined. The greatest positive slope was observed from Buoy observations in Central Lake Superior, Eastern Lake Ontario, and Lake St. Clair, which increased in temperature at a rate of 0.1°C, 0.09°C, and 0.08°C per year, respectively (Figure 19).

#### Measure 2:

Onset of spring stratification date appears to be decreasing (getting earlier) in all lakes since 1995. Only Lake Superior demonstrated a significant decline ( $p < 0.05$ ), but Lake Ontario is marginally significant ( $p = 0.055$ ) (Figure 20). Evaluation by sub-basin indicates that all of Lake Superior's subbasins (Figure 21, top) and western basin of Lake Ontario demonstrate significant declines in stratification date (all  $p < 0.05$ ) and the central basin of Lake Ontario demonstrated a marginally significant decline ( $p = 0.052$ ) (Figure 21, bottom). We did not observe any other significant declines in other sub-basins, although North Central Lake Michigan was marginally significant ( $p = 0.09$ ).

#### Measure 3:

Similarly, the Fall turnover date appears to be increasing (getting later) modestly in most lakes and subbasins since 1995. All 5 lakes demonstrate positive slopes in the fall turnover rate, with Lake Superior demonstrating the strongest delay in fall turnover (0.31 Days/year) (Figure 22). Nonetheless, the increase in fall turnover date is not significant (all  $p > 0.3$ ). Similarly, while most subbasins appear to be increasing in fall turnover day, none demonstrate significant relationships through time, and four subbasins (Western Superior, Central Superior, Southern Lake Michigan, and Lake St. Clair) are decreasing.

#### Measure 4:

Ice cover in the Great Lakes is decreasing throughout the entire Basin. Both maximum and average ice coverage are decreasing at the lakewide level on all lakes (Figures 23, 24). The largest decrease in maximum coverage is being observed on Lake Superior, which is decreasing at a rate of 0.86% per year. However, at the subbasin level, maximum ice coverage is decreasing fastest in North Central and Central Lake Michigan, both of which are decreasing at >1% per year (Figure 25), and is declining in all but three subbasins (Central Superior, Northern Michigan, and Western Ontario), all of which have consistently high (>95%) maximum ice coverage. In contrast to maximum ice coverage, all subbasins demonstrate declines in average ice coverage. Eastern Lake Ontario is exhibiting the fastest decline in average ice coverage, at a rate of 0.75% per year (Figure 26).

#### Data gaps and Recommendations

Data gaps relevant to the water temperature measure are specific to buoy coverage. Lake Ontario does not have as buoy data with as long a record as buoys in the other lakes. Buoys in Lake Erie are deployed after spring stratification and buoys across the basin are usually removed prior to fall turnover.

Concerning SAST and STD measures, both GLSEA and buoys can provide the data needed for calculation of these measures. The advantages of GLSEA-derived data are much better spatial resolution and coverage, but models are for a shorter timeframe (1995+) and are temperature estimates rather than actual measurements. In contrast, buoy data are actual measurements and contains records as early as 1979, but these buoys are all located offshore and are limited in spatial coverage (1-3 buoys per lake). We have included the available data from both data sources. However, analyses for a water temperature and Ice cover change manuscript (Mason et al., to be submitted soon) indicates that temporal change in water temperature and ice cover characteristics is not spatially universal across each lake. Instead, these data are best summarized by trends at the subbasin spatial extent. For this reason, we have also included change in measures summarized at the lake subbasin spatial extent. Analysis of SAST and STD at the subbasin spatial extent is not possible given the limited number of buoys with long-term data. The estimated dates of GLSEA- and buoy-derived spring stratification depended on the criteria used to determine the estimated date. Although spring stratification date was defined as the date when the 3.98 temperature is reached followed by subsequent warming of surface water, in reality the temperature would reach 3.98 in the spring and then fluctuate around 3.98 making pinpointing the actual date of stratification difficult. We used a 30-day warming criteria to pinpoint the estimated stratification, but using a different warming criteria will result in slightly different stratification dates. We also have concerns about the accuracy of the fall turnover dates (TOD) determined from the GSLEA models (the only available source of TOD data). TOD was defined as the first instance of water temperature at 3.98 in the fall. The GSLEA models may not be accurate enough to identify such a precise temperature as we observed many of the Lakes and lake subbasins did not turn over before December 31<sup>st</sup>. Accurate spring and fall turnover dates would likely necessitate vertical water profiles on a regular basis.

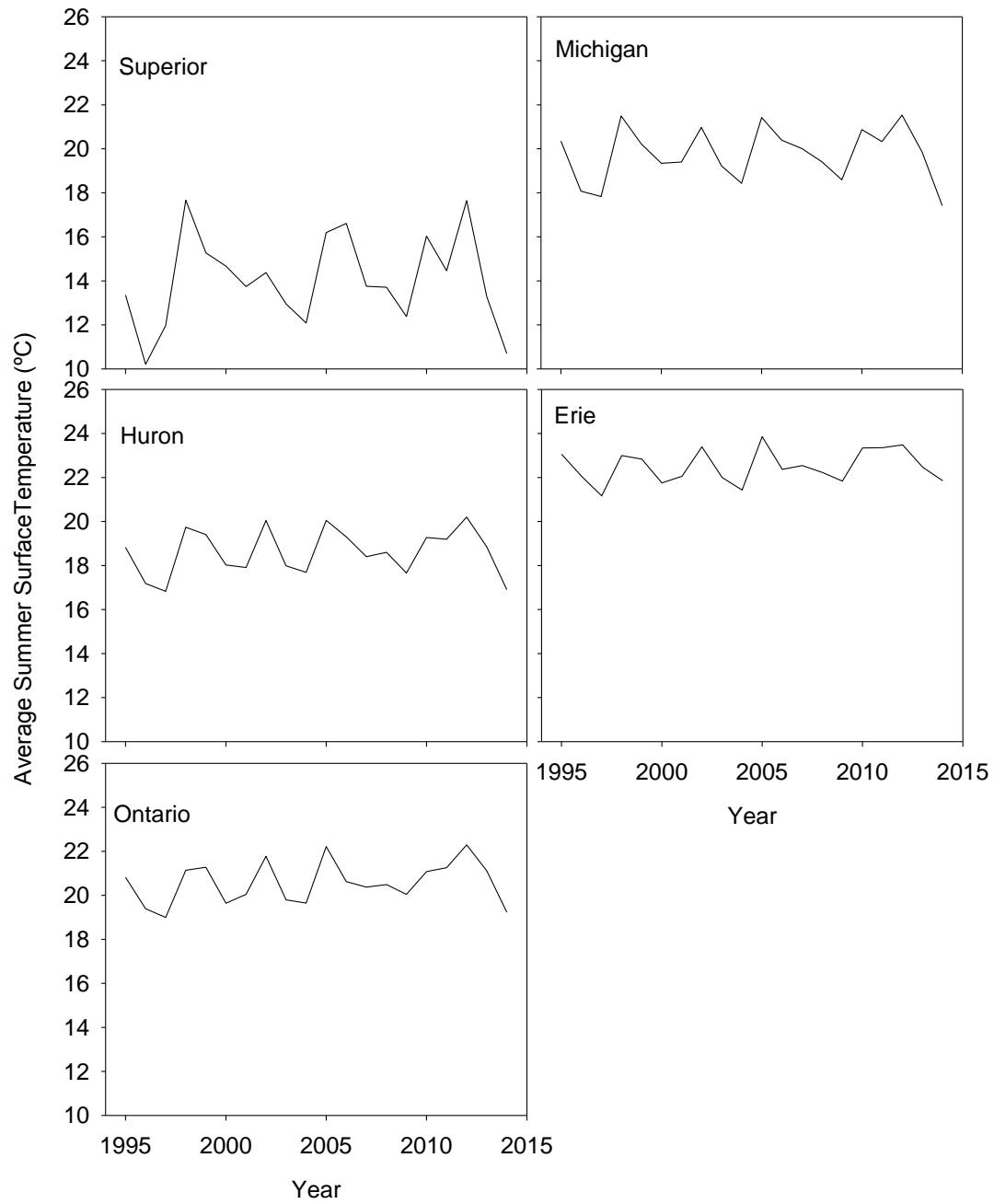


Figure 18. Summer temperatures as measured by GLSEA models for each of the five lakes.

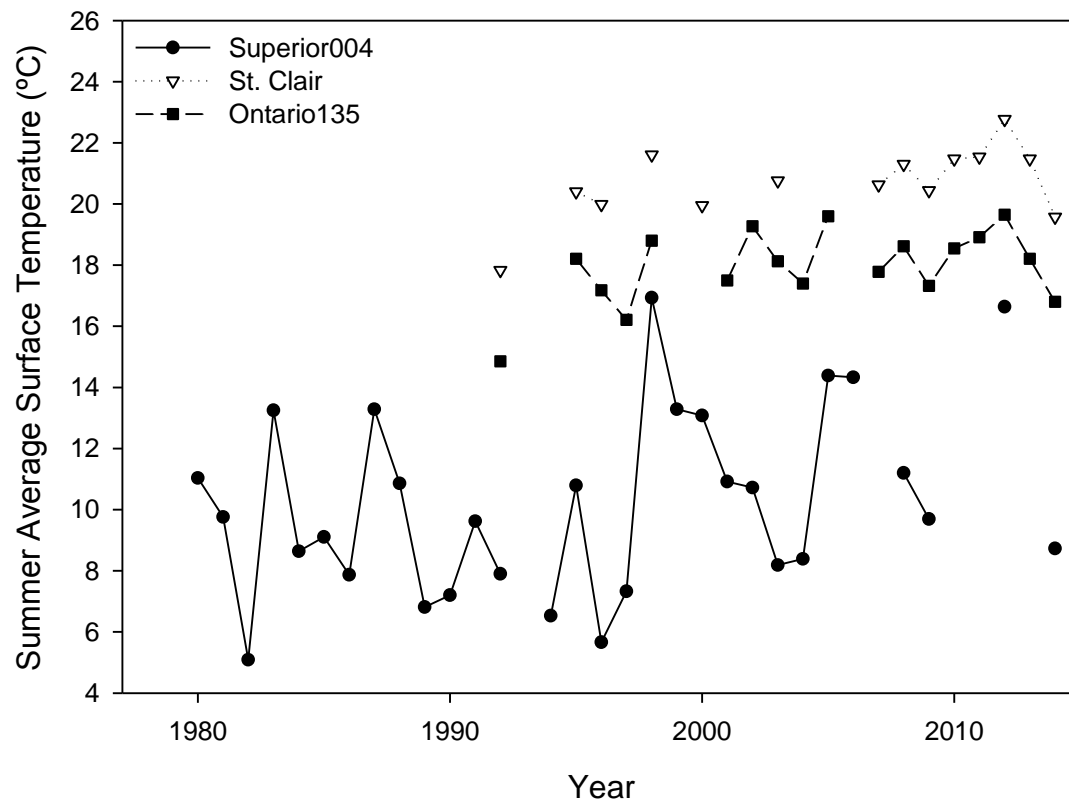


Figure 19. Summer average surface temperatures as measured by buoys at locations with the three largest positive increase in water temperatures.

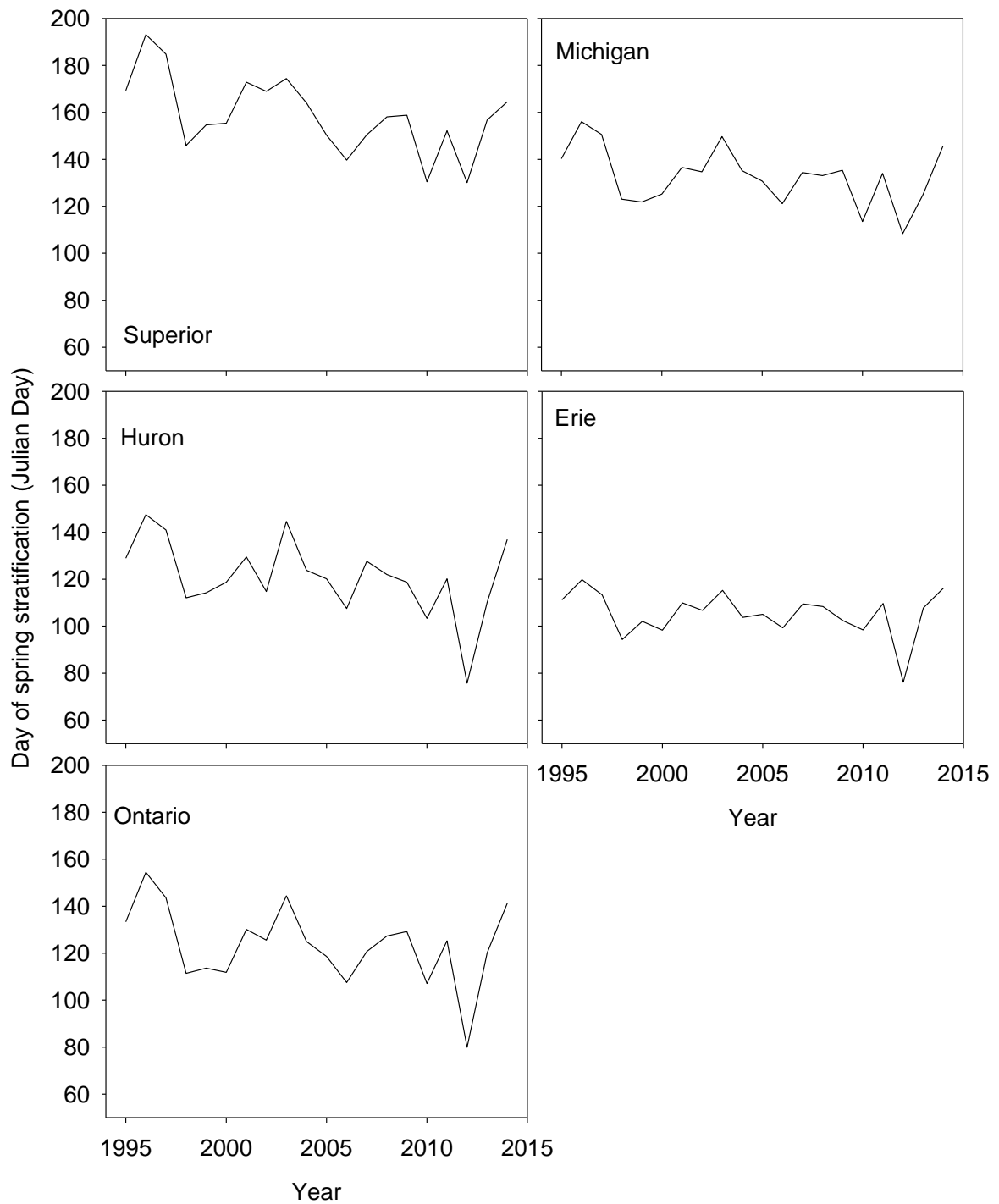


Figure 20. Julian day of spring stratification as indicated with GLSEA models on each of the five lakes

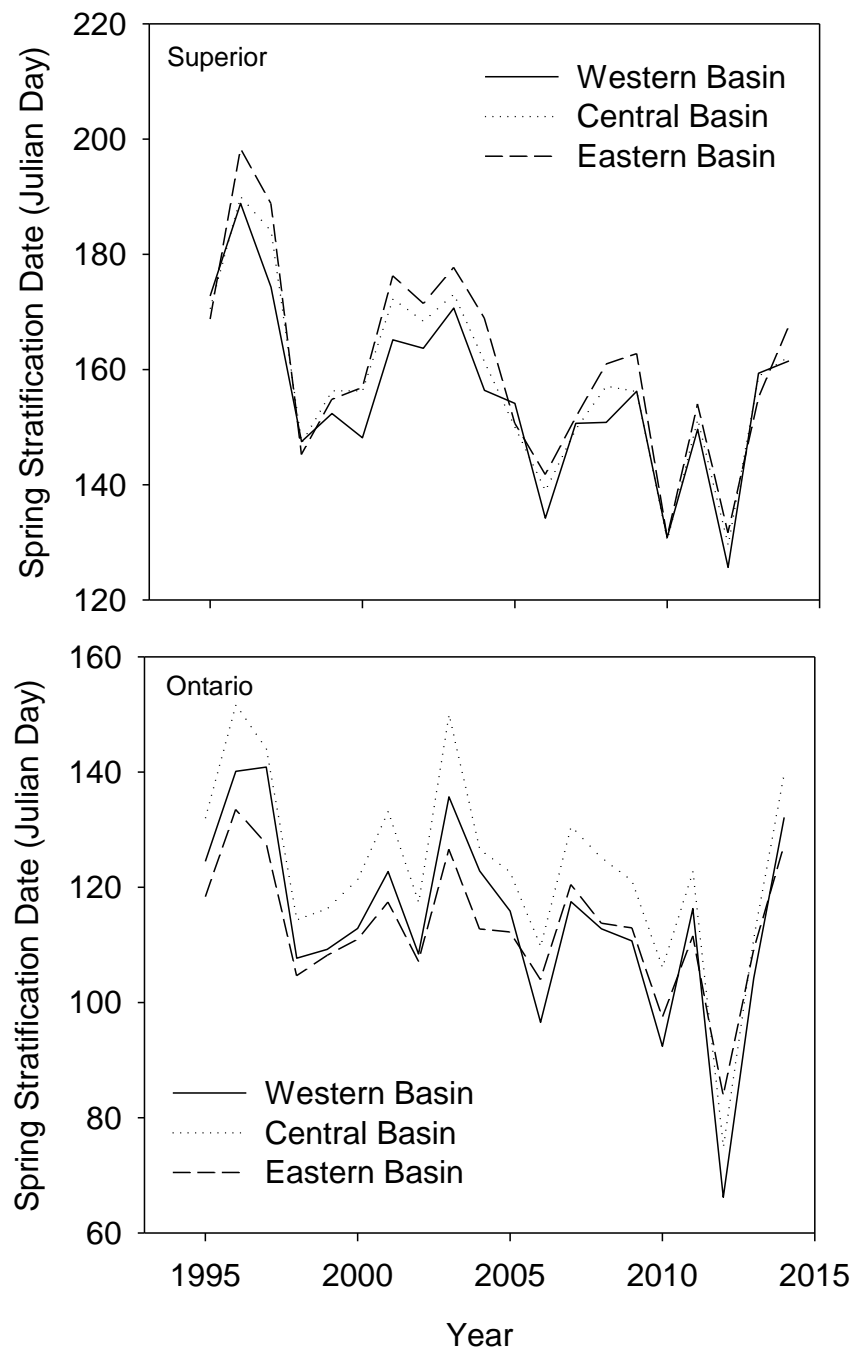


Figure 21. Date of spring stratification in lakes Superior and Ontario. All Lake Superior subbasins and the Western Basin of Lake Ontario have significant decline in spring stratification date.

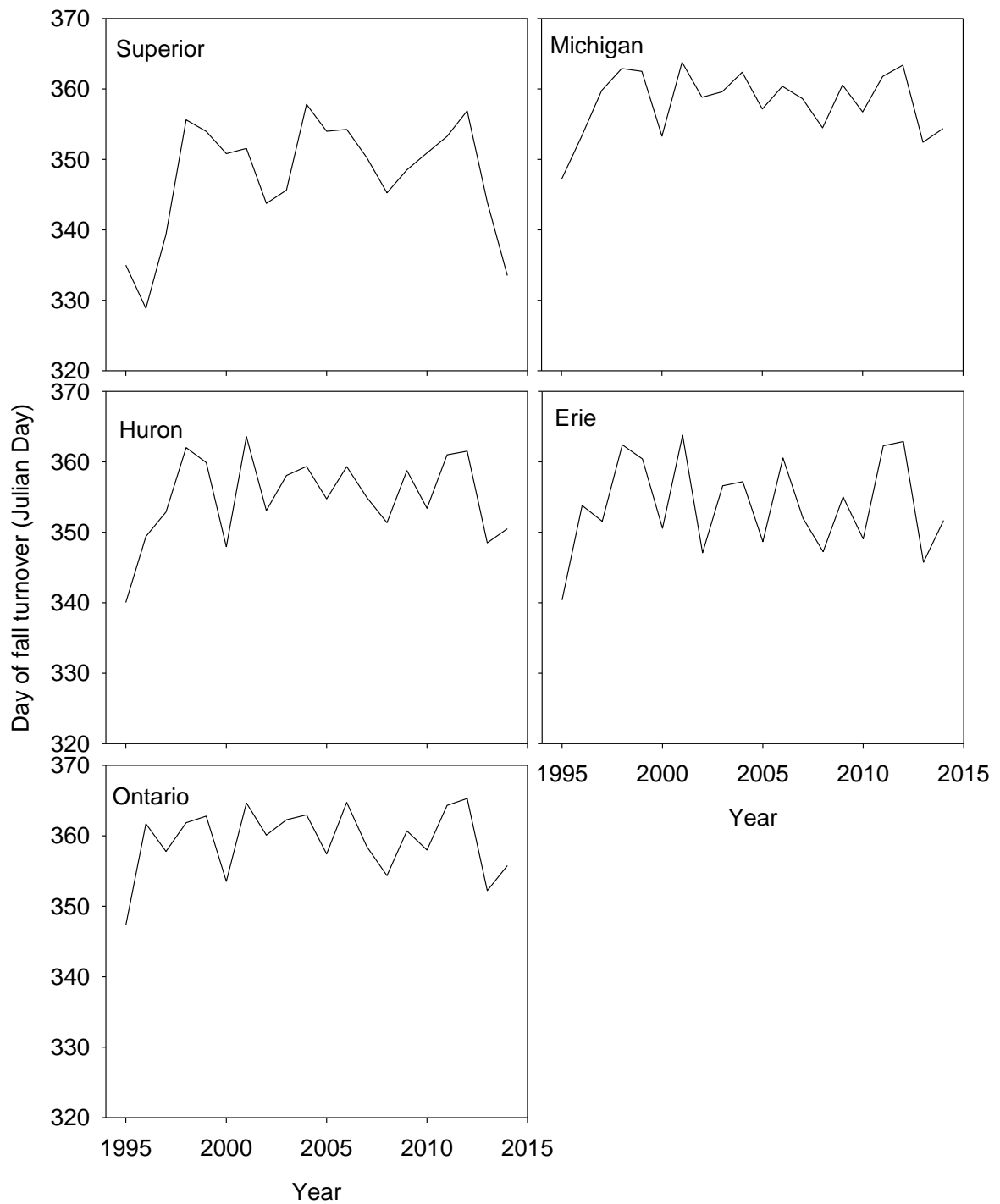


Figure 22. Fall turnover date as estimated with GLSEA models.



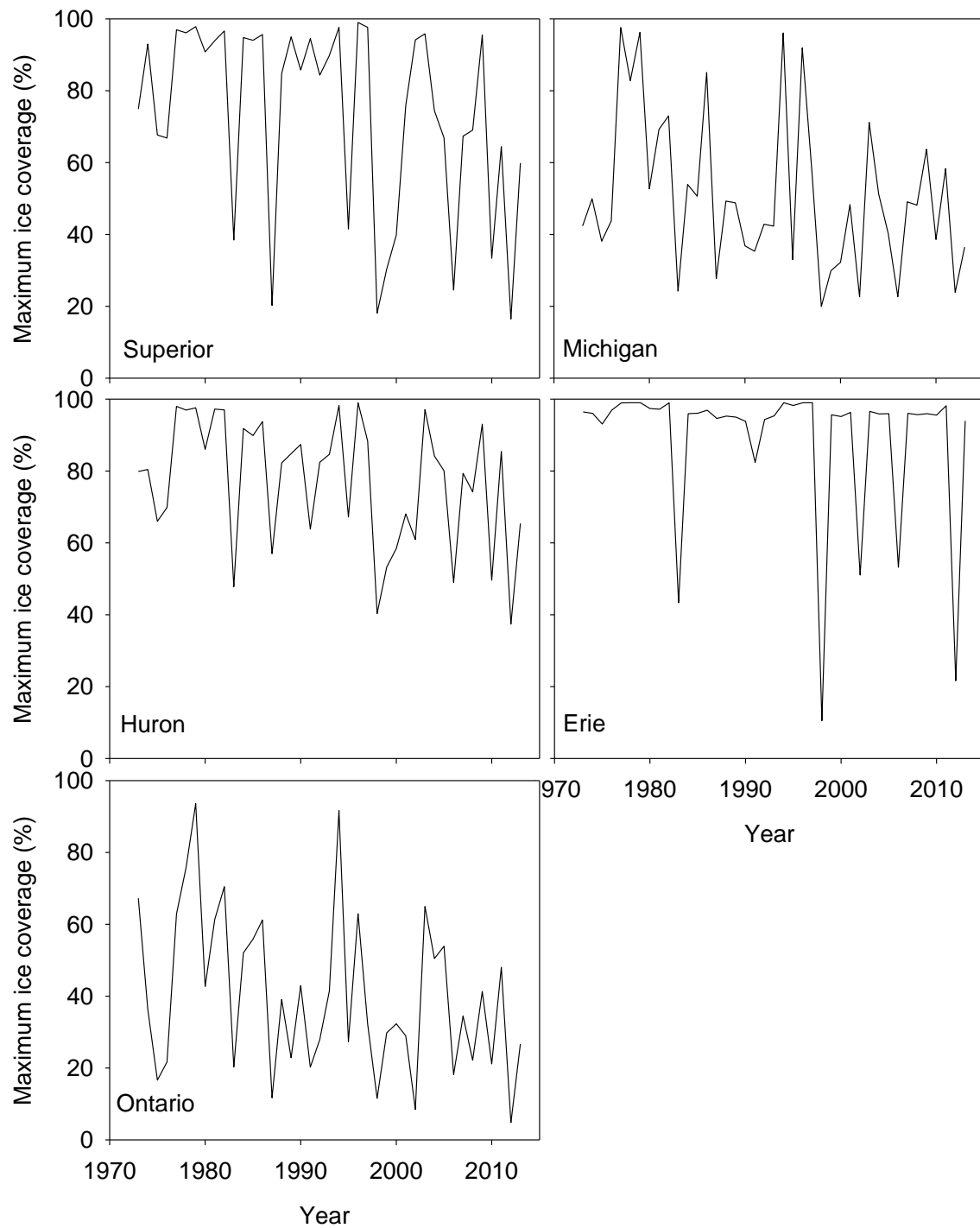


Figure 23. Maximum ice coverage (% extent) in the Great Lakes (1973-2013).

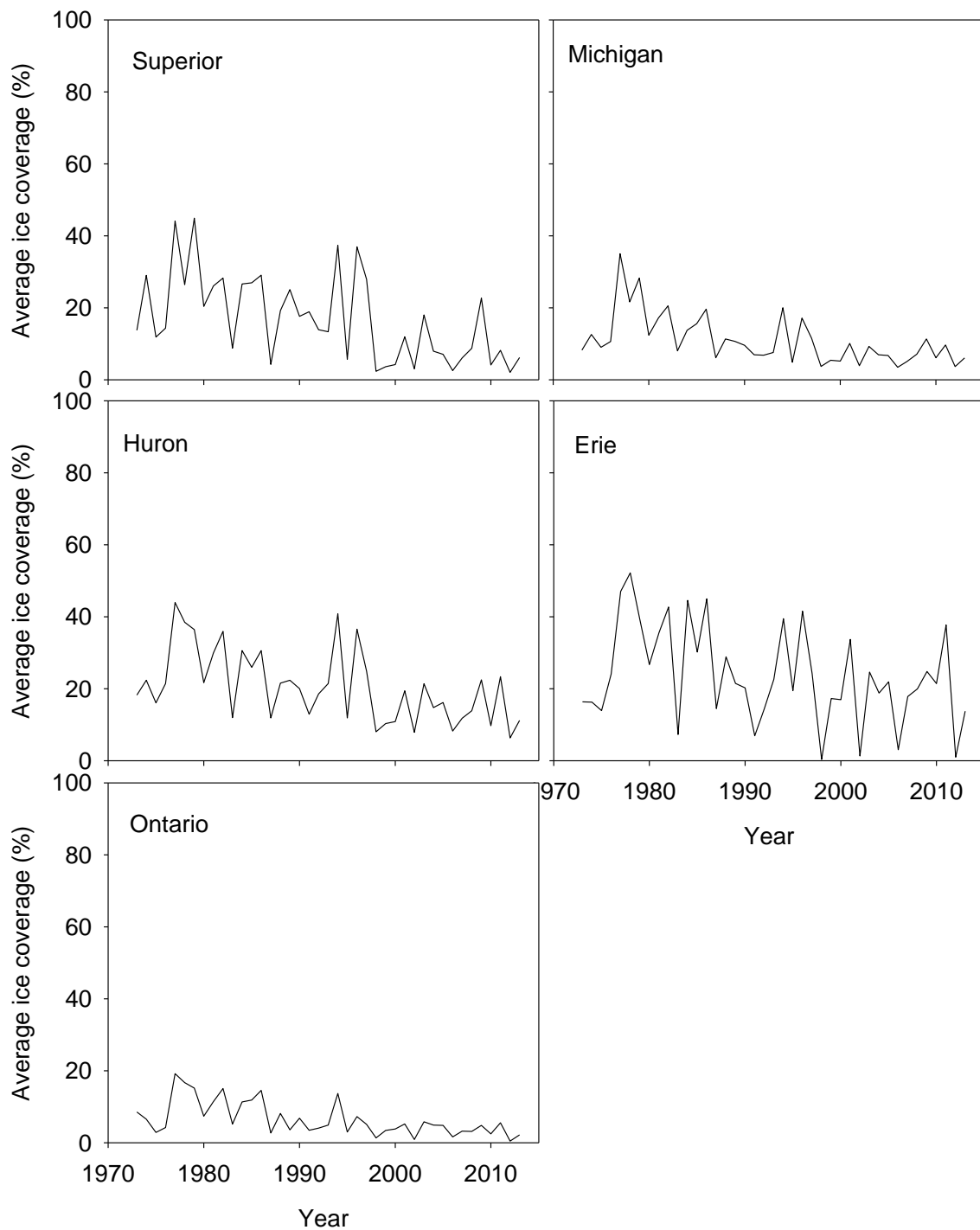


Figure 24. Average ice coverage (% extent) in the Great Lakes (1973-2013).

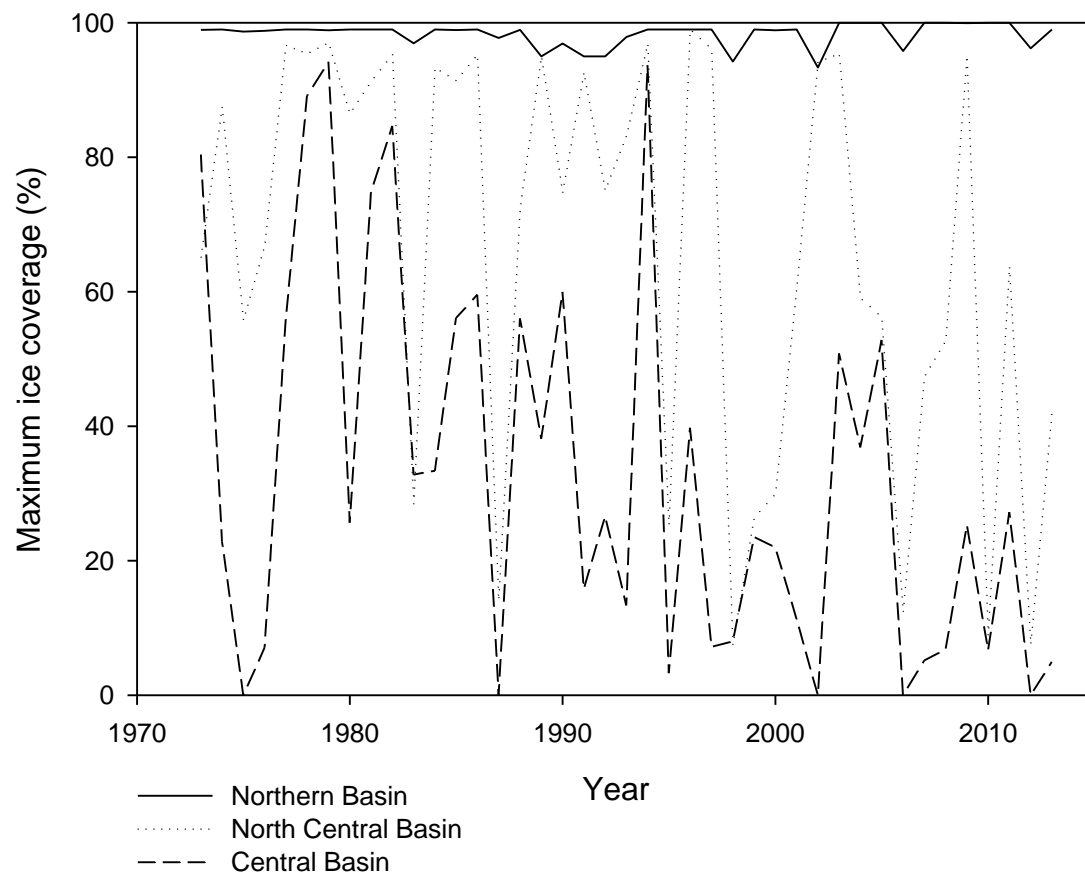


Figure 25. Lake Michigan maximum ice coverage (% extent) in three subbasins. The North Central and Central Basins are decreasing at a rate of >1% per year, while the Northern Basin does not demonstrate any trend.

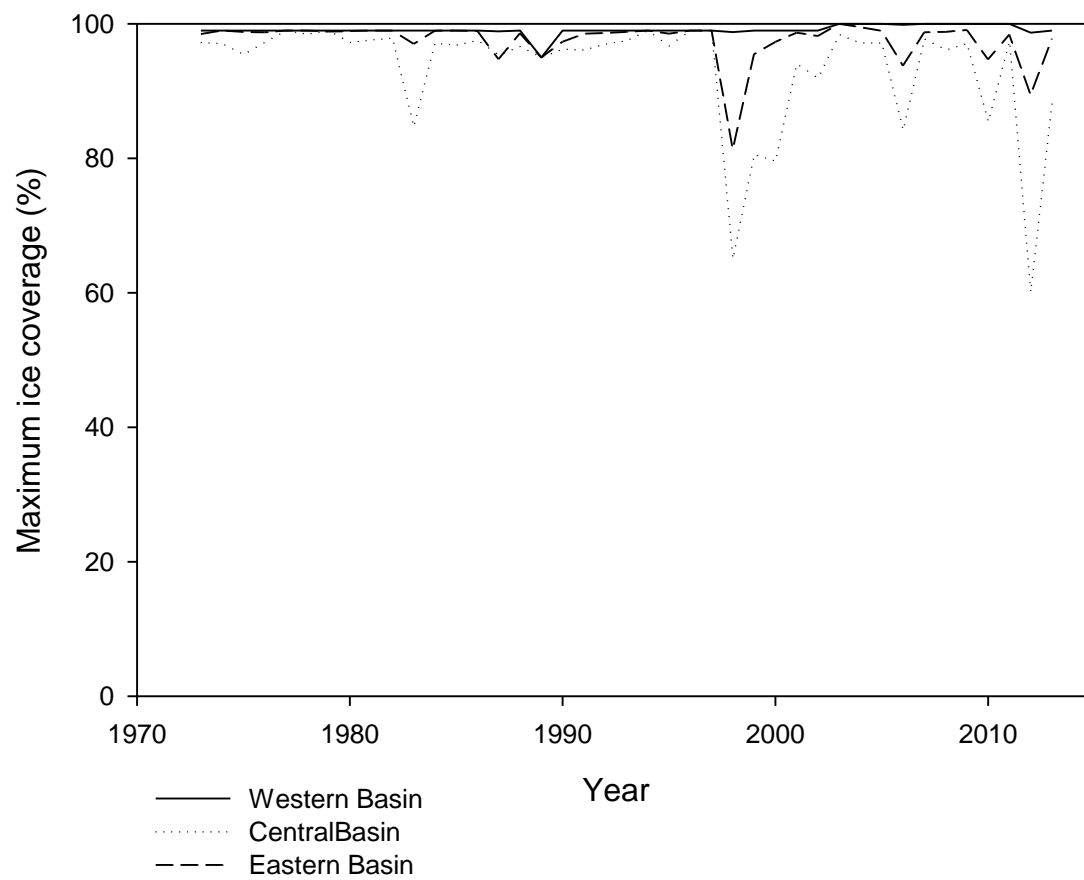


Figure 26. Lake Ontario maximum ice coverage (% extent) in three subbasins. The Western and Central Basins

## Atmospheric Deposition of Chemicals of Mutual Concern

### Summary:

This indicator tracks spatial and temporal trends in total concentrations of legacy toxic chemicals and chemicals of emerging concern in the atmosphere and precipitation of the Great Lakes region. The purpose of this indicator is to assess the levels of chemicals of mutual concern (CMCs) which can cause negative effects on Great Lakes aquatic ecosystems and to track progress towards removal of toxic chemicals from the basin. The Great Lakes Executive Committee as per Annex 3 of the GLWQA will select the final list of CMCs. Although the final list of CMCs has not been released, the draft list includes Bisphenol A, chlorinated paraffins, flame retardants, mercury, nonylphenol and its ethoxylates, perfluorinated compounds, and polychlorinated biphenyls.

