A WORK GROUP REPORT
TO THE INTERNATIONAL JOINT COMMISSION

TECHNICAL REPORT ON ECOSYSTEM INDICATORS

ASSESSMENT OF PROGRESS TOWARDS RESTORING THE GREAT LAKES

GREAT LAKES WATER QUALITY AGREEMENT

2012-2015 PRIORITY CYCLE

July 2013

FINAL

CONTENTS

EXECUTIVE SUMMARY

How are the Great Lakes doing and what progress are we making in protecting and restoring them? These are two of the most frequently asked questions about the largest source of surface fresh water in the world. Unfortunately, we do not have simple answers for them. With the tremendous efforts and resources invested in restoration by governments, the private sector, and non-profit organizations in the United States and Canada over the past 40 years, we need to be able to respond much more clearly and definitively in the future.

Recognizing this, the International Joint Commission (IJC) through its Science Advisory Board and Water Quality Board initiated a project to put the Great Lakes community in a position to respond. The focus of the work is to identify a limited number of ecosystem indicators especially important to the health of the Great Lakes basin ecosystem and which tell us the most about it. Extensive work has been done over the years to measure the condition of the Lakes as part of the State of the Lakes Ecosystem Conference (SOLEC), and this work will form the basis for many of the indicators. What is being done now is selecting “the fewest that tell us the most.”

The need for key indicators is even greater now with a new Great Lakes Water Quality Agreement (the Agreement) between the United States and Canada. The two countries have determined that we should be able to drink the water, eat the fish, and swim at the beaches. To assess progress toward these goals and the overall condition of the Lakes, the indicators presented in this report are aligned with the chemical, physical and biological integrity framework included in the Agreement. The focus here is on ecological indicators. Indicators for public health will be covered in a separate, but related, report.

INTRODUCTION

The Great Lakes Water Quality Agreement as amended in 1987 (the Agreement) commits the governments of the United States and Canada to restoring and maintaining the chemical, physical, and biological integrity of the waters of Great Lakes Basin Ecosystem. Also, under the Agreement, the governments are responsible for reporting every two years to the International Joint Commission on progress made towards fulfilling the General and Specific Objectives of the Agreement.

With the renewal in September 2012 of the Great Lakes Water Quality Agreement, the Commission has seized upon the occasion to renew its commitment to report to the Parties and to the State and Provincial Governments on progress toward the achievement of the General and Specific Objectives, including, as appropriate, matters related to Annexes of renewed Agreement. The Commission also intends to include in the report an assessment of the effectiveness of the programs and other measures undertaken pursuant to the Agreement and to provide advice and recommendations. However, the Commission acknowledges that such reporting has been hindered by the absence of a set of core indicators that are consistently monitored over time. Therefore, a key priority is the selection, further development, and reporting of indicators to aid the Commission in assessing and reporting on the health of the Great Lakes. This is specifically contemplated in the renewed Agreement where the parties commit to establish and maintain comprehensive, science-based ecosystem indicators.

OBJECTIVES

In January, 2012, the Commission identified the Assessment of Progress and Evaluation of Great Lakes Programs and Monitoring as a Priority to be undertaken by its Great Lakes Advisory Boards during the 2012-2015 Priority Cycle. Five separate projects were identified under this priority, and the desired outcomes at the end of the three-year cycle include:

- Selection of a short list of indicators to report progress against Agreement objectives
- An understanding of the monitoring capabilities to track the selected indicators
- Development of a report that will serve as a framework for assessing progress towards achieving objectives
- Designing of a framework for assessing the effectiveness of the programs and other measures undertaken pursuant to the renewed Agreement
- For new indicators, undertake case studies to test or validate the indicators and methods, as appropriate
- Influence the Parties with respect to the data they are collecting and providing to the Commission to facilitate the Commission's fulfillment of its core mandate to assess progress and the effectiveness of programs

As the first step, the Commission established a multi-Board Work Group (Appendix A) to develop a short list set of 10-30 core indicators that assess the integrity of the Great Lakes ecosystem. Further, the Commission suggested that many of these core indicators should have historical data, some should address the nearshore, a few should reflect human health conditions, and at least one should address atmospheric deposition. To assess progress made towards achieving General, Specific, and Annex objectives, a minimum of three types of status and trends indicators are needed, i.e. physical, chemical and biological. The initial focus of the Work Group was on the identification of these environmental indicators. A separate project (Project 2) is also underway to develop a set of human health indicators, as requested by the Commission, and will be reported on separately.

Because a vast amount of work has been done on the selection and monitoring of various indicators, this work was collected and synthesized. Accordingly, a work plan was developed by the Work Group on Environmental Indicators that encompassed the following activities:

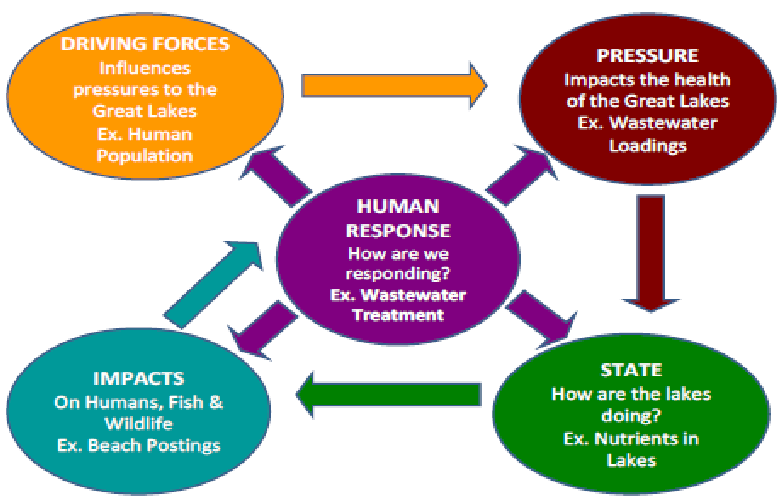
- Literature search and collection of documents
- Review of various national and international programs for assessing ecosystem health (Appendix B)
- Review of government programs and criteria used for selection of indicators (Appendix C)
- Development of an inventory of indicators used by the various programs (Appendix D)

The findings from these activities served as the foundation for an expert consultation held in Windsor, Ontario, on September 5-7, 2012. The workshop, which invited various stakeholders and experts on indicator development, was held with the primary objective of establishing a concise list of core environmental indicators. The Work Group's advice and recommended set of environmental indicators described in this report reflects the culmination of these activities.

ELEMENTS OF INDICATOR SELECTION

The context and geographic framework for the selection of environmental indicators is defined by the renewed Agreement. Ecosystem objectives retained in the renewed Agreement are to "restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." The geographic scope of the Agreement includes the basin of the five lakes, connecting channels, and the international section of the St Lawrence River.

Much work has been done by State of the Lakes Ecosystem Conference (SOLEC) in evaluating and refining the organizational and conceptual frameworks for indicator selection. The Work Group on Environmental Indicators reviewed this information and agreed to adopt and endorse the same DPSIR (Driving forces, Pressure, State, Impact, and Response) Framework that has been recently implemented by SOLEC.



The DPSIR framework is an underlying tool to aid in the selection, organization, and reporting on indicators, which allows decision makers to understand the linkages between the conditions of the ecosystem, pressures on the ecosystem, and how human activities are related. The Work Group further recommended that for the purposes of this project and expert consultation workshop, that priority be given to state and possibly Impact indicators which define the chemical, physical, and biological integrity of the Great Lakes ecosystem.

The Work Group also conducted a review of criteria used for the selection of environmental indicators by various national and international programs, and agreed upon a set of criteria to be used by the expert consultation workshop in selecting a core set of indicators. The criteria are divided among four "themes", including usefulness, data quality, availability, and practicality. The final criteria adopted by the Work Group are provided in Appendix E.

EXPERT CONSULTATION

An expert consultation workshop was held in Windsor, Ontario on September 5-7, 2012. The principle objective of the workshop was to develop a concise set of core environmental indicators. Participants at the workshop (Appendix F) included scientists with expertise in various disciplines and a diversity of affiliations. A summary of the diversity represented at the workshop is presented in the following tables:

Area of Expertise	Canadian	United States	Total
Biological	5	10	15
Biological – Human Health	1	1	2
Chemical	5	3	8
Physical	2	6	8
General	3	12	14

Affiliation	Canadian	United States	Total
Academia	4	8	12
Government	9	10	19
Industry/Consultant	1	5	6
NGO	1	6	7
First Nation/Tribal		3	3

Prior to the workshop the participants were requested to read a series of selected documents on environmental indicators (Appendix B). They were also asked to complete a pre-workshop assignment (Appendix G) by developing a preliminary list of potential indicators. Over 75% of the participants completed the assignment; the findings were compiled and used as the basis for discussions at the workshop (Appendix H).

During the workshop, plenary sessions were held on the opening day. On subsequent days, a combination of plenary and breakout sessions were held to discuss chemical, physical, and biological indicators. Final consensus on the selection and initial prioritization of the environmental indicators was reached in plenary.

WORKSHOP FINDINGS

The workshop participants reached consensus on 22 environmental indicators which addressed the chemical (6), physical (6), and biological (10) integrity of the Great Lakes ecosystem. Analysis of the selected indicators relative to the agreed criteria for indicator selection indicates that most of them met most of the criteria. Further, comparison of the selected indicators with the DPSIR framework suggested that the majority fall in the categories of State or Impact indicators. A more detailed analysis is presented in Appendix I.

During the workshop, a voting process was used to further prioritize the indicators in an attempt to identify the "top" core indicators. The results, in order of priority with number of votes, are presented in the table below.

	Top Priority Indicators	**Votes**
1.	**Nutrient Concentrations and Loadings** a) Phosphorus (Total and SRP) offshore and nearshore concentrations in lake b) Phosphorus loads (Total and SRP) to the lakes	31
2.	**Fish Species of Interest** • Condition, population, and natural reproduction of fish species of interest (e.g., sturgeon, walleye, lake trout, potentially other top predators)	28
3.	**Harmful Algae** • Extent, duration, frequency	14
4.	**Nuisance Algae** • Extent, duration, frequency, density	13
5.	**Lower food web productivity/health** a) Phytoplankton community structure and biomass b) Benthos abundance and diversity c) Preyfish abundance and diversity	26
6.	**Coastal Wetlands** • Extent, composition/quality	25
7.	**PBTs in Biota** a) PBTs in whole fish (sport or forage fish?) b) PBTs in fish-eating birds (herring gull, bald eagle, cormorant, tern)	25
8.	**Aquatic Invasive Species** • Status of aquatic invasive species (presence, number, and distribution)	25
9.	**Tributary Physical Integrity** a) Tributary connectivity b) Index of hydrologic alteration (including groundwater quantity) c) Sediment delivery	21
10.	**Land cover and conversion index**	18
	Medium Priority Indicators	**Votes**
11.	**Abundance and distribution of fish-eating and colonial nesting birds** a) Eagle, osprey, herons; b) Should enable assessment of chemical effects as well as ecological	10
12.	**Chemicals of mutual concern in water** • Concentrations of water soluble chemicals of mutual concern (e.g., PPCP)	10
13.	**Coastal habitat** • Percentage of hardened shoreline and type of armoring	8
14.	**Water Level** • Min/max, seasonable variability, change from historic record	9
15.	**Water Temperature** • Surface water temperature; min/max, seasonal variability; timing of onset of thermal stratification; ice extent and duration	7
16.	**Air deposition**	7

	• Net atmospheric deposition of toxics (mercury, sulfur, nitrogen?)	
17.	**New invasive species**: (number, rate) a) Invasive species introductions (number, rate) b) Existing high-risk invasive species status (presence, distribution)	7
	Low Priority Indicators	**Votes**
18.	**Water Chemistry** • Lakewide average concentrations of chloride and other major ions	3
19.	**Wetland fish index**	1
20.	**Wetland bird index**	1
21.	**Groundwater quality**	0
22.	**Biodiversity status report** • Extracts information from other physical and biological indicators already established	0

ECOSYSTEM INDICATORS

The primary objective of the Work Group was to develop a short list of core indicators that can be used to characterize the condition of the resource and the progress in protecting, restoring, and conserving it. In order to meet this objective following the workshop, the Work Group agreed to combine harmful and nuisance algae into a single indicator, combine the two related invasive species indicators into one, and to include the wetland bird and fish indices with the other wetland related indicators. By making these adjustments, and with the inclusion of the Groundwater indicator, the resulting set of 16 environmental indicators addresses the General and Specific Objectives of the Revised Great Lakes Water Quality Agreement. These indicators are briefly discussed below, and focus on the state of the lakes and impacts from many sources. More detailed descriptions of each of the 16 environmental indicators are found at the end of this report.