### Measures:

This indicator is based on the established SOGL indicator “Atmospheric Deposition of Toxic Chemicals”. The indicator is based on protocols established by the Integrated Atmospheric Deposition Network (IADN) and the Mercury Deposition Network (MDN). Measures are calculated using a variety of statistical tools currently employed by the IADN and MDN, but the specifics of how to calculate measures for this indicator are not clearly defined in the IJC Ecosystem Indicator Report (IJC 2014a). It is also unclear how trends across multiple CMCs should be integrated to develop a trend score.

### Data sources:

**Integrated Atmospheric Deposition Network (IADN)**, data for the IADN are available from 1992 – 2010 at the website, [www.ec.gc.ca/natchem/default.asp?lang=En&n=6562770F-1](http://www.ec.gc.ca/natchem/default.asp?lang=En&n=6562770F-1).

**Mercury Deposition Network (MDN)**, data for the MDN are available from 2001 – 2013 at the website, <http://nadp.sws.uiuc.edu/data/MDN/>.

**Todd Nettesheim**, IADN program manager, US EPA, 312.353.9153, [nettesheim.todd@epa.gov](mailto:nettesheim.todd@epa.gov).

**David Gay**, MDN program coordinator, Illinois Natural History Survey, 217.244.0462, [dgay@illinois.edu](mailto:dgay@illinois.edu).

### *Spatial Extent:*

The IADN and MDN have well-established international monitoring stations. The IADN has one master site on each of the Great Lakes (Eagle Harbor (USA), Lake Superior; Sleeping Bear Dunes (USA), Lake Michigan; Burnt Island (Canada), Lake Huron; Sturgeon Point (USA), Lake Erie; Point Petre (Canada), Lake Ontario) and additional satellite stations. The MDN has stations throughout the basin.

### *Temporal extent:*

The IADN takes measurements approximately every 12 days and has data available from 1992-2010 on the Environment Canada website. The MDN collects samples at a similar frequency and has data available on their website from at least 2001 – 2013.

### Summary of findings:

The data curators for this indicator are the authors for the SOGL report; therefore, we have not reached out to the data curators and are unable to provide a detailed summary for this indicator. Overall, data to calculate this indicator appear to be available because the indicator is included in the SOGL report and the monitoring programs tracking CMC in the atmosphere and precipitation are maintained at the federal level and cover the Great Lakes basin. However, the availability of data varies

by contaminants (e.g., IADN vs. MDN), which will influence the capacity to calculate spatial and temporal trends for different contaminants.

#### **Data gaps and recommendations:**

All data to calculate this indicator are from the IADN and MDN. Until the final list of CMCs is determined and data are shared between the SOGL authors and the IJC Indicator Project, calculation of data gaps and development of recommendations are not possible. We contacted Dr. Nettesheim (IADN) and Dr. Gay (MDN) about data available through these monitoring networks, but did not receive a response from either individual.

## **Chemicals of Mutual Concern in Water**

#### **Summary:**

This indicator tracks trends in total concentrations of toxic chemicals and chemicals of emerging concern in water at offshore and nearshore sites on a two-to-three year basis. The purpose of this indicator is to assess the magnitude and direction of trends of chemicals of mutual concern (CMCs) in surface waters of the Great Lakes, the potential for human and ecological impacts, and progress towards removal of toxic chemicals from the basin. The Great Lakes Executive Committee as per Annex 3 of the GLWQA will select the final list of CMCs. Though the final list of CMCs has not been released, the draft list includes bisphenol A, chlorinated paraffins, flame retardants, mercury, nonylphenol and its ethoxylates, perfluorinated compounds, and polychlorinated biphenyls.

#### **Measures:**

The measures contained within this indicator are based on the established SOGL indicator “Toxic Chemical Concentrations in Offshore Waters”. The indicator is based on integrating direct measurements of aqueous concentrations of various CMCs to determine spatial and temporal trends of CMCs across the Great Lakes basin. However, further descriptions of the actual measures and specific calculations for each measure are not provided in the indicator description.

#### **Data sources:**

**Great Lakes Surveillance Program**, open water cruises focusing on water quality parameters conducted by Environmental Canada. The survey was formally launched in 1968, became formalized in 1978, and now monitoring occurs in each lake every other year during spring and fall. Data are available through the Canada Centre for Inland Waters and can be retrieved upon request via [GLSP-PSGL@ec.gc.ca](mailto:GLSP-PSGL@ec.gc.ca).

**Great Lakes National Project Office Open Lake Water Quality Survey of the Great Lakes (GLNPO)**. These data are acquired from open water cruises conducted by US EPA, responsible for chemical parameter monitoring. Lakes Michigan, Huron, and Erie started in 1983, Lake Ontario started in 1986, and Lake Superior started in 1992. Surveys are typically conducted annually in spring and summer, though additional sampling is conducted every 5 years. The website does not provide clear descriptions of CMC monitoring. The primary contact Glenn Warren, [warren.glenn@epa.gov](mailto:warren.glenn@epa.gov).

**Alice Dove**, primary contact for Great Lakes Surveillance Program, Water Quality Monitoring and Surveillance, Environment Canada, 905.336.4449, [Alice.Dove@ec.gc.ca](mailto:Alice.Dove@ec.gc.ca).

#### ***Spatial Extent:***

Monitoring of CMCs is conducted across the Great Lakes basin at standardized sampling locations. The number of sites varies by lake, with the fewest sampling locations occurring in the upper lakes (Lakes Superior, Huron, and Michigan), and the most sampling locations occurring in Lakes Erie and Ontario.

*Temporal extent:*

The Great Lakes Surveillance Program has been monitoring toxic chemicals since 1986. Sampling is conducted every other year on each of the Great Lakes (except Lake Michigan) during the spring and fall. The frequency of toxic chemical monitoring in Lake Michigan likely occurs twice annually, though detailed information is not readily available on the GLNPO website.

**Summary of findings:**

The data curators for this indicator are the authors of the SOGL report; therefore, we have not reached out to the data curators and are unable to provide a detailed summary for this indicator. Overall, data to calculate this indicator appear to be available because the indicator is included in the SOGL report and the monitoring programs tracking CMC in water are maintained at the federal level and cover the Great Lakes basin. However, the availability of data varies by the individual contaminant, which will influence the capacity to calculate spatial and temporal trends for the suite of contaminants identified by SOGL and the IJC.

**Data gaps and recommendations:**

All data to calculate this indicator are from the Great Lakes Surveillance Program, Water Quality Monitoring and Surveillance, Environment Canada, and are supplemented for Lake Michigan from the Great Lake National Program Office, United States Environmental Protection Agency. Until the final list of CMCs is determined and data are shared between the SOGL authors and the IJC Indicator Project, calculation of data gaps and development of recommendations are not possible.

## **Contaminants in Groundwater**

**Summary:**

This indicator tracks trends in groundwater issues within the Great Lakes, focusing on 1) the quantity of groundwater, 2) groundwater and surface-water interactions, 3) changes in groundwater quality as development expands, and 4) ecosystem health in relation to quantity and quality of water. Candidate watersheds have been identified in each of the Great Lakes that encompass a range of land uses (e.g., agricultural, urban, and forested) and a suite of parameters that have been identified for all watersheds, as well as additional parameters that are relevant to specific land uses. For instance, phosphorus and triazine herbicides should be measures in agricultural watershed.

**Measures:**

Individual candidate watersheds and a suite of parameters have been identified for this indicator. However, the specific measures for this indicator and how to calculate them are not clearly defined, nor is it clear how to integrate stream and groundwater data. Important parameters for all watersheds include: location, water level and/or flow, temperature, pH, TDS, nitrate, chloride, sulfate, calcium, magnesium, sodium, potassium, carbonate, and bicarbonate. In urban watersheds, total chlorinated compounds, BTEX (benzene, toluene, ethylbenzene, xylenes), arsenic, cadmium, and zinc should be measured. In agricultural watersheds, phosphorus and triazine herbicides should be measured.

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

Watershed Type	Parameters
All	Location, water level and/or flow, temperature, pH, TDS, nitrate, chloride, sulfate, calcium, magnesium, sodium, potassium, carbonate, bicarbonate
Urban	Total chlorinated compounds, DTEX, benzene, toluene, ethylbenzene, xylenes, arsenic, cadmium, zinc
Agricultural	Phosphorus, triazine herbicides

#### Data sources:

**Canadian Groundwater Chemistry Database for Provincial Groundwater Monitoring Network (PGMN)** contains data for well locations, water levels, and groundwater data in Canada. Chemistry data are available by individual wells but are not available as a consolidated database (but could be in the future). **Contact: Heather Brodie-Brown.**  
<http://www.ontario.ca/data/provincial-groundwater-monitoring-network>

**Paired Groundwater – Surface Water PGMN Wells**, Ontario's integrated climate change monitoring stations combine groundwater, surface water, climate, and soil moisture monitoring. Contact: Scott MacRitchie. More information at: [http://www.latornell.ca/wp-content/uploads/files/presentations/2011/Latornell\\_2011\\_T1A\\_Dajana\\_Grgic.pdf](http://www.latornell.ca/wp-content/uploads/files/presentations/2011/Latornell_2011_T1A_Dajana_Grgic.pdf)



**Provincial (Stream) Water Quality Monitoring Network (PWQMN)** contains water quality monitoring data for a number of parameters including location, chlorine, nutrients, and metals. <http://www.ontario.ca/data/provincial-stream-water-quality-monitoring-network>

**Ontario Source Water Protection** data combines groundwater and surface water budgets for most of southern Ontario as part of water quantity risk assessment process. Contacts: Scott Bates (Ministry of Natural Resources and Forests) and Matthew Millar (Conservation Ontario).

**Baseflow Mapping in Great Lakes Report** by Andrew Piggott, <http://pubs.usgs.gov/sir/2005/5217/pdf/SIR2005-5217.pdf>.

**National Ground-Water Monitoring Network (NGWMN)** contains data from federal, state, and local groundwater monitoring networks across the United States. Many of these points are located within the Great Lakes basin but they are not evenly distributed within the basin and do not appear to be associated with a specific river. <http://cida.usgs.gov/ngwmn/index.jsp>

**National Water Information System (NWIS)** contains groundwater and surface data for sites across the United States including many sites within the Great Lakes basin. Identifying which data are appropriate for calculating this indicator will depend on the specifics of indicator calculation. Accessing information through this interface is likely straight-forward for individuals familiar with its organizational structure, but less clear for individual without experience using the interface. <http://waterdata.usgs.gov/nwis>

**Heather Brodie-Brown**, Senior Hydrogeologist, Ontario Ministry of Environment and Climate Change, 416.327.4665, [heather.brodie-brown@ontario.ca](mailto:heather.brodie-brown@ontario.ca)

**Scott MacRitchie**, Senior Hydrogeologist/Climate Change Vulnerability Specialist, Environmental Monitoring and Reporting Branch, Ministry of the Environment and Climate Change, 416.235.6533, [scott.macritchie@ontario.ca](mailto:scott.macritchie@ontario.ca)

**Scott Bates**, Water Budget Program Analyst, Ministry of Natural Resources and Forestry, 705.755.1523, [scott.bates@ontario.ca](mailto:scott.bates@ontario.ca)

**Matthew Millar**, Source Water Protection Planning, Conservation Ontario, 905.895.0716 x 234, [mmillar@conservationontario.ca](mailto:mmillar@conservationontario.ca)

#### *Spatial Extent:*

Data for this indicator are available at the location of specific wells and are geo-referenced by latitude and longitude (e.g., Figure 27). For some information, such as Baseflow Mapping, data have been summarized at the watershed level. Integrating monitoring data from individual wells or stream gauges at the watershed level will require more guidance on how to integrate stream and groundwater data and weight data from multiple locations to develop a watershed level average.

#### *Temporal extent:*

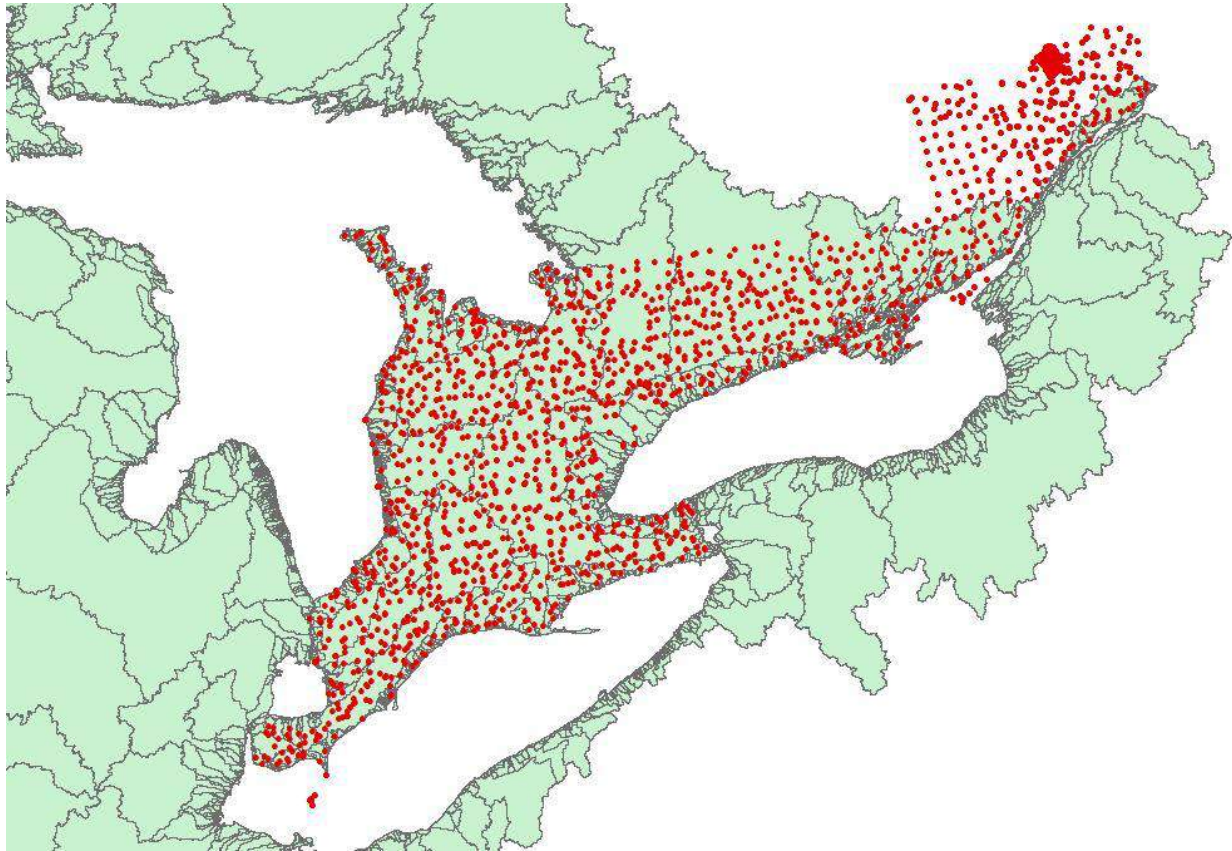
The duration of sampling and sampling frequency varies by well, stream gauge, and parameter. Some measures, such as temperature, are measured at high frequencies, while others may have only one measurement available. More guidance is needed to account for these inconsistencies when calculating measures for each parameter.

#### **Summary of findings:**

There is a wealth of data available for both stream and groundwater parameters; however, assessing whether or not these data can be used to calculate the measures for this indicator is not possible until the specific measures are determined.

#### **Data gaps and recommendations:**

Conducting the data gap analyses is contingent on the description of how to calculate the measures for this indicator. Many questions remain that will dictate whether or not a specific well should be included in measure calculation. Some of these considerations include the distance of the well from the stream, the number of measurements necessary for inclusion, what time of year the measurements should be taken, how to integrate measurements from multiple wells within a watershed, how to integrate stream and groundwater measurements, and many other technical considerations that are not addressed in the current indicator description.



**Figure 27.** Location of groundwater wells in the Provincial Groundwater Monitoring Network.

## Persistent, Bioaccumulating, and Toxic Substances in Biota

### Summary:

This indicator tracks trends in persistent, bioaccumulating, and toxic substances (PBTs) in whole fish and fish-eating birds. PBTs include PCBs, organochlorine pesticides, dioxins and furans, mercury, and other trace metals, as well as contaminants of emerging concern such as polybrominated diethyl esters (PBDEs), fluorinated chemicals, and synthetic musks. The purpose of this indicator is to: 1) describe the spatial and temporal trends of bioavailable contaminants throughout the Great Lakes, 2) infer impact of contaminants on the health of fish and bird populations, 3) infer the effectiveness of remedial actions related to the management of critical pollutants, and 4) to document and describe the trends of chemicals of emerging concern.

### Measures:

This indicator is based on the two well-established SOGL indicators, “Contaminants in Whole Fish” and “Contaminants in Fish-Eating Colonial Waterbirds”. The first measure tracks PBTs in whole fish for Lake Trout from Lakes Ontario, Huron, Michigan, and Superior, Walleye in Lake Erie, and Rainbow Smelt in Lakes Ontario, Huron, Superior, and Erie. The second measure tracks PBTs in Great Lakes Herring Gulls eggs and Bald Eagles.

Metric	Description
1	PBT chemicals in Great Lakes whole fish, including Lake Trout, Walleye, and Rainbow Smelt
2	PBT chemicals in Great Lakes Herring Gull eggs
3	PBT chemicals in Bald Eagles

### Data sources:

**Elizabeth Murphy**, Environmental Scientist, EPA Great Lakes National Program Office, 312.353.4227 or 1.800.621.8431 ext. 34227, [murphy.elizabeth@epa.gov](mailto:murphy.elizabeth@epa.gov)

**Daryl McGoldrick**, Environmental Scientist, Environment Canada, 905.336.4685 or 905.220.1173, [Daryl.McGoldrick@ec.gc.ca](mailto:Daryl.McGoldrick@ec.gc.ca)

**Pamela Martin**, Environment Canada, 905.336.4879, [pamela.martin@ec.gc.ca](mailto:pamela.martin@ec.gc.ca)

**Bill Bowerman**, Department of Environmental Science and Technology, University of Maryland, 301.405.1306, [wbowerma@umd.edu](mailto:wbowerma@umd.edu)

### *Spatial Extent:*

Monitoring of PBTs in fish and fish-eating birds is primarily done by Environment Canada and the U.S. Environmental Protection Agency. Whole fish measurements are collected at twelve sites in Canada (approximately 3 per lake) and ten sites in the USA (2 per lake on a rotating basis). Herring Gull eggs are monitored at 15 standard sites distributed across all five of the Great Lakes. Monitoring of Bald Eagles does not appear to be done systematically across the basin like whole fish tissues and Herring Gulls. The Michigan Department of Environmental Quality has been monitoring Bald Eagles as part of the Bald Eagle Biosentinel Project since 1999. This appears to provide fairly comprehensive coverage of areas bordering the Michigan waters of the Great Lakes (e.g. Huron, Superior, and Michigan).

### *Temporal extent:*

Whole fish and Herring Gull eggs measurements have been collected annually or biannually since 1977 and 1974, respectively. Consistent records for Bald Eagles have been collected in Michigan since

1999, and additional intermittent monitoring was conducted in 1987-1992 and 1990-2003 for the state of Michigan.

#### **Summary of findings:**

The data curators for this indicator are the authors of the SOGL report; therefore, we have not reached out to the data curators and are unable to provide a detailed summary for this indicator. Overall, data to calculate this indicator appear to be available because the indicator is included in the SOGL report and the monitoring programs tracking PBTs in Biota are maintained at the federal level and cover the Great Lakes basin.

#### **Data gaps and recommendations:**

Data are available for whole fish and Herring Gulls, but monitoring of Bald Eagles is less standardized. Calculation of the Bald Eagle component of this indicator will likely need to be based primarily on the long-term dataset available for Bald Eagles in the state of Michigan.

## **Phosphorous Loads and In-Lake Concentrations**

#### **Summary:**

This indicator tracks the magnitude and trends in total phosphorous (TP) and dissolved reactive phosphorous (DRP) loads delivered to the Great Lakes from multiple sources. The fate of delivered TP and DRP are reflected in measurements of in-lake concentrations and trends in concentration from nearshore and offshore areas in the Great Lakes. Measurement of loads and in-lake concentrations are supplemented with TP and DRP mass balance models.

#### **Measures**

<b>Measure</b>	<b>Description</b>
1	Total Phosphorus (TP) load for major tributaries of each lake basin using the methods in Dolan and Chapra (2012).
2	Dissolved Reactive Phosphorus (DRP) load for major tributaries of each lake basin using the methods in Dolan and Chapra (2012).
3	Average in-lake Total Phosphorus (TP) concentration as measured by spring and summer sampling programs
4	Average in-lake Dissolved Reactive Phosphorus (DRP) concentration as measured by spring and summer sampling programs

#### **Data sources:**

##### *Measure 1:*

For measure 1 we compiled data from two sources: basin wide coverage from Dolan and Chapra (2012) and western and central Lake Erie coverage from the Heidelberg Tributary Loading Program (HTLP). The Dolan and Chapra (2012) data were compiled from supplementary material and are in individual files for each lake and are provided as supplemental files in the database. Dolan and Chapra (2012) provided most load data at the tributary extent, although some load data are summarized for “complexes” of tributaries and at the subbasin extent for Lake Erie. Dolan and Chapra (2012) used the stratified Beale's Ratio Estimator to calculate loads. On days when chemistry samples were taken, the daily load was calculated as the product of measured concentration and mean daily flow. These data

were then sorted by flow and divided into one or more strata depending on the nature of the flow and concentration relationship within each stratum. The stratum load was calculated by multiplying the mean daily load for the stratum by the number of days in that stratum, and stratum loads for the year were then summed to obtain the total annual load for a given tributary.

For Lake Erie we have included TP and DRP load estimates provided by the Heidelberg Tributary Loading Program (HTLP). This program focuses on several US tributaries which drain into Western and Central Lake Erie. The HTLP sampling and analytical program provides a data set for monitored rivers containing the date and time of sample collection, provisional USGS instantaneous discharge at the time of sample collection, and the concentrations of TP and DRP. These data are converted into annual loads using a custom version of the Beale Ratio Estimator called Autobeale (Richards et al., 1996). This load calculation is very similar to that used by Dolan and Chapra (2012) and is described in more detail in Baker et al. 2014.

#### *Measure 2:*

Dolan and Chapra (2012) did not provide DRP as part of their load summaries. However, we have included some TDP (total dissolved rather than dissolved reactive phosphorus) load data for Lake Michigan that Dolan provided to Mark Rowe (NOAA CILER). Because these data are not DRP as required by the indicator, these data may be of limited use for calculating the indicator, but Rowe's approach to compiling and "cleaning" the data could serve as guidance as to how to process the TP loads in Dolan and Chapra (2012). As described above, DRP loads for several tributaries of Western and Central Lake Erie have been calculated by the Heidelberg Tributary Loading Program.

#### *Measures 3 & 4:*

TP and DRP in the Great Lakes are regularly monitored by Environment Canada (EC), the US Environmental Protection Agency Great Lakes National Program Office (EPA GLNPO), and the Ontario Ministry of the Environment (OMOE). These monitoring efforts include spring and summer cruises to collect water quality samples on the lakes. Briefly, EC generally monitors each lake (except MI) every second year, with several cruises conducted during that year. All regions (nearshore, offshore and major embayments) are monitored for the EC program. EPA GLNPO conducts one spring and one summer cruise annually on all waters except Georgian Bay, with stations located mostly in water deeper than 50 meters. EPA GLNPO samples about 75 offshore sites and EC samples about 275 sites. EPA GLNPO data were downloaded from the EPA CDX portal and EC data were provided by Alice Dove. The Ontario Ministry of the Environment (OMOE) visits 10-18 Ontario Great Lakes Index Stations (OGLIS) in nearshore areas each year with lakes sampled on a rotational basis.

In addition to the OMOE OGLIS sampling, we are aware of several nearshore sampling programs, but each dataset is limited in spatial extent, temporal extent, or both. As such, we describe these datasets briefly below and provide contact information in the metadata worksheet, but do not include these data in this database. The EPA National Coastal Condition Assessment (NCCA) program sampled 248 sites in 2010 and revisited some sites and sampled new sites in 2015. From 2009 to 2013 there were additional nearshore nutrient monitoring efforts in nearshore areas of the US shoreline of Lake Erie (the NOLENS and LENONS projects). Although we did not pursue acquiring these data, the Lake Erie LaMP Work Group Nutrient Management Task Group should be able to provide these data if desired.

#### *Temporal extent*

#### Measure 1:

The loads from Dolan and Chapra (2012) included in this dataset are annual loads from 1994 to 2008. Great Lakes TP loadings have been estimated since 1967, although the spatial extent at which

these loads are summarized varies with year, lake, and program. Load estimates calculated using comparable methods are available for approximately 1981-2008 but much older (i.e., prior to 1994) TP load data are available as summaries at the subbasin or basin spatial extent. Because the indicator specifies the load estimates are to be at the tributary spatial extent, we did not compile these older data and they are not included here. The Heidelberg Tributary Loading Program began as early as 1975 and is ongoing, but the specific period of record varies with tributary.

#### Measure 2:

Lake MI TDP is 1994-2008. The Heidelberg Tributary Loading Program began as early as 1975 and is ongoing, but the specific period of record varies with tributary.

#### Measure 3:

The period of record varies with the monitoring program. The GLNPO offshore period of record is as long as 1983-2013 (although the start year varies with lake, and some seasonal cruises were skipped in early years). The GLNPO monitoring program is ongoing with a year or two lag in data availability. EC water quality monitoring began in 1970 in most lakes but the EC data Alice Dove provided for analysis are from 1985 to 2014. The EC monitoring program is ongoing with about a year lag in data availability. The Ontario Great Lakes Index Station nearshore sampling by the Ontario Ministry of the Environment is from 2003-2010. The website descriptor of the OMOE OGLIS program indicates monitoring is ongoing, but no data since 2010 have been included for distribution.

#### Measure 4:

DRP is not collected with the same frequency as TP and monitoring times and efforts have changed over the period of record. There are also gaps in all DRP, SP, and SU sampling records. Lake MI has not had DRP monitoring since 1992 in either spring or summer, and DRP in Lake Superior is not monitored in the summer at all. Most current DRP data are collected by EC on a rotational basis.

#### *Spatial Extent*

#### Measures 1 & 2:

Dolan and Chapra (2012) provide loads for individual tributaries and tributary “complexes” for all Great Lakes, with the exception of Lake Erie where loads are summarized at the subbasin. The Heidelberg Tributary Loading Program (HTLP) data is for individual tributaries entering the US side of Western and Central Lake Erie. Mark Rowe compiled and “cleaned” TDP loads developed by Dolan for Lake Michigan.

#### Measures 3 & 4:

Average annual spring and summer TP and DRP concentrations are provided at the station level and are also averaged across all stations in a lake regardless of station depth. We have included two depth estimates for each monitoring station, 1) the average depth from soundings during sampling and 2) depth from a spatial join of the stations to the GLAHF bathymetry raster map. As the indicator description suggested, this will also allow exploration of the effects of station depth on trends in TP and DRP in-lake concentrations if desired. Likewise, because data are provided at the station level, data can alternately be summarized by lake subbasin if desired.

#### **Summary of Findings:**

#### *Measures 1 & 2:*

Dolan and Chapra (2012) report a trend of decreasing total (e.g., across all sources) TP loadings for all five Great Lakes (see Table 11 and Figure 28 below from Dolan and Chapra, 2012). This decreasing trend is only statistically significant in Lakes Huron and Ontario (Table 11). Figure 29 shows the decreasing trend in total TP loading relative to IJC target loadings, which suggests that while loading has decreased from 1960 to 1983, IJC target maximum loads for total phosphorus are still exceeded. For more details and analysis please see Dolan and Chapra (2012) which is included in the database folders.

**Table 11**

Results of linear fit of loading data (MTA) versus time for the period from 1980 through 2008 for each of the Great Lakes. The parenthetical percentages in the last column are coefficients of variation computed as the ratio of the standard error of the estimate (SEE) to the mean of the data.

Lake	Intercept 1980	Projection 2010	Decrease	Rate	$R^2$	Slope p-value	SEE (c.v.)
Superior	3062	3043	19	−0.6	$2.1 \times 10^{-5}$	0.9810	1190 (39%)
Michigan	3972	3310	662	−22.1	0.074	0.1543	678 (18.6%)
Huron	4235	2524	1711	−57.0	0.307	0.0018	742 (22%)
Erie	10,999	8874	2125	−70.8	0.061	0.1979	2418 (24.3%)
Ontario	6879	4497	2382	−79.4	0.255	0.0052	1176 (20.7%)

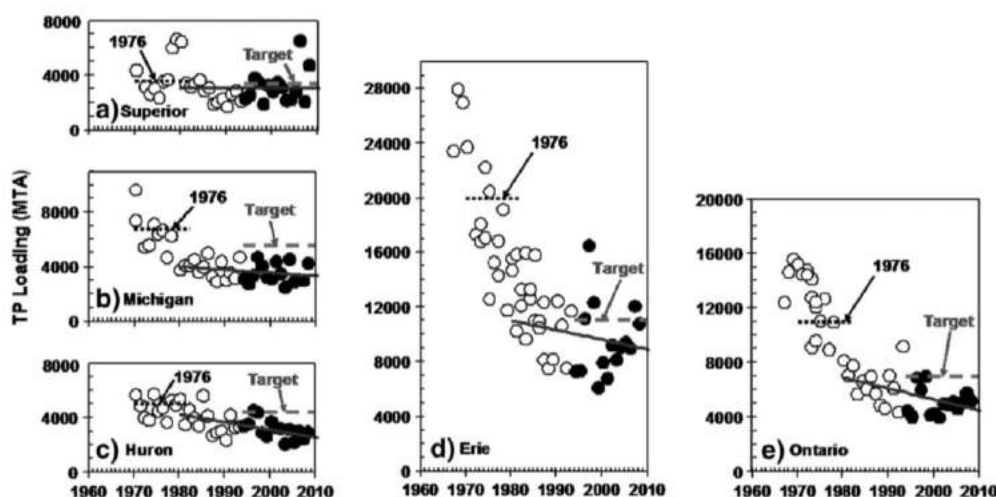


Fig. 2. Time series of TP loading (MTA is metric tonnes per annum) for each of the five Great Lakes (a–e). The filled points are new estimates reported in this paper. The open points are data compiled previously. The dotted lines are the 1976 loadings assumed by IJC and the dashed lines are the IJC target loadings. The solid lines are the trends from Table 11.

Figure 28. TP loading in the Great Lakes (from Dolan and Chapra 2012)

Trends in many tributaries monitored as part of the HTLP have also been addressed in project reports and the recent manuscript by Baker et al. (2014) (also included in database folder). Baker et al. (2014) indicate total phosphorus (TP) loads to Lake Erie continue to slowly decline, while DRP export from nonpoint sources in the Maumee and Sandusky rivers have increased substantially. DRP loads for the Cuyahoga River have also increased, although these increases were modest as compared to the increases in the Maumee and Sandusky Rivers.

In this report we provide the TP load data for all lakes from Dolans and Chapra (2012), HTLP TP and DRP loads for some tributaries of Lake Erie, and documentation of the efforts by Mark Rowe to compile and clean TP and TDP loads for Lake Michigan. We did not analyze trends in TP and DRP loads in part because experts had conducted and published detailed analyses up to 2008 for Dolan and Chapra

(2012) and up to 2010 for Lake Erie (Baker et al. 2014). Several issues prevented us from reporting TP (and DRP) loads for more recent years. First, we are not aware of any basin-wide attempt to continue estimating loads using the methods of Dolan and Chapra (2012), the only analyses that include load calculations for all five lakes to date. Second, compiling load data from Dolan and Chapra (2012) will require a significant effort to consolidate comparable data because data varies from year to year (e.g. tributaries sampled changed and tributary names changed from year to year). Finally, cross-referencing tributary locations from Dolan and Chapra (2012) with current watershed maps will require substantial work. The documentation Mark Rowe at NOAA CILER has shared specifically details how he approached these last two challenges and may serve as guideline for data compilation and tributary cross-referencing. The lack of continued comparable monitoring will likely limit the use of these load estimates for this indicator.

#### *Measure 3:*

All lakes demonstrated a negative trend in springtime TP with the exception of Lake Erie which may be experiencing increases in TP concentrations and Lake Superior, in which TP concentrations are stable and low (Figure 29). Lake Erie spring TP levels increased at a rate of approximately  $0.12 \mu\text{g P/L/yr}$  (as estimated by the slope of a line fit to the concentrations over the period of record). The largest observed decline in springtime TP was on Lake Ontario, which is declining at a rate of  $0.21 \mu\text{g P/L/yr}$ . All other lakes were intermediate to these extremes. In general, Lake Erie had the highest spring TP levels ( $\sim 18 \mu\text{g P/L}$ ), whereas Lake Superior had the lowest ( $\sim 3 \mu\text{g P/L}$ ).

All lakes demonstrated modest declines in summer TP levels (Figure 30). The largest decline was observed in Lake Ontario, which declined at a rate of  $0.14 \mu\text{g P/L/yr}$ . The smallest decline was observed in Lake Erie, which is only declining at a rate of  $0.01 \mu\text{g P/L/yr}$ .

#### *Measure 4:*

Trends in spring and summer DRP are somewhat similar to those observed for TP, but gaps in the data limit the ability to effectively graph these data. We should also caution that the discontinuation of DRP monitoring may limit the ability to interpret any trends observed. In the spring, Lake Erie appears to be demonstrating an increase in spring DRP as well as modest increase in Lake Superior ( $0.003 \mu\text{g P/L/yr}$ ). Lake Erie, Ontario and Huron also appear to have experienced increases in summer DRP: Lake Ontario is increasing the most rapidly at  $0.07 \mu\text{g P/L/yr}$ . DRP in the summer in Lake Superior is not monitored.

### **Data gaps and recommendations**

#### *Measure 1:*

TP loads Dolan calculated use consistent calculation methods to allow load estimates to be compared among years. However, Grannemann states "there are some new techniques to estimate loads that may eclipse the Beale estimator that Dolan used. Regardless, the Dolan work is the most consistent information if it can be updated from 2008 to present". However, we are unaware of any basin-wide efforts to update Dolan and Chapra's load calculations. From a brief email exchange with Russ Kreis, he believes one of Dolan's former students (unfortunately he remains unnamed) is in the process of updating the load calculations for Lake Erie tributaries, but those data are not currently available. We were also informed that Matt Maccoux or Alice Dove may be in the process of compiling TP load estimates for all Lake Erie tributaries as a part of the Annex 4 nutrient standards report.

There are also concerns regarding how to rectify the spatial aspect of this measure. Chapra and Dolan (2012) provide 1994-2008 annual TP loads for US and Canadian tributaries to Lakes Superior, Huron, Michigan, and Ontario. In contrast, their loads for Lake Erie are summarized at the subbasin



spatial extent. The original tributary-based load data for Lake Erie are likely available but we were not able to identify such a source and acquire those data.

Despite the lack of ongoing load estimates, primary data on which loads could be calculated are available and regularly monitored. However, an expert in load calculations will need to undertake this effort and account for the challenges in tributary phosphorus monitoring addressed in Ballard LaBeau et al. (2013). Compiling available load data for Great Lakes tributaries will require a targeted and funded effort to gather and standardize data for analysis. US daily average tributary flows for gauged tributaries are available from the National Water Information System (NWIS) database maintained by the Water Resources Division of the USGS and Canadian daily average tributary flows for gauged tributaries are available from the Hydromeasure Data (HYDAT) database maintained by Environment Canada, Water Survey Canada. US tributary TP concentrations available in STORET, the US EPA database for water quality data and Canadian tributary TP concentrations are available from the Provincial Water Quality Monitoring Network (PWQMN) database at the Ontario Ministry of the Environment.

#### Measure 2:

There are limited DRP or TDP load estimates available outside of targeted areas in Lake Michigan and Lake Erie. The only ongoing DRP load estimate program is the HTLP in Lake Erie.

#### Measure 3:

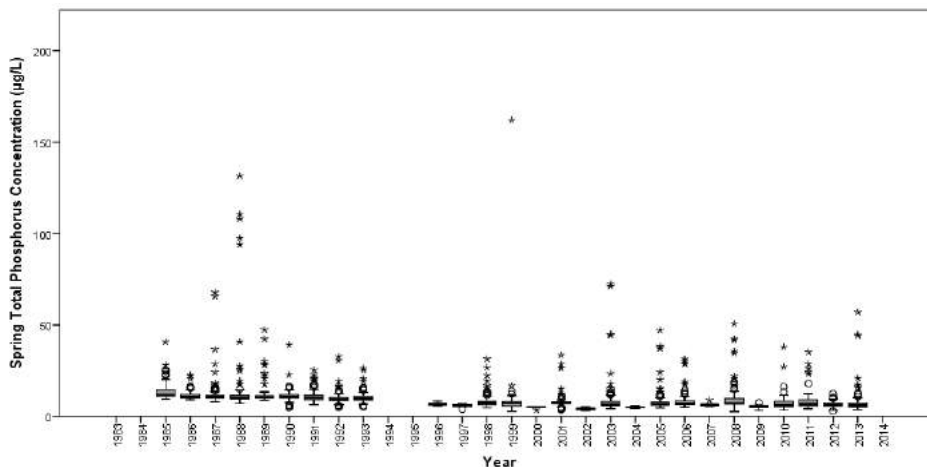
Lake Michigan has fewer samples because it is only monitored by EPA GLNPO. The majority of monitoring stations are offshore because of boat draft limitations.

#### Measure 4:

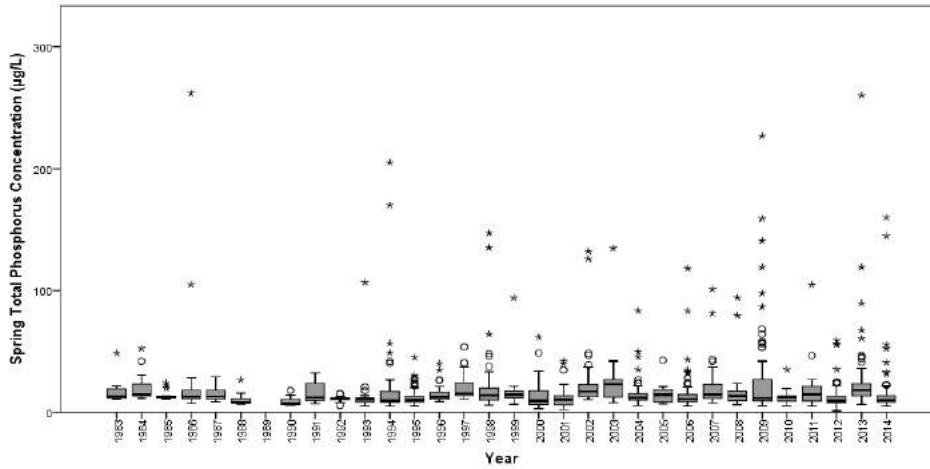
EPA GLNPO stopped monitoring DRP in 1996, therefore there has been no recent monitoring in Lake Michigan. Because EC monitoring is on a rotational basis, DRP monitoring by EC occurs every other year within a lake. This may limit the ability to explore short-term trends in DRP.

For both Measure 3 and 4, whole lake averages are based primarily on samples collected offshore (with the exception of some nearshore and embayment sites samples by EC and OMOE). We have provided metadata for additional nearshore data we were able to identify, but exactly how the nearshore data will be incorporated into trends analyses will require further discussion and calculation.

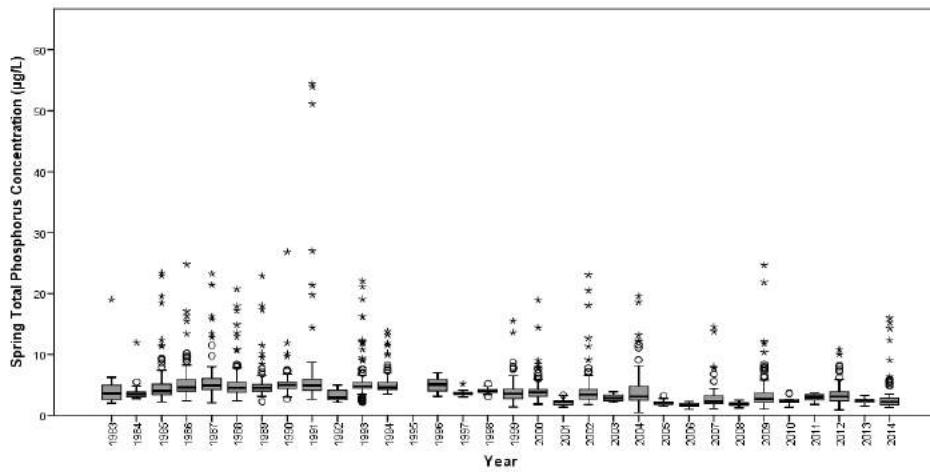
#### a) Lake Ontario



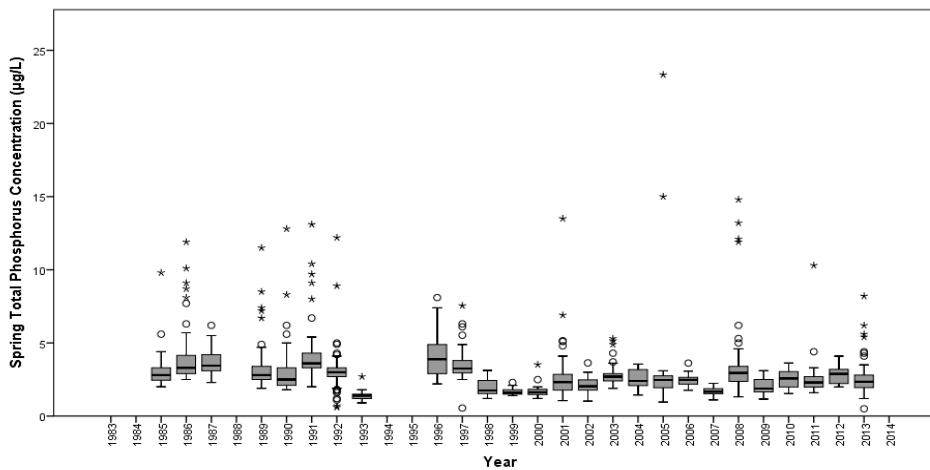
b) Lake Erie



c) Lake Huron



d) Lake Superior



e) Lake Michigan

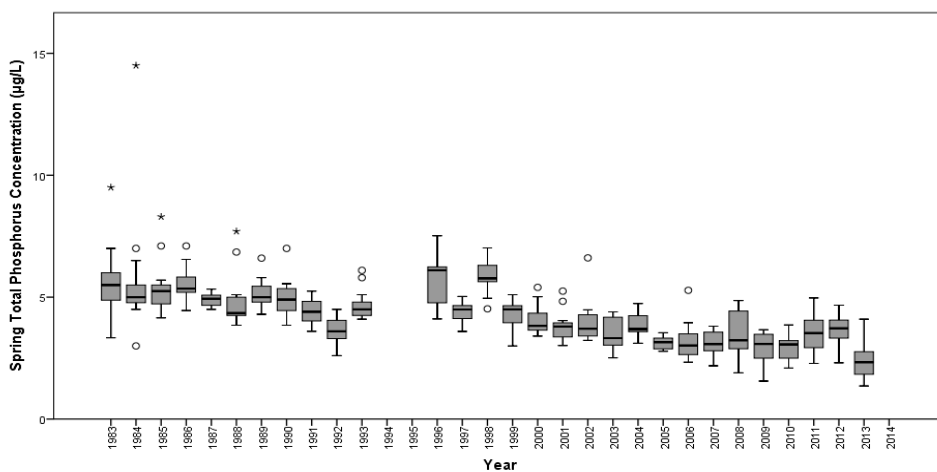
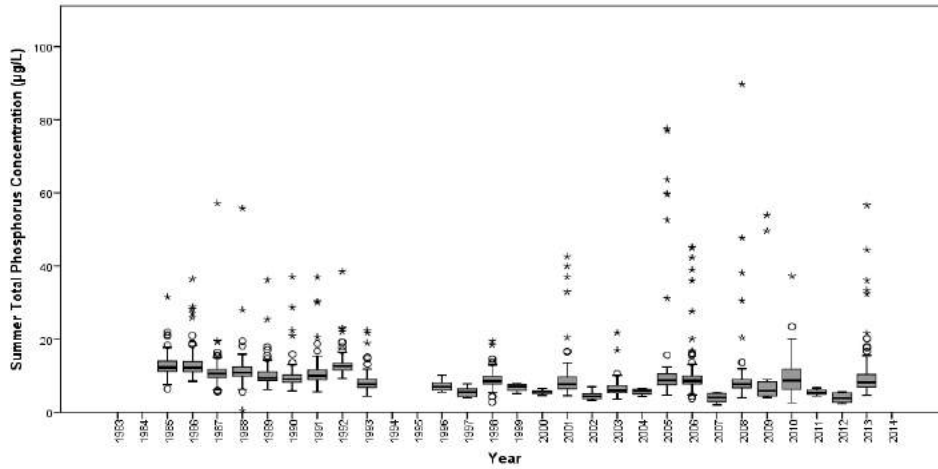
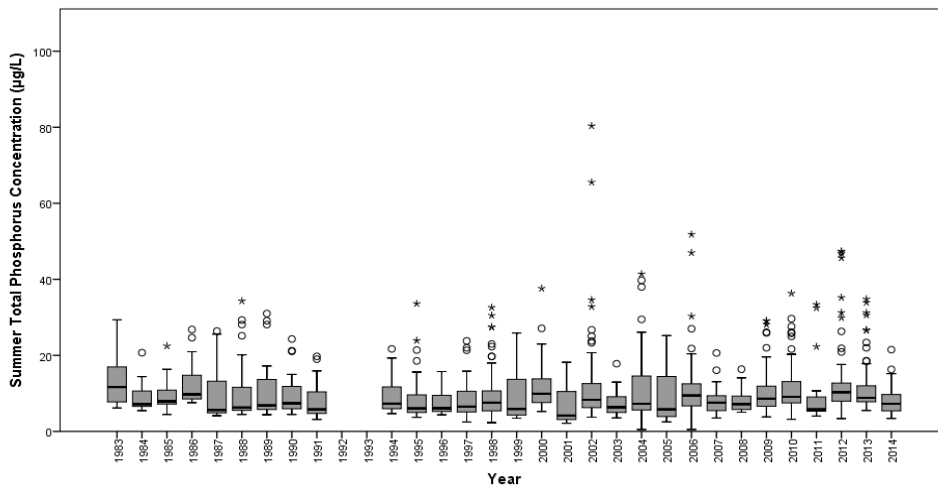


Figure 29: Boxplots illustrating the distribution of Total Phosphorus (TP) concentrations at monitoring stations in each lake during the spring.

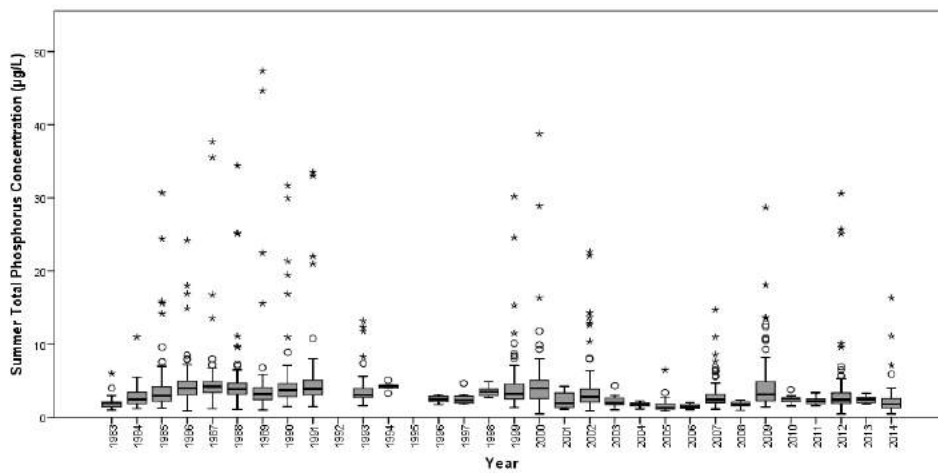
a) Lake Ontario



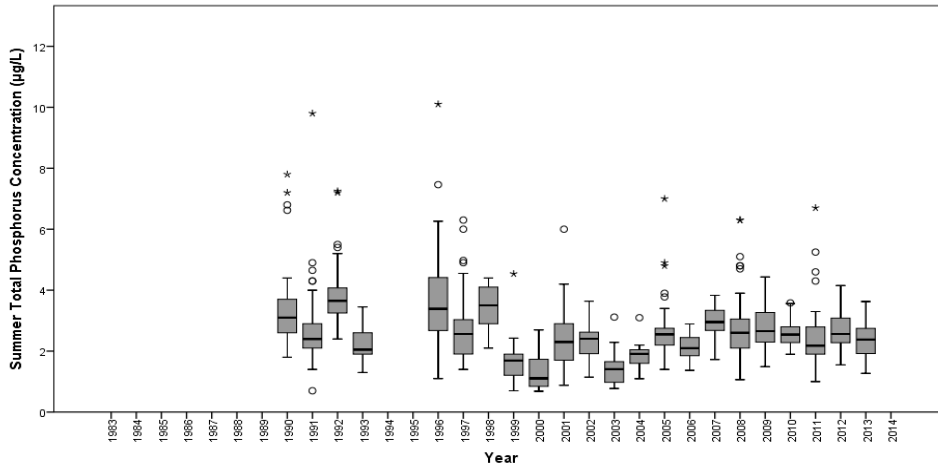
b) Lake Erie



c) Lake Huron



d) Lake Superior



e) Lake Michigan

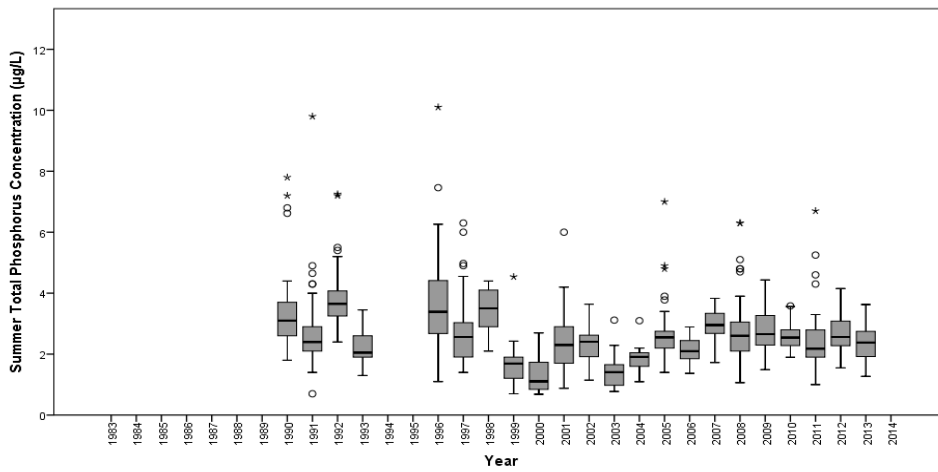


Figure 30: Boxplots illustrating the distribution of Total Phosphorus (TP) concentrations at monitoring stations in each lake during the summer.

## Aquatic Invasive Species: Invasion Rates and Impacts

### Summary:

This indicator measures the rate of invasion and status and impacts of aquatic invasive species (AIS) in the Great Lakes. The rate of invasion can be used to identify potential pathways of invaders and evaluate any long-term trends in the rate of invasion. Status and impacts of aquatic invasive species measures detrimental effects of AIS and focuses on the relative abundance of AIS to native species across multiple trophic levels in the Great Lakes.

### Measures:

This indicator consists of two measures: 1) the rate of invasion of AIS, and 2) the status and impacts of AIS.

Metric	Description
1	Rate of Invasion: Cumulative Number of Species Versus Time
2a	Sea Lamprey Abundance Vs. Target Set by Great Lakes Fisheries Commission by Lake
2b	Invasive Zooplankton Biomass Relative to Entire Zooplankton Community Biomass by Lake
2c	Occurrence, Abundance, and Reproduction of Asian Carp
2d	Dreissenid Mussel Abundance in Nearshore Zone Hard Substrate and in Offshore Zone Soft bottom by Lake
2e	Round Gobies Relative Abundance (biomass or number) Compared to All Benthic Fishes in Nearshore and Tributaries by Lake
2f	Relative Abundance (biomass or number) of Ruffe Compared to All Benthic Fishes Abundance in Nearshore and Tributaries by Lake

### Data sources:

**Great Lakes Aquatic Nonindigenous Species Information Network**, Rochelle Sturtevant - Regional Sea Grant Specialist - Outreach, NOAA Great Lakes Environmental Research Laboratory, 734.741.2287, rochelle.sturtevant@noaa.gov

**Jess Barber**, Marquette Biological Station, Jessica\_barber@fws.gov, provided Sea Lamprey abundance estimates and targets set by Great Lakes Fishery Commission.

**Great Lakes Aquatic Habitat Framework**, Beth Sparks-Jackson, Postdoctoral Fellow, University of Michigan, 734.615.4727, sparksb@umich.edu, compiled benthic data from both published reports and private sources shared directly through personal contacts. Sources include the EPA Great Lakes National Program Office (GLNPO) Monitoring program, data compiled by the Lake Erie Forage Task Group (LEFTG), the Lake Ontario Lower Aquatic Foodweb Assessment (LOLA), data for Lake Ontario from Steve Lozano, and data from Tom Nalepa, both published and unpublished datasets.

**United States Geological Survey** bottom trawls along depth contours in Lakes Michigan, Huron, and Superior. Jeff Shaeffer, USGS Great Lake Science Center, 734.214.7250, jshaefter@usgs.gov and Mark Vinson, USGS Lake Superior Biological Station, 715.682.6163, mvinson@usgs.gov.

### *Spatial Extent:*

Rate of invasion is available by basin and individual lake. Sea Lamprey abundance and target population sizes are available by lake. Dreissenid mussel density estimates are collected at a specific latitude and longitude but can be scaled up to the lake. Attempts to integrate multiple sites into a lake-

wide estimate will need to consider the impact of inter-annual differences in experimental design on density estimates. Round Goby, Eurasian Ruffe, and other benthic fish abundance and biomass estimates are collected at specific latitudes and longitudes and can be scaled up to broader spatial scales, though the specifics of how to weigh different sampling events will need to be evaluated (e.g., weighting catch at depth by depth contours within the lake).

*Temporal extent:*

Rate of invasion data are available annually from 1829 – 2015. Sea Lamprey abundance estimates are available annually from 1977 – 2014. Dreissenid mussel density estimates vary in their temporal extent but typically span from the mid- to late-1990s until present. The number of dreissenid density estimates within a year is highly variable and depends on the amount of sampling beyond the long-term monitoring programs (e.g., GLNPO). Round Goby and Eurasian Ruffe relative abundance data are available from the mid-1970s through 2008.

**Summary of findings:**

*Measure 1:*

The introduction of new species into the Great Lakes has increased dramatically since 1829. Currently, 184 species have been introduced (Figure 31). The most species have been introduced into Lake Erie (134 species) while Lake Huron has the fewest of the main lakes (97) (Figure 32). The vast majority of introductions occurred in the latter half of the 21<sup>st</sup> century, with cumulative introductions appearing to increase exponentially. The exception to this is in the most recent decade, when number of introductions appear to level off (Figure 33).

*Measure 2a:*

Sea Lamprey populations appear to be declining basin-wide since 1980. We found a significant ( $p=0.015$ ) decline in the basin-wide mean Sea Lamprey population estimate (Figure 34). However, this basin-wide trend appears to derive primarily from Lake Ontario, which has experienced a dramatic decline in Sea Lamprey abundance. Sea Lamprey in Lake Michigan are actually significantly increasing ( $p = 0.01$ ) (Figure 35). Although a moving-average analysis was not a component of this effort, it appears as though the mid 1990's was a nadir for lamprey abundance in Lake Superior and Erie. Sea Lamprey populations appear to be experiencing an increase in these lakes, although no significant increase was detected over the entirety of the dataset. On all lakes except perhaps Lake Ontario, Sea Lamprey abundance regularly exceeds target abundances (Figure 35).

*Measure 2b:*

We are currently waiting for zooplankton biomass data to be shared.

*Measure 2c:*

Asian Carp are currently not present in the Great Lakes; therefore there is no trend to calculate.

*Measure 2d:*

Dreissenid mussels have increased significantly in Lake Michigan ( $p = 0.04$ ) and Lake Erie ( $p = 0.03$ ), remained stable in Lake Ontario, and decreased in Lake Huron ( $p < 0.05$ ) (Figure 36). However, assessing these trends remains challenging because Indicator trends for dreissenid mussels are strongly influenced by the experimental design, what data are included, and the duration of the time series. Additional filtering is needed to ensure the greatest consistency across space and time and will require further consideration by the IJC expert working group. In addition, further development of this index

might consider stratifying the data by depth since Dreissenids seem to vary across depths and also have been found deeper in recent years.

It should also be noted that the available Dreissenid data is only for soft substrates. Nearshore Dreissenid samples are typically only collected every five years during the Cooperative Science and Monitoring Initiative monitoring for each lake.

#### *Measure 2e:*

Round Goby relative abundance has increased significantly for relative numbers and biomass in both Lake Michigan ( $p = 0.02$ ,  $p = 0.04$ , respectively) (Figure 37) and Lake Huron ( $p < 0.001$ ,  $p < 0.001$ , respectively) (Figure 38).

#### *Measure 2f:*

Ruffe relative abundance has increased significantly for relative numbers and biomass in Lake Superior ( $p < 0.001$ ,  $p < 0.001$ , respectively) (Figure 39).

#### **Data gaps and recommendations:**

The primary data gap is the availability of zooplankton data throughout the basin. These data do exist and we are currently working with data holders to obtain access to this information. Although we are not currently able to provide summaries for fish in Lakes Erie and Ontario, similar USGS bottom trawl data do exist for these lakes. Once the data are procured, a similar procedure could be used to calculate indicator measures. We are not aware of any consistent source of benthic fish samples for tributaries. A secondary data gap is the lack of Dreissenid samples on hard substrates and in the nearshore, which only occur every five years.

For other measures, including Measure 2d (Dreissenid mussels), Measure 2e (Round Goby) and Measure 2f (Ruffe), the IJC expert working group will need to determine how to address inter-annual differences in experimental design and data availability to avoid biases in trend calculations (*e.g.*, Dreissenid variation with depth and lack of hard substrate and limited nearshore samples). This will include further consideration of how to filter all available data and integrate data from multiple sources. In our analyses, we have treated all sampling events within a year equally and averaged these to calculate trends. The calculation method likely has a strongest effect on Dreissenid mussel trends which vary spatially with depth and other factors, but will also be important when attempting to scale up individual trawl estimates to lake-wide averages. Specifically, this will likely require that depth-specific catches are weighted by the percentage of lake surface area at a given depth.



Figure 31. Basin-wide introductions of non-native species through time.



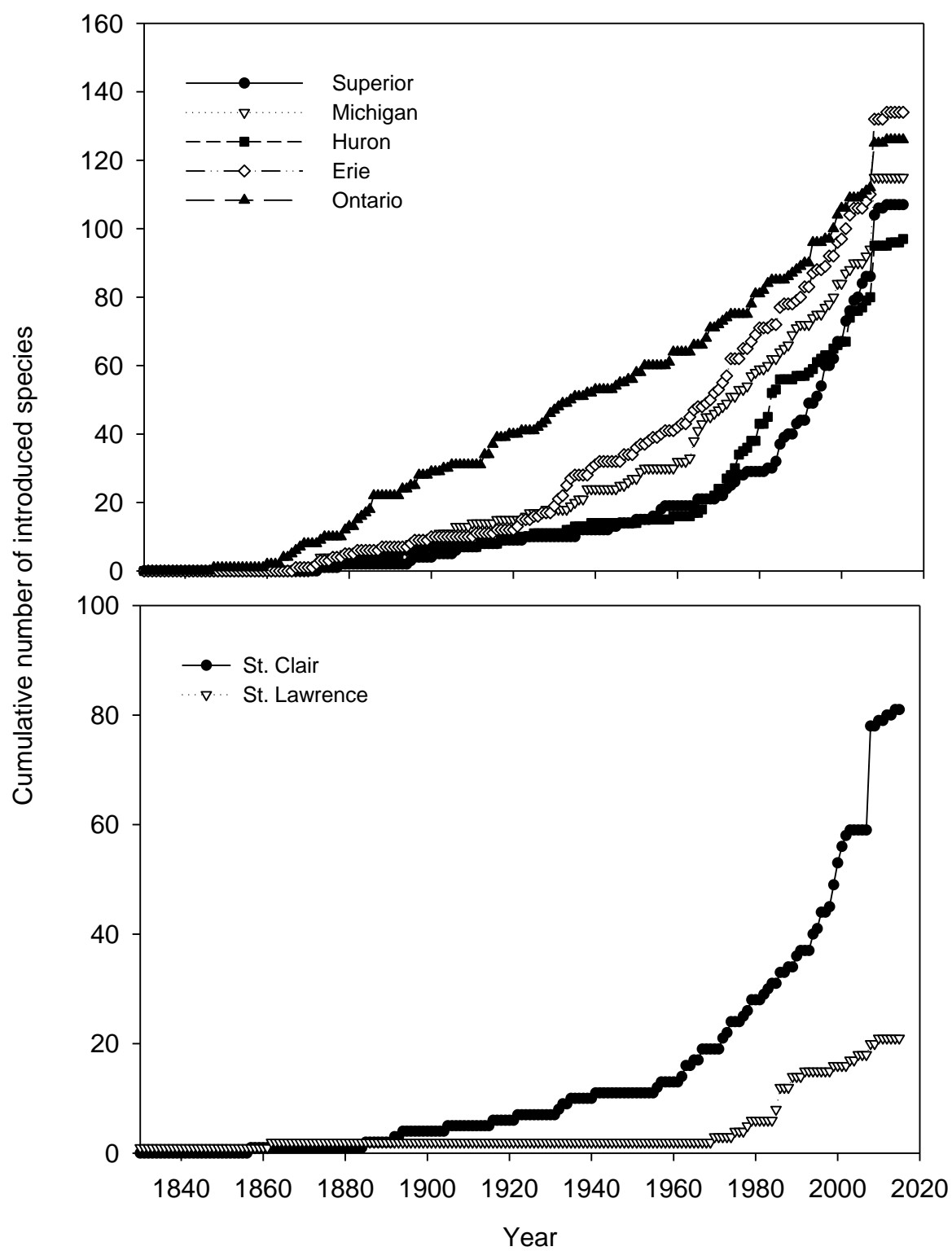


Figure 32. Lake specific cumulative introductions of non-native species

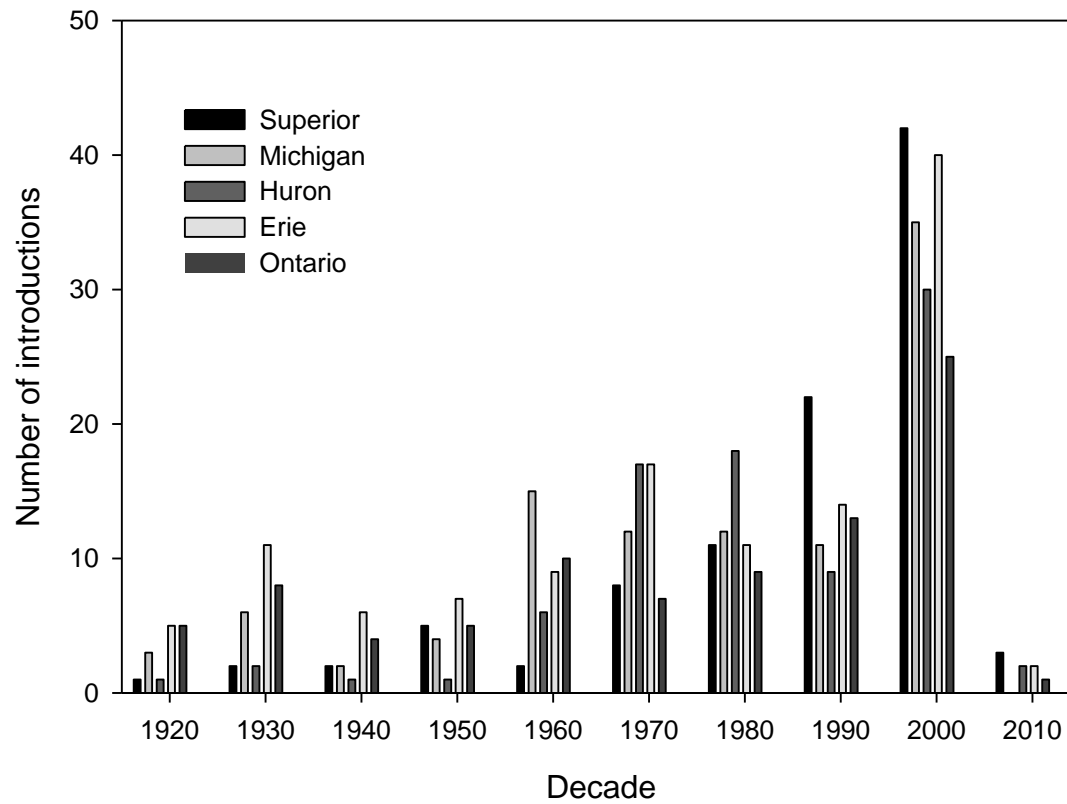


Figure 33. Number of unique introduced species by decade from 1920-2015 in each lake

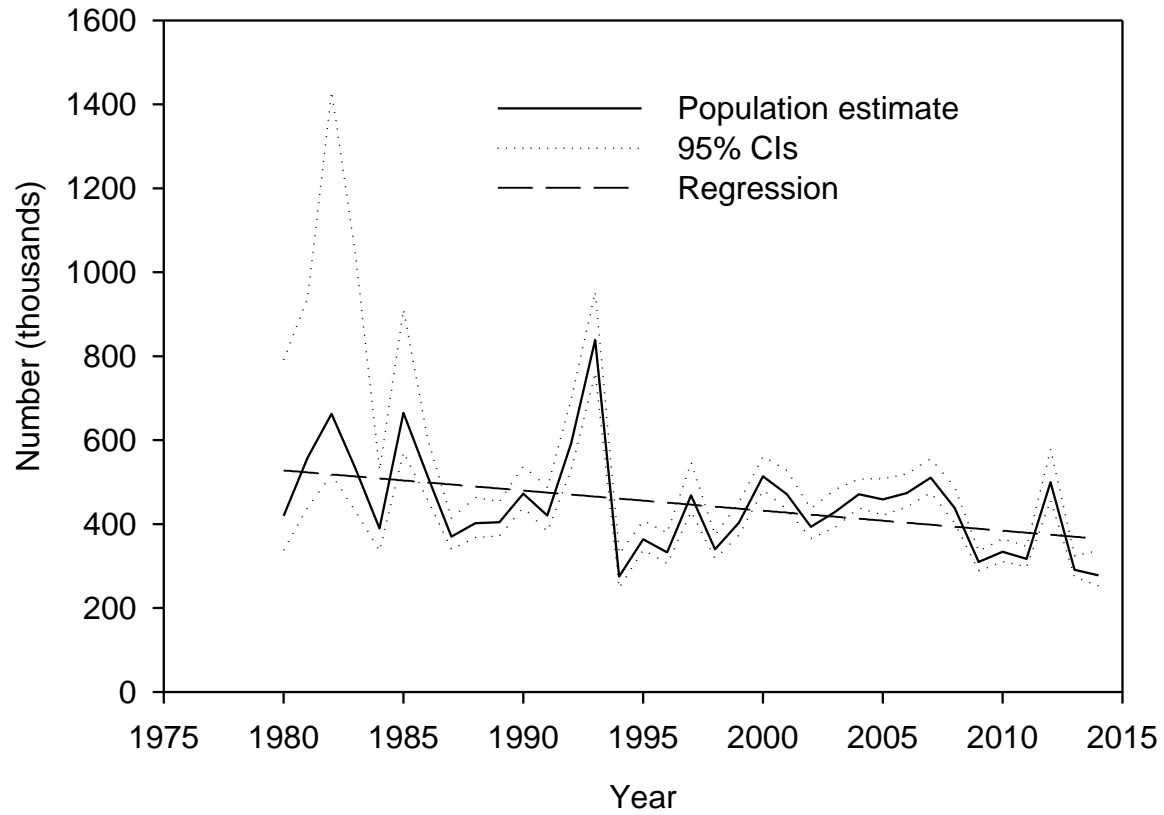


Figure 34. Basin-wide estimate of Sea Lamprey populations with associated 95% confidence intervals. The linear regression equation is (# of sea lamprey =  $10,007 - 4.79 \cdot \text{year}$ ;  $p = 0.0147$ ).