Chemical

Long-standing concerns over chemical loadings to the Great Lakes have been a major part of the WQA from the beginning. The list of chemicals of interest has grown, and they continue to be a major concern. The chemical indicators include nutrients, with a primary focus on phosphorus as a driver of eutrophication, PBTs in biota, chemicals of mutual concern in water, and the atmospheric loadings of chemicals of mutual concern.

i. Phosphorus - This indicator includes phosphorus loadings and concentrations in each of the Great Lakes. Both total phosphorus (TP) and dissolved reactive phosphorus (DRP) are important. The primary concern is human-induced eutrophication, the difficult problem that still has not been brought under control especially in Lake Erie. Excess phosphorus causes excessive growth of algae, which die and are decomposed by bacteria which in turn consume dissolved oxygen at depth, killing fish and other organisms. Blooms of blue-green algae (cyanobacteria) can produce hazardous toxins which have been known to kill birds and dogs, and are toxic to people as well. Excess nutrients also disrupt the normal flow of energy in the ecosystem, favoring unwanted species.

ii. Persistent Bioaccumulative Toxic (PBTs) Chemicals in Biota - The PBTs in biota indicator includes the concentration of persistent, bio-accumulating and toxic substances in whole fish and fish-eating birds. The PBT chemicals are identified as an indicator as they pose a danger to humans and wildlife that consume fish containing these chemicals.

iii. Chemicals of Mutual Concern (CMC) in Water – This indicator addresses the concentration in water of selected legacy toxic chemicals as well as chemicals of emerging concern selected by the Great Lakes Executive Committee in accordance with Annex 3 of the renewed Water Quality Agreement. The indicator of chemicals of mutual concern in water captures a wider set of chemicals, including some that are more water soluble than PBTs. The major concerns regarding chemical pollution are the inputs, concentrations, and exposures. Regarding the latter, the concern focuses on the adverse effects, such as impaired reproduction in fish or in fish-eating wildlife.

iv. Atmospheric Deposition of Chemicals of Mutual Concern (CMCs) - This indicator is the presence of toxic chemicals and other chemicals of concern in the atmosphere and precipitation of the Great Lakes region. These are important because of potential impacts of CMCs, including PBTs, via atmospheric deposition on the Great Lakes aquatic ecosystem.

v. Groundwater Quality and Quantity -This indicator includes the quality and quantity of the groundwater in the Great Lakes region, and its interaction with the surface water in the Great Lakes basin. Groundwater is an important component of the hydrologic cycle in the Great Lakes basin and, therefore, groundwater quality, quantity, and its interface with surface water is an important factor in determining the overall quality and quantity of water in the Lakes. It is important to the broader ecosystems in the Great Lakes region because it is, in effect, a large, subsurface reservoir from which water is released slowly to provide high quality, reliable flow of water to streams, lakes, and wetlands.

Physical

Physical integrity of the Great Lakes includes land cover, shoreline habitats, including wetlands, and tributaries that are most directly affected by human activity and are critical to wildlife and to humans. Physical integrity also encompasses such basic elements as the amount of water contained, as indicated by water level, and its temperature. Duration of ice-cover is related to temperature, and is an important factor in determining the effects of climate change on lake levels.

vi. Land Cover - This is an indicator of the rate and extent of change to, and the fragmentation of, natural land cover. The amount, rate, and pattern of change is important because as natural land cover is managed or changed to agriculture or urban use, the products and services provided by those cover types such as water storage and purification, wildlife habitat, carbon storage, recreation, and aesthetic beauty are diminished or lost.

vii. Tributary Physical Integrity - This is an indicator of the changes in stream flow as a result of changes in land use and climate, and of the connectivity of the tributaries to the lakes. It is important because the frequency, magnitude, and rapidity of short term changes in stream flow affect stream organisms and the transport of sediments. Connectivity is important to the organisms that use the streams as habitat for all or part of their life cycle.

viii. Coastal Wetlands - The coastal wetland indicator is a measure of the extent, composition and quality of wetlands greater than 4 hectares in size that have a direct surface water connection to the lakes. They are important because of the numerous important ecosystem functions they perform.

ix. Shoreline Integrity – Shoreline integrity is a measure of protected shoreline length that is physically and biologically unfavorable relative to the shoreline length that is favorable. Physical modifications to the shoreline have disrupted coastal and near shore processes, flow and littoral circulatory patterns, altered or eliminated connectivity to coastal wetlands/dunes, and have altered near shore and coastal habitat structure, all resulting in negative effects on the biological integrity of the lakes.

x. Water Levels - This indicator is the level for each of the five Great Lakes above sea level. Lake levels are important because they have a major influence on coastal wetlands, near shore land, and lake water quality, especially nutrient concentrations. They also affect commercial and recreational navigation, drinking water intakes, and shoreline erosion. Low levels can necessitate dredging, which may have adverse side effects.

xi. Surface Water Temperature and Ice Cover – The water temperature and the winter ice cover indicator include the surface temperature of the water and the extent, duration, and thickness of the ice on the lakes. The temperature and cover are important because they affect the wintertime evaporation from the lakes and can lead to more and earlier algae blooms, greater exposure of the shoreline to waves generated by winter storms that accelerate erosion, acceleration of the spread of some invasive species, and increased - turbidity that necessitates more water treatment for household use.

Biological

In considering the water quality of the Great Lakes, the biological conditions indicate the natural state of the lakes and their ability to provide important ecosystem services valued by the populations around the Lakes. Although some of the issues such as excessive algae and fish kills were thought to have been eliminated or reduced through earlier actions like reductions in phosphorus loading, their re-emergence indicates new ways in which various stressors impact these ecosystems. The biological indicators include the status of existing aquatic invasive species and the rate of additional species becoming established, the magnitude and frequency of harmful and nuisance algae blooms associated with levels of nutrients, fish and bird population abundance and distribution, habitat alterations on tributary connectivity and coastal wetlands, productivity of the lower food web and related fish species of interest and fish eating colonial birds, and the population stability of various biota as indicated by their underlying PBTs tissue loads.

xii. Lower Food Web Productivity and Health – This indicator includes phytoplankton community structure and biomass, benthos abundance and diversity, and prey fish abundance and diversity. The significance of the indicator is how it shows the current state and efficiency of the food web at transferring material and energy to fish at the top of the food chain.

xiii. Fish Species of Interest – The indicator is the populations of Lake Trout, Walleye, Lake Whitefish, Sturgeon, and Northern Pike in the Great Lakes. This is important because of their value for commercial, recreational, and aboriginal fisheries and to infer health of the ecosystem from the health of species at the top of the aquatic food chain.

xiv. Harmful and Nuisance Algae - This indicator includes those species of harmful algae with the potential to produce toxins that affect human health, as well as health of livestock, pets, and wildlife. Nuisance algae are a broader subset of algae that form- blooms which are not toxic to humans but which cause ecological and socioeconomic harm. Both forms of algae are important because of the damage they cause to the Great Lakes.

xv. Aquatic Invasive Species - This indicator is the status and impact of those aquatic invasive species present in the Great Lakes having detrimental effects to the ecosystem. It specifically excludes species that are benign or perceived to be desirable species. This indicator is important because it measures the extent to which Great Lakes are populated by detrimental invasive species and their negative impact. This indicator also includes the rate of new introductions because this assesses the efficacy of measures to curb the arrival of AIS.

xvi. Abundance and Distribution of Fish-Eating and Colonial Nesting Birds - This indicator includes herring gulls and bald eagles because of their position at the top of the Great Lakes aquatic food web. The health of these birds and their ability to reproduce are important because they indicate the effects of chemical, physical, and ecological stressors within the Great Lakes ecosystem.

These 16 chemical, physical, and biological indicators represent a consensus among Great Lakes scientific, technical, policy, and other experts as to which ones tell us the most about the ecological condition of the resource and the progress being made in protection and restoration.

ALIGNMENT WITH THE GREAT LAKES WATER QUALITY AGREEMENT

For the indicators to have the most value, they must be ones that will help measure progress toward achieving the General and Specific objectives of the WQA. In order to assess alignment, the environmental indicators were compared with both sets of objectives and the Annexes. The findings are presented below.

GENERAL OBJECTIVES The Waters of the Great Lakes should:		**ALIGNMENT CHECK**
(i)	be a source of safe, high-quality drinking water;	To Be Addressed in Project 2 (Health Professionals Advisory Board)
(ii)	allow for swimming and other recreational use, unrestricted by environmental quality concerns;	Addressed in Project 2 (HPAB)
(iii)	allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants;	PBTs in Biota Also Addressed in Project 2 (HPAB)
(iv)	be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain;	Chemicals of Mutual Concern • PBTs in Biota • Chemicals of Mutual Concern in Water • Atmospheric Deposition Also Addressed in Project 2 (HPAB)
(v)	support healthy and productive wetlands and other habitats to sustain resilient populations of native species;	Coastal Wetlands • Extent of coastal wetlands • Composition/quality of wetlands
(vi)	be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health, or human use of the ecosystem;	Algae • Nutrient concentrations and loadings • Harmful algae • Nuisance algae
(vii)	be free from the introduction and spread of aquatic invasive species and free from the introduction and spread of terrestrial invasive species that adversely impact the quality of the Waters of the Great Lakes;	Aquatic Invasive Species • Status (presence, number, distribution) • New Species (number, rate)

(viii)	be free from the harmful impact of contaminated groundwater; and	Groundwater
(ix)	be free from other substances, materials or conditions that may negatively impact the chemical, physical or biological integrity of the Waters of the Great Lakes;	Chemical substances are addressed; Conditions addressed by water level and temperature

	ANNEXES	**ALIGNMENT CHECK**
1.	Areas of Concern	Indicators specifically related to Beneficial Use Impairments
2.	Lakewide Management	Provides indicators relevant to defining status and tracking progress lake by lake
3.	Chemicals of Mutual Concern	Chemicals of Mutual Concern • PBTs in Biota • CMCs in Water • Atmospheric Deposition
4.	Nutrients	Algae • Nutrient concentrations and loadings • Harmful algae • Nuisance algae
5.	Discharges from Vessels	PARTIAL GAP • Invasive Species and • Chemicals of Mutual Concern are addressed
6.	Aquatic Invasive Species	Invasive Species • Status of Existing (presence, number, distribution) • New Species (number, rate)
7.	Habitat and Species	Indicators address the following attributes • Abundance/Distribution of Birds • Coastal Wetlands Extent/Quality/Composition • Coastal habitat • Fish Species of Interest • Land Cover and Habitat • Lower Food Web (offshore) Productivity/Health • Tributary Physical Integrity/Health
8.	Groundwater	Groundwater
9.	Climate Change Impacts	• Water Level and • Water Temperature
10.	Science D. Ecosystem Indicators	Addressed as above

Clearly, the selected indicators closely align with the objectives of the WQA and will serve as excellent measures for progress in the future.

DISCUSSION AND RECOMMENDATIONS

Using the Core Environmental Indicators for Communicating Ecological Integrity of the Great Lakes

In order to assist the Commission with assessing and reporting on the environmental health of the Great Lakes, several groupings of the indicators into a series of key themes or stories for communication with the public have been discussed. For example, one suggested approach would be to group the indicators according to key issues of public concern in the lakes:

- Nutrient Concentrations and Impacts (Indicator 1,3,4)
- Ecological Integrity (Indicators 2,3,4,5,6,11,13,17)
- Invasive Species (Indicator 17)
- Nearshore, and Land-Margin (Indicators 4,6,9,10,13)
- Water Quality, Toxic Chemicals and Impacts (Indicators 1,2,7,11,12,16)

Another suggestion was to group the indicators by "key themes"

- Land Cover and Habitat (Indicators 6,9,10,13)
- Tributary Health (Indicators 9,10)
- Coastal Wetland Health (Indicators 6,9,11,13,14)
- Algae (1,3,4)
- Chemicals of Mutual Concern (7,12,16)
- Offshore Health/Productivity of the Lakes (1,2,3,5)
- Invasive Species (17)

The Work Group recommends adopting a framework consistent with that around which we organized the expert consultation workshop, i.e., communicating the status of efforts to restore and maintain Chemical, Physical, and Biological Integrity of the Great Lakes basin. However, we recognize that other schemes are possible and may be desired depending on the message and the audience.

Chemical Integrity encompasses various attributes related to water quality. Long-standing concerns over chemical loadings to the Great Lakes were the impetus for the first Great Lakes Water Quality Agreement, and while the list of chemicals of interest has grown, they continue to be of major concern. The chemical indicators include nutrients (with a primary focus on phosphorus as a driver of eutrophication), PBTs in biota, and chemicals of mutual concern in water, and the atmospheric loadings of both PBTs and chemicals of mutual concern.

These indicators provide a view of the two major concerns with chemical pollution. The first is human-induced eutrophication, the devilish problem that still has not been brought under control in our Great Lakes (especially Lake Erie). Excess phosphorus causes algal blooms, which die and are decomposed by bacteria which in turn consume dissolved oxygen at depth. In some cases, the algal blooms produce hazardous toxins which have been known to kill birds and dogs. The excess nutrients also disrupt the normal flow of energy within the ecosystem. The second major concern regarding chemical pollution is the inputs, exposures, and bioaccumulation of toxic chemicals that are of concern from a human health perspective and from an ecosystem health perspective. In regards to the latter, the concern focuses on the health of top predators in the ecosystem that are affected by these toxins, for example reproduction effects in lake trout or in fish-eating birds. The PBT chemicals are identified out as an indicator as they pose a danger to humans and wildlife that consume fish containing these chemicals. The indicator of chemicals of mutual concern in water capture a different and more diverse set of chemicals that are more water soluble than PBTs and do not bioaccumulate, but nonetheless pose a potential risk to aquatic organism reproduction and human health.

Physical Integrity of the Great Lakes includes such basic elements as the amount of water they contain (indicated by water level) and its temperature. Duration of ice-cover is related to the latter, and is an important driver of the effects of climate change on lake level. The physical indicators also encompass the shoreline habitats, including wetlands, and tributaries that are most directly affected by human activity.

The physical indicators relate strongly to water quality and biological integrity. Land cover conversion in the basin drives habitat fragmentation, tributary flashiness (in concert with climate change), tributary connectivity, shoreline hardening and wetland area and extent. Together, these pressures affect the delivery of nutrients and sediments to the lakes, and the habitat for the many fishes that require the tributaries for feeding or spawning.

A second set of issues concerning the physical indicators is climate change. Climate change is expected to increase air and water temperatures in the Great Lakes, with associated changes in duration of thermal stratification in warmer months and ice cover in the cold months. Although climate change impacts on precipitation are less certain, a change in the frequency of severe storms is widely anticipated aggravating the effect of land conversion (forest to agriculture, agriculture to urban) on tributary flashiness. Climate change has been identified as a leading cause of low water levels in the upper Lakes, with their significant ecological and economic effects.

Biological Integrity relates to the natural state of the lakes and their ability to provide important ecosystem services valued by the populations around the Lakes. Although some of the issues (e.g., excessive algae, fish kills) were thought to have been eliminated or reduced through earlier actions (e.g., reductions in phosphorus loading), their re-emergence indicates new ways in which various stressors impact these ecosystems. The biological indicators include the status of existing invasive species and the rate of additional species becoming established, the level of nutrients and the associated harmful and nuisance algae, habitat alterations on tributary connectivity and coastal wetlands, productivity of the lower food web and related fish species of interest and piscivorous/colonial birds, and the underlying PTBs in various biota.

Indicators can be loosely grouped into those providing integrated assessments of the biological function of the ecosystems and those more strongly associated with how human populations relate to, and interact with the lakes. Changes to the phosphorus loading to the lakes combined with altered food webs, often dominated by invasive species, have changed the nearshore and offshore energy pathways in the lakes resulting in different concerns in the two regions. Furthermore, changes to the tributaries and coastal wetlands strongly impact the higher trophic levels through the loss of essential habitat or access to it. Human populations around the lakes see direct connections to these altered energy pathways due to the harmful and nuisance algae issues, but also with changes in fishing opportunities via altered impacted production, composition, and PBTs.

Adaptive Management – Recommendation for Indicator Review and Evolution

The Work Group recommends that these indicators be reviewed every five years by the Science Advisory and Water Quality Boards, to incorporate new science and progress on data collection, and validation of existing indicators. Indicators may be added, and it is recommended that indicators also be considered for being dropped if not meeting the objectives of the WQA or if they are outdated. It will be important to avoid "indicator creep" where only new indicators are added and none dropped.

Many of these indicators are focused on assessing concentrations of chemicals, including conventional water chemistry, legacy contaminants, and other contaminants of mutual concern. While concentrations are useful, the impact on biological communities from exposure to these chemicals is inferred rather than directly measured. Ultimately what we want to know is the "health" of the lakes. There is current cutting-edge research that is developing such indicators, particularly in the area of the effects of endocrine disrupting chemicals. Ideally, we will want to monitor fish health in addition to the concentrations of the chemicals. For example, many chemicals can cause a decrease in fish reproduction. In addition to measuring these chemicals and reproductive hormones in individual fish, we will want a measure of fish population reproduction success. There will soon be tools such as gene array responses that will provide such integrated biological response and impacts. Such impact indicators should be considered for addition to the apex indicators as they are fully developed and field tested, as the next generation of indicators.

Recommendations

The Work Group recommends the Commission:

- Adopt the 16 environmental indicators as described
- Adopt the key themes for communication
- Establish a formalized process for periodically updating the indicators
- Encourage the Parties to establish endpoints for each of the indicators

DETAILED INDICATOR DESCRIPTIONS

The following sections present more detailed descriptions of 16 environmental indicators which address the chemical, physical, and biological integrity of the Great Lakes. Note that the multi-Board Work Group identified experts (individuals or teams) to be assigned the task of drafting detailed descriptions from the participants that attended the expert consultation workshop. These draft descriptions were subsequently reviewed by members of the Science Advisory Board, Water Quality Board, as well as the entire group of workshop participants to ensure alignment with discussions at the meeting.

CHEMICAL INDICATORS

Nutrients - Phosphorus Loads and In-Lake Concentrations
Prepared by: Joe DePinto

Definition
This indicator tracks the trends in phosphorus loading to each of the Great Lakes, including specification of loading to major embayments/basins of the lakes. The loads of both total phosphorus (TP) and dissolved reactive phosphorus (DRP) will be tracked. A second component of the indicator is to track and understand the spatial and temporal trends of TP and DRP concentrations in the lakes and embayments/basins in response to the external loads.

Indicator Relevance
Eutrophication and its associated consequences have re-emerged as a major concern in the Great Lakes, despite the assessment that it had been addressed within the Great Lakes Water Quality Agreement by the mid-1980s. Excessive phosphorus concentrations on a lake- and basin-specific basis continue to be the primary stressor leading to excessive harmful and nuisance algal conditions. Also, watershed phosphorus load control continues to be the primary management action that can be taken to address the eutrophication issues. But two factors primarily impact the understanding and establishment of target phosphorus loads necessary to achieve eutrophication-related targets in the lakes:

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

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

Measures
Phosphorus Loads
Recommend continuation of the annual load computation and reporting program that Dave Dolan has employed and recently updated for all the Great Lakes (Dolan and Chapra, 2012). However, this program should be expanded to include both TP and DRP. In order to improve the accuracy of this load estimation for each lake basin and embayments, the following data collection approach is recommended for the major tributaries to each basin (major tributaries are those that taken together contribute >80% of the TP load to the system of concern): daily flow measurement by USGS gage station with at least between 12 and 24 TP and DRP concentration measurements annually (depending on flashiness of the tributary) with an emphasis of the concentration sampling (~2/3 of samples) on high-flow events in late fall and spring.

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

TP and DRP. In other words, the addition of nearshore stations to the existing monitoring locations would have to be implemented.

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

References

Dolan, D. and S. Chapra. 2012. Great Lakes Total Phosphorus revisited: 1. Loading Analysis and update (1994-2008). *Journal of Great Lakes Research*. 38:730-740.

Chapra, S. and D. Dolan. 2012. Great Lakes Total Phosphorus revisited: 2. Mass Balance Modeling. *Journal of Great Lakes Research*. 38:741-754.

PBTs in Biota
Prepared by: Jeff Ridal, Michael Murray and Conrad deBarros

Definition
The PBTs in biota indicator is an assessment of the trends in the concentrations of persistent, bioaccumulating and toxic substances in whole fish and fish-eating birds.

Purpose and Importance
- To describe temporal and spatial trends of bioavailable contaminants in representative biota from throughout the Great Lakes
- To infer the impact of contaminants on the health of fish and waterbird populations.
- To infer the effectiveness of remedial actions related to the management of critical pollutants
- To document and describe the trends of chemicals of emerging concern.

Indicator Relevance
This indicator is relevant to the following General Objectives of the WQA as amended by the Great Lakes Water Quality Protocol of 2012:

> (iii) allow for human consumption of fish and wildlife unrestricted by concerns due to harmful pollutants;
>
> (iv) be free from pollutants in quantities or concentrations that could be harmful to human health, wildlife, or aquatic organisms, through direct exposure or indirect exposure through the food chain;

The indicator is also relevant to the following WQA Annexes: 1 (Remedial Action Plans), 2 (Lakewide Management Plans), 3 (Chemicals of Mutual Concern) and 10 (Science) of the 2012 Protocol.

Measures
The indicator has two components:

1. Concentrations of persistent, bioaccumulating, toxic (PBT) chemicals in Great Lakes whole fish, specifically the top predators Lake Trout (*Salvelinus namaycush*), Walleye (*Sander vitreus*) and the forage fish, Rainbow Smelt (*Osmerus mordax*). Other species of forage fish could also be considered (e.g., yellow perch, spottail shiners).
2. Concentrations of persistent, bioaccumulative, toxic (PBT) chemicals in Great Lakes Herring Gull (*Larus argentatus*) eggs. Consideration should also be given to adding PBTs in Bald Eagles as a component of the PBTs in Biota indicator. A Bald Eagle indicator is currently being developed for the SOLEC indicator program for 2014.

Contaminants to be measured include legacy PBTs: PCBs, organochlorine pesticides, dioxins and furans, trace metals including mercury, and chemicals of emerging concern such as brominated flame retardants, fluorinated compounds, and synthetic musks.

It is proposed that the PBTs in Biota indicator be largely based on two well-established SOLEC indicators: (1) Contaminants in Whole Fish and (2) Contaminants in Fish-eating Colonial Waterbirds. The Whole Fish indicator assesses the temporal and geographic trends in the chemical contaminant levels in Lake Trout from Lakes Ontario, Huron, Michigan and Superior, and Walleye from Lake Erie. Environment Canada and the USEPA both contribute data to this indicator, although different methodologies limit the statistical analyses that can be performed (McGoldrick et al., 2011). Environment Canada also provides data on Rainbow Smelt, a common forage species. Samples are collected and analyzed at least every two years at 10 established sites (2 in each of the 5 Great Lakes) for the USEPA program and annually at the 12 sites established by Environment Canada in Superior, Huron, Erie and Ontario. It is recommended that sampling be conducted at a minimum at 2 sites per lake, and at a frequency of at least every two years. In addition, consideration by the program managers should be given to including a warmwater fish species (e.g. largemouth bass) to greater represent the whole fish community. Criteria for selection could include significance as a food source, relevance of the species to the whole lake community, and ease of monitoring (e.g., via existing contaminant monitoring in state and provincial programs, assuming a similar protocol is adopted).

Through USEPA and Environment Canada monitoring, contaminant analyses in whole fish reported include legacy PBTs such as PCBs, organochlorine pesticides, dioxins and furans, mercury and other trace metals, and also contaminants of emerging concern such as polybrominated diethyl ethers (PBDEs), fluorinated chemicals and synthetic musks. Trends through time are assessed using first-order log-linear regression models of annual median concentrations to estimate percent annual declines. Concentrations are also compared to applicable benchmarks for concentrations in whole fish. It is recommended that this chemical suite and trend analysis approach be continued. Regarding the second indicator component, Herring Gull eggs are collected annually by Environment Canada at 15 sites representative of all 5 Great Lakes. Contaminants analyzed include PCBs, organochlorine pesticides, dioxins and furans, mercury and other trace metals, and (since 2000) PBDEs. An archival database of sample extracts has been established and should be maintained for retrospective analysis. In addition, it is recommended that sampling and analysis continue on an annual basis.