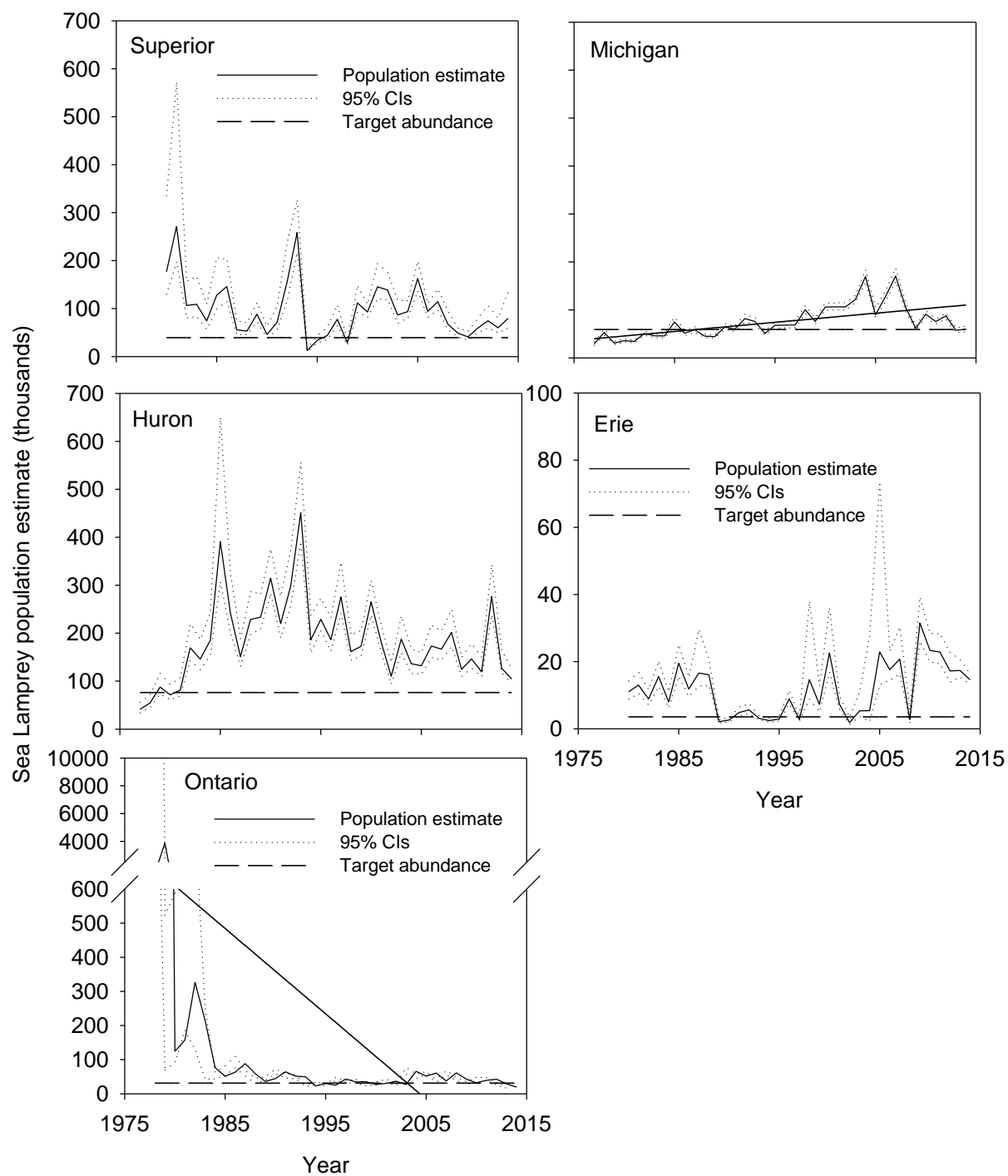


Figure 35. Lake-specific Sea-Lamprey abundances with associated 95% confidence intervals and abundance targets. Lines through abundances indicate significant linear regression estimates ( $p < 0.05$ ).

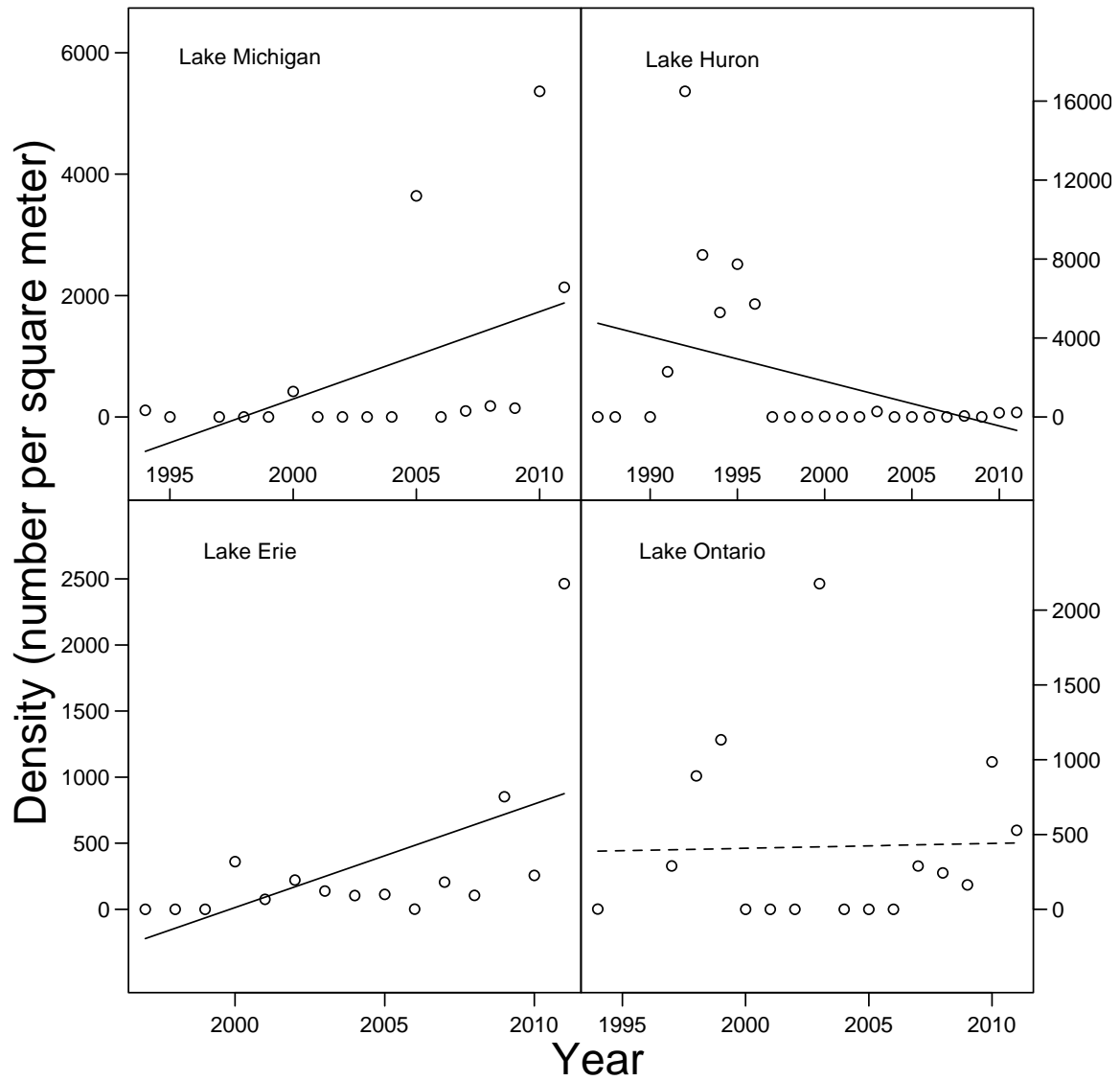


Figure 36. Temporal trends in lake-wide density estimates of dreissenid mussels in the Great Lakes. Significant trends over time are indicated with a solid line. Lake Superior was not included because dreissenid mussels are not present in the available data.

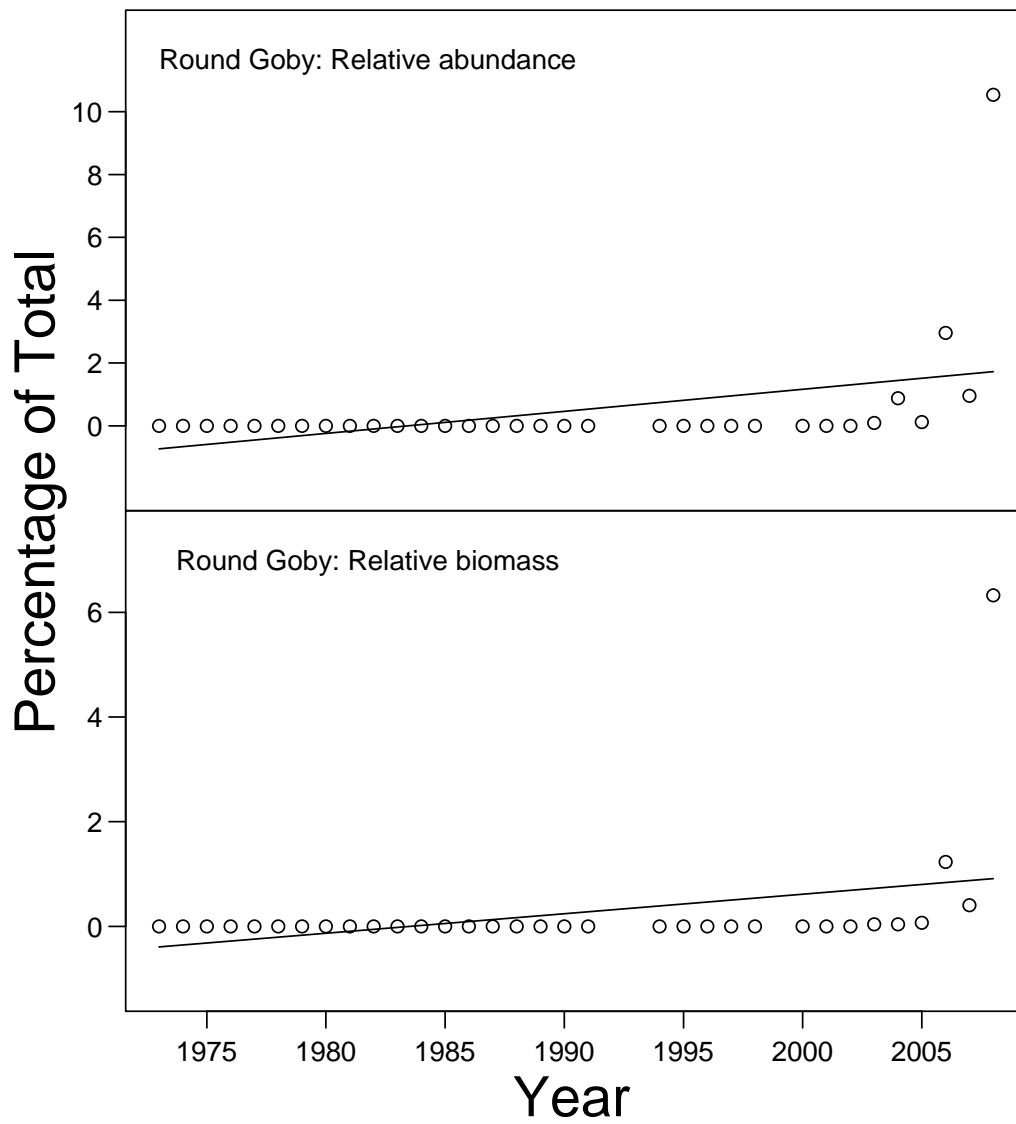


Figure 37. Ratio of Round Goby abundance and biomass to all benthic fish in USGS trawl surveys conducted in Lake Michigan. Significant trends over time are indicated with a solid line.

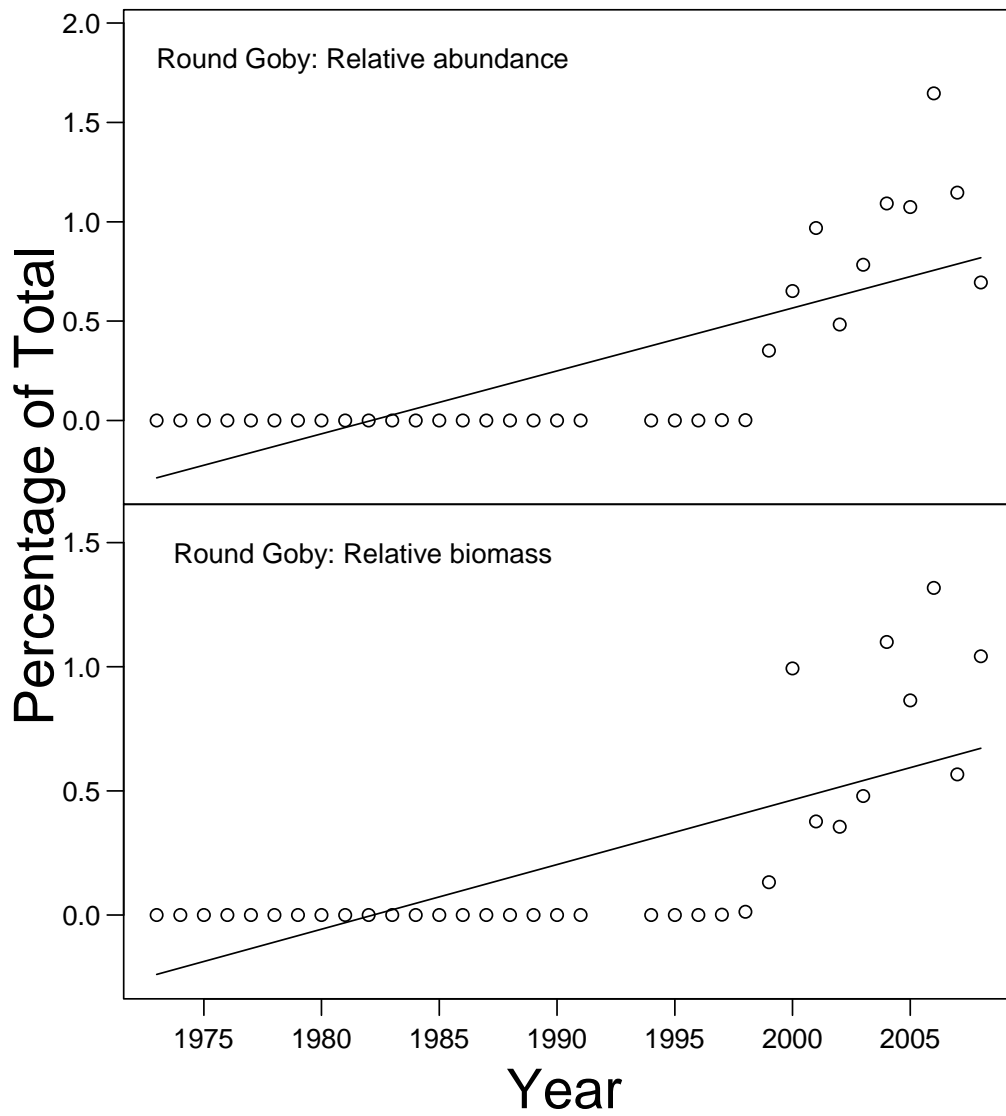


Figure 38. Ratio of Round Goby abundance and biomass to all benthic fish in USGS trawl surveys conducted in Lake Huron. Significant trends over time are indicated with a solid line.

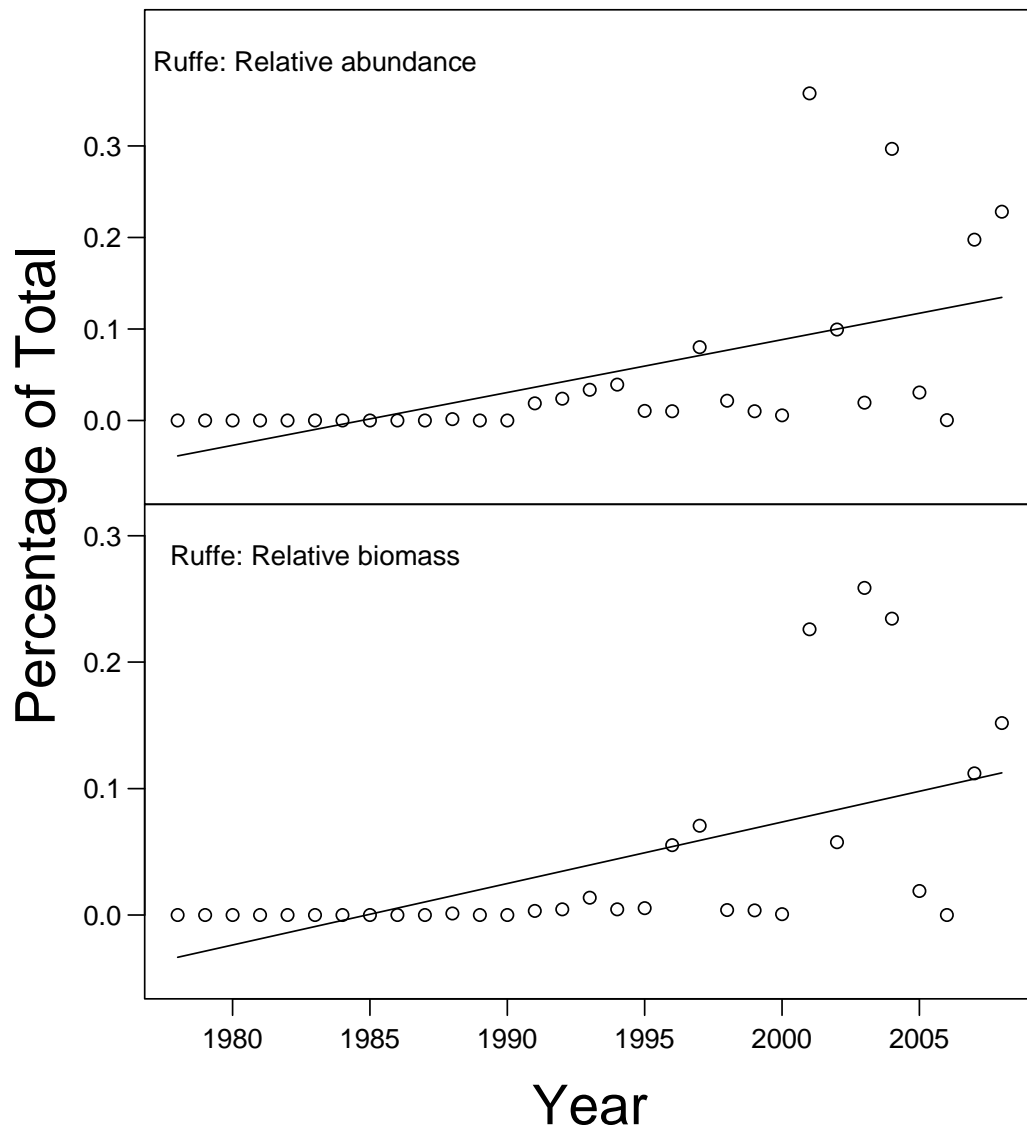


Figure 39. Ratio of Ruffe abundance and biomass to all benthic fish in USGS trawl surveys conducted in Lake Superior. Significant trends over time are indicated with a solid line.



## Lower Food Web Productivity and Health

### Summary:

The Lower Food Web Productivity and Health indicator consists of phytoplankton, zooplankton, *Mysis*, benthos, and prey fishes components. Data exist for all five of these measures, although data we were not able to acquire data for all measures and unrestricted sharing of data may be a particular challenge for prey fish data. Zooplankton measures may be available from Jim Watkins (Cornell University) in the next few months. Two of the three primary sources of *Mysis* biomass data (Dave Warner at USGS Great Lakes Science Center and Dave Jude at the University of Michigan) are still running quality assurance and control (QAQC) checks. The three *Mysis* datasets will need to be compiled prior to indicator calculation.

### Measures:

Measure	Description
1	<u>Phytoplankton</u> : Total biovolume of phytoplankton (volume/volume) and taxonomic composition for spring and late summer. Abundances of taxa (e.g., blue-green algae or large diatom blooms) will reflect conditions relative to known historical condition within a lake.
2	<u>Zooplankton</u> : Crustacean biomass, including <i>Daphnia retrocurva</i> , <i>D. galeata</i> , Cyclopoida, <i>Limnocalanus</i> , and other Calanoida.
3	<u>Mysis biomass</u> : Date of sampling should target time periods of higher numbers of larger mysids in the population.
4	<u>Benthos</u> : Abundance of dreissenid mussels, <i>Diporeia</i> , <i>Hexagenia</i> , <i>Gammarus</i> , Chironomidae (individuals/m <sup>2</sup> ), and Oligochaete Trophic Index (EC and USEPA). Separate indices are needed for nearshore vs. offshore and hard vs soft substrate.
5	<u>Prey fishes</u> : Prey fish biomass per unit effort for all lakes and prey fish diversity (Shannon–Wiener Index).

### Data sources:

#### Measure 1:

The US EPA Great Lakes National Program Office (GLNPO) offshore monitoring program is the most consistent and long-term phytoplankton monitoring program. Dr. Euan D. Reavie (NRRI, University of Minnesota-Duluth) coordinates phytoplankton monitoring, sample processing, and database management. GLNPO phytoplankton sampling and processing standards established in 2001 continue today. Although earlier phytoplankton samples do exist, these were analyzed by different taxonomists and underwent different quality assessment procedures and are therefore not included in the provided data. GLNPO sampling surveys are conducted during the spring isothermal period and summer stratified period. Spring surveys are conducted as early as possible after ice out (usually in April) and summer surveys are conducted during the period of stable thermal stratification (usually in August). Some sampling stations have 12 years of phytoplankton data (the 14 “master stations”) while all 72 stations have the most recent six years (2007 through 2012). More detail on sample collection and processing can be found in Reavie et al. 2014. Reavie has shared his master data table with the IJC and summarizations at two spatial extents have been developed.

#### Measure 2:

The US EPA Great Lakes National Program Office (GLNPO) offshore monitoring program is the most consistent and long-term zooplankton monitoring program. GLNPO zooplankton cruises began in 1998 and sampling surveys are conducted during the spring and summer as described in the phytoplankton measure. About 70 stations are sampled each season and these stations are distributed across all five lakes, but are largely in deep, offshore areas. Zooplankton are collected by vertical tows taken from two depths: 1) a depth of 100 meters or 2 meters from the bottom, whichever was shallower with a 153- $\mu$ m mesh (large mesh size was used to avoid problems with clogging), and 2) a depth of 20 meters, or 1 meter above the bottom at shallower stations, with 64  $\mu$ m mesh net.

#### Measure 3:

Sampling for *Mysis* biomass is not coordinated across the Great Lakes Basin. Biomass estimates are collected and processed under the auspices of three lead investigators, 1) David Jude (University of Michigan), 2) David Warner (USGS Great Lakes Science Center), and Steve Pothoven (NOAA GLERL Lake Michigan Field Station). Each dataset, hereafter referred to by the lead investigator's last name, differs in sampling protocols although all sampling occurs at night with ship lights off and use a similar net. Jude: *Mysis* are collected at some EPA GLNPO stations during spring and summer cruises each year. These stations are not consistent across years and the number of stations sampled varies by year and lake (although each lake usually has samples for between 2 and 5 stations each year). This is because Dave Jude is only able to sample when the boat happens to be at a station at night and sampling conditions are appropriate. Warner: *Mysis* are collected in Lake-wide cruises on Lakes Michigan (in August) and Lake Huron (in September) at stations all less than 50 m deep. Pothoven: Fairly regular sampling at 45 and 110 meter stations off of Muskegon, Michigan and a lake-wide survey of Lake Michigan in the year 2000. Steve Pothoven provided his *Mysis* biomass to the IJC. Dave Warner and Dave Jude are still running quality assurance and control (QAQC) checks. The three *Mysis* datasets will need to be compiled prior to indicator calculation.

We also should mention a manuscript by Peter T. Euclide, Nicholas J. Strayer, and Jason D. Stockwell titled "Are *Mysis* in decline across the Laurentian Great Lakes submitted to the Journal of Great Lakes Research for review in summer 2015. This manuscript is not included in the references folder nor are the data currently available because the manuscript is currently under review. However, David Jude indicates that these authors have compiled data for *Mysis* density estimates from "15 sources (9 from Lake Michigan between 1967 and 2008, 5 from Lake Ontario between 1973 and 2011, 1 from Lake Huron between 1971 and 2008, and 1 from Lake Superior between 1971 and 2005. No published *Mysis* density estimates were found for Lake Erie." This compilation does not include either Dave Jude's or Dave Warner's datasets. It does include many "one-off" sampling efforts where sampling is over a short period of time (e.g. within a year) and is not part of a long-term monitoring program.

#### Measure 4:

Data for all benthic measures are included in the database. Two datasets are available for this measure, one from USEPA GLNPO monitoring program and a compilation of benthic data that can be used for the Dreissenid density portion of the measure. All benthos densities and the Oligochaete Trophic Index: The US EPA Great Lakes National Program Office (GLNPO) offshore monitoring program is a standardized and long-term benthic monitoring program. GLNPO benthic sampling began in 1997 and sampling surveys are conducted during the spring isothermal period and summer stratified period. Spring surveys (usually in April) are conducted as early as possible after ice out and only records the abundance of the mayfly *Hexagenia*. Summer surveys (usually in August) are conducted during the period of stable thermal stratification and sample the entire benthic assemblage. About 70 stations are sampled each season and these stations are distributed across all five lakes, but are largely in deep offshore areas.

In addition to the GLNPO data a “Dreissenid Compilation” dataset can be used for the Dreissenid density portion of the measure. As part of the Great Lakes Aquatic Habitat Framework (GLAHF), GLAHF personnel compiled benthic data from both published reports and private sources shared directly through personal contacts. Data sources vary in their spatial extent, temporal extent, and target of sampling efforts (some included data on all benthic taxa while others only include data on certain target species (often Dreissenids)). Sources include the EPA Great Lakes National Program Office (GLNPO) Monitoring program described above, data compiled by the Lake Erie Forage Task Group (LEFTG), the Lake Ontario Lower Aquatic Foodweb Assessment (LOLA), data for Lake Ontario from Steve Lozano, and data for Lakes Huron and Michigan from Tom Nalepa (both published and unpublished datasets). More specific details of each dataset are included in the metadata.

#### Measure 5:

We pursued both the raw data needed calculate the preyfish measure and measures precalculated for the 2016 prey fish SOGL report. Both potential data sources rely heavily on USGS bottom trawls in the Great Lakes. The assessment of Great Lakes prey fish stocks have been conducted annually with bottom trawls since the 1970s by the USGS Great Lakes Science Center, assisted by partner agencies in Lakes Ontario and Erie. Although all these annual surveys are conducted using bottom trawls, they differ among the lakes in the proportion of the lake covered, seasonal timing, trawl gear used, and the manner in which the trawl is towed (across or along bottom contours). Abundance data from trawls will need to be acquired and converted to CPUE estimates. In general, fisheries biologists have been reticent to share trawl data for Lakes Ontario and Erie. However, Brian Weidel has shared the prey fish diversity (Shannon–Wiener Index) measure and the total prey fish biomass data he developed for the 2016 SOGL report.

#### *Spatial extent:*

##### Measure 1:

Monitoring stations are in all five Great Lakes. Monitoring stations are largely offshore. Includes station-level data and summarizations by lake and 9 major “lake regions” developed by Reavie.

##### Measure 2:

Monitoring stations are in all five Great Lakes. Monitoring stations are largely offshore.

##### Measure 3:

Jude: Monitoring is at a limited number of stations in all five Great Lakes. Monitoring stations are largely offshore. Warner: Monitoring is limited to stations in Lakes Michigan and Huron. Pothoven: Most samples are from two stations near Muskegon, Michigan, although the data also include a lake-wide survey for the year 2000.

##### Measure 4:

Monitoring stations are in all five Great Lakes. Monitoring stations are largely offshore. For the Dreissenid compilation dataset, some sources only sample within a certain lake or within a certain area of a lake (e.g. Saginaw Bay).

##### Measure 5:

Bottom trawls monitor fish at least annually in regularly sampled areas of each lake. In Lake Superior, most trawls are located around the perimeter of the lake and go cross-contour (i.e. shallow to deep) although offshore sampling targeting sites deeper than 100 meters began in 2011. In Lakes

Michigan, Huron, and Ontario, trawls are nearshore and offshore and along contour (i.e. at a constant depth). We were not able to assess the spatial coverage of trawls in Lake Erie because we were not able to acquire the trawl data.

*Temporal extent:*

Measure 1:

Spring and summer samples from years 2001 to 2012. 2001 to 2006 samples only include the 14 master stations while 2007 to 2012 includes all 72 stations. This monitoring program is ongoing.

Measure 2:

Spring and summer samples from 1998 to 2011 and this monitoring program is ongoing.

Measure 3:

Jude: Spring and summer samples from 2006 (MI and HU only) and 2007-2011 (All lakes). Warner: Lakes MI (August samples) and HU (September samples) only; "10 years of data" but 2011-2014 are the closest to release. Pothoven: Approximately monthly samples from March to December for Station near Muskegon in 1995/96, 1998-2000, and 2007-2014, and some lake-wide sampling in 2000. Funding for continuation of these monitoring and sample processing efforts is not secure.

Measure 4:

The availability of data for this measure varies with the benthic measure. *Hexagenia* samples are from 2001-2011 from 2-5 stations each spring in Lakes ER, HU, and MI only (i.e. 1-2 stations per lake) and from 1997-2011 for approximately 75 stations each summer in Lakes ER, HU, and MI. EPA GLNPO taxa densities and OTIs are from 1997 to 2011. The Dreissenid compilation includes data from as early as 1987 (prior to invasion) to 2011, although the temporal extent of each dataset varies (see metadata for complete details).

Measure 5:

Bottom trawls began in Lakes Superior and Ontario in 1978 and in Lake Michigan in 1973. Bottom trawls began in Lake Huron in 1973, continued until 1991, and resumed in 1994. A change trawl timing and methodology may limit the ability to use the 1973-1991 trawls in trend analyses. Trawls in Lake Erie began as early as 1961 in a single location, but we were not able to assess the period of record for lake-wide sampling.

**Summary of Findings**

*Measure 1:*

Please see Reavie et al. 2014, "Phytoplankton Trends in the Great Lakes, 2001–2011." This manuscript discusses trends in phytoplankton abundance, composition, and seasonal effects across and within lakes. From the abstract: "Data analysis identified qualitative and quantitative changes in algal densities, biovolume, and taxonomic composition of assemblages. Since 2001, Lake Superior has changed subtly with an increase in small-celled blue-green algae in spring and a recent decline in summer centric diatoms, possibly a result of lake warming and changes in water quality. Spring phytoplankton declines mainly attributed to diatoms occurred in Lakes Huron and Michigan, a probable result of invasions by non-native dreissenids that have reduced pelagic nutrients and selectively consumed certain taxa. The decline in Lake Huron's spring phytoplankton biovolume was earlier and more severe than that in Lake Michigan, despite a faster and more abundant dreissenid invasion in Lake

Michigan (Figure 40). Lake Erie's central basin had a notable increase in spring centric diatoms (largely *Aulacoseira*), while the whole of Lake Erie shows a summer increase in cyanobacteria, complementing that found in coastal regions. The composition of Lake Ontario's species assemblage shifted, but little overall change in algal abundance was observed with the exception of higher summer densities of cyanophytes." An example figure from Reavie et al. 2014 is included below (Figure 40) and may serve as a template for future trend analyses.

*Measure 2:*

We were not able to assess trends in zooplankton as we were unable to acquire the data or calculate the measure.

*Measure 3:*

We have not assessed the trends in *Mysis* biomass because we were only able to acquire one of the three major sources of *Mysis* monitoring data. David Warner and David Jude both anticipate their cleaned datasets will be available within the next six months. David Jude has done some trends analyses with the EPA GLNPO samples, but these are preliminary and he would prefer to share them after he quality controls the more recent data.

*Measure 4:*

The indicator is calculated but trends in the benthic indicator cannot be assessed until a spatial unit for the analyses is selected and how to deal with seasonality of sampling is addressed. Possibilities include summaries of trends at stations, within lake subbasins, within each lake, or across the entire Great Lakes Basin. Seasonality should only affect certain taxa and could be ignored or only summer samples (the majority of samples) included in analysis.

*Measure 5:*

We did not assess trends in prey fish as we were unable to acquire the raw data required to calculate the measure. However, in a draft of the 2017 prey fishes SOGL report, Brian Weidel provides a preliminary graph of trends in lake-wide prey fish diversity and total prey fish biomass (Figure 41). In the draft report he addresses the trends in prey fish for each lake. We have not included these trend assessments in this report because they are preliminary, based on slightly different measures than the IJC indicator, and tailored to the SOGL report, but we have included a copy of the draft 2017 SOGL Prey fishes report in the references folder. This report is shared with the IJC under Brian Weidel's authority and any questions should be directed to him (bweidel@usgs.gov).

## **Data gaps and Recommendations**

*Measure 1:*

There are no data gaps although sampling at most stations began in 2007. Euan Reavie supplied the necessary data with the IJC and will continue data sharing as samples are processed.

*Measure 2:*

There are no data gaps and the delay in processing post 2006 samples appears to be resolved. Jim Watkins (Cornell University) may be able to share the computed measures with the IJC in the next few months.

*Measure 3:*

Two of the three primary sources of *Mysis* biomass data (Dave Warner at USGS Great Lakes Science Center and Dave Jude at the University of Michigan) are still running quality assurance and control (QAQC) checks. The three *Mysis* datasets will need to be compiled prior to indicator calculation and trend analyses.

#### Measure 4:

The indicator description indicates Environment Canada may be a data source for the Oligochaete Trophic Index component, but due to time constraints, we have only included US-collected benthic data. Lee Grapentine at Environment Canada (lee.Grapentine@ec.gc.ca) is the likely the source of Canadian benthic data. The vast majority of the benthic data are from offshore, soft substrates sampled via ponar. Nearshore and hard substrates are not a focus of any established, basin-wide monitoring programs.

#### Measure 5:

Data for prey fish in Lake Erie is largely missing in the data provided by Brian Weidel. Additionally, if the IJC desires a more detailed analysis of prey fish trends, proper calculation of prey fish CPUEs and trend analyses will require the involvement of fisheries experts for each lake. First, although these trawls are funded through public sources, we encountered strong reticence to freely share trawl data for Lakes Ontario and Erie. Second, although the number of fish caught in a trawl can be extracted from the USGS fish trawl database, the area swept in each trawl should be provided by experts for each lake. These swept areas are needed to convert abundance to CPUE. Third, extractions for the USGS database include all trawls. Experts for each lake, however, know which trawls to include or exclude from analyses. For example, in personal communication with Jeff Schaeffer, he knows that certain Lake MI trawls should be excluded because the boat captain was trawling too quickly and the nets were not actually on the bottom (as evidenced by a lack of Salmonid carcasses).

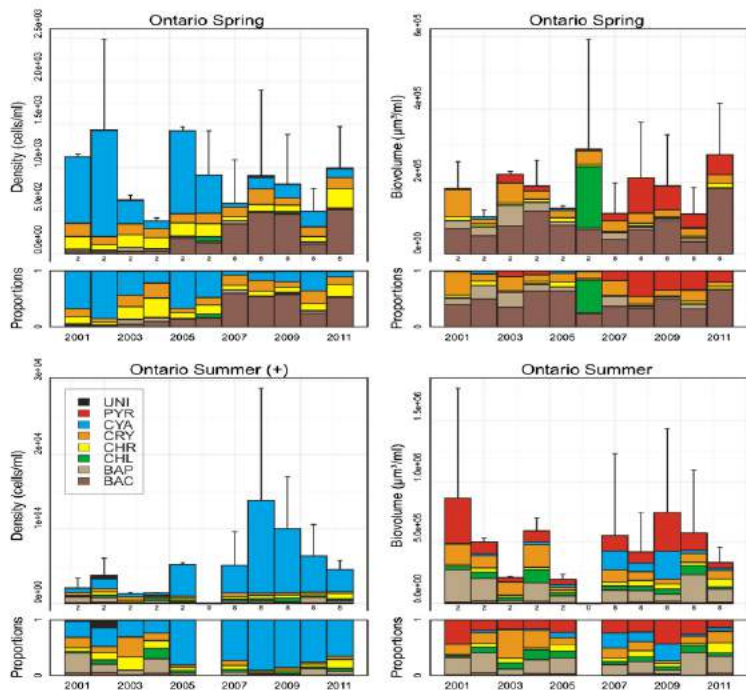


Fig. 13. Basin-wide averages of phytoplankton abundance in spring (top) and summer (bottom), from 2001 to 2011 in Lake Ontario. Algal cell densities (left) and biomass (right) are presented. Numbers at the bottom of each absolute abundance bar indicate the number of samples averaged, and below that the relative abundances are shown as proportions. Error bars represent a standard error of the sample totals. A significant (increasing (+)) trend (Kendall's rank correlation test,  $P < 0.05$ ) for the 11-year period is indicated in the respective headings. Significant positive trends for the 11-year period (+) are indicated in the respective heading. Taxon group codes match those from Fig. 2.

Figure 40. Phytoplankton biomass in Lake Ontario (from Reavie et al. 2014).

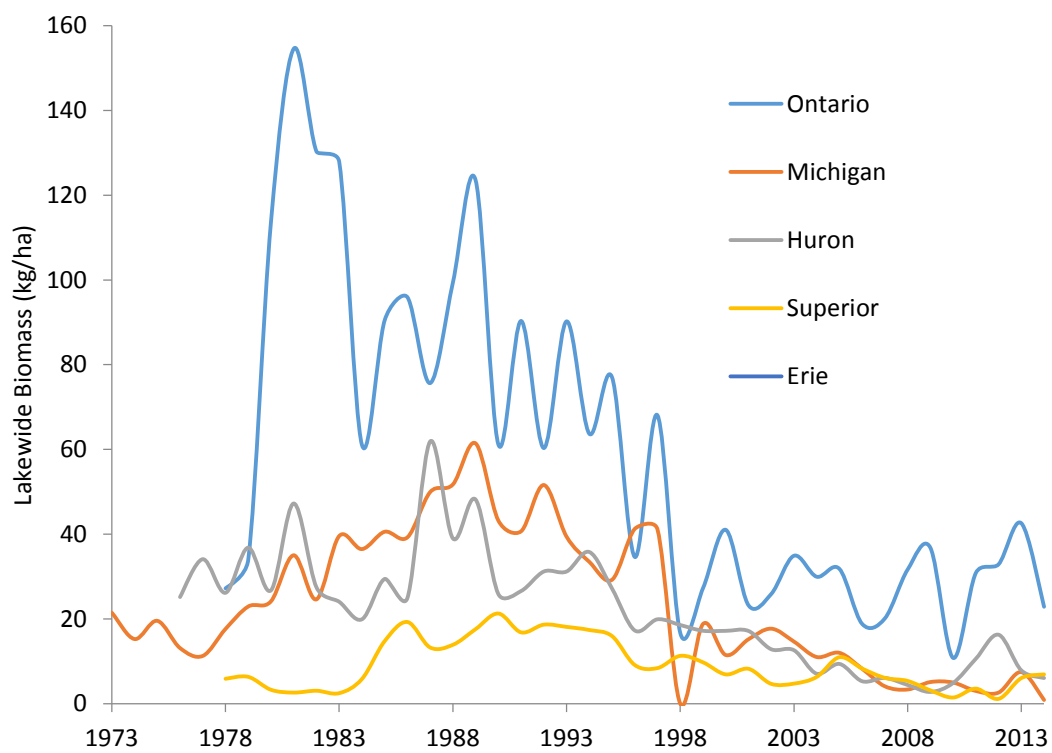
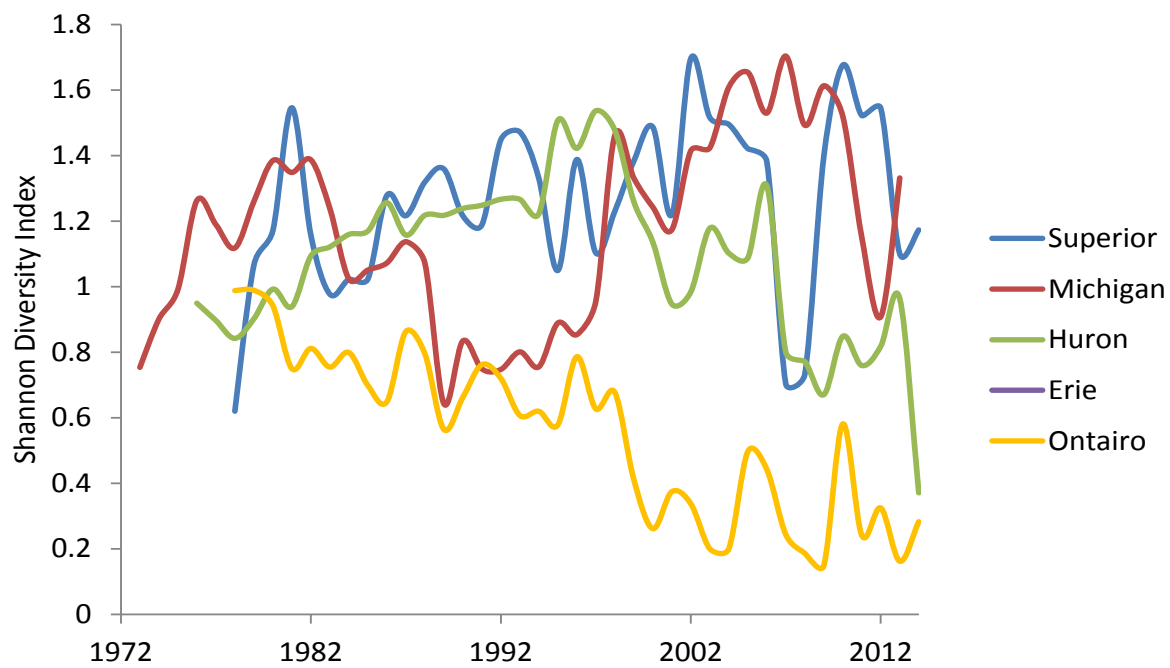


Figure 41. Diversity and biomass of prey species in the Great Lakes.

## Fish Species of Interest

### Summary:

This indicator measures status and trends in population abundance and recruitment for Lake Trout, Lake Whitefish, Walleye, Lake Sturgeon, and a suite of nearshore predators (Northern Pike, Smallmouth Bass, Largemouth Bass, and Yellow Perch). Assessment of trends should be based on a hierarchy of available data, with model-generated estimates of abundance at age given the highest priority, followed by catch-per-unit-effort (CPUE) from fishery-independent survey gears and commercial and angler fisheries.

### Measures:

This indicator is comprised of measures of recruitment and abundance for each of the fish species identified by the International Joint Commission. Individual Great Lakes Fishery Commission Technical Committees can add additional species to the list if they consider it to be an important component of the fishery within the lake. For instance, Yellow Perch are an important species in both Lake Erie and Lake Michigan. Measure calculations are based on the expert advice of members of the inter-jurisdictional GLFC Lake Technical Committees through a scoring system based on quartiles/percentiles of historic abundance and recruitment estimates. Higher scores demonstrate that current abundance and recruitment are within the higher quartiles.

Metric	Description
1a	Adult abundance of Lake Trout
1b	Recruitment of Lake Trout
2a	Adult abundance of Lake Whitefish
2b	Recruitment of Lake Whitefish
3a	Adult abundance of Walleye
3b	Recruitment of Walleye
4a	Adult abundance of Lake Sturgeon
4b	Recruitment of Lake Sturgeon
5a	Adult abundance of Northern Pike, Largemouth Bass, Smallmouth Bass, and other nearshore species
5b	Recruitment of Northern Pike, Largemouth Bass, Smallmouth Bass, and other nearshore species

### Data sources:

Data sources to calculate the measures for this indicator are highly diffuse across the basin. Identifying who maintains different datasets is challenging and often requires contacting multiple people before determining who curates the data and whether they can be shared. For many species, multiple surveys exist within the same lake and are maintained by several individuals across different agencies. Additional individuals not included in the following list have been identified as potential data contributors but we have been unable to confirm if they are the data curator and what data are available for trend calculation.

**Mark Ebener**, Chippewa Ottawa Resource Authority, mebener@lighthouse.net, provided abundance and recruitment trends available for Lake Huron.



**Dave Clapp**, Research Biologist Manager, Michigan DNR, 231.547.2914, clappd@michigan.gov, primary contact for data pertaining to Lake Michigan. We have been unable to coordinate a time to discuss data availability and potential contacts for Lake Michigan.

**Phil Schneeberger**, Lake Superior Basin Coordinator, Michigan DNR, 906.249.1611, schneebergerp@michigan.gov, provided contact information for Lake Superior data sources. Does not possess any data.

**James Frances**, Lake Erie Basin Coordinator, Michigan DNR, 517.284.5830, francisj@michigan.gov, provided contact information for potential data sources in Lake Erie.

**Brian Lantry**, Field Station Supervisor, Lake Ontario Biological Station, USGS Great Lakes Science Center, 315.343.3951 ext 6518, bflantry@usgs.gov. Primary contact for Lake Ontario.

**David Caroffio**, MDNR Fisheries, Tribal Coordination Unit, 231.547.2914 x232, caroffinod@michigan.gov, provided 1836 treaty data for Lake Trout and Lake Whitefish.

**James Markham**, New York State Department of Environmental Conservation, Lake Erie Fisheries Unit, 716.366.0228, james.markham@dec.ny.gov, provided Lake Trout and Lake Whitefish for eastern Lake Erie.

**Todd Wills**, Lake Huron-Lake Erie Area Research Manager, Michigan Department of Natural Resources, 586.465.4771 x 22, willst@michigan.gov, provided Walleye data for Lake Erie.

**Joshua Schloesser**, US Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 715.682.6185 x 113, joshua\_schloesser@fws.gov, provided Lake Sturgeon recruitment data for Lake Superior.

#### *Spatial Extent:*

Fish community sampling is conducted across the Great Lakes basin and generally coincides more with management units or subbasins, but can be presented at the lake level. Model generated abundance and recruitment estimates are either at the scale of individual management units or the entire lake. Fishery-independent surveys and commercial and angler fisheries range from catch data assigned to a specific latitude and longitude to broad geographic areas (e.g., specific bays or subbasins).

#### *Temporal extent:*

The duration of abundance and recruitment data varies substantially across the basin for model-generated estimates and indices of CPUE. In general, model-generated estimates and fishery-independent surveys date back to the 1970s and 1980s. Commercial fisheries provide some of the longest records of fish community trends in the basin, with some dating back to the early 1900s. Abundance and recruitment estimates are typically available on an annual basis.

#### **Summary of findings:**

Trend calculation and interpretation of findings will need to involve experts for the GLFC Lake Technical Committees, because the fish species included within this indicator are affected by many interacting drivers that include stocking, harvest, invasive species, changes in productivity, climate change, food web interactions, and other factors. Additionally, there are numerous fish community surveys conducted within the basin by individual management agencies. Identifying the different surveys, reaching out to the appropriate contact person, and gathering the data to ensure all information has been collected would benefit from presenting this information at Great Lakes Technical Committee meetings where experts within the region are present and can provide immediate feedback regarding the diversity of efforts to assess spatial and temporal fish community dynamics. This effort should identify exactly what types of information the IJC aims to gather from each survey.

In general, lake trout appear to remain stable or are increasing in most management units for which we have data (Figure 42). Exceptions to this generality include MH5 (Lake Superior) and MH1 (Huron), but only for the last decade. Overall, lake trout appear to be increasing basin-wide since the 1980s despite highly variable recruitment (Figure 43).

Lake whitefish populations appear to be characterized by large increases in abundance followed by deep recessions (Figure 44). For almost all management units for which we could obtain data, lake whitefish are currently in such a recession, with little recruitment to support any potential increase (Figure 45).

Walleye appear to be variable over the duration of the datasets from both Lake Erie and Lake Huron. However, walleye populations increased substantially around 2006 in Lake Huron, but appear to be declining after an initial peak (Figure 46). Similarly, Walleye in Lake Erie have declined rapidly since the early 2000s, with little recruitment (Figure 46). In Lake Michigan, walleye have remained stable (Figure 47). Both the Les Cheneaux Islands and Saginaw Bay of Lake Huron have observed a significant increase, with the steepest increase at Les Cheneaux Islands.

Our only estimate of Lake Sturgeon were derived from observations in the Ontonagon River in Lake Superior. Detecting a trend in this river is difficult, as only 10 years of data are present, and only one peak was observed (in 2007) (Figure 48).

Northern Pike abundances in Lake Huron demonstrate no significant trend or are decreasing (St. Mary's River) (Figure 49). However, Northern Pike do appear to be increasing (albeit not significantly) in Little and Big Bays du Noc, Lake Michigan.

Smallmouth Bass populations appear to be increasing at all locations for which we have data in Lakes Michigan and Huron. However, only one of these sites (Les Cheneaux Islands) demonstrate a significant positive trend (Figure 50).

Yellow perch populations in Lakes Michigan and Huron appear to be relatively stable, with only one site (Little and Big Bays du Noc) demonstrating a negative trend (Figure 51). Nonetheless, most sites be evaluated appear to be declining, albeit very slowly.

#### **Data gaps and recommendations:**

We have been able to successfully locate and acquire data from a variety of sources for Lake Trout, Lake Whitefish, and Walleye and have contacted other individuals from across the basin. The data are primarily from Lake Superior, Lake Huron, Lake Erie, and Lake Ontario, and we are still accessing additional data from contacts within these lakes. We recently made contacts with individuals in Lake Michigan, but were unable to obtain data from these lakes prior to completion of the final report (except for Lake Trout and Lake Whitefish in Michigan waters of Lake Michigan).

Trends in abundance and recruitment for Lake Trout, Lake Whitefish, and Walleye are generally available throughout the basin in locations where they are common. For Lake Trout and Lake Whitefish, these areas include most of Lake Superior, Lake Huron, Lake Michigan, Lake Ontario, and eastern Lake Erie. Many of these estimates are model-generated, particularly in Treaty waters where quotas are allocated to multiple stakeholder groups, while others are based on catch-per-unit-effort trends in fishery-independent surveys. Walleye are primarily located in shallow areas of the Great Lakes, including all of Lake Erie and large bays across the basin, including Saginaw Bay, Green Bay, Bay du Noc, Bay of Quinte, and Black River. Though population models exist for Walleye in Lake Erie and Lake Huron, future trend analyses will need to be based on trends in CPUE in fisheries independent surveys conducted by individual management agencies.

Data for Lake Sturgeon, Northern Pike, Smallmouth Bass, Largemouth Bass, and other species identified by the GLFC Lake Technical Committees are generally lacking across the basin. Trends in abundance and recruitment will need to be based on fishery-independent surveys and creel survey data for these species.

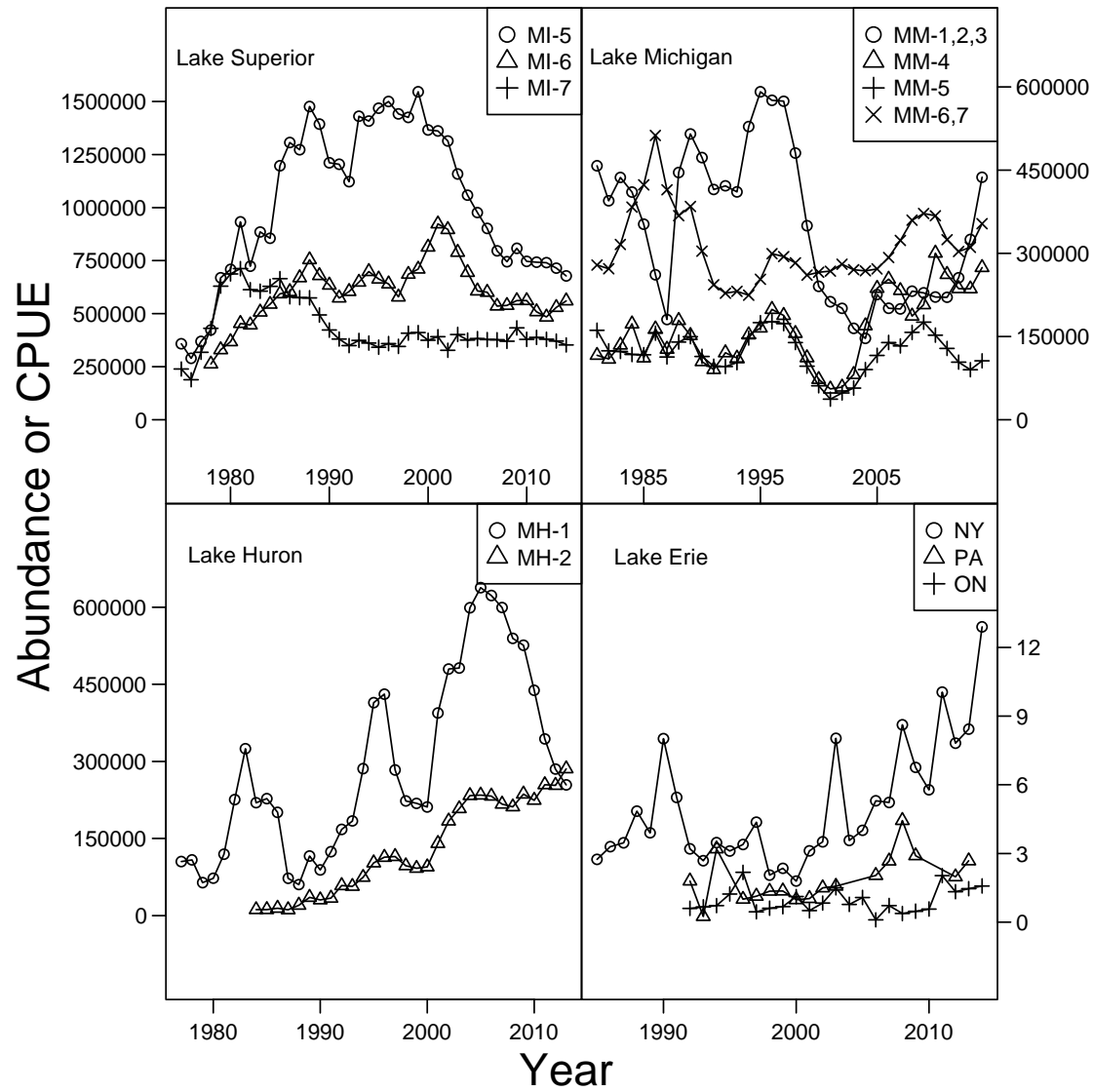
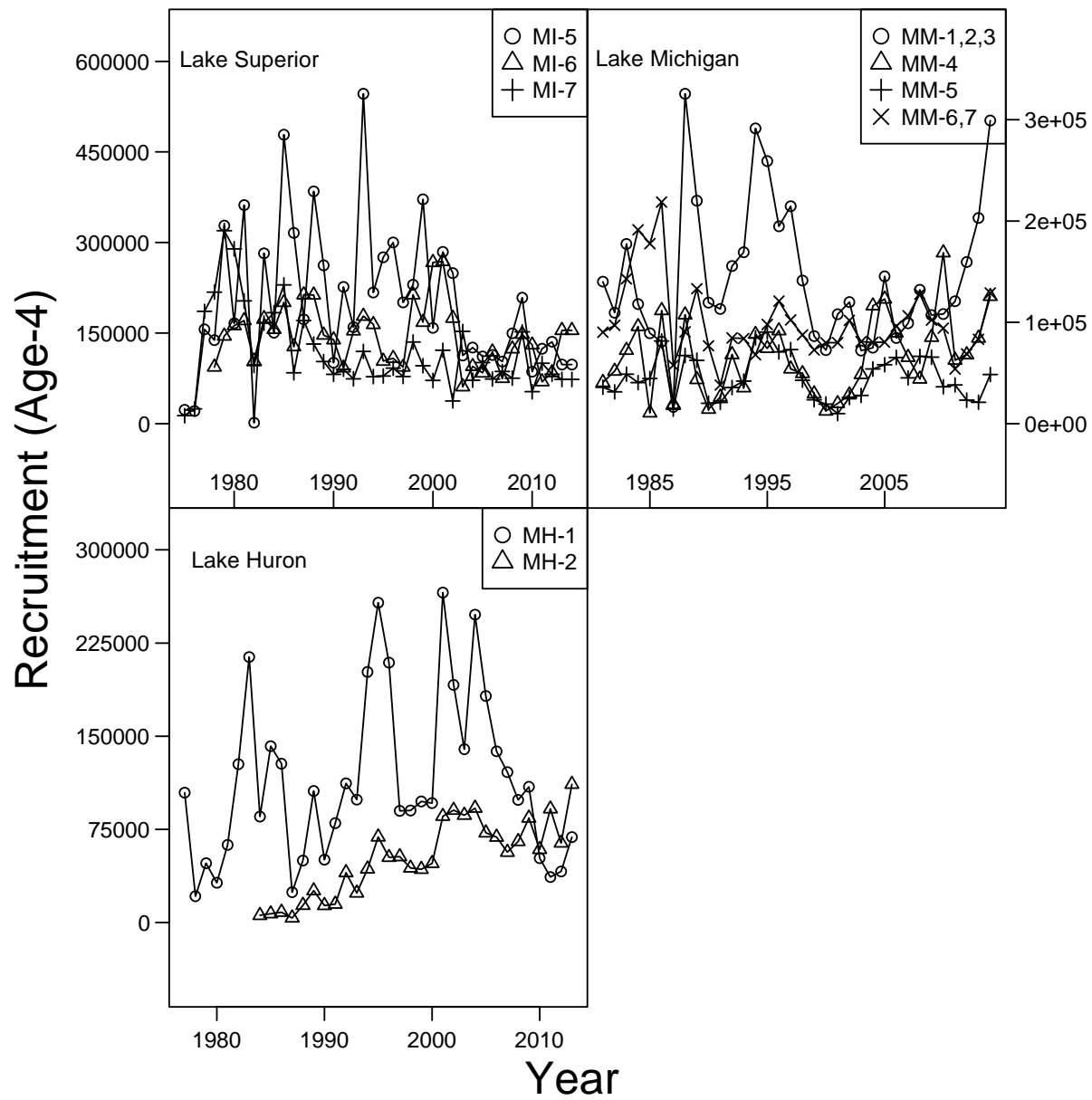
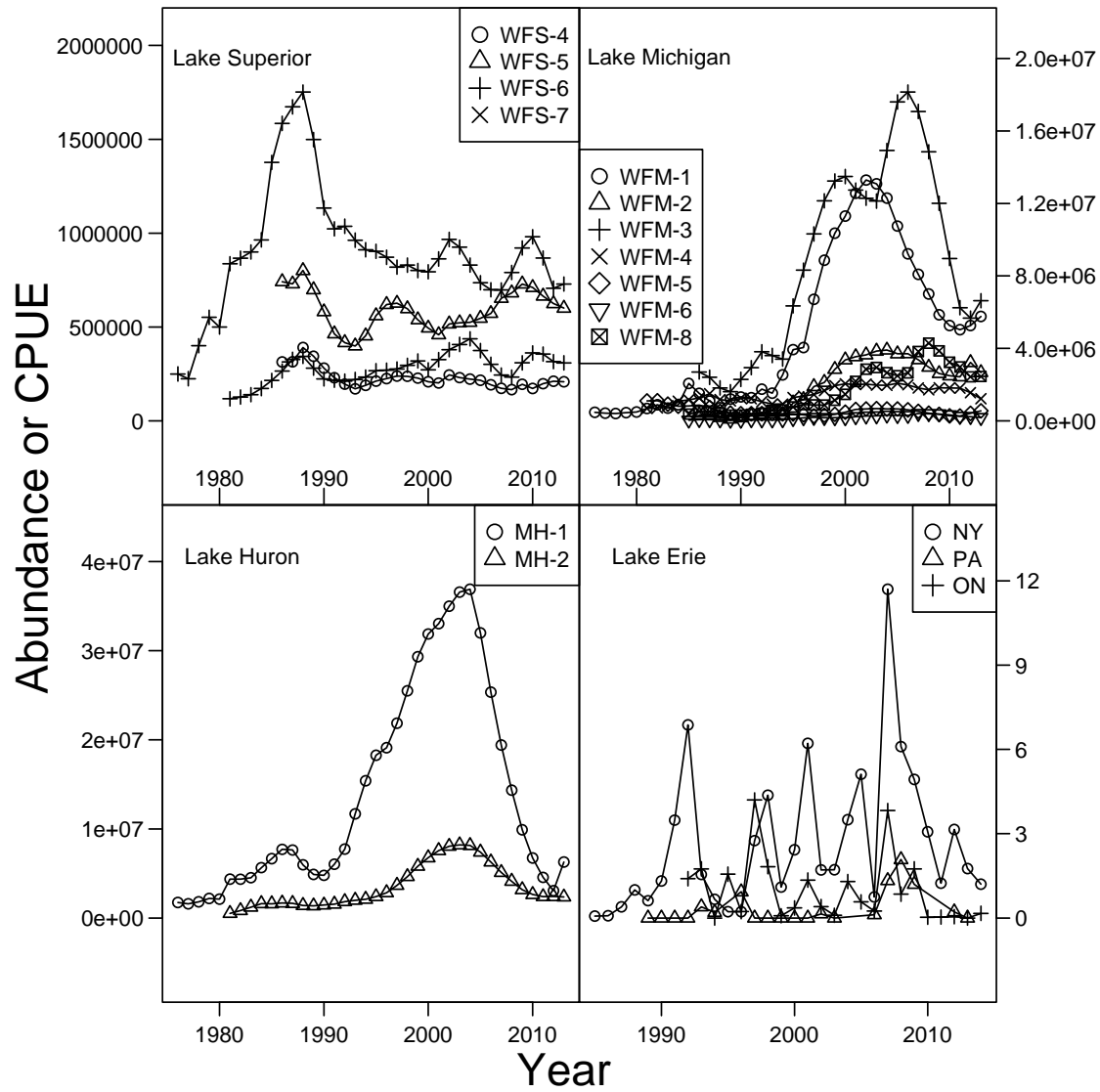


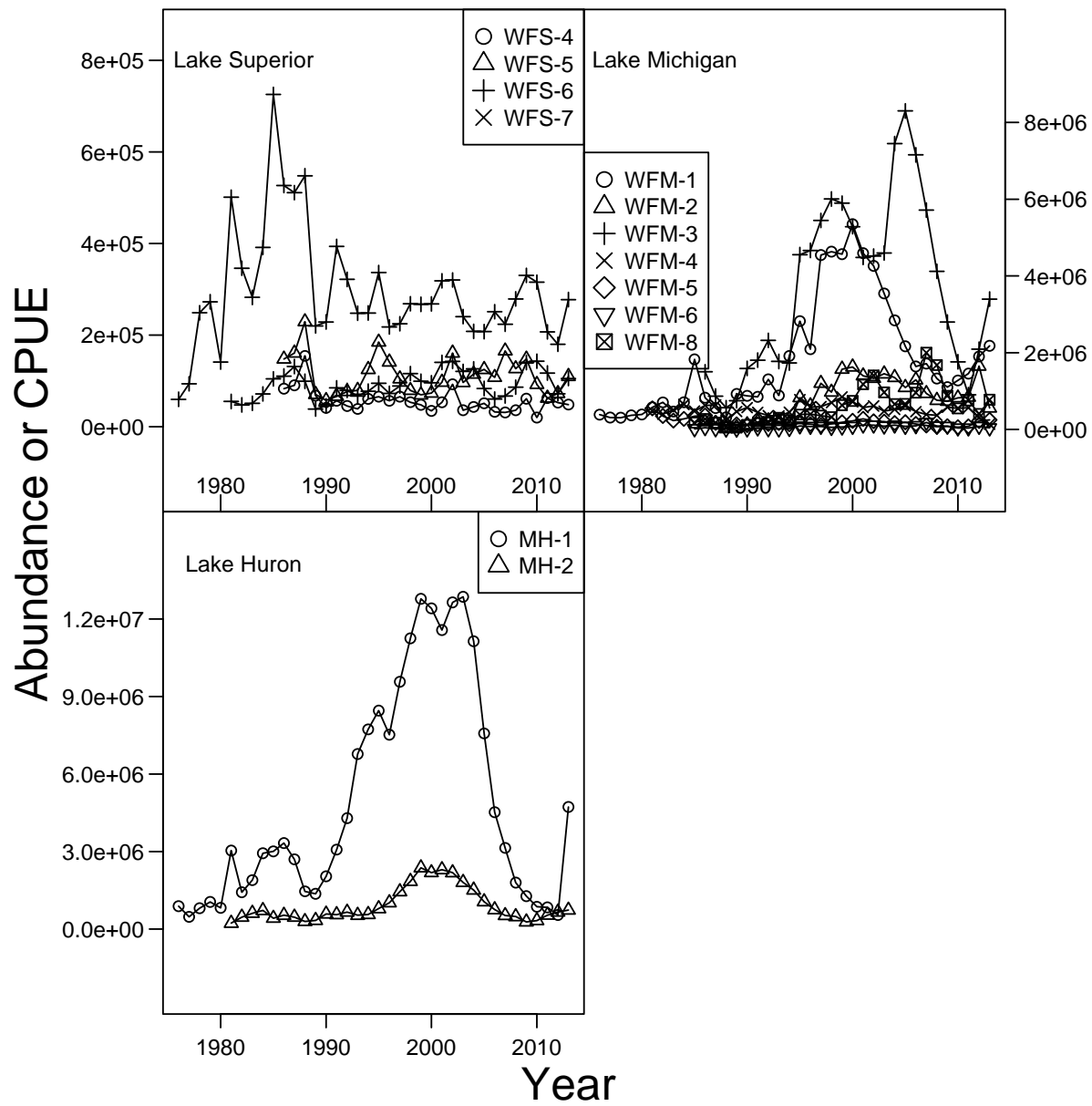
Figure 42. Abundance of Lake Trout across the Great Lakes basin.



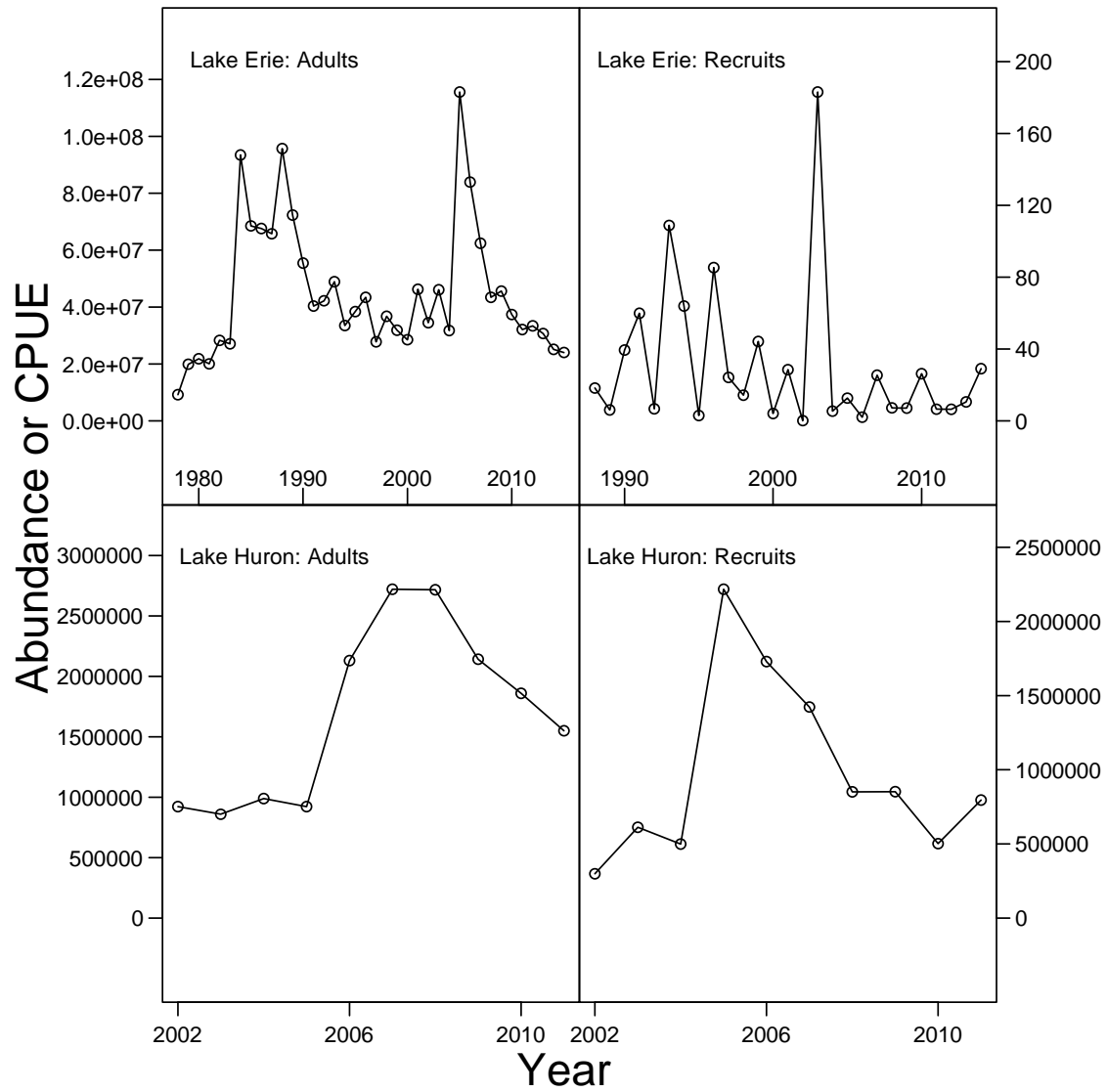
**Figure 43.** Recruitment of Lake Trout (age-4) across the Great Lakes basin.