Several factors affect the annual concentrations of PBTs in biota (e.g. Carlson et al. 2010, Weseloh et al., 2011; Chang et al. 2012). These include changing food webs, prey availability, growth rates, and climatic variability; therefore, ancillary data is required for detailed interpretation of the whole fish trend data. The Herring Gull and USEPA and Environment Canada Contaminants in Whole Fish monitoring programs have established ancillary data collections that include fish age, length, weight, sex, and lipid content of the fish collected. Egg moisture and lipid contents, and a gull diet index based on stable isotopes, trophic position, and diet fatty acid content are collected for the Herring Gull egg program. Additional physiological measures are conducted on the colonies from which the eggs are collected (Weseloh et al., 2011). Detailed data on sample size, location and the complete suite of ancillary measurements can be sourced from the program leads for the Contaminants in Whole Fish and Contaminants in Fish-eating Colonial Waterbirds programs.

It is recommended that an effects-based indicator be developed as part of the IJC Great Lakes indicator suite, either associated with the PBT in biota indicator, the fish community assessment indicator or as a standalone indicator. It should be based on a well-accepted measure that can be tied to specific chemicals of concern (e.g. a biomarker or other manifestation of injury). Also, consideration should also be given to adding PBTs in Bald Eagles as a component of the PBTs in Biota indicator. A Bald Eagle indicator is currently being developed for the SOLEC indicator program for 2014.

<u>References</u>

Carlson, D.L., De Vault, D.S., Swackhamer, D.L. 2010. On the rate of decline of persistent organic contaminants in lake trout (*Salvelinus namaycush*) from the Great Lakes, 1970-2003, Environ. Sci. Technol., 44:2004-2010.

Chang, F., Pagano, J.J., Crimmins, B.S., Milligan, M.S., Xia, X., Hopke, P.K., Holsen, T.M., 2012. Temporal trends of polychlorinated biphenyls and organochlorine pesticides in Great Lakes fish, 1999–2009, Sci. Tot. Environ. 439:284-290.

McGoldrick, D., M. Clark and E. Murphy. 2011. Contaminants of Whole Fish, draft SOLEC report accessed at www.solecregistration.ca/documents/ContaminantsinWholeFishDRAFTOct2011.pdf

Weseloh, D.V.C., D.J. Moore, C.E. Hebert, S.R. de Solla, B.M. Braune, D.J. McGoldrick. 2011. Current concentrations and spatial and temporal trends in mercury in Great Lakes Herring Gull eggs, 1974–2009. Ecotoxicology, 20:1644–1658.

Weseloh, D.V.C and D. Moore. 2011. Contaminants in Fish-Eating Waterbirds, draft SOLEC report accessed at www.solecregistration.ca/documents/Contaminants in Waterbirds DRAFT Oct2011.pdf

More detail on the USEPA's Open Water Trend Program can be found at http://www.epa.gov/glnpo/monitoring/fish/contaminant_concentrations.html

More detail on Environment Canada's Fish Contaminants Monitoring and Surveillance Program can be found at http://www.ec.gc.ca/scitech/default.asp?lang=en&n=828EB4D2-1#bank

Chemicals of Mutual Concern in Water
Prepared by: Michael Murray, Deborah Swackhamer, Gail Krantzberg, and Conrad DeBarros

Definition
Total concentrations of selected legacy toxic chemicals and chemicals of emerging concern in water, determined at selected offshore and nearshore sites in each lake on a two-to-three-year basis. The specific chemicals of mutual concern will be selected by the Great Lakes Executive Committee as per Annex 3 of the renewed Water Quality Agreement.

Purpose and Importance
The purpose of the indicator is to assess the magnitude and direction of trends of chemicals of mutual concern (CMC) in Great Lakes surface water, the potential for human or ecological impacts, and progress toward virtual elimination of toxic substances in the Great Lakes basin. (This purpose draws from the analogous draft SOLEC indicator, *Toxic Chemical Concentrations in Offshore Waters* – see Dove 2011).

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

Measures
The indicator would be obtained through integrating data from direct measurements of aqueous concentrations of various CMCs selected from those listed pursuant to Annex 3 of the renewed Great Lakes Water Quality Agreement. It is proposed that sampling would be done every two-three years, and at selected offshore and some nearshore sites, during the spring isothermal period. Site selection should be representative of the diversity of aquatic habitats in each lake (i.e., nearshore sites at different distances from major tributary mouths, offshore sites in different basins), building off current efforts used through SOLEC. Sampling protocol could follow the current SOLEC approach (i.e., 16-24 l volume collection in field followed by extraction in the lab). However, it is recommended that managers also consider the potential additional monitoring value of passive techniques, such as semipermeable membrane devices (for SOCs, e.g. Alvarez 2010) and the polar organic chemical integrative sampler (POCIS) technique for more polar compounds (e.g. Li *et al.* 2010). Such techniques are already in use in selected areas, and could be phased in to existing monitoring programs for toxic chemicals in the Great Lakes more broadly following a method development and evaluation phase. Resulting data could assist in determining local and regional differences in CMCs as well as further monitoring and management actions that might be pursued concerning CMCs in the Lakes.

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

References

Alvarez, D.A., 2010, Guidelines for the use of the semi-permeable membrane device (SPMD) and the polar organic chemical integrative sampler (POCIS) in environmental monitoring studies: U.S. Geological Survey, Techniques and Methods 1–D4, 28 p., available from http://pubs.usgs.gov/tm/tm1d4/pdf/tm1d4.pdf.

Carlson, D.L., De Vault, D.S., Swackhamer, D.L. 2010. On the rate of decline of persistent organic contaminants in lake trout (*Salvelinus namaycush*) from the Great Lakes, 1970-2003, *Environ. Sci. Technol*., 44:2004-2010.

Chang, F., Pagano, J.J., Crimmins, B.S., Milligan, M.S., Xia, X., Hopke, P.K., Holsen, T.M., 2012. Temporal trends of polychlorinated biphenyls and organochlorine pesticides in Great Lakes fish, 1999–2009, *Sci. Tot. Environ*. 439:284-290.

Dove, A., 2011, Toxic Chemicals in Offshore Waters, State of the Great Lakes 2012 - Draft indicator report, available from http://www.solecregistration.ca/documents/Toxic%20Chemicals%20In%20Offshore%20Waters%20DRAFT%20Oct2011.pdf.

Li, H. X., Helm, P. A., Metcalfe, C. 2010. Sampling in the Great Lakes for pharmaceuticals, personal care products, and endocrine-disrupting substances using the passive polar organic chemical integrative sampler, *Environ. Toxicol. Chem*., 29(4):751-762.

Atmospheric Deposition of Chemicals of Mutual Concern

Prepared by: Todd Nettesheim

Definition

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

Indicator Relevance

The atmosphere is still the primary source of many persistent, bioaccumulative, and toxic chemicals to the Great Lakes and hence into Great Lakes fishes. The atmosphere was first recognized as an important source in 1980s and later confirmed with data from the Integrated Atmospheric Deposition Network (IADN) and Lake Michigan Mass Balance. Recent IADN and Mercury Deposition Network (MDN) indicate that the atmosphere is still a significant source.

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

The purpose of Annex 3 of the amended WQA of 2012 is "reduce the anthropogenic release of chemicals of mutual concern, recognizing: (i) that chemicals of mutual concern released into the air, water, land, sediment, and biota should not result in impairment to the quality of the Waters of the Great Lakes; and (ii) the need to manage chemicals of mutual concern including, as appropriate, by implementing measures to achieve virtual elimination and zero discharge of these chemicals." Annex 3 of the amended WQA of 2012 further calls for the Parties to (i) monitor and evaluate the progress and effectiveness of pollution prevention and control measures; (ii) exchange, on a regular basis, information on monitoring, surveillance…; (iii) identify and assess the occurrence, sources, transport, and impact of chemicals of mutual concern, including spatial and temporal trends in the atmosphere…; and (iv) identify and assess loadings … from the atmosphere.

Measures

It is proposed that the Atmospheric Deposition indicator be largely based on the well-established SOLEC indicator Atmospheric Deposition of Toxic Chemicals.

Chemicals of mutual concern in the atmosphere and precipitation will be measured at IADN stations, using the protocols established by the binational IADN network. Air (vapor and particle) samples are collected for 24 hours every 12 days. Precipitation samples are integrated over each month. Annual average concentrations will be calculated and reported using these measurements. Spatial and temporal trend analyses will be performed on the IADN data using a variety of statistical tools (see references).

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

<u>References</u>

Nettesheim, T., M. Craddock, S.C. Lee, and H. Hung. 2011. Atmospheric Deposition of Toxic Chemicals, draft SOLEC report accessed at http://www.solecregistration.ca/documents/Atmospheric%20Deposition%20of%20Toxic%20Chemicals%20DRAFT%20Oct2011.pdf

Integrated Atmospheric Deposition Network
http://www.epa.gov/glnpo/monitoring/air2/index.html
http://www.epa.gov/glnpo/monitoring/air2/index.html
https://www.ec.gc.ca/rs-mn/default.asp?lang=En&n=BFE9D3A3-1

Venier, M., Hung, H., Tych, W., Hites, R. 2012. Temporal Trends of Persistent Organic Pollutants: A Comparison of Different Time Series Models. *Environ. Sci. Technol*. 46(7), pp 3928-3934.

Ma. Y., Venier, M., Hites, R. 2012. 2-Ethylhexyl Tetrabromobenzoate and Bis(2-ethylhexyl) Tetrabromophthalate Flame Retardants in the Great Lakes Atmosphere. *Environ. Sci. Technol*. 46(1), pp 204-208.

Salamova, A. and Hites, R. 2011. Discontinued and Alternative Brominated Flame Retardants in the Atmosphere and Precipitation from the Great Lakes Basin. *Environ. Sci. Technol*. 45(20), pp 8698-8706.

Venier, M. and Hites, R. 2010. Time Trend Analysis of Atmospheric POPs Concentrations in the Great Lakes Region Since 1990. *Environ. Sci. Technol*. 44(21), pp 8050-8055.

Venier, M. and Hites, R. 2010. Regression Model of Partial Pressures of PCBs, PAHs, and Organochlorine Pesticides in the Great Lakes' Atmosphere. *Environ. Sci. Technol*. 44(2), pp 618-623.

Mercury Deposition Network
http://nadp.sws.uiuc.edu/mdn/

Risch, M.R., Gay, D.A., Fowler, K.K., Keeler, G.J., Backus, S.M., Blanchard, P., Barres, J.A., Dvonch, J.T. 2012. Spatial patterns and temporal trends in mercury concentrations, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002-2008. Environmental Pollution. 161, pp 261-271.

Prestbo, E.M. and Gay, D.A. 2009. Wet deposition of mercury in the U.S. and Canada, 1996-2005: Results and analysis of the NADP mercury deposition network (MDN). Atmos. Environment. 43 pp 4223-4233.

Contaminants in Groundwater
Prepared by: Norm Granneman

Definition
This indicator includes the quality and quantity of the groundwater in the Great Lakes region, and its interaction with the surface water in the Great Lakes basin.

Indicator Relevance
Groundwater is an important component of the hydrologic cycle in the Great Lakes basin and, therefore, groundwater quality is an important factor in determining the overall quality of water in the Lakes. In most parts of the Great Lakes basin, the interaction of groundwater and surface water is an important pathway that is generally considered to be a single resource.

Groundwater is important to ecosystems in the Great Lakes Region because it is, in effect, a large, subsurface reservoir from which water is released slowly to provide a reliable minimum level of water flow to streams, lakes, and wetlands. Groundwater discharge to streams generally provides good quality water that, in turn, promotes habitat for aquatic animals and sustains aquatic plants during periods of low precipitation. Because of the slow movement of groundwater, the effects of surface activities on groundwater flow and quality can take years to manifest themselves. As a result, issues relative to groundwater are often seemingly less dire than issues related to surface water alone.

The major groundwater resources issues in the Great Lakes Region revolve around 1) the quantity of groundwater, 2) groundwater and surface-water interaction, 3) changes in groundwater quality as development expands, and 4) ecosystem health in relation to quantity and quality of water.

Surface runoff is a short-term component of flow that results from precipitation moving overland to a stream without percolating into an aquifer. Groundwater discharge is a long-term, persistent component that results from that part of precipitation that infiltrates into the soil, percolates into an aquifer, and then flows to a stream, lake, or wetland. Most groundwater/surface-water interaction in the Great Lakes basin takes place in the near surface unconsolidated glacial-deposit aquifers.

Measures
Because groundwater is so highly distributed in the Great Lakes basin, representative locations to conduct measurements of changes in groundwater quality that demonstrate the state of the groundwater resource as it relates to Great Lakes issues.