**Figure 44.** Abundance of Lake Whitefish across the Great Lakes basin.

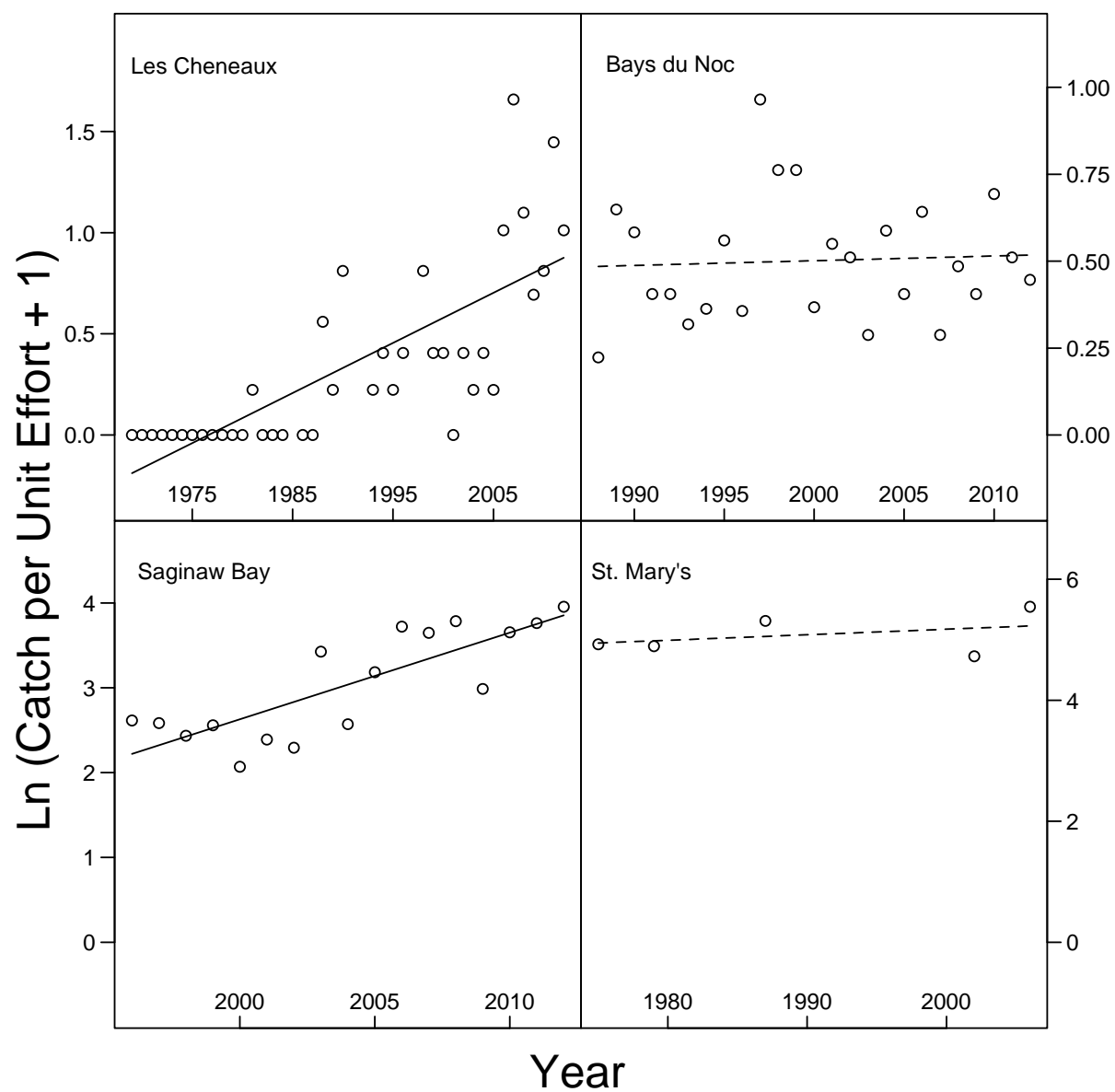


**Figure 45.** Recruitment of Lake Whitefish (Age-4) across the Great Lakes basin.



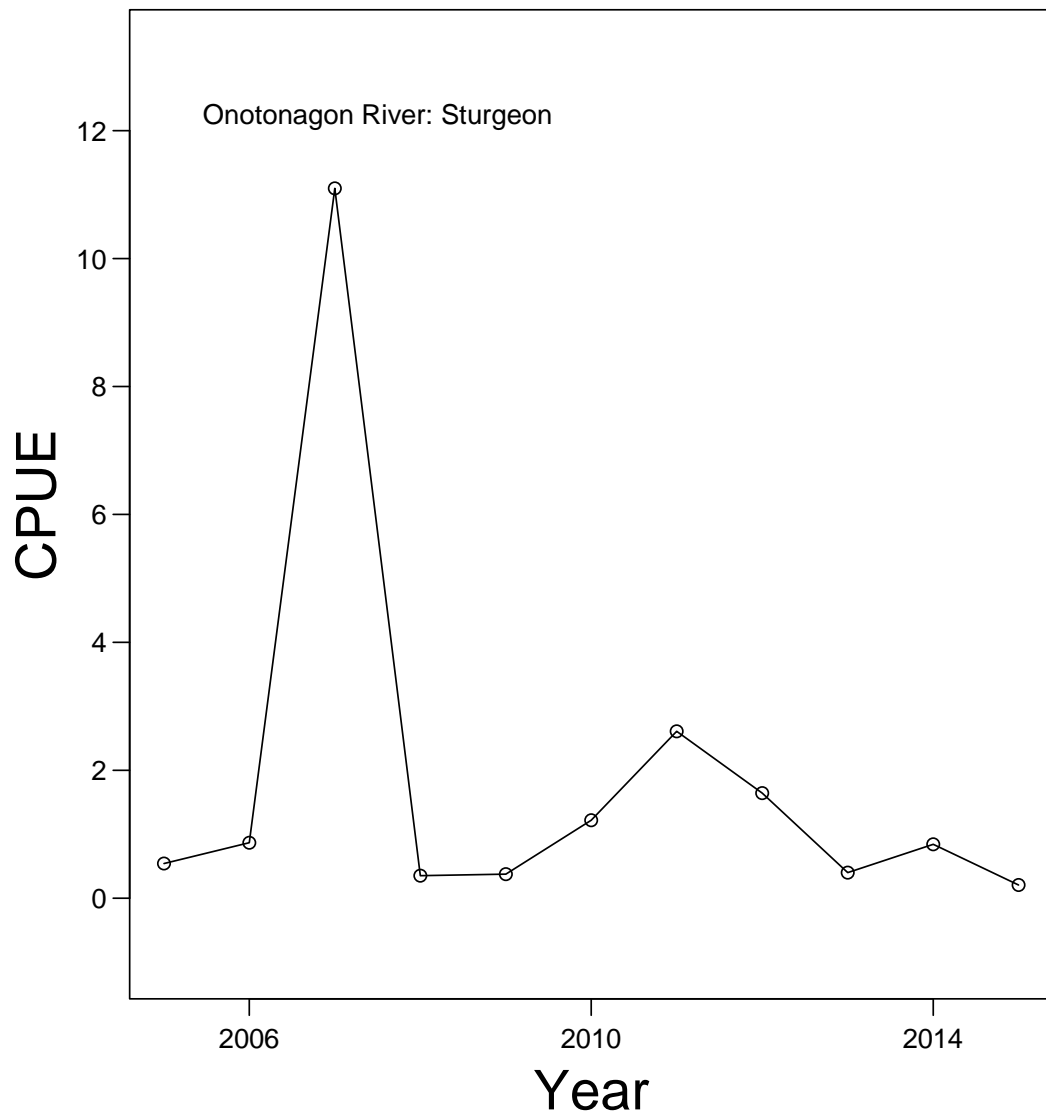
Figure

46. Abundance and recruitment of Walleye across the Great Lakes basin.



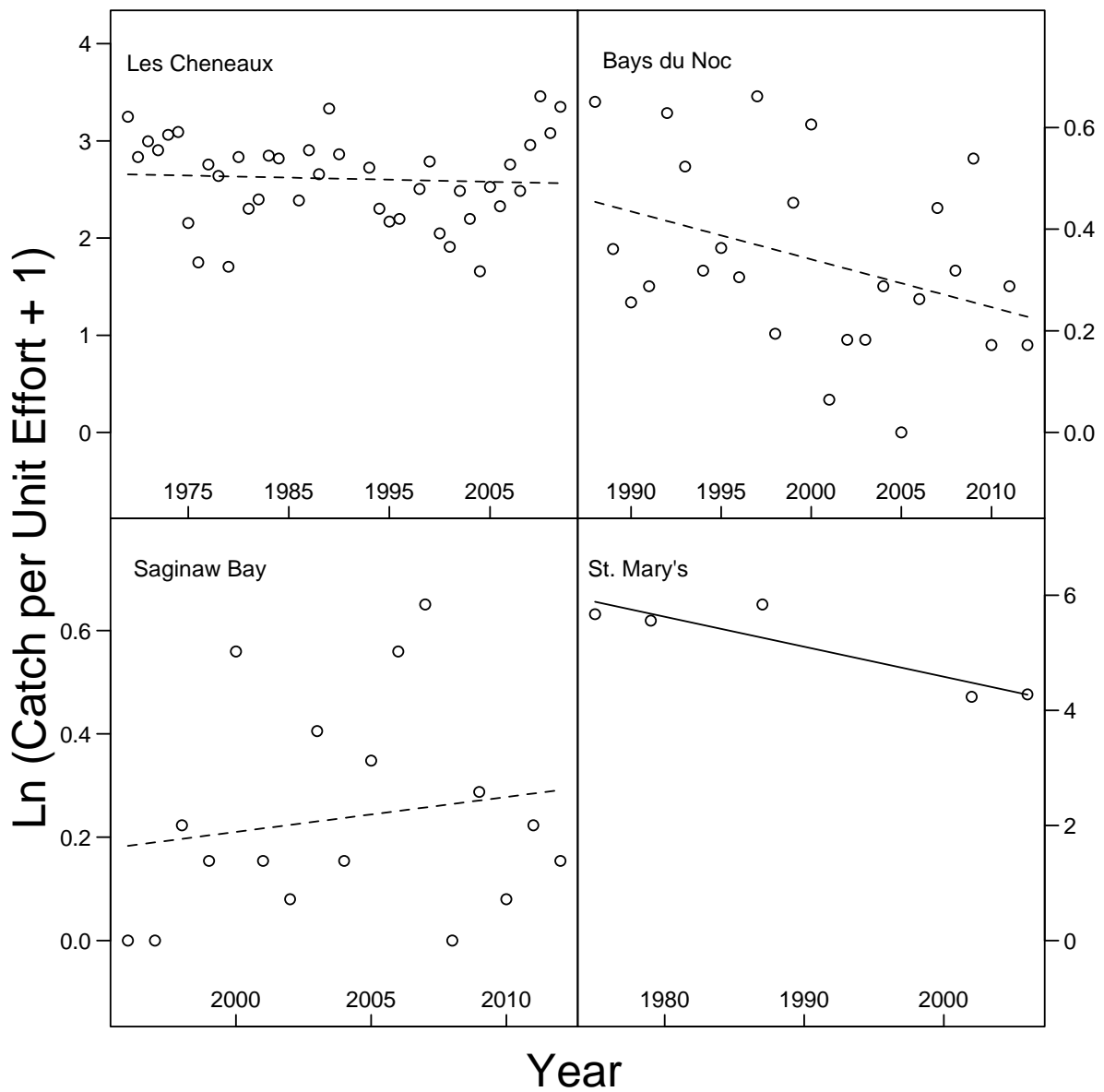
**Figure 47.** Trends in Walleye catch-per-unit-effort from four fish community surveys conducted by the Michigan Department of Natural Resources. Significant trends are denoted with solid lines.



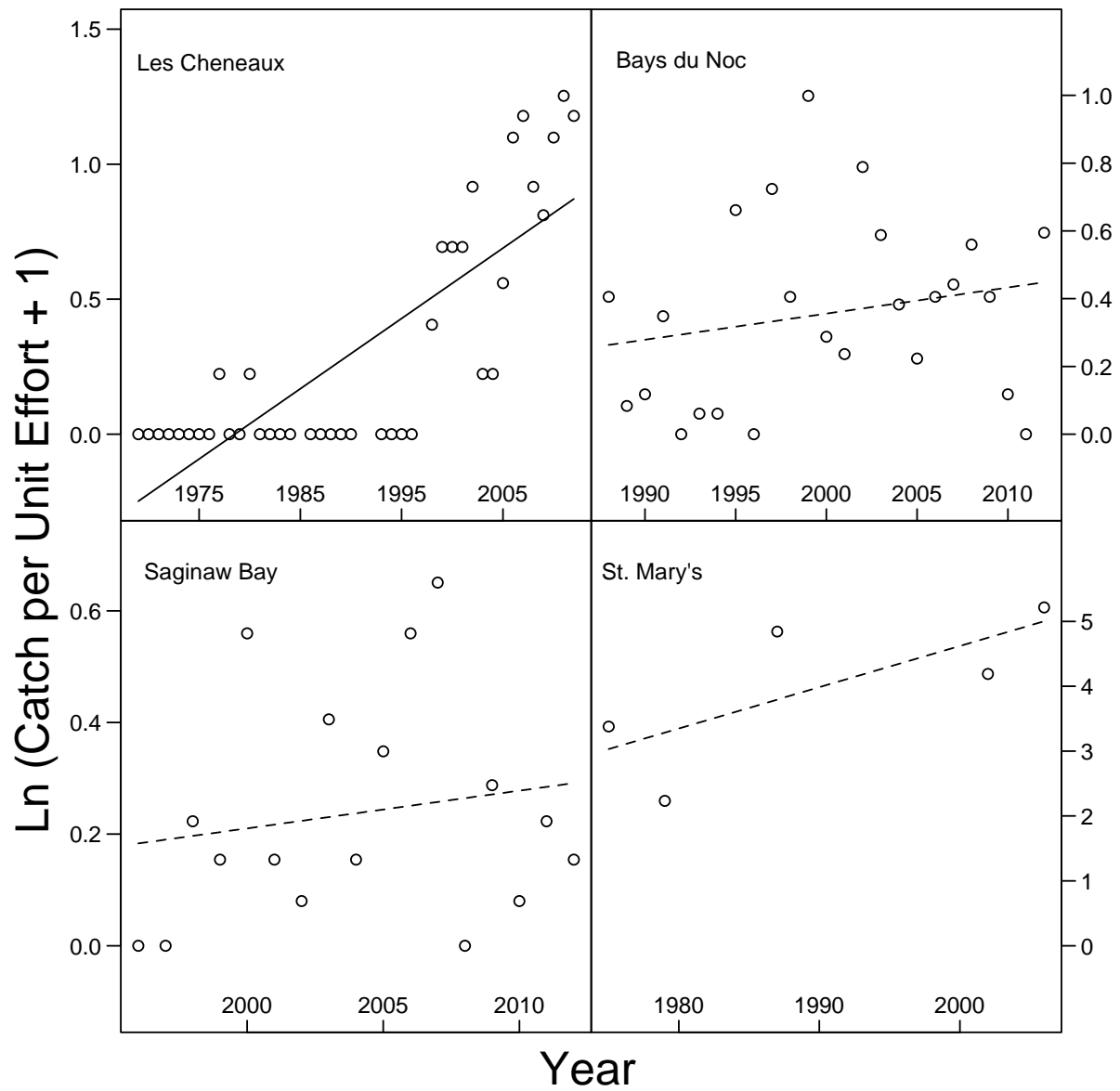


Figure

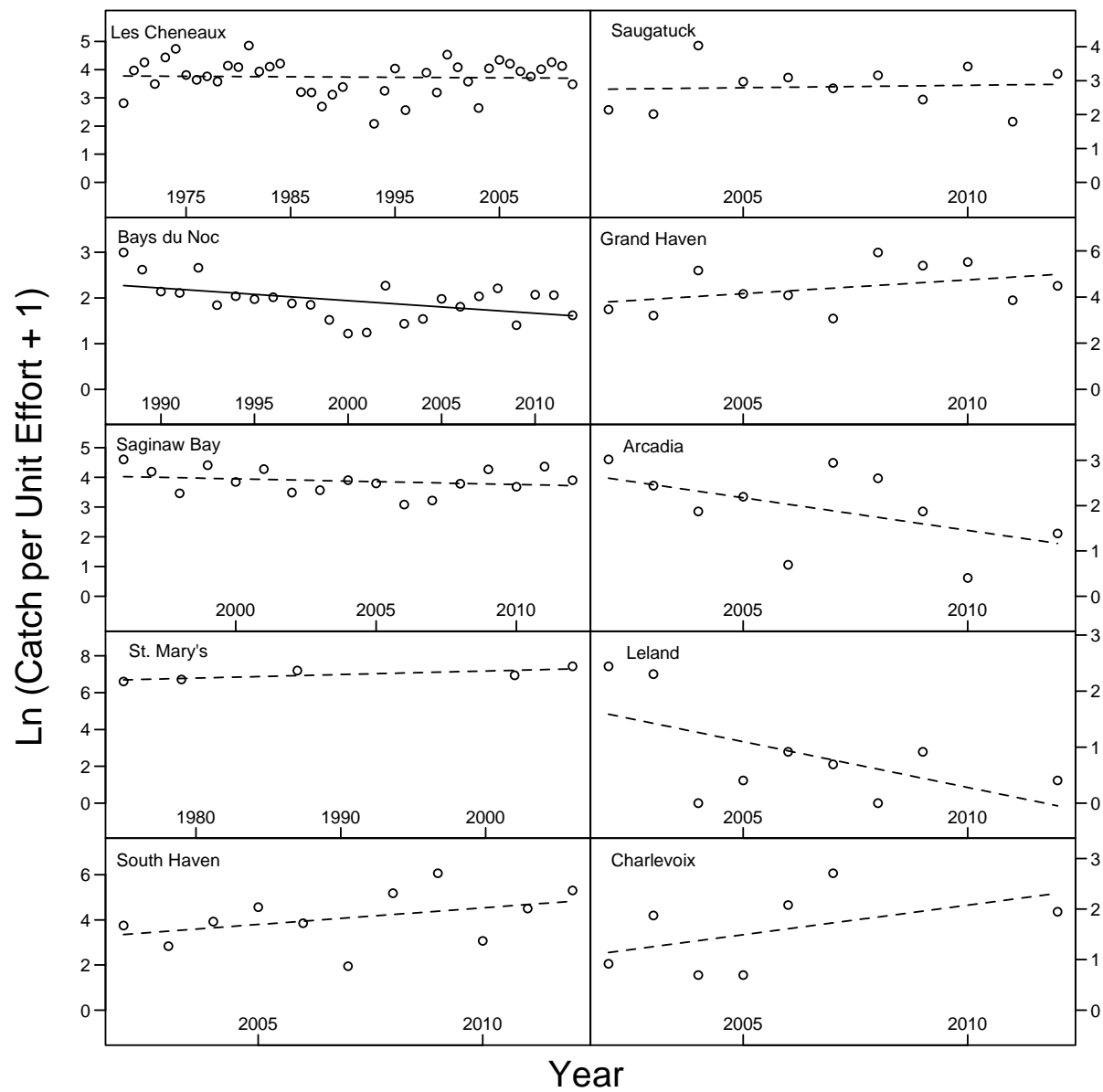
48. Recruitment of Lake Sturgeon from Ontonagon River, Lake Superior.



**Figure 49.** Trends in Northern Pike catch-per-unit-effort from four fish community surveys conducted by the Michigan Department of Natural Resources. Significant trends are denoted with solid lines.



**Figure 50.** Trends in Smallmouth Bass catch-per-unit-effort from four fish community surveys conducted by the Michigan Department of Natural Resources. Significant trends are denoted with solid lines.



**Figure 51.** Trends in Yellow Perch catch-per-unit-effort from ten fish community surveys conducted by the Michigan Department of Natural Resources. Significant trends are denoted with solid lines.

## Harmful and Nuisance Algae

### Summary:

This indicator tracks spatial and temporal trends in the occurrence of harmful and nuisance algal blooms in the Great Lakes. Harmful algae refer to blooms that contain toxins or contain species that have the potential to produce toxins that can affect the health of humans, livestock, pets, and other organisms. Nuisance algae refer to blooms that contain a subset of algae or cyanobacteria species that form blooms that are nontoxic to humans but cause ecological or socioeconomic harm. Excessive algae refer to blooms where information about the composition or ecosystem effects is lacking, but the extent is measured by remote sensing.

### Measures:

This indicator consists of three measures that track the occurrence of harmful, nuisance, and excessive algal blooms beyond specific thresholds identified by the IJC expert working group members. Criteria for harmful algal blooms are set based on concentrations of Microcystin-LR or dominance of algal communities by a suite of potentially toxic cyanobacterial species. Criteria for nuisance algal blooms are based on chlorophyll-a measurements, levels of common algal odour compounds, or number of beach postings due to excessive algal material. Criteria for excessive algal abundance are based on percent coverage of nuisance algae at reference sites or the occurrence of extensive pelagic blooms measured by remote sensing techniques. For each measure, an area (bay, subbasin, basin, lake) is given a score of 1 (good), 2 (moderate), or 3 (severe).

Metric	Algal Type	Description
1	Harmful	Occurrence/frequency of Microcystin-LR concentrations $> 10 \mu\text{g/L}$ (pelagic) or $> 300 \mu\text{g/gram}$ (benthic) or algal community dominated by suite of potentially toxic cyanobacterial species
2	Nuisance	Occurrence/frequency of chlorophyll-a $> 30 \mu\text{g/L}$ and levels of common algal odour compounds are greater than human detection thresholds or significant number of beach postings or closures due to excessive algal material
3	Excessive	Occurrence/frequency of high levels of % coverage of nearshore by nuisance algae $> 50\%$ coverage or $50 \text{ grams dwt/m}^2$ or extensive pelagic blooms as measured by timing, intensity, duration, and areal extent

### Data sources:

Data available for this indicator are primarily collected in western Lake Erie, though some additional sampling occurs in Saginaw Bay. Additional data may be available in Green Bay, Hamilton Harbor, and other relatively small geographic areas across the basin, but we are unable to confirm this. Current sampling in western Lake Erie is conducted by a variety of agencies and universities, including Ohio EPA, USGS Sandusky, Ohio DNR, University of Toledo, USGS Ann Arbor, Ohio State Stone Lab, University of Michigan, Heidelberg University, and angling charter boats. Numerous efforts are underway to integrate and summarize these data and more information should be available within the

next year. Specifically, LimnoTech is working on developing a web interface that can be used to assess data availability/compatibility and allow access to available data.

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**Justin Chaffin**, Senior Research, Ohio State Stone Lab, chaffin.46@osu.edu

#### *Spatial Extent:*

There are approximately 40 standard sites sampled in western Lake Erie. There does not appear to be data available to assess nuisance algae measure because there is no standardized monitoring of odour compounds across the basin (*personal communication* with Sue Watson). Determining the spatial extent of data available to determine scores for excessive algae measures is not possible because we have been unable coordinate with the appropriate contact (Colin Brooks).

#### *Temporal extent:*

Sampling in western Lake Erie is conducted by participating agencies every other week or monthly, depending on the agency, during summer months. There is approximately 8-10 years of data available, but this varies depending on the data source. Temporal extent of excessive algae measure appears to be done infrequently and does not appear to be part of a standard monitoring program.

#### **Summary of findings:**

One of the major challenges for this indicator is the high spatial and temporal variability of harmful and nuisance algal blooms. Many of the contacts above expressed frustration with trying to develop a system to track these types of events, characterizing their spatial and temporal extents, and assessing their effects on the ecosystem. Many scientists are currently working on improving our capabilities to address these challenges. An additional complication is that much of the potential data available to calculate this indicator were collected recently and researchers are currently working on analyzing the data and publishing their findings. The availability of this information is likely to improve in the next year or two once researchers have had a chance to improve data compatibility, publish their research findings, and make these data publicly available via the LimnoTech web interface that is currently being developed.

#### **Data gaps and recommendations:**

Significant data gaps exist to calculate this indicator. Not surprisingly, locations across the Great Lakes where data are collected tend to be locations where harmful and nuisance algal blooms have been a problem in the past, while areas with no history of harmful and nuisance algal blooms have very little data available. In locations where data are available, researchers are still trying to understand how best to monitor and track harmful and nuisance algal blooms which have very high variability across both time and space. An additional concern is how to integrate and improve the compatibility of data sources collected by multiple agencies and improve the spatial and temporal resolution of trend analyses. A number of research projects are currently underway in the western basin of Lake Erie that should be completed within the next year or two that will clarify what data are available, how they can

be used to assess trends over time, and what methods can be developed to improve monitoring by integrating remote sensing with field collections.

I was unable to locate any systematic monitoring programs for odour compounds. Assessment of nuisance benthic algae appears to be limited to a few studies that are limited to a single year or a limited number of locations for a few years.

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# IDENTIFYING FUTURE IMPROVEMENTS TO GREAT LAKES ECOSYSTEM & HUMAN HEALTH INDICATORS



*A Contractor Report Submitted to the International  
Joint Commission's Science Advisory Board's  
Research Coordination Committee*

Prepared by: **ECT** Environmental  
Consulting &  
Technology, Inc.

*April, 2016*

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- Mr. Gavin Christie, Fisheries & Oceans, Canada
- Dr. John Dellinger, Concordia University - Wisconsin
- Dr. Elaine Faustman, University of Washington
- Mr. Norm Grannemann, U.S. Geological Survey
- Dr. Lucinda Johnson, University of Minnesota
- Mr. Kyle McCune, U.S. Army Corps of Engineers
- Mr. Dale Phenicie, Council for Great Lakes Industries
- Dr. Howard Shapiro, Toronto Public Health
- Dr. Thomas Speth, U.S. Environmental Protection Agency
- Mr. David Ullrich, Great Lakes and St Lawrence Cities Initiative
- Dr. Chris Winslow, Ohio State University

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Last, but not the least, our utmost appreciation to a number of technical experts (identified in Section 4) that participated in a workshop that was key to completing this project.

For purposes of citation of this report, please use the following:

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Any related communications can be directed to Sanjiv Sinha, Ph.D., at [ssinha@ectinc.com](mailto:ssinha@ectinc.com).

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# 1.0 EXECUTIVE SUMMARY

Funded by the International Joint Commission (IJC), this project was a five-month effort (December 2015 – April 2016) that sought to identify improvements to the Great Lakes ecosystem and human health indicators. The project had three objectives: a) assess the completeness of data for various metrics of the twenty-one IJC indicators, b) assess the gaps of forty-three State of the Great Lakes (SOGL) metrics vis-à-vis the nine objectives of the Great Lakes Water Quality Agreement (GLWQA), and c) assess which IJC indicators and metrics may be able to fill those gaps.

Choosing effective indicators for human and ecosystem health is vital to the long-term viability of programs that protect and restore the Great Lakes ecosystem. This need was first recognized by the GLWQA amendment of 1987 that included multiple ecosystem and human health priorities under a single document. After that landmark expansion, multiple groups led by the United States Environmental Protection Agency (EPA) and Environment Canada (EC) (now Environmental and Climate Change Canada or ECCC), under the State of the Lakes Ecosystem Conference (SOLEC), have developed indicators that address the GLWQA priorities. Groups of experts were also convened by the International Joint Commission (IJC) to evaluate the effectiveness of the SOLEC indicators at communicating the health of the Great Lakes to a general audience. One of the largest challenges has been creating a system identifying indicators and measures with data from that works across the two countries, multiple states and provinces, and local governments that covers the differences among the five Great Lakes.

To meet such challenges, the IJC has identified ecosystem and human health indicators through consultation with the Great Lakes regional experts. To meet the mandates of the 2012 GLWQA on assessing progress, the IJC has recommended that the governments of United States and Canada consider using the set of indicators identified by the IJC expert involvement process. The governments have accepted those indicators that have available data for the assessment of progress in 2017 State of the Great Lakes (SOGL) report. The IJC is interested in identifying possible improvement for the future assessment of progress (SOGL report in 2020) by reviewing the indicators identified by the IJC that have not been used by the government due to their unavailability of data. More specifically, indicators and metrics that were not adopted by the Parties were reviewed in terms of availability of data and ease of implementation.

This project sought to identify areas of assessment of progress for improvement through the use of expert working group that helped identify which indicators lack data and were not integral to accurate assessment of Great Lakes systems. Overall, the project found that the following nine IJC indicators have detailed data, and thus can be used effectively:

- Persistent Bio-accumulative Toxics (PBT) in biota
- Chemicals of mutual concern (CMC) in water
- Air deposition of CMC
- Coastal wetlands
- Lower food web
- Aquatic invasive species (AIS)
- Water levels
- Water temperature
- Land uses

For the remaining 12 indicators, there were significant limitations to acquiring full data that included some of the following reasons:

- Data does not currently exist and high barriers exist to develop the data (federal law may preclude public knowledge of source water locations and intakes).
- The data does exist for many areas on both sides of the lake, but hasn't been brought together in a single format. The estimated effort to completely integrate datasets across national boundaries and formats is considerable.
- Major gaps exist with no temporal information attached to surveys.
- Multiple agencies and jurisdictions collect data using different sampling methods, making comparison across years and across states challenging and time consuming.
- Some states and provinces have made important strides towards mapping biological characteristics, however this progress has not been uniform.
- Data for sturgeon and other species is lacking throughout the basin. These species will need to be assembled from survey data that is fishery independent.
- For Phosphorus loading data, certain areas have fine-scale estimates, while other areas have large-scale, averaged estimates.

In November of 2015, an invitation was sent to nearly 35 experts in the region to participate in the indicator review and prioritization process. Over half of those invited were able to attend the workshop held on December 17 and 18, 2015, in Ann Arbor, Michigan. During this workshop, factors for deciding which indicators to recommend included completeness of data as well as discussions related to the relevance to ecological function, data quality, measurement error, discriminatory power, links to thresholds, and linkage to management action etc.

In addition, of the remaining twelve indicators with partial or no data, the experts prioritized eight for their relevance to measuring the health of the Great Lakes. The top nine indicators are:

- |  |  |
|--|--|
| • Algal Blooms   | • Fish Species of Interest               |
| • Biological Hazards/ Chemical Integrity of Source Water | • Illness Risk at Great Lakes Beaches    |
| • Coastal Shoreline Alteration Index                     | • Contaminants in Ground Water           |
| • Phosphorus (P) Loads and In-lake concentrations        | • Sources of Risk at Great Lakes Beaches |

In summary, the following three indicators with no/incomplete data were not considered a high priority by the workgroup:

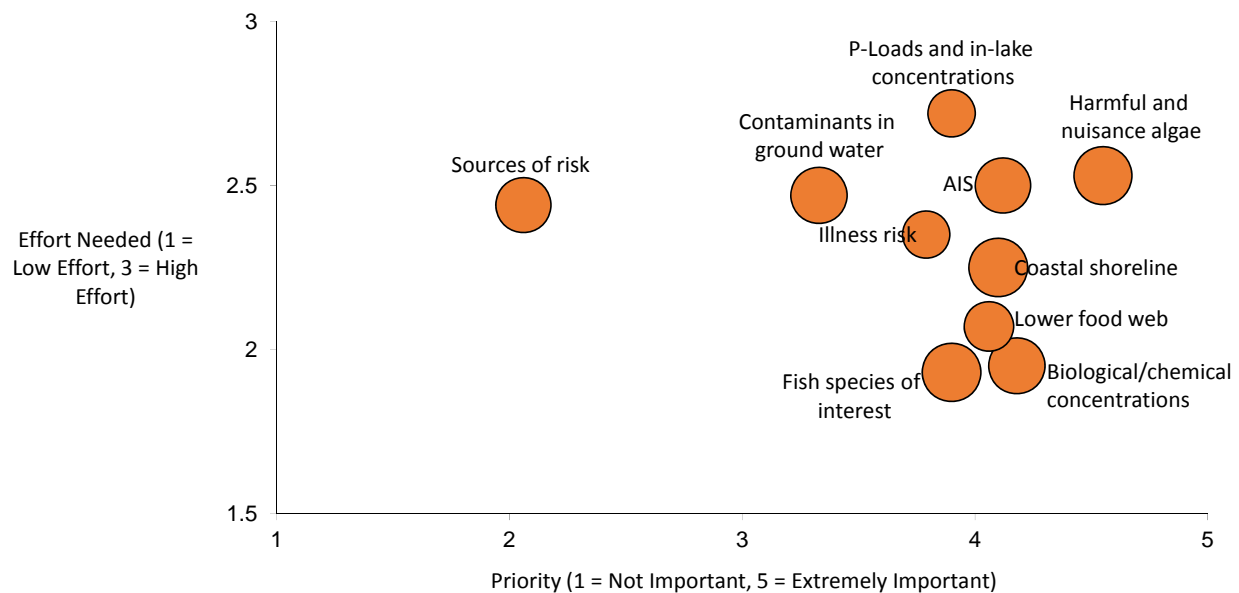
- Abundance and Distribution of Fish Eating Colonial Nesting Birds
- Contaminant Levels in Great Lakes Edible Fish Species
- Tributary Physical Integrity

Note that while prioritizing the indicators with full or no data, experts also ranked “lower food web” and “aquatic invasive species”, indicators previously identified with full data, as high priority indicators. This discussion was not meant to convey that the other indicators with full data had lower priorities.

A discussion was also carried out to assess the efficient presentation of data by the IJC and SOGL indicators. A summary of the expert deliberations is presented in Figure E-1.

**Figure E-1: Bubble chart summarizing the findings of the workshop**

(note that the size of the circles is proportional to the “time commitment” scores assigned by the attendees)



Workshop attendees agreed that only four of the nine objectives of the GLWQA were fully addressed, and additional input was needed for the following:

- Assessment of the quality of drinking water sources in the Great Lakes (pursuant to Objective 1)
- Assessment of recreational impairments in the Great Lakes (pursuant to Objective 2)
- Assessment of the integrity of the food web in the Great Lakes (pursuant to Objective 5)
- Assessment of non-wetland shoreline habitats in the Great Lakes (pursuant to Objective 5)
- Assessment of nutrients in the Great Lakes (pursuant to Objective 6)
- Assessment of the current status of invasive species in the Great Lakes (pursuant to Objective 7).

To address these gaps, the attendees agreed to the addition of the following:

- Biological Hazards and Chemical Integrity of Source Water (Objective 1)
- Illness risk at Great Lakes beaches (Objective 2)
- Undefined Biological Shoreline Metric (Objective 5)
- Nearshore predators (Objective 5)
- Nutrients in lakes (open water) (Objective 6)
- Plankton, Asian Carps, Round Goby, and Ruffe (Objective 7)

Overall, this report to the IJC’s Research Coordination Committee (RCC) has recommended improvements outlined above to the monitoring and indicators to be used beyond 2016, and provides the background and rationale for the IJC in its Triennial Report to make a recommendation to the Parties on this issue.

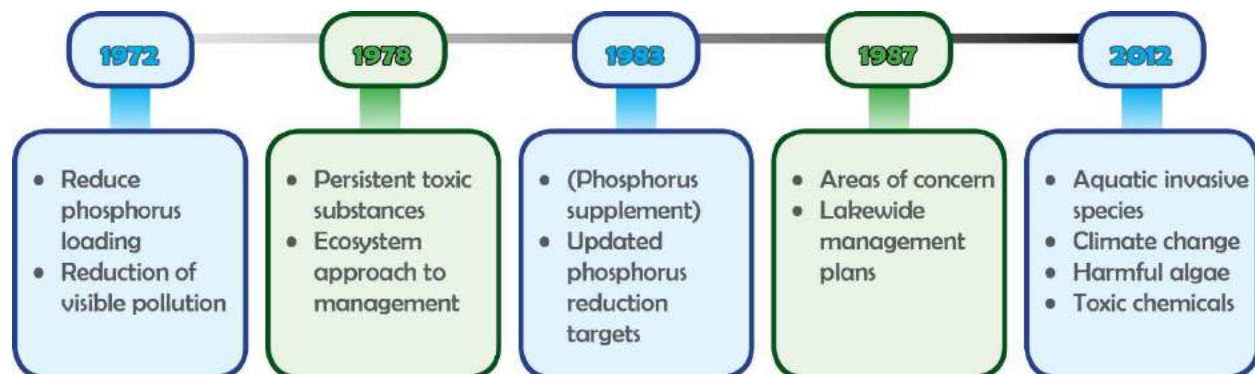


## 2.0 PROJECT BACKGROUND

### 2.1 GREAT LAKES WATER QUALITY AGREEMENT (GLWQA)

The Great Lakes Water Quality Agreement (GLWQA) is a commitment between the United States and Canada to restore and protect the waters of the Great Lakes. GLWQA provides a framework for identifying binational priorities and implementing actions that improve water quality. The United States and Canada first signed the agreement in 1972. At the time, the focus of GLWQA was nutrient loadings within the lakes. It was amended in 1978, 1983, 1987, and 2012. The 1978 and 1983 revisions of the GLWQA was aimed to reflect a more nuanced understanding of the ecology and dynamics within the Great Lakes, and to codify other priorities beyond reducing algal blooms. When revised again in 1987, GLWQA included Areas of Concern (AOCs), as well as parameters that measured progress towards restoring beneficial uses to the Great Lakes.

**Figure 2-1: Changes in GLWQA over time**



Most recently, in 2012, the GLWQA was changed by protocol to enhance water quality programs that improve the “chemical, physical, and biological integrity” of the Great Lakes. The 2012 agreement facilitated actions against threats to Great Lakes water quality and strengthened measures to anticipate and prevent ecological harm. New provisions addressed aquatic invasive species, habitat degradation, and the effects of climate change, while supporting continued work on existing threats such as harmful algae, toxic chemicals, and ballast and waste discharges from vessels to the environment in the Great Lakes Basin as well as how these threats may affect human health.

The 2012 protocol of the GLWQA includes nine general objectives, which are presented in Table 2-1.

**Table 2-1: Nine objectives of the 2012 GLWQA**

GENERAL OBJECTIVES OF THE GLWQA	DESCRIPTION
Objective 1	Be a source of safe, high-quality drinking water.
Objective 2	Allow for swimming and other recreational use unrestricted by environmental quality concerns.
Objective 3	Allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants.
Objective 4	Be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, via direct or indirect exposure through the food chain.
Objective 5	Support healthy and productive wetlands and other habitats to sustain resilient populations of native species.
Objective 6	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.
Objective 7	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.
Objective 8	Be free from the harmful impact of contaminated groundwater.
Objective 9	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.