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

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

The following is a possible list of physical and chemical data:

- Location, water level and/or flow, Temperature, pH, Specific or electrical conductance
- Sodium, Calcium, Magnesium, Potassium, Chloride, Sulfate, Alkalinity, Nitrate, Nitrite, Ammonia
- Dissolved Phosphorus, Dissolved oxygen, Total dissolved solids, Oxygen reduction potential, Iron, Manganese

Other supplemental analytes if available:

- Synthetic organics
- Emerging Contaminants
- Selected Isotopes

PHYSICAL INDICATORS

Tributary Physical Integrity
Prepared by: Scudder Mackey

Sub-Indicator: Hydrologic Alteration – R-B Flashiness Index

Definition
This indicator quantifies the hydrologic responsiveness (i.e. flashiness) of a tributary to daily or hourly changes in precipitation and runoff. Flashiness is an important component of the hydrologic regime as it reflects the frequency and rapidity of short term changes in streamflow to which aquatic ecosystems are adapted. Increasing or decreasing trends in flashiness may result in increased ecosystem stress.

Indicator Relevance
A variety of land use and land management changes may lead to increased or decreased flashiness, often to the detriment of aquatic life. Periodic changes in flow rate are characteristic of streams and rivers, and the organisms that live in them are adapted to those changes. Spring floods may be important in opening up spawning areas or nurseries. Higher energies associated with storm runoff flush finer sediment from gravel beds, improving them as habitats for invertebrates and as spawning sites for salmonids. But changes in the hydrologic regime, either by reduced flashiness such as occurs when a dam is constructed, or increased flashiness such as occurs with urbanization, may adversely impact resident organisms.

Metric Description
The Richards-Baker Flashiness Index (R-B Index) is a quantitative measure of the hydrologic response of a stream or river to changing precipitation/runoff events. The R-B Index is calculated using USGS mean daily flows on an annual basis by dividing the path length of flow oscillations for a time interval (i.e., the sum of the absolute values of day-to-day changes in mean daily flow) by total discharge over that time interval (Baker et al. 2004).

$$\text{R-B Index} = \frac{\sum_{n=1}^{365} |q_n - q_{n-1}|}{\sum_{n=1}^{365} q_n}$$

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

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

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

Trend data (i.e the relative increase or decrease of the R-B Index) would be reported on a watershed-by-watershed basis across the Great Lakes basin every three to five years. In almost all cases, reductions in the R-B Index would be considered desirable (i.e. negative change values). Conversely, increases in the R-B Index (i.e. positive change values) would be considered undesirable. For example, watersheds undergoing rapid urbanization would typically show increases in flashiness due to increased channelization and imperviousness. The following trend categories are suggested for the R-B Index:

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

Absolute values of the R-B Index are not indicative of either good or bad conditions, especially if comparisons are made between watersheds of different types or sizes. However, when considering watersheds with similar flow regimes (e.g. event, variable, stable, or superstable – see Richards 1990), it may be possible characterize a statistically appropriate range of R-B Index values by watershed type or ecoregion (Baker et al. 2004). Additional analyses are needed to develop appropriate criteria and measures to assess differences between absolute values of the R-B Index within similar watershed types.

Data Availability and Monitoring

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

Large watersheds would reflect long-term systematic changes in tributary flow regimes perhaps driven by regional changes in land use and climate; and smaller watersheds could act as potential sentinel basins indicative of potential future regional changes to come.

References

Baker, D.B., R.P. Richards, T.T. Loftus, and J.K. Kramer. 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. Journal of the American Water Resources Association 40(2): 503-522.

Richards, R.P. 1990. Measures of Flow Variability and a New Flow-Based Classification of Great Lakes Tributaries. Journal of Great Lakes Research 16(1): 53-70.

Sub-Indicator: Tributary Connectivity to Receiving Waters

Definition

This indicator quantifies the percent of mainstem channel length (naturally accessible) that is connected to the receiving water body. The indicator can be calculated for a single tributary (or watershed) or multiple watersheds. The indicator can be applied to watersheds of any size and is dimensionless.

Indicator Relevance

Dams, reservoirs, and stream crossings impair connectivity and may restrict movement of anadromous and resident fishes and alter the distribution of other aquatic species in Great Lake's rivers and streams. As used in for this indicator, habitat connectivity is defined as the longitudinal connectivity between main stem rivers and associated receiving waters necessary to meet the life history requirements of anadromous fish and aquatic species, including access to critical spawning and nursery habitats. For example, in Lake Huron 86% of the major tributaries are no longer connected to the Lake Huron basin (Gebhardt et al. 2003). The loss of tributary habitat has resulted in significant declines in native fish populations, such as lake herring, yellow perch, walleye, lake sturgeon, river redhorse, black redhorse, eastern sand darter and the channel darter (Liskauskas et al. 2007, Roseman et al. 2012)

Metric Description – Tributary and Watershed Connectivity to Receiving Waters

C_{rw} is the percent of mainstem channel length (naturally accessible) that is connected to the receiving water body.

$C_{rw} = (L_{rw}/L_m) \times 100$

C_{rw} is dimensionless and can be calculated for an individual watershed/tributary.

For multiple watersheds, connectivity to receiving waters is calculated by summing the total length of mainstem channels (naturally accessible) and then dividing by the total sum of mainstem channel lengths connected to the receiving water body.

$$\text{Watershed Connectivity}_{rw} = \frac{\sum_{n=1}^{ntot} L_{rw_n}}{\sum_{n=1}^{ntot} L_{m_n}} \times 100$$

Watershed connectivity to receiving waters is the percent of summed mainstem channel length (naturally accessible) for multiple watersheds. Changes in watershed connectivity through time can be calculated using historical maps, aerial photographs, and other data. These calculations should be updated every five years (due to ongoing dam construction and/or removals).

Endpoints and Categories

Values range from 0 to 100. A value of 0.0 represents a main stem channel that is not connected to the receiving water body (no connectivity) and a value of 100 represents a main stem channel with unimpaired connectivity. These values are also applicable to watershed connectivity (to receiving waters).

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

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

Data Availability and Monitoring

With the advent of GIS tools, tributary main stem lengths and dam locations are easy to overlay and plot. The data are readily available for the entire Great Lakes Basin. A critical requirement will be periodic updates and validation of the dam inventory database. Examples exist where these type of data have already been used to identify and prioritize potential restoration targets in Lake Huron watersheds (e.g. Herbert et al. 2012; Roseman et al. 2009; Liskauskas et al. 2007; and Gebhardt et al. 2003).

References

Gebhardt, K., J. Bredin, R. Day, T.G. Zorn, A. Cottrill, D. McLeish, and M.A. MacKay. 2003. Status of the near-shore fish community. In The State of Lake Huron in 1999. Edited by M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 03-XX. pp. 22-37.

Herbert, M., M. Khoury, T. Bowe, and L. Cole. 2012. Development of Conservation Priorities for Migratory, River-spawning Fishes in the Michigan Waters of Lake Huron. Final Report submitted to Michigan CMP and the Michigan DEQ, Project #10D-0.10, The Nature Conservancy, March 2012.

Liskauskas, A., J. Johnson, M. McKay, T. Gorenflo, A. Woldt, and J. Bredin. 2007. Environmental Objectives for Lake Huron. A Report of the Lake Huron Technical Committee, Great Lakes Fishery Commission.

Roseman, E. F., J. S. Schaeffer, and P. J. Steen. 2009. Review of fish diversity in the Lake Huron basin. Aquatic Ecosystem Health & Management 12(1): 11-22.

Land Cover Conversion and Fragmentation Index
Prepared by: Scott Sowa

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

Indicator Relevance
Amount of conversion: As natural land cover is changed to agriculture or urban use, the products and services provided by those cover types such as timber, water storage and purification, wildlife habitat, carbon storage, recreation, and aesthetic beauty, etc. are lost. The loss of natural habitat, particularly forest, can also have profound economic impact on communities that rely on the forest for food and economic development. Furthermore, conversion of natural land cover to urban and agricultural lands leads to increased runoff and associated increased inputs of sediments, nutrients, and contaminants to inland waters and the Great Lakes (Allan et al. 2003; Wolter et al. 2006).

Rate of conversion: High rates of conversion place stress on the natural ecosystem and are typically associated with inefficient land use, such as urban sprawl. Population growth is a driver for more development which displaces both agricultural and natural lands. Other things being constant, high conversion rates are associated with rapid rates of development which is economically inefficient (Wu 2006).

Pattern of conversion: Land use conversion affects type, amount, and spatial pattern of wildlife habitat, which in turn can affect the ecological function and associated wildlife populations and communities. For example, fragmentation of natural or seminatural land cover can create migration barriers or inhospitable habitats for wildlife and interfere with other ecological processes. Breeding birds in the Great Lakes and other ecoregions have been shown to have higher breeding success in relatively unfragmented landscapes than fragmented landscapes (Robinson et al. 1995). The size and number of natural habitat patches has been shown to have a significant influence on a variety of wildlife populations, including populations in the Great Lakes region (Saunders et al. 2002). Finally, small ownership parcels found in fragmented landscapes complicate management and cooperation at landscape and watershed scales due to the increased number of stakeholders that must be involved in land management decisions (Pijanowski and Robinson 2011).

Measures
Land Cover Conversion Index: consists of six metrics computed from spatially-explicit comparisons of historic baseline natural land cover and current land cover over time using a geographic information system (GIS). Percentages for each of these metrics are calculated within a, yet to be determined, nested set of watershed and/or ecoregional assessment units that provide a local to basin-wide perspective on spatial and temporal changes in natural land cover. Each of these metrics provides information that is of interest to managers, yet there is a need for a robust and meaningful approach to aggregating these metrics into an overall index.
Metrics:

1. Natural land cover type unchanged
2. Minor change in natural land cover type (still natural land cover)
3. Major change in natural land cover type (still natural land cover)

4. Major change to anthropogenic non-urban or industrial land use (restorable)
5. Major change to urban or industrial land use ("Unrestorable")
6. Changed to water

Fragmentation Index: Consists of two metrics that pertain only to natural land cover classes that are derived from current land cover maps. Similar to the metrics in the Land Cover Conversion Index, these two metrics are calculated within a, yet to be determined, nested set of watershed and/or ecoregional assessment units that provide a local to basin-wide perspective on spatial and temporal changes in natural land cover. As with the conversion metrics, these fragmentation metrics could be aggregated into an overall index; the aggregation approach is yet to be determined.

Metrics:

1. Average number of patches for each natural land cover class
2. Average patch size for each natural land cover class

Required Data Inputs

1. Historic Baseline Natural Land Cover Maps
   a. United States: Biophysical Settings from LANDFIRE for United States (Holsinger et al. 2004; Rollins 2009). http://www.landfire.gov/NationalProductDescriptions11.php
   b. Canada: *Currently not available*

2. Current Land Cover and Use Maps
   a. United States: National Land Cover Datasets for 1990, 2001, and 2006 (Homer et al. 2012). http://www.mrlc.gov/index.php
   b. Canada: 28 Class Ontario Provincial Land Cover Raster (OMNR 2000). http://www.lib.uwo.ca/madgic/geospatial/lcraster_2000_data.htm

References

Holsinger, L, R. E. Keane, R. Parsons, and E. Karau. 2006. Development of Biophysical Gradient Layers for the LANDFIRE Prototype Project. Pp. 99-122 *In* Rollins, M.G.; Frame, C.K., tech. eds. 2006. The LANDFIRE Prototype Project: nationally consistent and locally relevant geospatial data for wildland fire management. Gen. Tech. Rep.RMRS-GTR-175. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Available online at: http://www.landfire.gov/NationalProductDescriptions11.php

Homer, C.H., Fry, J.A., and Barnes C.A., 2012, The National Land Cover Database, U.S. Geological Survey Fact Sheet 2012-3020, 4 p.

OMNR. 2000. *28 Class Ontario Provincial Land Cover Raster* [computer file]. Peterborough: Ontario Ministry of Natural Resources. Available online at: http://www.lib.uwo.ca/madgic/geospatial/lcraster_2000_data.htm

Pijanowski, B. C. and K. D. Robinson. 2011. Rates and patterns of land use change in the Upper Great Lakes States, USA: A framework for spatial temporal analysis. Landscape and Urban Planning 102(2):102-116.

Robinson, S.K., F.R. Thompson, III, T.M. Donovan, D.R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987-1990.

Rollins, M. G. 2009. LANDFIRE: A nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire 18(3) 235–249

Saunders, S. C., M. R. Mislivets, J. Chen, and D. T. Cleland. 2002. Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA Biological Conservation 103(2): 209–225

Vogelmann, J.E., S.M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and J. N. Van Driel.   2001. Completion of the 1990's National Land Cover Data Set for the conterminous United States, Photogrammetric Engineering and Remote Sensing 67: 650-662.

Wolter, P.T., C. A. Johnston, G. J. Niemi. 2006. Land Use Land Cover Change in the U.S. Great Lakes Basin 1992 to 2001Journal of Great Lakes Research 32(3):607-628.

Wu, J. J. 2006. Environmental amenities, urban sprawl, and community characteristics. Journal of Environmental Economics and Management52(2): 527–547.

<u>Coastal Habitat – Shoreline Alteration Index</u>

Prepared by: Scudder Mackey

<u>Definition</u>

The Shoreline Alteration Index (SAI) is a measure of protected shoreline length that is physically and biologically unfavorable. The physical and biological components used to calculate the SAI can be measured using conventional high-resolution aerial photography or satellite imagery at multiple scales. The physical component is ratio of the lineal length of armored shoreline relative to total lineal length of the shoreline. The biological component is based on lineal length of biologically incompatible shoreline structures relative to the total lineal length of protected shoreline.

<u>Indicator Relevance</u>

Physical modifications to the shoreline have disrupted coastal and nearshore processes, flow and littoral circulatory patterns, altered or eliminated connectivity to coastal wetlands/dunes, and have altered nearshore and coastal habitat structure. Continued coastal redevelopment and expanding suburban growth along the coasts of all of the Great Lakes from urban centers suggests that these trends will continue into well into the future.

<u>Metric Description</u>

The proposed indicator combines the ratio of protected to unprotected shoreline (physical characteristics) modified by the proportion of structures that biologically compatible (biological impacts). The physical shoreline indicator is 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). A value of zero (0) would represent an unprotected natural shoreline and a value of one (1) would represent a highly modified or 100% engineered shoreline.

Unprotected **Physical** 100% Protected

0 ⟵⟶ 1

The biological shoreline indicator is the ratio of the lineal length of biologically incompatible structures (shore perpendicular structures, vertical sheet pile or concrete walls…) relative to total lineal length of protected shoreline. A value of zero (0) would represent no biological or ecological impact (high compatibility) and a value of one (1) would represent significant biological or ecological impact (low compatibility).

High Biological Compatibility **Biological** Low Biological Compatibility

0 ⟵⟶ 1

For a given reach of shoreline, a Shoreline Alteration Index (SAI) would be calculated by multiplying the physical and biological shoreline indicator values and subtracting the resulting value from one (1).

SAI = 1 – (P ratio x B ratio)

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 still be armored).

Highly Altered Low Compatibility **SAI** Unaltered High Compatibility

0 ⟵⟶ 1

Within the context of this proposed indicator, alteration means impacted biological or ecological functions caused by modifications to the shoreline and/or associated natural coastal processes. Simply put, the SAI is a measure of protected shoreline length that is physically and biologically unfavorable. The greater the SAI value, the more unaltered and biologically compatible the shoreline is. The SAI is scalable to any reach length, and can be applied to present day and historical data for comparison and trend analyses.

The advantage of this approach is that as structures are removed and/or modified to provide habitat enhancements, the indicator will shift toward a more unaltered or natural state. Conversely, if the number and extent of biologically incompatible shoreline structures increases, the indicator will shift toward a more altered state.

Categories and Endpoints

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

The endpoints and categories for the physical indicator are identical to those proposed in the SOLEC draft indicator report for Coastal Habitats (8). The biological indicator is not categorized as it is a value used to “adjust” the physical shoreline alteration ratio by accounting for biologically compatible shore structures.

Data Availability and Monitoring
Coarse-scale basin-wide historical data are available but should be augmented using existing, new, or historical high-resolution aerial photography and/or satellite imagery. For selected coastlines and reaches, existing data are adequate to demonstrate long-term historical trends. It is recommended that the SAI indicator be calculated on a 5- year cycle. By applying the SAI at multiple spatial scales, comparisons between specific geographic areas can be made.

With respect to implementation, the physical component of this indicator can be *developed and applied immediately*. However, additional work is needed to develop consensus on consistent biological/ecological criteria to evaluate impacts of shoreline modifications on nearshore and coastal biological systems.

References
Cherwaty-Pergentile, S.and Adams, J. 2012. *13. Coastal Habitat: [8] Percentage of hardened shoreline and type of armoring*. Great Lakes (SOLEC) Indicator Descriptions. p. 67-70.

Fuller, J.A., B. Gerke. 2005. *Distribution of shore protection structures and their erosion effectiveness and biological compatibility*. Ohio Department of Natural Resources, Sandusky, OH (unpublished technical report).

Livchak, C., S.D. Mackey. 2007. *Lake Erie shoreline hardening in Lucas and Ottawa Counties, Ohio*. in: State of the Strait, Status and Trends of Key Indicators. Edited by: Hartig, J.H., M.A. Zarull, J.J.H.

Ciborowski, J.E. Gannon, E. Wilke, G. Norwood, A. Vincent. Detroit River-Western Lake Erie Basin Indicator Project. p. 86-90. http://www.epa.gov/med/grosseile_site/indicators/sos-indicators.html

SOLEC 2009. *Extent of Hardened Shoreline Indicator #8131*. Silk, Schneider, J., Heaton, D. and H. Leadlay. Indicator Progress Report. p. 372-374.

Water Level
Prepared by: Norm Granneman

Definition
This indicator tracks the trends in lake levels for each of the five Great Lakes. The most important natural factors associated with long-term water level changes in the Great Lakes include the various processes that contribute inflow to, outflow from, and storage in the lake system which makes up the Lakes' water balance. Over-lake precipitation, tributary inflow, the flow characteristics of the outlet/connecting channels, and evapotranspiration are the primary parts of the hydrologic cycle that alter lake levels.

Indicator Relevance
Water levels influence some ecosystem functions: Lake levels have a major influence on undiked coastal wetlands and are basic to any analysis of wetland change trends. These wetlands play important roles to give refuge to larval fish and plant assemblages that are critical to a stable ecosystem. They also influence lake water quality, especially nutrient concentrations. Non wetland nearshore terrestrial ecosystems are also affected by water-level fluctuations. Naturally fluctuating water levels are needed to maintain and restore healthy coastal wetlands and nearshore terrestrial ecosystems especially emergent vegetation in these ecosystems.

Water levels are important for human uses of the lakes: Navigation is directly influenced by lake levels. Vessel loads must be adjusted for low lake levels to reduce vessel draft. In extreme conditions, navigation may be curtailed. Dredging is usually increased during periods of low lake levels which may have effects on ecosystems both at the site of dredging but, also, related to disposal of dredged materials. Drinking water intakes may be too shallow to withdraw water of adequate quality during periods of low lake levels. Recreational uses including the amount of beach exposed and harbor access for small vessels are affected by water levels. Shoreline erosion may be increased during periods of high lake level.

Measures
For each lake, the following information is reported:
1. Mean lake level
2. Lake-wide annual range in monthly averages
3. Lake-wide seasonal peak (days after January 1)
4. Lake-wide seasonal minimum (days after September 1)
5. A measure of the effects of water levels on emergent wetland vegetation

Water-level data are easily available in near real time in the U.S. at the following online sites:
http://www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/waterlevelforecasts/monthlybulletinofgreatlakeswaterlevels/
http://www.glerl.noaa.gov/res/glcfs/

Similar information is available from Environment Canada.
http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=F6F3D96B-1

The data from the Corps of Engineers, NOAA, and Environment Canada is published monthly. This monthly data will be used to determine items 1 through 4 listed above. A separate evaluation on the effects of water levels on emergent vegetation will need to be written annually.

For additional information see SOLEC Indicator 4861.

Water Temperature
Prepared by: Norm Granneman

Definition
This indicator tracks the trends in water temperature and extent of winter ice cover for each of the five Great Lakes

Indicator Relevance
Water temperature and the extent of winter ice cover are related to Great Lakes ecosystem function and to wintertime evaporation from the lakes which can reduce water levels. Higher water temperatures and less ice cover may be related to more and earlier algae blooms which damage water quality and habitat. Less ice cover exposes the shoreline to waves generated by winter storms that accelerates erosion. In addition, less ice cover and higher temperatures may signal climate change conditions. Higher temperatures may also be related to the spread of some invasive species.

Measures
Ice Cover Atlas Data and Analysis Products
Original Ice Charts. The original ice chart data set consists of over 1200 digitized ice charts. These ice charts display observed ice cover over each Great Lake throughout every winter season from 1973 to 2002. Ice chart data is available as Arc/Info Export, ASCII grids, and graphic files.
Analysis Products. There are three analysis products. The first product includes ice charts of the following: dates of the first reported ice, dates of the last reported ice, and ice duration for each winter, as well as, the maximum, minimum and average ice cover concentrations.
The second product is the 30-year annual daily ice cover time series. The daily time series was used to create: 1) computer animations of spatial patterns of ice cover for each winter, 2) line plots of lake averaged ice cover for each lake over the 30 winters.
The third product is weekly statistics. There are weekly ice charts and grids of: maximum, 3rd quartile, median, 1st quartile, and minimum ice cover concentrations for the 30-winter base period. The weekly statistics are based on the original ice chart data set and not on the daily time series.
http://www.glerl.noaa.gov/data/ice/atlas/
The ice charts are available from 1973 to 2011 in three separate publications as indicated on the NOAA website. Analysis of ice cover data will be published at regular intervals as NOAA Technical Memoranda.

Water Temperature Data
Water-temperature at the lake surface from MODIS satellite data are easily available in near real time in the U.S. at the following online site:
http://www.glerl.noaa.gov/res/glcfs/kml/glcfsmap.php?lake=a&param=temps&time=now

Additional data are available at the following online sites:
http://coastwatch.glerl.noaa.gov/cwdata/lct/glsea.png
http://www.coastwatch.msu.edu/

Discussion is still needed to determine how to properly represent the surface temperature data. It is suggested that annual summer (July-September) average temperatures be calculated for each lake. These data will be used as the summer corollary to winter ice conditions. Contours of surface water temperature for open water is visually descriptive but average values by lake segment (2 to 4 segments per lake) may be more easily understood by most interested persons.

Some lake buoys in both Canadian and U.S. water have both surface temperature data and water column temperatures. These data are available online from the Great Lakes Observing System by launching the observations explorer. They could be considered ancillary to the surface-water temperature data.

For additional information see http://data.glos.us/obs/

BIOLOGICAL INDICATORS

Fish Species of Interest
Prepared by: Gavin Christie

Definition
Population abundances of important members of the fish communities in different ecological areas of the Great Lakes.

Purpose and Importance
- To describe status and trends in abundance of populations of species representative of the health of fish communities and the habitats on which they depend.
- To indicate the status of populations supporting valued commercial, recreational, and aboriginal fisheries in the Great Lakes.
- To infer health of the ecosystem from the status of species at the top of the aquatic food chain.

Indicator Relevance
This indicator is relevant to the following general objectives of the Water Quality Agreement as amended by the Great Lakes Water Quality Protocol of 2012:

v. support healthy and productive wetlands and other habitats to sustain resilient populations of native species

This indicator is also relevant to those other objectives that affect the food web and ultimately fishes including objectives:

iv. be free from pollutants in quantities or concentrations that could be harmful to … aquatic organisms, through direct exposure or indirect exposure through the food chain;
vi. be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health.;
vii. be free from the introduction and spread of aquatic invasive species … that adversely impact the quality of the Waters of the Great Lakes

The indicator is also relevant to the Water Quality Agreement 2012 Annex 7 – Habitat and Species.

Measures
The indicator includes measures of 5 species representing 4 specific ecological zones of the Great Lakes:
1. Cold water, off shore - Lake Trout (*Salvelinus namaycush*), and Lake Whitefish (*Coregonus clupeaformis*)
2. Cool water, near shore - Walleye (*Sander vitreus*)
3. Cool water, near shore, rivers, and connecting channels - Lake Sturgeon (*Acipenser fulvescens)*
4. Warm water, near shore – Northern Pike (*Esox lucius*)

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

Native fish species are selected as indicator species because they represent the original fish communities in the different habitats, they have value to the ecosystem and to fisheries, and they are the focus of fisheries management and restoration efforts. Being co-evolved with the rest of the fish community and the natural ecosystem of the Great Lakes, these native represent the natural biodiversity of the lakes. Many are of high economic value and have been affected by fishing, often to the point of extirpation. They have been subjected to the full slate of other environmental effects caused by human disruption of the Great Lakes including habitat loss, nutrient pollution, and persistent toxic pollutants. These species are the focus of active fisheries management and of restoration efforts. While restoration efforts like stocking can complicate interpretation of their status, the successes of these species are indicative of progress toward the goals of the Great Lakes Water Quality Agreement. Introduced and naturalized non-native species are of significant public interest because they support valuable fisheries and while their status reflects the productivity of the food web, the native species are selected as indicators representing Great Lakes fish communities and habitats.