## **2.2 IJC'S PROPOSED WATER QUALITY INDICATORS**

The GLWQA charges the IJC with the responsibility to assess and report the progress of the governments of Canada and the United States regarding their implementation of the Agreement. To meet this charge, the IJC established a three-year priority (2012-2015) to develop approaches and tools for undertaking the assessment of Great Lakes Indicators. The IJC (2014) report on ecosystem indicators was a synthesis of extensive scientific analyses and provided additional technical analysis building upon the work of the governments of U.S. and Canada on indicators and recommendations of IJC's two 2013 binational workgroup reports titled "[\*Great Lakes Ecosystem Indicators Summary Report: the Few That Tell Us the Most\*](#)" and "[\*Technical Report on Ecosystem Indicators – Assessment of Progress Towards Restoring the Great Lakes – 2012-2015 Priority Cycle\*](#)".

The 2014 report concluded that an assessment of the Agreement's progress should include measuring and reporting quantifiable indicators related to the objectives. Scientifically sound indicators applied consistently over time were deemed essential to track changes in Great Lakes water quality (IJC 2014).

IJC's Triennial Report has the dual purpose of assessing progress and outlining the program effectiveness by the governments within the Great Lakes. The reporting goal serves as an overarching summary of the Great Lakes system that is easily communicable to the public and decision makers, and necessitates using the least number of indicators that would tell the most about the health of the Great Lakes. These indicators needed to be scientifically sound as well as able to be applied consistently over time, ensuring continued monitoring efforts throughout the region (IJC 2014). Identifying a limited set of indicators would also allow funding to be prioritized as effectively as possible to support long-term monitoring efforts (IJC 2014).

To this end, the IJC created a list of 21 indicators to summarize progress within the Great Lakes, drawing from the SOGL indicators in some cases, and in others creating indicators to ensure capturing various aspects of the nine objectives. The IJC also recommended that the new set of indicators be included in future SOGL reports, when data are available, to improve tracking of GLWQA objectives (IJC 2014).

IJC's indicators can be divided into two general types. The first type addresses GLWQA Objectives 1-3 and primarily focus on monitoring factors that impact human health. The second type of indicator focuses on the remaining objectives (four through nine) and primarily measure the Great Lakes ecosystem. These two types are described below.

### 2.2.1 Human Health Indicators

IJC's human health indicators range from direct measures of water quality to the ability to use the Great Lakes for recreation, and are presented in Table 2-2.

**Table 2-2: IJC's Human Health Indicators (Bodkin et al 2014)**

TYPE OF ECOSYSTEM INDICATOR	INDICATOR	PURPOSE
Human Health	Biological Hazards of Source Water	Examines trends in the endemic, seasonal, and episodic presence of sewage and agricultural effluent and other contaminated runoff in the Great Lakes, and examines seasonal and geographic distribution of selected human pathogens
	Chemical Integrity of Source Water	Examines trends in seasonal and geographic variability or targeted chemical compounds in waters used as sources for regional drinking water supply, and assesses the level of hazard and infers the impact of chemical contaminants in the drinking water sources
	Illness Risk at Great Lakes Beaches	Infers potential harm to human health at routinely-monitored beaches through use of fecal indicator organisms as surrogates for pathogens
	Source of Risks at Great Lakes Beaches	Identifies pollution sources at individual beaches in the Great Lakes in the United State and Canada
	Contaminant Levels in Great Lakes Edible Fish Species	Measures the contaminant levels in the various fish species (Lake Trout, Walleye, Yellow Perch, Whitefish, and Smallmouth Bass) that are routinely consumed within the Great Lakes

### 2.2.2 Ecosystem Indicators

The 16 ecosystem indicators that IJC has defined can be further subdivided into the following three subcategories presented in Table 2-3.

**Table 2-3: IJC's Ecosystem Indicators (*Great Lakes Ecosystem Indicators Project Report 2013*)**

TYPE OF ECOSYSTEM INDICATOR	INDICATOR	PURPOSE
Physical Indicators	Coastal habitat – Shoreline Alteration Index (SAI)	To measure of the length of human modified shoreline that is physically and biologically unfavorable to Great Lakes ecosystems
	Extent, Composition, and Quality of Coastal Wetlands	Tracks trends in Great Lakes coastal wetland ecosystem health by measuring wetland area and extent, monitoring water quality, and calculating condition indices for vegetation, macroinvertebrates, fish, plants, amphibians, and birds
	Water Levels	Tracks trends in the average, timing, and variability of lake water levels
	Tributary Physical Integrity	Examines the physical conditions of tributaries throughout the Great Lakes watersheds including daily discharge measurements, a measure of connectivity to receiving waters, total main stem lengths, and a measure of turbidity
	Water Temperature	Monitors the temperature fluctuations of the lakes through time
	Land Cover	Assesses land cover change as well as the rate of habitat fragmentation within the Great Lakes
Biological Indicators	Aquatic Invasive Species: Invasion Rates and Impacts	Tracks the rate of invasion and status and impacts of aquatic invasive species (AIS) in the Great Lakes
	Lower Food Web Productivity and Health	Monitors the health of Great Lakes lower food web by tracking phytoplankton, zooplankton, <i>Mysis</i> , benthos, and prey fishes
	Fish Species of Interest	Measures status and trends in population abundance and recruitment for lake trout, lake whitefish, walleye, lake sturgeon, and a suite of nearshore predators (northern pike, smallmouth bass, largemouth bass, and yellow perch)
	Algal Blooms	Measures the chemical integrity of Great Lakes source water and impacts from agricultural and industrial activities, point source contamination by wastewater treatment facilities and uncontained landfills, and industrial population-induced sprawl by monitoring the presences of pesticides (atrazine), endocrine disrupting compounds (estrogenicity assay), and harmful algal blooms (cyanotoxin levels).
	Biological Integrity of Fish Eating and Colonial Nesting Birds	Measures the biological integrity of fish-eating and colonial birds, and links the biological integrity to both chemical integrity and physical integrity (indicators of physical and chemical stress)
Chemical Indicators	Atmospheric Deposition of Chemicals of Mutual Concern	Assesses the impact of chemicals of mutual concern (CMCs) on Great Lakes aquatic ecosystems
	Chemicals of Mutual Concern in Water	Assesses the magnitude and direction of trends of chemicals of mutual concern (CMCs) in surface waters of the Great Lakes
	Contaminants in Groundwater	Assesses the quantity of groundwater; groundwater and surface-water interactions; changes in groundwater quality as development expands; and, ecosystem health in relation to quantity and quality of water
	Persistent, Bioaccumulating, and Toxic Substances in Biota	Describes the spatial and temporal trends of bioavailable contaminants throughout the Great Lakes, and infers impact of contaminants on the health of fish and bird populations
	Phosphorus Loads and In-Lake Concentrations	Tracks the magnitude and trends in total phosphorous (TP) and dissolved reactive phosphorus (DRP) loads delivered to the Great Lakes from multiple sources, and tracks the fate of delivered TP and DRP are reflected in measurements of in-lake concentrations and trends in concentration from nearshore and offshore areas in the Great Lakes

## 2.3 STATE OF THE GREAT LAKES (SOGL) INDICATORS & ITS RELEVANCE

Since 1994, the U. S. Environmental Protection Agency (EPA) and Environment Canada have hosted a conference, State of the Lakes Ecosystem Conference (SOLEC), every two years in response to the binational GLWQA. The conferences are intended to provide a forum for exchanging information on the ecological condition of the Great Lakes and its watershed. A major purpose of SOLEC was to reach a large audience of people in government (at all levels), corporate, and not-for-profit sectors who make decisions that impact the lakes. The stated objectives of SOLEC are (SOLEC 2015):

1. Assess the state of the Great Lakes ecosystem based on accepted indicators
2. Strengthen decision-making and environmental management concerning the Great Lakes
3. Inform local decision makers of Great Lakes environmental issues
4. Provide a forum for communication and networking among Great Lakes stakeholders

Until 2008, the Conferences were held in even numbered years, and were the focal point of engaging a variety of organizations and gathering the best available science to study the Great Lakes. In the year following each conference, the governments prepared a report, called State of the Great Lakes (SOGL), based in large part upon the science presented and the stakeholders at the conference. This report was widely distributed to inform Great Lakes decision makers of current trends in the ecosystems.

The 2012 GLWQA modified the reporting cycle to every three years. In the effort to apply scientifically sound indicators consistently over time, the U.S. and Canadian governments accepted those IJC recommended indicators with available data but, correctly, noted that some IJC Indicators did not have data to create a report (16th Biennial Report 2013). For the 2016 governments' SOGL report, 43 sub-indicators were put forward to assess progress toward achieving the nine general objectives of the GLWQA (Table 2-1). The SOGL sub-indicators are:

- Treated Drinking Water
- Beach Advisories
- Contaminants in Edible Fish
- Toxic Chemicals in Great Lakes Whole Fish (Lake Trout/Walleye)
- Toxic Chemicals in Great Lakes Herring Gull Eggs
- Toxic Chemical Concentrations (open water)
- Toxic Chemicals in Sediment
- Atmospheric Deposition of Toxic Chemicals
- Water Quality in Tributaries
- Fish Eating and Colonial Nesting Water Birds
- Coastal Wetland Invertebrates
- Coastal Wetland Fish
- Coastal Wetland Plants
- Coastal Wetland Amphibians
- Coastal Wetland Birds
- Coastal Wetlands: Extent and Composition
- Hardened Shorelines
- Phytoplankton (open water)
- Zooplankton (open water)
- Benthos (open water)
- Diporeia (open water)
- Preyfish (open water)
- Lake Trout
- Walleye
- Lake Sturgeon
- Nutrients in Lakes (open water)
- Harmful Algal Blooms
- Cladophora
- Aquatic Invasive Species
- Sea Lamprey
- Dreissenid Mussels
- Terrestrial Invasive Species
- Water Levels
- Surface Water Temperature
- Ice Cover

- Precipitation Events
- Baseflow Due to Groundwater
- Watershed Stressors
- Forest Cover
- Land Cover
- Tributary Flashiness
- Habitat Connectivity
- Human Population

The number of SOGL indicators and the detailed documentation of each one means that the SOGL documents are lengthy.

## **2.4 DATA AVAILABILITY FOR INDICATORS**

For both the SOGL and the IJC indicators, whether or not sufficient and necessary data exists to evaluate each indicator is a key aspect of understanding if an indicator can be considered functionally viable. This functional viability has two components, spatial and temporal availability of the data.

### **2.4.1 *Spatial Availability of the Data***

Data that is “complete” should be available throughout the Great Lakes region and not be limited to only one or two of the lakes. As the purpose of the indicators is to track the health of the Great Lakes in its entirety, data that is partially available does not serve the purpose. Indicators with partial data need to be carefully assessed for the length of time and amount of effort necessary to obtain the remaining data.

### **2.4.2 *Temporal Availability of the Data***

Data that is “complete” should also have a baseline. Whether that baseline is a historical dataset or a reference goal, it is a yardstick to measure against and is necessary to monitor the lakes. In the Great Lakes, datasets such as those for the health and populations of fish or animal species, have been collected for several decades. On the other hand, there are indicators, like land cover, which do not have continuous reference datasets throughout the Great Lakes. For these indicators, the reference condition for the data must be reconstructed, which can be very difficult and costly in time and resources. Thus, similar for spatial availability, indicators with partial temporal data need to be carefully assessed for the amount of effort necessary to obtain the remaining data.

## 3.0 STATUS OF IJC INDICATORS & THEIR METRICS

Recognizing the need for continuous improvement to meet the needs of future assessments, additional reviews of IJC indicators/metrics that currently have partial or no data is needed. Because data collection is expensive and time consuming, it is critical to evaluate the necessity of the additional indicators.

To carry out this work, IJC provided the Roth et al. (2015) report to the project team. A summary of the report is provided below.

### 3.1 IJC INDICATORS WITH FULL DATA

Based on the project team's analyses, nine out of 21 IJC indicators had data that could be procured for careful analyses of the Great Lakes. These indicators depend on a variety of datasets, from long-term chemical sampling efforts to continuous sampling of coastal wetland species, and, accordingly, the data needs are varying, but all share two important qualities:

- The dataset draws from sample sites distributed throughout the Great Lakes at an appropriate spatial scale with widespread, past and present comprehensive sampling efforts.
- The dataset includes a reference or baseline against which continuing monitoring efforts can be compared.

These indicators are presented in Table 3-1. For brevity, no further explanations are provided, and the reader is referred to Roth et al. (2015) for additional information.

**Table 3-1: IJC indicators with full data**

IJC INDICATORS		IJC METRICS
PBT in Biota		PBT chemicals in Great Lakes whole fish
		PBT chemicals in Great Lakes, herring gull eggs, and in bald eagles
Chemicals of Mutual Concern in Water		Based on Annex 3 recommendation
Air Deposition of Chemicals of Mutual Concern		Based on SOLEC indicator Atmospheric Deposition of Toxic Chemicals
Coastal Wetland		Invertebrates
		Fish
		Plants
		Amphibians
		Birds
		Area and extent
Lower Food Web		Phytoplankton biovolume
		Zooplankton biomass
		Benthos abundance
		Mysis biomass
		Prefish biomass and diversity index
Aquatic Invasive Species	Rate of Invasion	Plotting cumulative numbers of invasions versus time
	Status and Impacts	Plankton
		Asian carps

IJC INDICATORS		IJC METRICS
		Round goby
		Ruffe
		Sea lamprey
		Dreissenid mussels
Water Level		Long-term water level variability
		Timing of seasonal water level maximum and minimum
		Magnitude of seasonal rise and decline
		Lake-to-lake water level difference
Water Temperature		Annual summer (July-September) surface average temperature for each lake
		Fall lake water turnover date
		Maximum and average ice concentrations
Land Uses	Land Conversion Rate	Percent natural land type unchanged
		Percent change in natural land types
		Percent change to non-urban or industrial land
		Percent change to urban or industrial land
	Land Fragmentation	Average number of patches for each natural land-cover class
		Average patch size for each natural land cover class

### 3.2 INDICATORS WITH INCOMPLETE DATA

Based on the project team's analyses, 12 out of 21 IJC indicators had partial or no data. These indicators are presented in Table 3-2.

**Table 3-2: IJC indicators with partial or no data**

IJC INDICATORS		IJC METRICS
Biological Hazards of Source Water		E. coli
		Nitrate
		Turbidity
Chemical Integrity of Source Water		Atrazine
		Estrogenicity
		Cyanotoxins
Illness Risk at GL Beaches		95th % # of E. coli/colony-forming units of E. coli per 100 ml
Source of Risks at GL Beaches		Percent beaches with Beach Sanitary Survey or Environmental Health & Safety Survey in a given year
Contaminant Levels in GL Edible Fish Species		Concentrations of PCBs, dichlorodiphenyltrichloroethane (DDT), mercury, chlordanes, toxaphane, and mirex in edible portions of lake trout
		Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, and mirex in edible portions of walleye
		Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, and mirex in edible portions of yellow perch
		Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, and mirex in edible portions of whitefish
		Concentrations of PCBs, DDT, mercury, chlordanes, toxaphane, and mirex in edible portions of smallmouth bass
Abundance and Distribution of Fish-Eating and Colonial Nesting Birds	Population Status	Nest counts of bald eagles, double-crested cormorants, herring gulls, and other colonial water birds
		Number of adult and number of young birds
	Health Status	Bald eagle productivity and hatch rates for double-crested cormorants, herring gulls, and others
		Deformities of bald eagles, double-crested cormorants, and herring gulls



IJC INDICATORS	IJC METRICS
Shoreline Alteration	Physical shoreline indicator
	Biological shoreline indicator
	SAI-Combined physical and biological index
Fish Species of Interest	Recruitment and abundance of lake trout and whitefish
	Recruitment and abundance of walleye
	Recruitment and abundance of lake sturgeon
	Recruitment and abundance of northern pike or yellow perch or smallmouth/largemouth bass
Phosphorus Loading and In-lake Concentration	In Lake Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP) concentrations
	TP and DRP loading from tributaries
Algal Blooms	Harmful Algal Blooms
	Nuisance Algal Blooms
	Excessive Algal Abundance
Contaminants in Groundwater	Measure greater than ten chemicals from ag and urban watersheds
Tributary Physical Integrity	Hydrologic Alteration (R-B Flashiness Index)
	Sediment-turbidity measure
	Tributary connectivity to Great Lakes

A short summary of each indicator follows, along with a brief description of the available dataset, metrics, calculation methodologies, spatial, and temporal resolutions.

### 3.2.1 Biological Hazards Index for Source Water

The purpose of this indicator is to (Roth et al. 2015):

- Examine trends in the endemic, seasonal, and episodic presence of sewage and agricultural effluent and other contaminated runoff in the Great Lakes,
- Examine seasonal and geographic distribution of selected human pathogens, and
- Infer the effectiveness of management actions taken to reduce the impact of pathogens and nitrates in source waters.

**Table 3-3: Summary of data gaps for indicator “biological hazards index for source water”**

METRICS	SPATIAL RESOLUTION	TEMPORAL EXTENT	RECOMMENDATIONS
Trend analyses on extremes and exceedances of measurements beyond provisional baselines for <i>E. coli</i>	Data would be associated with sites near drinking water intakes around the lake. This data does not currently exist.	If available, data would be collected daily. Data does not currently exist.	After surveys were conducted, it was determined that the data does not currently exist and high barriers exist to develop the data (federal law may preclude public knowledge of source water locations and intakes).
Trend analyses on extremes and exceedances of measurements beyond provisional baselines for Nitrate			
Trend analyses on extremes and exceedances of measurements beyond provisional baselines for turbidity			

### 3.2.2 Chemical Integrity of Source Water

The purpose of this indicator is to (Roth et al. 2015):

- Examine trends in seasonal and geographic variability or targeted chemical compounds in waters used as sources for regional drinking water supply,

- Assess the level of hazard and infer the impact of chemical contaminants in the drinking water sources on the health of the human population in the Great Lakes that are served by water from the Lakes,
- Infer the effectiveness of management actions taken to reduce the overall levels of pesticides, nutrients, and endocrine disrupting chemicals in the Great Lake source water for drinking, and
- Examine indications for possible improvements to potable and waste water treatment.

**Table 3-4: Summary of data gaps for indicator “chemical integrity of source water”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
Trend analyses on extremes and exceedances of measurements beyond provisional baselines for atrazine	Data would be associated with specific sites around the lake, but it doesn't exist currently.	If available, data would be collected daily. Data doesn't currently exist.	After surveys were conducted it was determined that the data does not currently exist and high barriers exist to developing the data (federal law may preclude public knowledge of source water locations and intakes.).
Trend analyses on extremes and exceedances of measurements beyond provisional baselines for endocrine disrupting compounds			
Trend analyses on extremes and exceedances of measurements beyond provisional baselines for cyanotoxins			

### 3.2.3 Illness Risk at Great Lakes Beaches

The purpose of this indicator is to (Roth et al. 2015):

- Infer potential harm to human health at routinely monitored beaches through use of fecal indicator organisms as a surrogate for pathogens,
- Describe temporal and spatial trends in recreational water quality at monitored Great Lakes beaches, and
- Allow comparisons of recreational water quality across jurisdictions using a common methodology.

**Table 3-5: Summary of data gaps for indicator “illness risk at Great Lakes beaches”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
95 <sup>th</sup> percentile of numbers of E. coli measured as the most probable number (MPN)/colony forming units (CFU) of E. coli per 100 ml of water at Great Lakes beaches to determine change over time	Data is sampled on a beach-to-beach basis on both sides of the lakes. Certain areas, especially those heavily used by people, have higher sampling clusters than areas with less traffic.	Some beaches have very long term sampling records (10 years<) but others have only been sampled for a few years; it is highly site dependent.	The data does exist for many areas on both sides of the lake, but hasn't been brought together in a single format. The estimated effort to completely integrate datasets across national boundaries and formats is considerable. On the Canadian side, the data is maintained by multiple, separate agencies, requiring a lot of effort to bring together under one database. The U.S. maintains a database under “BEACON” but there is also data maintained by state agencies not included in this system.

Finally, how to use this data to calculate the metric is unclear because while the E.coli data exists, its link to the risk of illness is not explicit. Clarifying the calculation method is essential to using this indicator effectively.

### 3.2.4 Source of Risks at Great Lakes Beaches

The purpose of this indicator is to (Roth et al. 2015):

- Characterize sources of risk at Great Lakes beaches,
- Identify the main pollution sources,
- Measure the percentage of beaches that employ Beach Sanitary Surveys (USA), and Environmental Health and Safety Surveys (Canada) in a given year.

**Table 3-6: Summary of data gaps for indicator “source of risks at Great Lakes beaches”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
Main pollution sources identified at beaches that employ Beach Sanitary Survey or Environmental Health and Safety Survey	Beach to beach sanitary surveys are conducted to a varying degree of completeness throughout the basin (e.g., some lakes may have a very small percentage of beaches surveyed).	Data only shows whether or not a survey has been conducted, not the date of the first survey or the survey’s frequency.	Major gaps exist with no temporal information attached to surveys, very few of the beaches have latitudes or longitudes recorded, and a complete lack of source identification when conducting surveys.
Percentage of beaches that employ Beach Sanitary Survey or Environmental Health and Safety Survey in a given year			

### 3.2.5 Contaminant Levels in Great Lakes Edible Fish Species

This purpose of this indicator is to (Roth et al. 2015):

- Analyze temporal trends in contaminants in Great Lake Fish Species, and
- Assist in further investigation of exposure pathways through fish consumption.

**Table 3-7: Summary of data gaps for indicator “contaminants in Great Lakes edible fish species”**

METRIC	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
None identified to date	Sampling regimes are variable. Some areas have random sampling locations with little consistency year to year while other areas have set locations revisited throughout the year. Another variable is sample time, which can range anywhere from annually to biannually.	Sampling goes back to as late as 1970 in some datasets with variation on whether the sampling event is annual or biannual, and whether the sample site rotates or not.	Multiple agencies and jurisdictions collect this data using different sampling methods, making comparison across years and across states challenging and time consuming. States are also not required to report this data to the EPA affecting the total overall coverage that exists within the region. Finally, how to calculate this metric was never made explicit, which has prevented full assessment of the indicator.

### 3.2.6 Abundance & Distribution of Fish-Eating & Colonial Nesting Birds

The purpose of this indicator is to (Roth et al. 2015):

- Measure the biological integrity of fish-eating and colonial birds,
- Measure indicators of physical and chemical stress, and
- Allow direct comparison of avian health across spatial and temporal scales.

**Table 3-8: Summary of data gaps for indicator “abundance and distribution of fish-eating and colonial nesting birds”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
Nest counts of bald eagles, double-crested cormorants, herring gulls, other colonial water birds	The spatial scale is variable with many sites being sampled allowing for analysis on any scale, from provinces and states down to watersheds. This is true for bald eagles, herring gulls, as well as colonial nesting birds.	Both species have long-term sample regimes that have been very effective.	Definition of indicator calculation method is necessary before gaps can be known. Additionally, a definition of the sampling regime is necessary.
Number of adult and number of young individuals			
Bald eagle productivity and hatch rates for double-crested cormorants, herring gulls, and others			
Deformities of bald eagle, double-crested cormorants, herring gulls, and others			

### 3.2.7 Coastal habitat – Shoreline Alteration Index (SAI)

The purpose of this indicator is to measure the length of human-modified shoreline that is physically and biologically unfavorable to Great Lakes ecosystems (Roth et al. 2015).

**Table 3-9: Summary of data gaps for indicator “coastal habitat-shoreline alteration index (SAI)”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATION
SAI = 1 – (P Ratio x B Ratio)	Survey data can be taken from multiple different sources (AVHRR, orthographic photos, Landsat, etc.) and many of these are quite fine scale allowing detailed analysis of the shoreline characteristics.	Surveys can be quite costly so tremendous amounts of time can pass between major, formal surveys of shoreline characteristics. It is difficult to pinpoint initial survey dates but many of the first formal surveys were done in mid-1970 to 80's.	Detailed shoreline data on biological characteristics of the lakeshore does not exist widely within the lakes. Some states and provinces have made important strides towards mapping biological characteristics, however this progress has not been uniform and the biological component does not have enough data available to be calculated. How to calculate the biological indicator has also been left ambiguous, preventing full assessment of this metric.
Biological component: the ratio of the lineal length of biologically incompatible structures (shore perpendicular structures, vertical sheet pile, concrete walls, and other “human-made” structures that cannot serve as biological habitat) relative to total lineal length of “human-modified” shoreline (B Ratio).			
Physical component: Ratio of the lineal length of armored shoreline relative to total lineal length of the shoreline (i.e. the ratio x 100 = percent of armored shoreline). More specifically, the P Ratio equals human modified shoreline/total shoreline. The P Ratio is also assigned scores of "poor" (0.7 to 1.0), "fair" (0.4 to 0.7), "good" (0.15 to 0.4), and "excellent" (<0.15).			

### 3.2.8 Fish Species of Interest

The purpose of this indicator is to measure the status and trends in population abundance and recruitment for lake trout, lake whitefish, walleye, lake sturgeon, and a suite of nearshore predators (northern pike, smallmouth bass, largemouth bass, and yellow perch) (Roth et al. 2015).

**Table 3-10: Summary of data gaps for indicator “fish species of interest”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
Recruitment and abundance of lake trout and whitefish	Trawls and surveys generally are associated with management units or basins, but are sometimes presented at the lake level. Other surveys, such as creel surveys, have a very specific location and are geo-referenced.	Data has been collected in many different ways throughout the basin with some areas conducting yearly collections and other areas only doing so sporadically.	Data for lake trout, lake whitefish, and walleye is generally easy to obtain and readily available throughout the basin. Data for sturgeon and other species is lacking throughout the basin. These species will need to be assembled from survey data that is fishery independent.
Recruitment and abundance of walleye			
Recruitment and abundance of lake sturgeon			
Recruitment and abundance of northern pike or yellow perch or smallmouth/largemouth bass			

### 3.2.9 Phosphorus Loads & In-Lake Concentrations

The purpose of this indicator is to (Roth et al. 2015):

- Track the magnitude and trends in total phosphorus (TP) and dissolved reactive phosphorus (DRP) loads delivered to the Great Lakes,
- Assess the fate of delivered TP and DRP in-lake, and
- Monitor concentrations and trends in concentration from nearshore and offshore areas in the Great Lakes.

**Table 3-11: Summary of data gaps for indicator “phosphorous loads and in-lake concentrations”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
Total phosphorus (TP) load for major tributaries of each lake basin using the methods in Dolan and Chapra (2012).	Dolan and Chapra (2012) have loads down to the tributary level with some areas generalized into “complexes” or subbasins. The lakewide information is a result of averaging station samples, though individual station level data is also available.	Dolan and Chapra (2012) used TP loads from 1994- to 2008, but, by and large, the data prior to 1994 is too generalized to be useful for calculation of the first metric. DRP has been collected, at some sites, for Lake Michigan from 1994-2000 and from 2010 to 2014, and Heidelberg University has estimated tributary loads in the Western Lakes Erie Basin as far back as 1975 but the period of record varies widely. Depending on the monitoring program for in-lake TP, the sampling in the period of record spans from 1970 to present.	While there is good coverage within the lakes, there are two key issues with the TP loading data in tributaries. First, is that improvements have been made to load estimation techniques and reassessing the data would produce a more accurate picture of TP in the Great Lakes. That reassessment needs to be done. Secondly, the lakes are not sampled uniformly. Certain areas have fine-scale estimates, while other areas have large-scale, averaged estimates. This discrepancy prevents straightforward comparisons among systems.
Dissolved reactive phosphorus (DRP) load for major tributaries of each lake basin using the methods in Dolan and Chapra (2012).			
Average in-lake TP concentration as measured by spring and summer sampling programs			
Average in-lake DRP concentration as measured by spring and summer sampling programs			

### 3.2.10 Algal Blooms

The purpose of this indicator is to track spatial and temporal trends in the occurrence of harmful and nuisance algal blooms in the Great Lakes (Roth et al. 2015).

**Table 3-12: Summary of data gaps for indicator “algal blooms”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
<b>Harmful algal bloom (HAB):</b> Occurrence/frequency of Microcystin-LR concentrations > 10 ug/L (pelagic) or >300 ug/gram (benthic) or algal community dominated by a suite of potentially toxic cyanobacterial species	There are 40 sites sampled in western Lake Erie for HABs, however no sampling occurs for nuisance or excessive blooms because there are no established sampling methods. No other lake is sampled routinely for algae, however, sampling in Green Bay and Saginaw Bay are ongoing.	Sampling in western Lake Erie occurs every other week or monthly and there are 8-10 years of data available.	Data is only available for very specific locations around the Great Lakes and monitoring doesn't occur in areas where blooms have not been a problem in the past. Additionally, integration of data from multiple sources is difficult and there's no easy solution to the problem.
<b>Nuisance algal bloom (NAB):</b> Occurrence/frequency of chlorophyll-a > 30 ug/L and levels of common algal odor compounds are greater than human detection thresholds or significant number of beach posting or closures due to excessive algal material			
<b>Excessive algal bloom (EAB):</b> Occurrence/frequency of high levels of percent coverage of nearshore by nuisance algae (>50 percent coverage or 50 grams dwt/m <sup>2</sup> ) or extensive pelagic bloom as measured by timing, intensity, duration, and areal extent.			

### 3.2.11 Contaminants in Groundwater

The purpose of this indicator is to (Roth et al. 2015):

- Track the quantity of groundwater,
- Assess groundwater and surface-water interactions,
- Assess changes in groundwater quality as development expands, and
- Document ecosystem health in relation to quantity and quality of water.

**Table 3-13: Summary of data gaps for indicator “contaminants in groundwater”**

METRICS	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	RECOMMENDATIONS
There is currently no defined metric for this indicator, however, metrics based on nitrate and chloride from groundwater are being developed.	Data is taken from individual wells within a watershed and must be generalized to other spatial scales.	Many different sampling regimes are used across the watershed and, considering the different durations and frequencies, more guidance must be applied in order to fully calculate this metric.	There currently is no guidance on how exactly to calculate this metric, which makes identifying gaps difficult. The data likely exists to calculate this metric many different ways once a methodology is decided upon.

### 3.2.12 Tributary Physical Integrity

The purpose of this indicator is to (Roth et al. 2015):

- Measure physical integrity of Great Lakes watersheds,

- Measure connectivity to receiving waters, and
- Measure turbidity in relation to a turbidity threshold.

**Table 3-14: Summary of data gaps for indicator “tributary physical integrity”**

	METRICS
<p><b>SPATIAL RESOLUTION:</b> The calculations are based on single gauged locations and rivers within the lakes rather than having any in-lake calculation. Extrapolating out from these locations to basin-wide trends can be difficult since not all lakes have the same number of gauged tributaries and there is no system for placing the gauges in a uniform way.</p>	<p><i>Hydrologic Alteration (R-B Flashiness Index):</i> 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 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).</p> $\text{R-B Index} = \frac{\sum_{n=1}^N  q_n - q_{n-1} }{\sum_{n=1}^N q_n}$
<p><b>TEMPORAL RESOLUTION:</b> Data has been collected on a monthly basis from 1960 through 2013.</p> <p>The flows reported are mean daily, not monthly.</p>	
<p><b>RECOMMENDATION:</b> There are no known gaps for flashiness and connectivity, however that doesn’t mean there aren’t issues related to temporal and sampling components. Some areas have very few gauges and other gauges have only been active for a very short period of time, compromising the overall usefulness of this data.</p>	
<p><b>RECOMMENDATION:</b> The sediment turbidity index has data gaps that revolve around only 23 stations having the full data needed to calculate the turbidity index.</p>	<p><i>Tributary connectivity to receiving waters:</i> Tributary connectivity for an individual watershed = <math>(L_b/L_m) \times 100</math> where <math>L_b</math> is the distance between the Great Lakes and the first barrier on the main stem channel and <math>L_m</math> is the total length of the main stem channel.</p>
	<p><i>Tributary connectivity to receiving waters:</i> Tributary Connectivity for multiple watersheds is calculated by summing the total length of main stem channels without barriers and then dividing by the total sum of main stem channel lengths.</p>
	<p><i>Sediment-turbidity measure:</i> Turbidity Exceedance Time is the proportion of time that the turbidity threshold (T) is exceeded during the time series (<math>t_n &gt; T</math>) divided by the total time within the series (see equation in cell to the right). For example, a turbidity exceedance value of 0.50 indicates that the turbidity threshold was exceeded 50 percent of the time on an annual basis (N=365). In other words, days in the year that the mean daily turbidity value exceeded the threshold divided by days of data in that year.</p>
	<p><i>Sediment-turbidity measure:</i> 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 (<math>c_n &gt; T</math>) 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. In other words, of the days that the threshold was exceeded, find the average turbidity value across those exceedance days and divide it by the threshold value.</p>

### **3.3 SUMMARY**

The IJC's prepared indicators vary in their readiness to use due to the amount of data readily available. Many can be easily integrated because the appropriate data exists, while others require significant efforts to bring them to a level at which they can be included in the indicator suite. Only nine of the 21 indicators had full data.

Accordingly, a prioritization of the remaining indicators was needed to consider the necessity of those indicators. That prioritization process is described in Sections 4 and 5.



## 4.0 WORKSHOP – INDICATOR EVALUATION

### 4.1 IJC INDICATORS WORKSHOP: GOALS & ATTENDEES

Based upon discussions with and feedback from the IJC's indicators workgroup, it was necessary to host an IJC indicator review workshop that had the following goals:

- Review the IJC indicators and their metrics so far as data availability, and assess if any gaps existed with the GLWQA objectives
- Review the SOGL sub-indicators and assess if any gaps existed with the GLWQA objectives
- Review IJC indicators with partial or no data, and prioritize them for filling gaps

In November of 2015, an invitation was sent to nearly 35 experts in the region to participate in the indicator review and prioritization process. A high percentage of those invited were able to attend the workshop held on December 17 and 18, 2015, in Ann Arbor, Michigan. As listed in Table 4-1, nearly 30 attendees participated in the workshop, with the majority attending in person.

**Table 4-1: List of IJC Indicators Workshop Attendees**

	BY-WEBINAR		IN-PERSON	
	DEC 17, 2015	DEC 18, 2015	DEC 17, 2015	DEC 18, 2015
<b>Indicator Experts</b>				
Bill Taylor, University of Waterloo	x	x		
Carol Miller, Wayne State University			x	x
Catherine Riseng, University of Michigan				x
Chris Winslow, Ohio Sea University		x	x	
Dale K. Phenicie, Council for Great Lakes Industries	x	x		
Debbie Lee, NOAA			x	x
Donald Uzarski, Central Michigan University	x			
Ed Ruthford, NOAA			x	x
Gavin Christie, Fisheries and Oceans Canada			x	x
Greg Boyer, SUNY	x	x		
Howard Shapiro, Toronto Public Health			x	x
Ian D Campbell, Agriculture and Agri-Food Canada			x	x
Jan Ciborowski, University of Windsor			x	x
Jeff Ridal, St. Lawrence River Institute		x		
Jim Ludwig, retired water birds toxicologist			x	x
Joseph V. DePinto, Limnotech			x	x
Lucinda Johnson, University of Minnesota			x	x
Michael Murray, National Wildlife Federation			x	x
Norm Grannemann, U.S.G.S.			x	x
Phillip Chu, NOAA Great Lakes Environmental Research Laboratory			x	x
Roger Knight, Great Lakes Fisheries Commission				x
Steve Cole, Great Lakes Commission			x	
Tom Speth, U.S. Environmental Protection Agency	x	x		
Vic Serveiss, IJC	x	x		
Virginia Roberts, U.S. Center for Disease Control	x	x		
<b>Facilitators</b>				
Ankita Mandelia, IJC			x	x
James Ridgway, P.E., ECT			x	x

	BY-WEBINAR		IN-PERSON	
	DEC 17, 2015	DEC 18, 2015	DEC 17, 2015	DEC 18, 2015
<b>Facilitators</b>				
Li Wang, Ph.D., IJC			x	x
Robert Pettit, ECT			x	x
Sanjiv Sinha, Ph.D., P.E., ECT			x	x
Total	7	8	20	20

## 4.2 ADOPTED PROCEDURE

Based upon discussions with and feedback from workshop attendees, the following questions were agreed upon as primary variables for prioritization:

- How important is this indicator, as far as filling a gap between SOGL indicator and the GLWQA objective, to be included in the Great Lakes monitoring efforts?
- Estimate of the relative effort, i.e. level of professional resources necessary to create appropriate datasets, required to resolve any issues with that indicator
- Estimate of the time commitment, such as weeks or months or years, required to resolve the issues with that indicator

After a short presentation on each indicator, the attendees were requested to discuss the indicator's relevance to the GLWQA objectives. Eventually, for each indicator, responses to the above three questions were recorded from the participants, which were analyzed and are summarized in Section 5.