Native species of interest selected include top predators and large benthivores, that is fish feeding on benthic organisms. The Lake Trout is the native top predator in deeper, open waters of all of the Great Lakes. The Lake Whitefish is the top benthivore of those same waters. The Walleye is the top predator in the cool near-shore waters of all the Great Lakes. The iconic Lake Sturgeon is the longest lived and largest of all Great Lake fishes, and an indicator of the connectivity of tributaries. The Lake Sturgeon inhabits near shore and river habitats in all the Great Lakes, connecting channels, and St. Lawrence River. The Northern Pike is the top predator in near-shore waters and embayments.

Relative abundances of adults (catch per unit effort) measured annually will be used for these species either from assessment sampling or from assessments catch in commercial, aboriginal, or recreational fisheries. Data on condition and reproductive success are valuable supplementary information to interpret abundance trends and, while they are not included explicitly in this indicator, are invaluable to management and assessment. Fisheries management agencies carry out assessment netting and sampling programs. While none of these species have agency assessments using same methods, timing, and sample design in all five lakes over time, many index netting programs have long histories in select locations. Lake Trout, Walleye, and Lake Whitefish have the most consistent targeted assessment programs to support fisheries management and to evaluate restoration efforts, and in some lakes population estimates are developed to establish allowable harvest rates. Data about adult abundance also comes from assessment of the catch and by catch from commercial, aboriginal, and recreational fisheries. Records of historic and current commercial and recreational fishery harvest exist for all of these species. Direct assessments of Lake Sturgeon abundance in the lakes are somewhat rare and where not available status of Lake Sturgeon spawning in rivers has been used to indicate status of this species. The assembly of the indicators for these species of interest will include both fisheries independent assessments and fisheries data to produce relative abundance for each lake from which status and trends can be compared.

References

Bronte, C. R. et al. 2012. Lake Trout Indicator – State of the Great Lakes (SOLEC) 2012 – Draft – http://www.solecregistration.ca/en/indicator_reports.asp

Kayle, K. et al. 2012, Walleye Indicator – State of the Great Lakes (SOLEC) 2012 – Draft – http://www.solecregistration.ca/en/indicator_reports.asp

Elliott, R. et al. 2012. Status of Lake Sturgeon in the Great Lakes – State of the Great Lakes (SOLEC) 2012 – Draft – http://www.solecregistration.ca/en/indicator_reports.asp

Muir, A. M. et al. 2012. Re-Establishing Lake Trout in the Laurentian Great Lakes: Past, Present, and Future. In Taylor, W. W. et al. (eds) 2012 Great Lakes Fisheries Policy and Management: A Binational Perspective, Second Edition. Michigan State University Press.

Claramunt, R.M. et al. 2012. Pacific Salmonines in the Great Lakes Basin. In Taylor, W. W. et al. (eds) 2012 Great Lakes Fisheries Policy and Management: A Binational Perspective, Second Edition. Michigan State University Press.

Many, B. and L. Mohr, 2012. Rehabilitation of Lake Sturgeon in the Great Lakes: Making Progress. In Taylor, W. W. et al. (eds) 2012 Great Lakes Fisheries Policy and Management: A Binational Perspective, Second Edition. Michigan State University Press.

Harmful and Nuisance Algae
Prepared by: Sue Watson and Greg Boyer

Definition
Many algal and cyanobacterial blooms have harmful socioeconomic and/or ecological effects, but in this definition, '*Harmful*' *Algae (HA)* refers to those species with the genetic potential to produce (lethal or non-lethal) toxins[1] that affect human health, as well as health of livestock, pets, wildlife and other organisms (criteria I-III, below). In the Great Lakes and most other freshwaters, HA toxins are exclusively produced by certain species of cyanobacteria which may not always express their toxin genes (Rinta-Kanto & Wilhelm 2006; Boyer 2007). '*Nuisance' Algae (NA)* refers to a broader subset of algae and cyanobacteria that form blooms which are not toxic to humans but which cause ecological and socioeconomic harm (criteria II, III, below). Collectively, these can be referred to as Harmful and Nuisance Algae (HNA).

HNA definition criteria include (Smayda 1997; Watson & Boyer (2010):

I. *Human health effects:* these include acute, chronic or non-lethal effects from direct exposure to HA toxins, or indirect effects, e.g., via tainted food or high levels of bacterial pathogens in shoreline mats.
II. *Ecosystem effects:* these include impaired water quality**,** foodwebs and ecosystem services from toxic/bioactive algal metabolites, impaired foodweb nutrition and energy flow, degraded benthic habitat (e.g. shading, physical displacement, impaired spawning sites and reproductive success), and anoxia/hypoxia from HNA biomass degradation.
III. *Socioeconomic effects:* these include increased costs to health care; increased costs for drinking water utilities and industries for toxin/odour/TOC[2] removal, public relations; increased costs resulting from fouling of water intakes and shorelines; lost income to fisheries, aquaculture, and recreation/tourism; and decreased property values.

Indicator Relevance
HNA blooms (HNABs) are one of the most visible indicators of impaired water quality and receive widespread attention at all levels of society. HNABs are both a result of, and exacerbate, impaired water quality. Therefore:

1. The HNA indicator provides an index of ecosystem impairment and biological integrity and a direct measure of 'drinkable, swimmable, fishable' water as defined under the WQA.

2. The HNA indicator is relevant to 11 of the 14 listed AOC Beneficial Use Impairments (BUIs; Table below). The HNA index is directly related to (and can be used to assess) #s 1, 2, 6, 8, 9, 10, 11, 12, 13. In addition, HNA (and this index) can be indirectly related to BUIs #s 3 and 14.

Great Lakes Areas of Concern Beneficial Use Impairments (BUIs)
1. Restrictions on Fish and Wildlife Consumption
2. Tainting of Fish and Wildlife Flavour
3. Degraded Fish and Wildlife Populations

[1] e.g. microcystins, anatoxin-a, cylindrospermopsin, nodularin, saxitoxin, cytotoxins or irritants
[2] Total organic carbon

4. Fish Tumors or Other Deformities
5. Bird or Animal Deformities or Reproductive Problems
6. Degradation of Benthos
7. Restrictions on Dredging Activities
8. Eutrophication or Undesirable Algae
9. Restrictions on Drinking Water Consumption or Taste and Odour Problems
10. Beach Closings
11. Degradation of Aesthetics
12. Added Costs to Agriculture or Industry
13. Degradation of Phytoplankton and Zooplankton Populations
14. Loss of Fish and Wildlife Habitat

3. Because HNA respond rapidly to changes in nutrients and environmental stressors (e.g., climate, AIS) the HNA Indicator is a good performance assessment indicator which can track long and short-term management actions towards nutrient input and other factors and also provides a measure of energy, and material flow through food webs

4. HA blooms (HABs) have human health implications and this index should be integrated into other human health indicators

Measures

Cost effective and feasible measures promote long-term continuity of monitoring programs to evaluate trends. Differences in sampling regimes and analytical protocols affect data compatibility and the resolution of long term trends, and sparse sampling regimes can miss spatial and temporal peaks in HNA abundance. Most focus is on shoreline mats of attached algae (*Cladophora, Lyngbya;* Higgins et al 2008) or surface scums of cyanobacteria. These can appear/disappear rapidly with changes in mixing, currents and wind, producing significant spatial/temporal variance in biomass and toxin concentrations that makes quantification difficult. Therefore, multiple sites and frequent sampling are required so as to capture episodes of impaired water quality.

The following combined or separate metrics of the Harmful Algae Indicator (HAI) and/or Nuisance Algae Indicator (NAI) can be used to evaluate HNAI from biweekly samples (or more frequently during high risk periods if feasible) taken at high risk and reference[3] monitoring site**s** from discreet surface (0.5-1m) samples and/or euphotic zone integrated samples[4] and/or benthic mats from June-November (except HNAI_7, below). The sampling period should be adapted to local conditions and previous records of HNA seasonality, and may include winter (under ice) sampling if warranted.

HAI_1: Toxicity[5] i) annual % samples with Microcystin-LR (MC-LR)[6] concentrations > 10 µg/L (pelagic) or >20 µg/L (benthic) and ii) seasonal/ long term changes in MC-LR concentrations at focal monitoring sites

[3] i.e. no or low risk of impairment
[4] provides an estimate of HNAs under a given lake surface area with the potential to cause surface blooms
[5] It is assumed that untreated water is not directly consumed hence drinking water MC guidelines are overly stringent. The rationale for MC ≥10ug/L in one or more field sample is that monitoring is usually periodic (e.g.

HAI_2: Cyanobacterial (or other HNA taxa) dominance. % samples with chlorophyll-a (Chla) > 30 µg/L and HNA dominance (> ~80%), evaluated using microscopic, flow cytometric or fluorometric methods[7] b) taxonomic index (e.g. Downing et al 2001; Kane et al. 2004)

NAI_3: Pelagic chlorophyll with offensive malodour or taste. % samples with Chla > 30 µg/L and levels of common algal odour compounds (geosmin, 2-MIB, b-cyclocitral, decadienal) greater than the human odour threshold concentrations (OTCs; Watson 2003) or ii) malodour or taste unacceptable to sensory screening (sniff tests or standardized Flavour Profile Analysis; e.g. Dietrich 2004).

NAI_4: % or absolute benthic NA areal coverage[8]. % coverage of nearshore (up to 15 m depth) of NAs at high risk and reference sites, sampled from quadrants; or % coastline with > 50% coverage or 50 gm dwt/m^2 (Auer et al 2010; SOLEC 2012)

NAI_5: Benthic NA resulting in beach closures or similar negative shoreline impact. (see A(III) above). % positive scores where, if at a given site, there is a beach posting or closure[9] due to excess algal material.

NAI_6: Pelagic or benthic NA with other harmful effects. Using quantitative or qualitative criteria; these may be site specific (see A(III) above). Index is % positive scores for one or more of these harmful effects.

HNAI_7: Satellite-derived algal bloom metrics. Timing, intensity (average Chla concentration), duration, aerial extent (e.g. Binding et al 2010).

Organizations and HAB websites

CDC - http://www.cdc.gov/hab/cyanobacteria/facts.htm
HAB links - http://www.bigelow.org/hab/links.html
Toxic cyanobacteria - http://www-cyanosite.bio.purdue.edu/cyanotox/cyanotox.html
WHO - http://www.whoi.edu/redtide/
NOAA /GLERL - http://www.glerl.noaa.gov/res/Centers/HABS/
Non toxic HABs, inland waters -
http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/otherhab/
Satellite imagery - http://coastwatch.glerl.noaa.gov/
www.ec.gc.ca/scitech/default.asp?lang=En&n=4B40916E1&xsl=privateArticles2,viewfull&po=25208D0C

References

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weekly/biweekly/event-based), and the likelihood of similar or higher toxin levels around the collection date and site is very high. 20 µg/L MC represents the Health Canada/ WHO recreational guideline.

[6] >90 known variants (congeners) vary in toxicity; MC-LR is the most commonly measured and most toxic.

[7] based on a qualitative microscope inspection. Cyanobacteria abundance measures are problematic because they can be present as individual cells and/or aggregates (filaments, colonies, bundles, rafts etc)

[8] Over sufficient area to incorporate substrate heterogeneity; e.g. cumulative metric (median %cover, biomass) from 5 transects along a 1 km shoreline: from quadrats at multiple depths weighted by substrate availability.(D. Depew, pers. comm)

[9] Issued by a government or similar regulatory agency. Site is scored each week independent of whether a posting is new or prolonged

Auer, M.T., Tomlinson, L.M., Higgins, S.N., Malkin, S.Y., Howell, E.T., Bootsma, H.A. 2010. Great Lakes *Cladophora* in the 21st century: same algae – different ecosystem. J Great Lakes Res 36: 248 – 255.

Binding, C.E., T.A. Greenberg, J.H. Jerome, R.P. Bukata and G. Letourneau. 2010. An assessment of MERIS algal products during an intense bloom in Lake of the Woods. J. Plankton Res., doi: 10.1093/plankt/fbq133

Boyer, G. L. 2007. Cyanobacterial toxins in New York and the lower Great Lakes Ecosystems. Adv. Exp.Med. Biol. 619**:** 151-163

Dietrich A. 2004 Practical Taste-And-Odor Methods of Routine Operations: Decision Tree. American Waterworks Association report. A36p. ISBN 1583213384

Downing JA, Watson SB, McCauley E. (2001). Predicting Cyanobacteria dominance in lakes. Can. J. Fish. Aquat. Sci. 58:1905-1908.