## 4.3 SUMMARY

The process employed by the project team helped synthesize the expert opinions into easily comparable responses so each indicator could simultaneously be ranked by multiple criteria. A summary of these results is presented in Section 5.

## 5.0 WORKSHOP FINDINGS – A REVIEW OF GAPS & PRIORITIZED INDICATORS

### 5.1 WORKSHOP FINDINGS

Workshop attendees identified gaps in addressing GLWQA objectives by SOGL sub-indicators that could be improved by using the following eight IJC indicators that had partial or no data:

- Biological Hazards/Chemical Integrity of Source Water
- Illness Risk at Great Lakes Beaches
- Sources of Risk at Great Lakes Beaches
- Phosphorus Loads and In-lake Concentrations
- Algal Blooms
- Fish Species of Interest
- Coastal Shoreline Alteration Index
- Contaminants in Ground Water

Along with the above list, experts also reviewed “lower food web” and “aquatic invasive species”, indicators previously identified with full data, for prioritization purposes, because their measures were different. The SOGL indicator suite tracks invasive species as an aggregate metric without breaking the information out by species. In contrast the IJC indicators make explicit what species are being tracked providing an opportunity to examine trends in specific species of interest over time. Similarly, the IJC’s lower food web indicator examines mysis as well as other species in ways that are distinct from the SOGL suite, and the attendees felt that it was important to use the more comprehensive IJC indicators.

These indicators were discussed carefully, and a survey of the three goals (presented in Section 4.1) was carried out. These IJC indicators were prioritized by the attendees, and that prioritized list is presented in Table 5-1. In addition, a description of related discussions among the attendees is also outlined in Sections 5.1.1 through 5.1.10 in the priority order of Table 5-1.

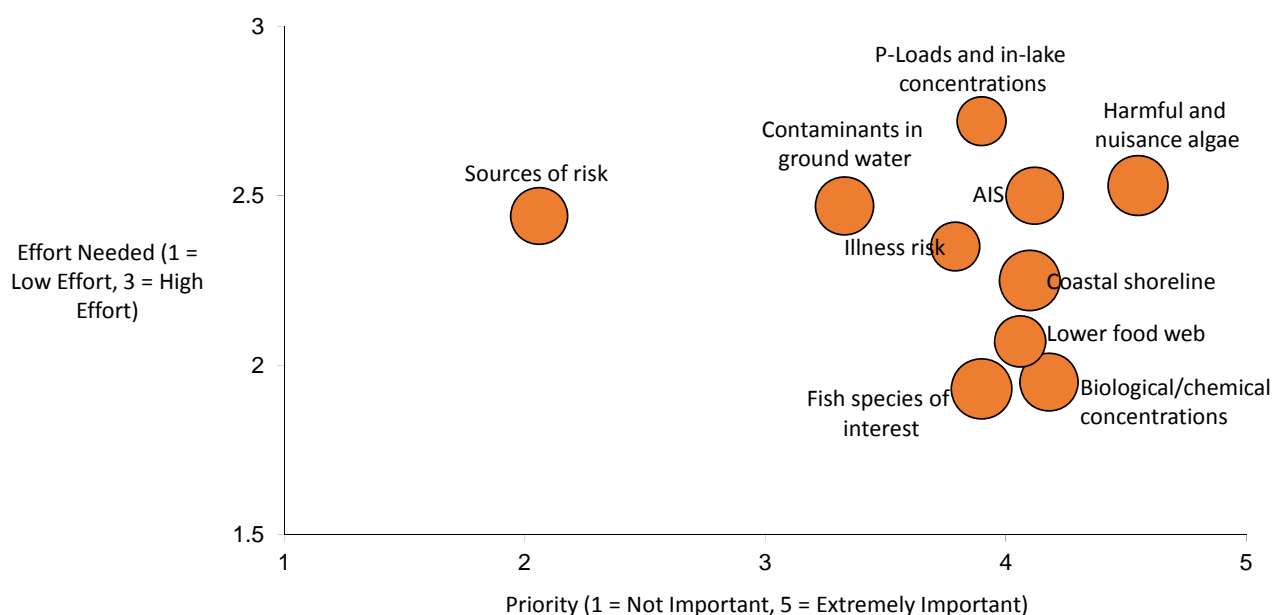
**Table 5-1: Prioritized list of IJC indicators**

INDICATOR	AVERAGE SCORE (1 = NOT IMPORTANT, 5 = EXTREMELY IMPORTANT)	PRIORITY BASED ON SCORE	AVERAGE SCORE (1 = LOW EFFORT, 3 = HIGH EFFORT)	RELATIVE EFFORT BASED ON SCORE	AVERAGE SCORE (1 = NO TIME COMMITMENT, 4 = HIGH TIME COMMITMENT)	TIME COMMITMENT BASED ON SCORE
Algal Blooms	4.55	Essential	2.53	High	3.93	High
Biological Hazards/Chemical Integrity of Source Water	4.18	Essential	1.95	Middle	3.68	High
AIS - Invasion rates and impacts	4.12	Essential	2.5	High	3.56	High
Coastal Shoreline Alteration Index	4.10	Essential	2.25	High	4	High
Lower food web	4.06	Essential	2.07	High	2.87	Middle
Phosphorus Loads and In-Lake Concentrations	3.90	Important	2.72	High	2.61	Middle
Fish Species of Interest	3.90	Important	1.93	Middle	4	High

INDICATOR	AVERAGE SCORE (1 = NOT IMPORTANT, 5 = EXTREMELY IMPORTANT)	PRIORITY BASED ON SCORE	AVERAGE SCORE (1 = LOW EFFORT, 3 = HIGH EFFORT)	RELATIVE EFFORT BASED ON SCORE	AVERAGE SCORE (1 = NO TIME COMMITMENT, 4 = HIGH TIME COMMITMENT)	TIME COMMITMENT BASED ON SCORE
Illness Risk at GL Beaches	3.79	Important	2.35	High	2.6	Middle
Contaminants in Ground Water	3.33	Important	2.47	High	3.68	High
Sources of Risk at GL beaches	2.06	Neutral	2.44	High	3.55	High

**Figure 5-1: Bubble chart summarizing the findings of the workshop**

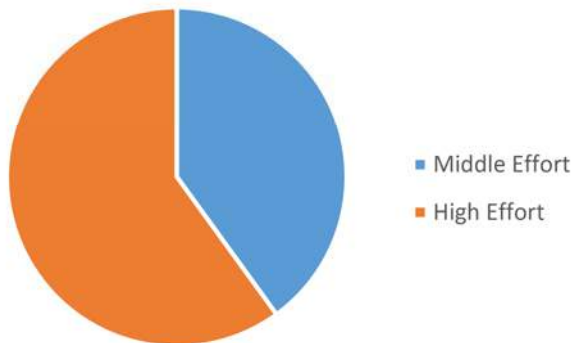
(note that the size of the circles is proportional to the “time commitment” scores assigned by the attendees)



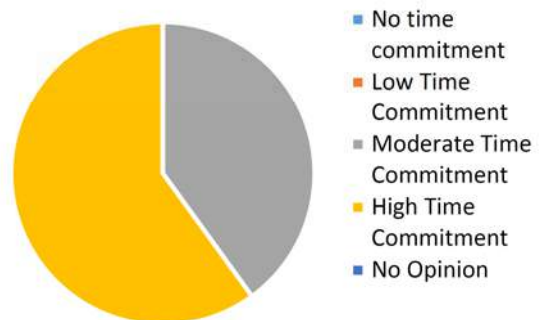
### 5.1.1 Algal Blooms

The attendees agreed that monitoring algal blooms and enhancing the existing algal bloom datasets was very important. The attendees felt that this IJC indicator added significant value to the current SOGL indicator suite by tracking several different types of algae, instead of focusing exclusively on microcystis. However, the group also felt that rewording of the metrics was necessary to showcase the algal species being measured, before the indicator was included.

Estimate relative effort required to resolve issues with this indicator.



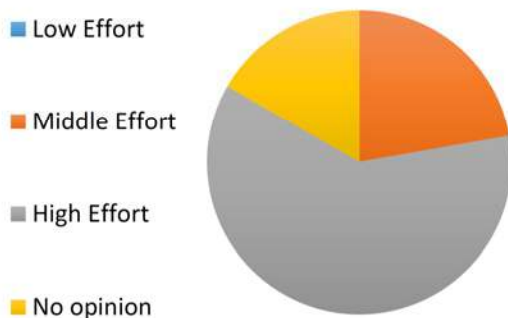
Estimate time commitment required to resolve lingering issues with this indicator.



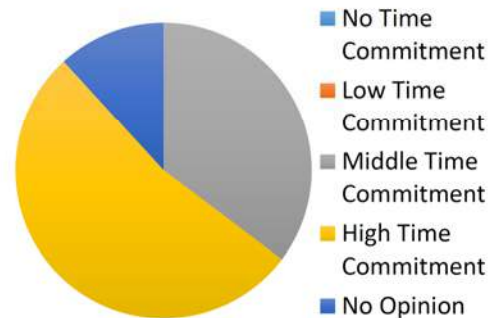
### 5.1.2 Biological Hazards/Chemical Integrity of Source Water

For the purposes of discussion, the “Biological/Chemical integrity of Source Water” indicators were combined into one topic. Ultimately, the workgroup felt that it was vital to include these IJC indicators in the SOGL suite of indicators in order to ensure that source water was being assessed (i.e., not just the treated water).

Estimate relative effort required to resolve issues with this indicator.



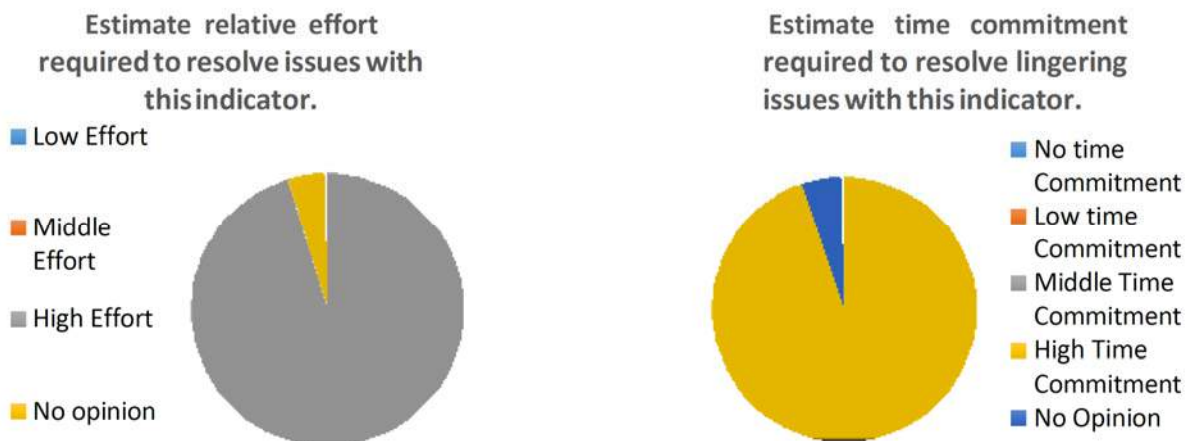
Estimate time commitment required to resolve lingering issues with this indicator.



### 5.1.3 AIS – Invasion Rates & Impacts

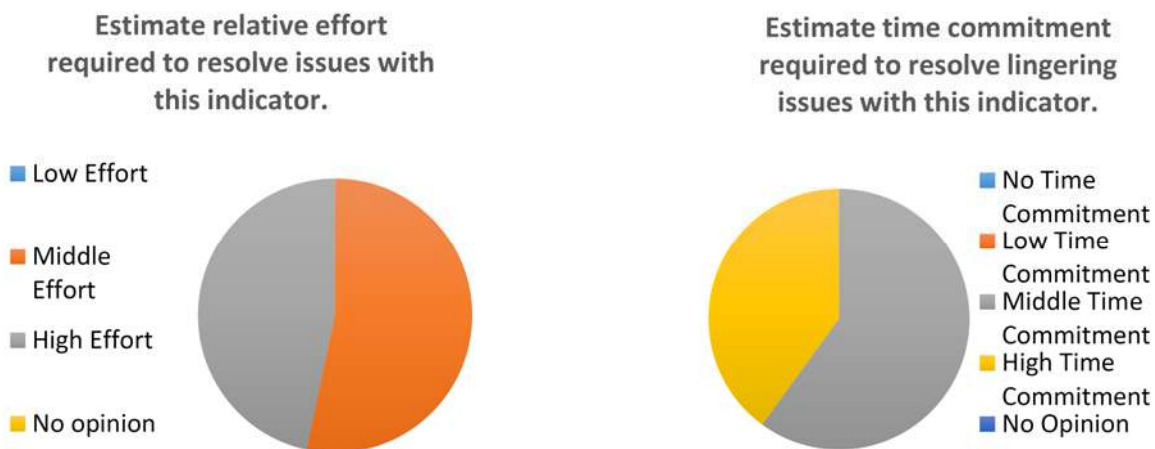
The IJC “AIS-Invasion rates and impacts” indicator is similar to the SOGL indicator in terms of the species that it tracks, however, the IJC indicator presents this information differently. The IJC indicator tracks many species individually, but also includes an overarching rate of invasion indicator. This tracking of both individual species and aggregate invasions was considered to be vital by the workgroup, and so it

was recommended for inclusion. Additional conversations revolved around ensuring certain species of concern.



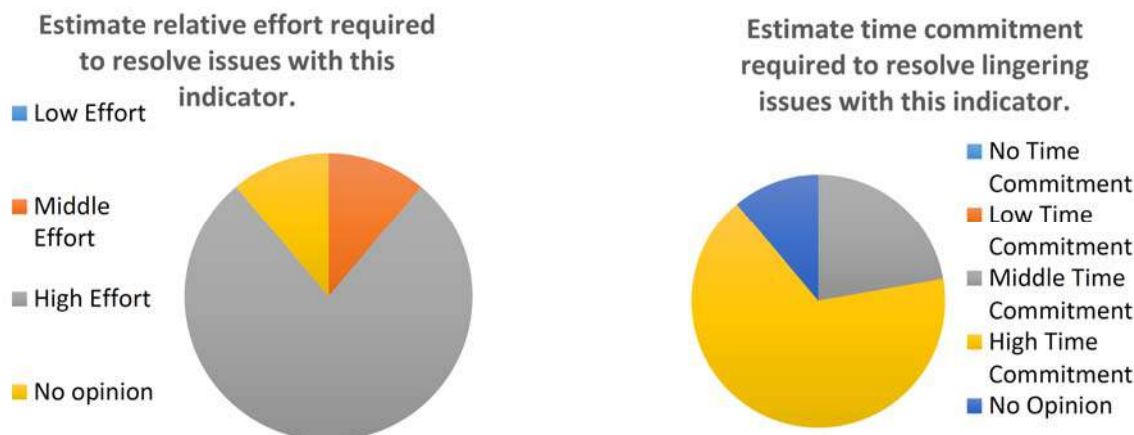
#### 5.1.4 Coastal Shoreline Alteration Index

The IJC “Coastal Shoreline Alteration Index” indicator had some similarities to the current SOGL assessments, but also included a biological metric that the SOGL indicator did not. This metric is not fully defined at this point, but the workgroup felt that capturing the quality of habitat along shorelines was an essential exercise to carry out. Further, the workgroup felt that assessing non-shoreline and non-wetland habitats (e.g., interior stream habitats) were essential to making this biological integrity indicator more useful.



### 5.1.5 Lower Food Web

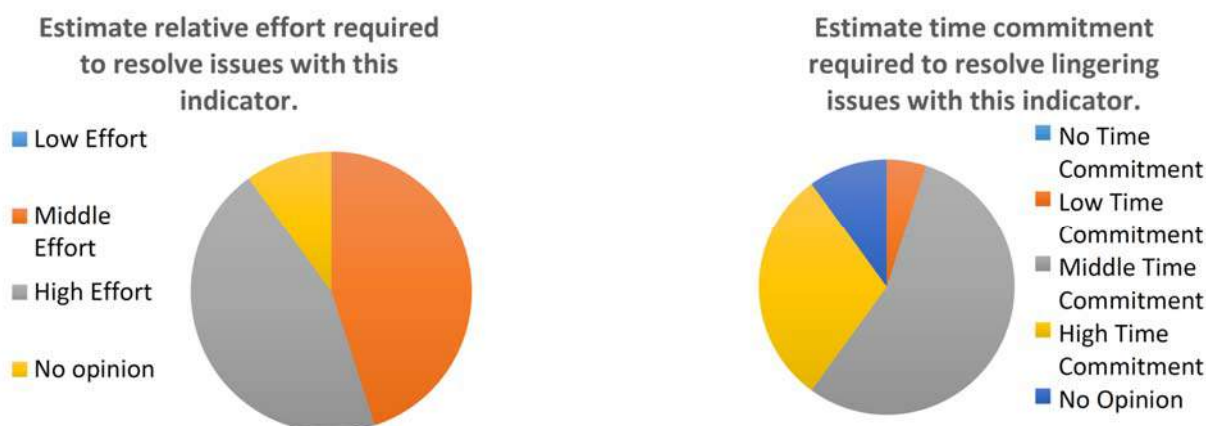
The “Lower Food Web” indicator is primarily focused on tracking several important species that contribute to the base of the Great Lakes food chain. While broadly similar to the SOGL indicator, attendees recommended including Mysis biomass and nearshore benthic macroinvertebrates. The workgroup ultimately chose to recommend this indicator for inclusion.



### 5.1.6 Phosphorus-loads & In-lake Concentrations

The attendees felt that it was important to capture nearshore nutrient concentrations as well as in-lake concentrations to more accurately reflect phosphorus dynamics within the Great Lakes system. The group also suggested a different method of calculating load than what is currently employed by either set of indicators. This method uses flow-weighted means to more accurately reflect phosphorus loading by smoothing out the variability due to time of year or other factors.

Ultimately, it was felt by the workgroup that tracking phosphorous and nitrogen as separate metrics would be useful, substituting the separated metrics of the IJC for the combined Nitrogen and Phosphorous metric of SOGL.





### 5.1.7 Fish Species of Interest

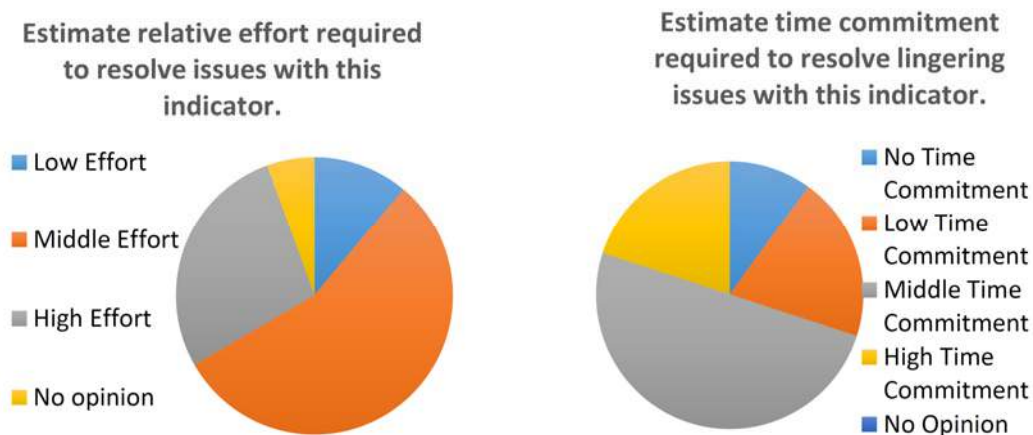
The “Fish Species of Interest” indicator is broadly similar to the existing indicators in the SOGL suite. Attendees recommended that it was important to include a few new elements in the SOGL indicator suite to ensure that multiple fish species were being tracked separately instead of as a single indicator.

The attendees also specified that it was essential to include nearshore predators in the indicator measures, as the IJC indicator does, because nearshore predators show some of the fastest response times to environmental perturbations. Lastly, the attendees felt that including measures of natural and artificial recruitment were necessary to assess the integrity of Great Lakes fish species.



### 5.1.8 Illness Risk at Great Lakes Beaches

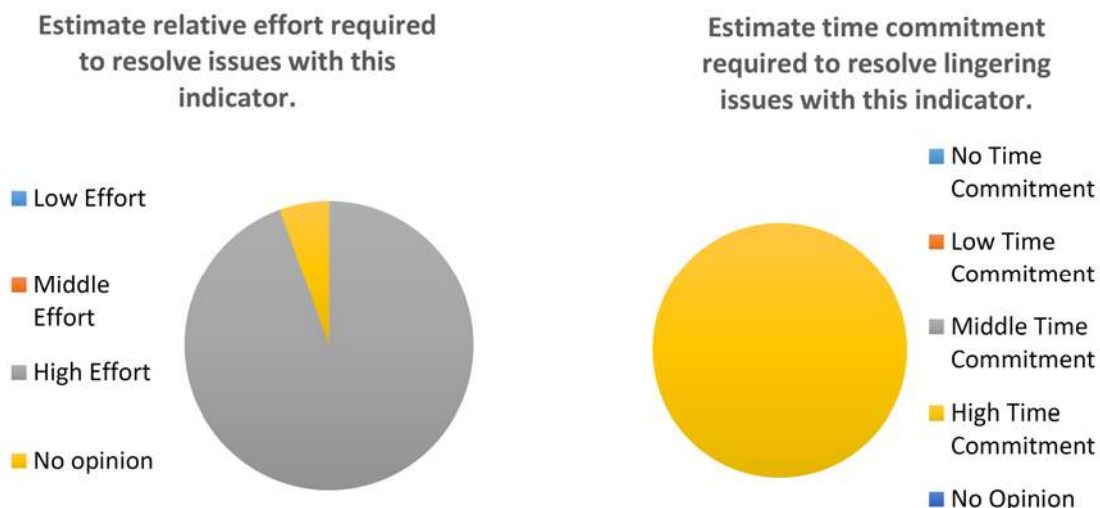
The workgroup felt that it would be important to add this indicator to the SOGL indicator suite, primarily because its metric (95<sup>th</sup> percentile E. coli measurements at Great Lakes beaches) captures elements of human health in the Great Lakes that are currently going unassessed. The current SOGL measure relies on beach closures as a measure of beach health instead of using a better surrogate for measuring health risks. The workshop attendees pointed out that beach closures can occur for any number of reasons, such as regular maintenance to undertows to algal blooms. To this end, the IJC measure of colony forming E. coli was felt to be a more effective measure of illness risk, even though it, too, is not directly measuring a pathogen.





### 5.1.9 Contaminants in Groundwater

The “Contaminants in groundwater” indicator was evaluated by attendees and deemed to be a high value indicator. The indicator appears in both the SOGL and IJC suites, but the IJC dataset further defined the types of contaminants monitored. Thus, until the SOGL report fully defines the indicator, the attendees recommended the IJC indicator be included.



### 5.1.10 Sources of Risks at Great Lakes Beaches

The workgroup also considered the indicator “Sources of Risks at Great Lakes Beaches,” a measure that attempted to assess what the specific sources of beach impairments is present across the Great Lakes. The workgroup’s consensus was that, while this would be information with potential utility, it seemed to be difficult to obtain with certainty, and would require a tremendous investment of time and resources to produce a functional dataset. The indicator focused on E. coli which may not leave a unique enough signature to be traceable to its source. As such, the workgroup did not recommend this indicator for inclusion in the final suite.



## 5.2 GAPS ANALYSES AND FINAL LIST OF INDICATORS

After reviewing all indicators lacking data, the workgroup felt that two indicators (Abundance and distribution of fish-eating and colonial nesting birds, and Contaminants in Great Lakes edible fish), were adequately addressed and monitored despite imperfect data availability. The workgroup did not discuss any improvements to these indicators.

Workshop attendees agreed that the following SOGL indicators did not fully assess the objectives of the GLWQA:

- Assessment of the quality of drinking water sources in the Great Lakes (pursuant to Objective 1)
- Assessment of recreational impairments in the Great Lakes (pursuant to Objective 2)
- Assessment of the integrity of the food web in the Great Lakes (pursuant to Objective 5)
- Assessment of non-wetland shoreline habitats in the Great Lakes (pursuant to Objective 5)
- Assessment of nutrients in the Great Lakes (pursuant to Objective 6)
- Assessment of the current status of invasive species in the Great Lakes (pursuant to Objective 7).

To address these gaps, the attendees agreed to the inclusion of the following indicators and metrics in order to more fully monitor progress towards the GLWQA:

- Chemical integrity of source water and biological integrity of source water (Objective 1)
- Illness risk at Great Lakes beaches (Objective 2)
- Nearshore predators (Objective 5)
- Undefined Biological shoreline metric (Objective 5)
- Nutrients in lakes (open water) (Objective 6)
- Plankton, Asian Carps, Round Goby, and Ruffe (Objective 7)

The attendees also suggested modifications to the following SOGL metrics:

- Harmful and Nuisance Algae
- AIS
- Food web (Benthos (nearshore), Mysis, Lake Trout, Walleye, Lake Sturgeon)
- Contaminants in groundwater

The modifications to the SOGL metrics are detailed in Table 5-2. The modifications are meant to enhance the legibility of data (as in the case of modifications to the reporting regime for Aquatic Invasive Species), or ensure that the metric is being fully assessed (as in the case of Lake Trout where it is suggested that natural and artificial recruitment for the population be considered).

Based on the workshop's discussions, a final list of indicators was then put together and is presented in Table 5-2. Indicators highlighted in **RED** are IJC indicators that have been suggested for inclusion in the SOGL suite. Indicators in **BLACK** are SOGL indicators. Metrics with **RED** text have been modified under the advisement of the workgroup.

**Table 5-2: Final list of SOGL and IJC indicators** (*red font indicating changes recommended in the workshop*)

GLWQA GENERAL OBJECTIVES	HIGH LEVEL-INDICATORS	SUGGESTED INDICATORS	SUGGESTED METRICS
<b>Objective 1:</b> Be a source of safe, high-quality drinking water	HUMAN HEALTH	Treated Drinking Water	
		Biological Hazards of Source Water	E. coli
			Nitrate
			Turbidity
		Chemical Integrity of Source Water	Atrazine
			Estrogenicity
			Cyanotoxins
<b>Objective 2:</b> Allow for swimming and other recreational use, unrestricted by environmental quality concerns	HUMAN HEALTH	Beach Advisories	Percentage of Great Lakes beach season days that are monitored by beach safety programs and are open and safe for swimming
		Illness Risk at GL Beaches	95th % # of E. coli/colony-forming units of E. coli per 100 ml, suggested measures include viruses and phages
<b>Objective 3:</b> Allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants		Contaminants in Edible Fish	Concentrations of contaminants of concern (e.g., polychlorinated biphenyls (PCBs), mercury) in fish fillet species, most consumed by Great Lakes basin citizens
<b>Objective 4:</b> 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	TOXIC CHEMICALS	Toxic Chemicals in Great Lakes Whole Fish (Lake Trout/Walleye)	Contaminant levels in whole fish from the five Great Lakes, legacy compounds (e.g., PCBs), compounds that are in current or recent use (e.g., polybrominated diphenyl ethers (PBDEs)), as well as results of surveillance activities for chemicals of emerging concern
		Toxic Chemicals in Great Lakes Herring Gull Eggs	Annual concentrations of PCBs; dioxins and furans; organochlorine pesticides, such as Dichlorodiphenyltrichloroethane (DDT) and related metabolites; other organic contaminants; and, trace metals including mercury in herring gull ( <i>Larus argentatus</i> ) eggs from 15 Environment Canada's Great Lakes Herring Gull Monitoring Program (GLHGMP) sites throughout the Great Lakes (U.S. and Canada)
		Toxic Chemical Concentrations (Open Water)	Organochlorine pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, chlorobenzenes, polybrominated diphenyl ethers, metals, current use pesticides, and other compounds of mutual concern for Annex 3 of the GLWQA
		Toxic Chemicals in Sediment	The chemicals that will be assessed may include HCB, PCBs, DDT, dioxins, lead, and mercury, as well as PBDEs, non-brominated flame retardants, and chlorinated paraffins

GLWQA GENERAL OBJECTIVES	HIGH LEVEL-INDICATORS	SUGGESTED INDICATORS	SUGGESTED METRICS
		Atmospheric Deposition of Toxic Chemicals	Lead and mercury, as well as PBDEs, non-brominated flame retardants, and chlorinated paraffins
		Water Quality in Tributaries	
		Fish Eating and Colonial Nesting Waterbirds	Eleven focal species of colonial waterbirds breed at sites (predominantly islands) distributed across all of the Great Lakes: Herring, Ring-billed and Great Black-backed gulls, Caspian, Common, Forster's and Black terns, Great Blue Herons, Great Egrets, Black-crowned Night-Herons and Double-crested Cormorant
			Nest counts of colonial waterbird species across all water bodies and connecting channels - Annual and 10-year
<b>Objective 5:</b> Support healthy and productive wetlands and other habitats to sustain resilient populations of native species	HABITATS & SPECIES	Coastal Wetland Invertebrates	Relative abundance of sensitive taxa (e.g., mayflies, caddisflies), tolerant taxa (e.g. Chironomina as a proportion of total Chironomidae abundance, Isopoda), richness of specific taxa, and functional feeding groups (e.g., herbivores, detritivores, carnivores)
		Coastal Wetland Fish	Index of Biotic Integrity
		Coastal Wetland Plants	Presence, abundance, and diversity of aquatic macrophytes
		Coastal Wetland Amphibians	Measures of composition and relative abundance of calling frogs and toads
		Coastal Wetland Birds	Composition and relative abundance of wetland breeding birds
		Coastal Wetlands: Extent and Composition	Areal extent of coastal wetlands by hydrogeomorphic type in a five-year period; data from Landsat-8, Sentinel-2, and L-band SAR data from Japan's PALSAR-2 and Argentina's SaoCom (to be launched in early 2016) will allow for an approximate five-year update
		Hardened Shorelines	Ratio of human-modified shoreline to the total shoreline, in kilometers
		Undefined Biological Shoreline Indicator	Should include non-wetland ecosystem quality
		SAI-Combined Physical and Biological Index	
	FOOD WEB	Phytoplankton (Open Water)	Biovolume and density of phytoplankton and taxonomic composition for spring and late summer
		Zooplankton (Open Water)	Offshore zooplankton index is overall areal biomass (g dry weight/m2)
		Benthos (open water)	Oligochaete Trophic Index
		Benthos (nearshore)	
		Mysis	Biomass
		Diporeia (Open Water)	Density (number/m2) of Diporeia in cold, deep-water habitats of the Great Lakes

GLWQA GENERAL OBJECTIVES	HIGH LEVEL-INDICATORS	SUGGESTED INDICATORS	SUGGESTED METRICS
		Preyfish (Open Water)	Two-time series including: 1) the prey fish community diversity as quantified by the Shannon diversity index, and 2) the proportion of native prey fish in the total prey fish catch; <b>natural and artificial recruitment</b>
		Lake Trout	Absolute abundance, relative abundance, harvest, and self-sustainability through natural reproduction; <b>natural and artificial recruitment</b>
		Walleye	Abundance, spawner biomass, recruitment, age/length at maturity, and fishery performance (effort, catch rate, yield); <b>natural and artificial recruitment</b>
		Lake Sturgeon	Standardized scoring of lake-specific adult abundance, juvenile abundance, and number of self-sustaining populations for lake sturgeon; <b>natural and artificial recruitment</b>
		Nearshore Predators	<b>Natural and artificial recruitment</b> and abundance of northern pike, yellow perch, or smallmouth/largemouth bass
<b>Objective 6:</b> Be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts 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 & NUISANCE ALGAE	Nutrients in Lakes (Open Water)	Nitrates (NO3) concentrations in the Waters of GL suggested metrics include other nitrogen species
			<b>In Lake TP and DRP concentrations</b>
			<b>TP and DRP loading from Tribs (suggested measurements include flow weighted means in part to account for seasonal variability.</b>
		Algal Blooms	<b>Harmful Algal Blooms</b>
			<b>Nuisance Pelagic Algal Bloom</b>
			<b>Excessive Benthic Algal Abundance</b>
		Cladophora	Biomass of Cladophora in grams dry weight (DW)/m2; no regular measurements of biomass by provinces, states, or federal government; lack of systematic surveys
<b>Objective 7:</b> 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	INVASIVE SPECIES	Aquatic Invasive Species	Cumulative number of AIS established in the Great Lakes basin; rate of new AIS found in GL or annual numeric reduction in established AIS
		Plankton	
		Asian Carps	
		Round Goby	
		Ruffe	
		Sea Lamprey	Indices of adult sea lamprey abundance (sum of spawning run estimates for a subset of streams in a given lake basin. The numbers of adult sea lampreys migrating into each index stream are estimated with traps using

GLWQA GENERAL OBJECTIVES	HIGH LEVEL-INDICATORS	SUGGESTED INDICATORS	SUGGESTED METRICS
			mark/recapture estimates. Indices of adult sea lamprey abundance are updated on an annual basis
		Dreissenid Mussels	Dreissenid abundances, biomass, size-frequency distributions, and length-weight relationships
		Terrestrial Invasive Species	
<b>Objective 8:</b> Be free from the harmful impact of contaminated groundwater	GROUND WATER	Contaminants in Groundwater	Measure >10 chemicals from agriculture and urban watersheds <u>More definition needed</u>
<b>Objective 9:</b> 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	CLIMATE CHANGE	Water Levels	Long-term water level variability timing of seasonal water level maximum and minimum, and magnitude of seasonal rise and decline lake-to-lake water level difference
		Surface Water Temperature	Annual summer (July-September) surface average temperature for each; first date at which water temperatures warm/cool to the natural marker of 4°C.
		Ice Cover	Annual maximum and average ice concentrations of the Great Lakes
		Precipitation Events	
		Baseflow Due to Groundwater	Measure long term average baseflow relative to total stream flow, referred to as the Baseflow Index; index is a dimensionless value between 0 and 1
	TRANSFORMING WATERSHEDS	Watershed Stressors	Use a combined agriculture and development stress index (AgDev) to calculate scores for individual Great Lakes watersheds using a consistent scale among reporting periods
		Forest Cover	Measure, using remote sensing, the forest cover percentage changed over time within Great Lakes watersheds, and the forest cover percentage changed over time within riparian zones by watershed
		Land Cover	Measure areal coverage (km <sup>2</sup> ) of various types of land cover and the percent changed over time relative to a benchmark set in 2000 (should measure remediation actions)
		Tributary Flashiness	Richards-Baker Flashiness Index (R-B Index)
		Habitat Connectivity	Count the number of dams/barriers in the Great Lakes basin, number of fish, and restoration/mitigation projects, and measure the length of the river to the first dam
		Human Population	Calculate percentage change for total human population using Canadian and U.S. census data and intercensal data

### **5.3 ADDITIONAL MONITORING SUGGESTIONS FOR FUTURE INCLUSION**

Lastly, workshop attendees recommended the following topics should be considered for future inclusion as they merit further discussion either as potential indicators or as potential metrics. They are conceptual in nature, and are presented here to illustrate both the scope of the conversations as well as general areas that may not be being monitored fully with the proposed indicator suite:

- Septic system monitoring
- Spiny water flea
- Phragmites
- Bacterial community biomass
- Harmful impacts of invasive species
- Positive impacts of best management practices
- Tributary habitat quality
- Nearshore phosphorus
- Agricultural impairments

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