Higgins, S.N., Malkin, S.Y., Howell, E.T., Guildford, S.J., Campbell, L., Hiriart-Baer, V. & Hecky, R.E. 2008. An ecological review of C*ladophora glomerata* (Chlorophyta) in the Laurentian Great Lakes. J. Phycol 44: 839-854.

Kane, D., S. Gordon, M. Munawar, M. Charlton, & D. Culver. 2005. A Planktonic Index of Biotic Integrity (P-IBI) for Lake Erie: A new technique for checking the pulse of Lake Erie. In *Checking the Pulse of Lake Erie*, eds. M. Munawar and R.T. Heath. Backhuys. Leiden, The Netherlands.

Rinta-Kanto J.M., & Wilhelm S.W. 2006. Diversity of microcystin-producing cyanobacteria in spatially isolated regions of Lake Erie. Appl. Environ. Microbiol.72:5083-5085.

Smayda T.J. 1997. Harmful Algal Blooms: their ecophysiology and general relevance to phytoplankton blooms in the sea. Limnol. Oceanog. 4:1138-1153.

SOLEC 2012 Draft State of the Great Lakes 2012 indicator reports; http://www.solecregistration.ca/en/indicator_reports.asp)

Watson SB, Molot L. Harmful Algal Blooms. *In* Férard JF., Blaise C. (Eds) Encyclopedia of aquatic ecotoxicology. Springer. (in press)

Watson, S.B & Boyer, G.L. Harmful Algal Blooms (HABS) in the Great Lakes: current status and concerns. 2011 SOLEC report

Watson, S.B. 2003. Chemical communication or chemical waste? A review of the chemical ecology of algal odour. Phycologia **42**: 333-350

Lower Food Web Productivity/Health
Prepared by: Bill Taylor

Definition
This indicator has three components: a) phytoplankton community structure and biomass; b) benthos abundance and diversity; c) prey fish abundance and diversity.

Indicator Relevance
Pelagic communities, on average, have approximately equal biomass in exponentially widening size classes (Sheldon et al. 1972; Sprules and Goyke 1994). Material and energy flow up this size spectrum from bacteria and phytoplankton via zooplankton to fish with varying efficiency (Borgmann 1987). Some of this production sinks from the surface euphotic zone to nourish the benthos. It may flow efficiently, with high productivity across the size-spectrum, or it may accumulate as algae, negatively affecting water quality while little energy reaches top predators. The purpose of this indicator is to measure the trophic efficiency of the food web at transferring algal production to fish. It is directly relevant to Annex 2 and 4 of the new WQA.

Measures
Phytoplankton community structure and biomass. Biomass can be assessed as chlorophyll a, which can be measured from water samples, *in situ* fluorometers, or (at the surface) via satellite. The ratio of Chl-a to total phosphorus (TP) constitutes a secondary indicator that indicates how much of the limiting nutrient is represented as algae, and can indicate the extent to which phytoplankton is controlled by grazing versus nutrients. Phytoplankton composition is quantified by microscopic counts, but information can now be generated by *in situ* fluorometry, as can the productivity of the phytoplankton and future monitoring should embrace these new tools (see sub-indicators below). Endpoints need to be established for all of these measures.

Benthos abundance and diversity is sampled with benthic grabs, whose contents are sieved, picked, measured or weighed, and identified. A knowledgeable benthologist could assess such samples, but there are no suitable endpoints or indicators available at this time. The abundance of the benthic amphipod *Diporeia* might be considered as an index, but *Diporeia* has declined recently and the cause of that decline is a matter of current research.

Preyfish abundance and diversity is sampled using trawl surveys. The SOLEC indicator "Preyfish Populations and Communities" has endpoints for prey fish biomass taken from Fish Community Goals and Objectives for each lake. As well, the SOLEC indicator "Zooplankton populations" uses mean length of zooplankton sampled with a specific net size (153 µm) as an index of the balance between forage fish and their zooplankton food (see sub-indicators below). An endpoint (0.8 mm mean size) has been proposed but may need further examination.

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

Potential sub-indicators (1, 2, 4, 5 are recommended above)

1. Chl-a/TP ratios. This ratio indicates the amount of phytoplankton relative to phosphorus. Small values would indicate a system with relatively little phytoplankton biomass and high turnover. Large values indicate a system where relatively more of the TP is expressed as algae indicating a food web that is inefficient at transferring production to higher trophic levels. Experimental and empirical studies support the interpretation of this ratio in the context of the balance between forage and predatory fishes (Carter et al. 1995), although more recently it has been interpreted with respect to the impact of dreissenids (Nichols et al. 1999). It should be possible to reconstruct this ratio as TP and Chla have been measured frequently for many years.

2. Zooplankton mean size directly assesses the balance between forage fishes and zooplankton through the well-known effect of planktivory by fishes on zooplankton size-distribution, although it may be problematical or need recalibration for lakes with *Mysis* (Mills and Schiavone 1982). It has been used in and around the Great Lakes by several authors (Mills and Schiavone 1982, Almond et al. 1996, Taylor and Carter 1997).

3. Plankton stoichiometry. The ratios of C/P, C/N and N/P in seston were calibrated against phytoplankton nutrient limitation by Healey and Henzel (1979, 1980) and have been extensively used in the Great Lakes to indicate nutrient status of phytoplankton (e.g., Guildford et al. 2005). Like Chla/TP, it is likely possible to calculate this variable from historical records of POC, PON, and PP.

4. Fv/Fm. New fluorometric probes allow the determination of *in situ* photosynthesis and the efficiency of photosynthesis (Fv/Fm) to diagnose the productivity of phytoplankton, e.g., Pemberton et al. (2006). These probes allow data to be collected relatively rapidly, as in profiling and towing, and have been calibrated against traditional, and much more tedious, measures (Rattan et al. 2012). They could be monitored from buoys. Although there are no historical records, their promise for diagnosing performance of the phytoplankton is sufficient that their addition to current monitoring protocols should be considered.

5. Relative abundance of major phytoplankton phyla. Phytoplankton composition is an important indicator of water quality, particularly the relative abundance of Cyanobacteria versus diatoms and flagellates. While counting phytoplankton is time-consuming, limiting the number of samples that can be processed, fluorometry now offers the ability to determine plankton composition *in situ* with a probe (Ghadouani and Smith 2005) although there may still be issues with calibration to Great Lakes conditions (Twiss 2011). Phytoplankton counting can then be restricted to the number of samples required to calibrate the fluorometer and to investigate blooms. New devices coming to the market promise to combine determination of phytoplankton abundance and prevalence of taxa of special importance (e.g., toxin producers) with phytoplankton productivity.

6. Particulate phosphorus size-distribution (PP slope). This measure was first used by Mazumder et al. (1989) in a study of the effect of fish manipulations and nutrient additions on the phosphorus cycle in large mesocosms. It employs sequential filtration of lakewater to determine the distribution of particulate P with size, and is summarized as the slope of particulate P fraction against particle size. A system with equal PP in 4 exponential size-classes (picoplankton, nanoplankton, microplankton and mesoplankton) has a slope of 0.25, and slope varies among lakes from about 0.2 (large-particle dominated) to about 0.3 (small-particle dominated). It has been used in many studies subsequently, and is technically straightforward. On the downside, there are few historical data for the Great Lakes.

7. Normalized Size-Spectra. This measure is similar in principal to the previous one, but depends on biomass determination across the particle spectrum from phytoplankton to fish, and has been used to compare Great Lakes and estimate productivity (Sprules et al. 1991, Sprules and Goyke 1994).

8. Particle-size conversion efficiency. This measure, introduced by Borgmann (1982, 1987) and applied to the Great Lakes, expresses the efficiency with which energy moves up the pelagic size-spectrum. It is based on both the size-spectrum and a measure of production at some point along the spectrum, usually the zooplankton, so it resembles the normalized spectrum approach. However, it can be estimated by the concentration of PBTs at different trophic levels, e.g., zooplankton and predatory fish (Borgmann and Whittle 1983). Therefore, it may be possible to reconstruct PSCE from historical data.

<u>References</u>

Almond, M.J.R., E. Bentzen and W.D. Taylor. 1996. Size-structure and species composition of plankton communities in deep Ontario lakes with and without *Mysis relicta* and planktivorous fish. Can. J. Fish. Aquat. Sci. 43: 315-325.

Borgmann, U. 1982. Particle-size-conversion efficiency and total animal production in pelagic ecosystems. Can. J. Fish. Aquat. Sci. 39: 668-684.

Borgmann, U. 1987. Models on the slope of, and biomass flow up, the biomass size-spectrum. Can. J. Fish. Aquat. Sci. 44 (suppl. 2) 136-140.

Borgmann, U. and D.M. Whittle. 1983. Particle-size-conversion efficiency and contaminant concentrations in Lake Ontario. Can. J. Fish. Aquat. Sci. 40: 328-336.

Carter, J.C.H., W.D. Taylor and C. Tudorancea. 1995. A horizontal gradient in plankton community structure at Twelve Mile Bay, Georgian Bay, and its implications for the relationships among mesozooplankton, microzooplankton, and phytoplankton. Arch. Hydrobiol. 133: 197-222.

Ghadouani, A. and R.E.H. Smith. 2005. Phytoplankton distribution in Lake Erie as assessed by a new in situ spectrofluorometric technique. J. Great Lakes Res. 31 (Suppl. 2) 154-167.

Guildford, S.J., R.E. Hecky, R.E.H. Smith, W.D. Taylor, M.N. Charlton, L. Barlow-Busch, and R.L. North. 2005. Phytoplankton nutrient status in Lake Erie in 1997. J. Great Lakes Res. 31: 72-88.

Healey, F.P. and L.L. Hendzel. 1979. Indicators of phosphorus and nitrogen deficiency in five algae in culture. J. Fish. Res. Bd. Can. 36: 1364-1369.

Healey, F.P., and L.L. Hendzel. 1980. Physiological indicators of nutrient deficiency in lake phytoplankton. Can. J.Fish. Aquat. Sci. 37:442–453.

Mazumder, A., D.J. McQueen, W.D. Taylor, and D.R.S. Lean. 1988. Effects of fertilization and planktivorous fish (yellow perch) predation on size-distribution of particulate phosphorus and assimilated phosphate: large enclosure experiments. Limnol. Oceanogr. 33: 421-430.

Mills, E.L. and A. Schiavone. 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. North Am. J. Fish. Management 2: 14-27.

Nicholls, K.H. et al. 1999. Reduced chlorophyll to phosphorus ratios in nearshore Great Lakes waters coincide with the establishment of dreissenid mussels. Can. J. Fish. Aquat. Sci. 56: 153-161.

Pemberton, K.L., Smith, R.E.H., Silsbe, G.M., Howell, T. and Watson, S. 2006. Controls on phytoplankton physiology in Lake Ontario during the late summer: Evidence from new fluorometric methods. Can. J. Fish. Aquat. Sci. 64: 58-73.

Rattan, K.J., W.D. Taylor and R.E.H. Smith. 2012. Nutrient status of phytoplankton across a trophic gradient in Lake Erie: Evidence from new fluorescence methods. Can. J. Fish. Aquat. Sci. 69: 94-111.

Sheldon, R.W., A. Prakash, and W,H, Sutcliffe, Jr. 1972. The size distribution of particles in the ocean. Limnol. Oceanogr. 17: 327-340.

Sprules, W.G., S.B. Brandt, D.J. Stewart, M. Munawar, E.H. Jin, and I.M. Gray. 1991. Biomass size spectrum of the Lake Michigan pelagic food web. Can. J. Fish. Aquat. Sci. 48: 105-115.

Sprules, W.G., and A.P. Goyke. 1994. Size-based structure and production in the pelagia of Lakes Ontario and Michigan. Can. J. Fish. Aquat. Sci. 51: 2603-2611.

Taylor, W.D. and J.C.H. Carter. 1997. Zooplankton size and its relationship to trophic status in deep Ontario lakes. Can. J. Fish. Aquat. Sci. 54:2691-2699.

Twiss, M.R. 2011. Variations in chromophoric dissolved organic matter and its influence on the use of pigment-specific fluorometers in the Great Lakes. J. Great Lakes Res. 37: 124-131.

Extent, Composition, and Quality of Coastal Wetlands
Prepared by: Don Uzarski

Definition and Overview
This indicator currently tracks the trends of Great Lakes coastal wetland ecosystem health by measuring the composition and density of macroinvertebrates, fish, plants, amphibians, and birds at approximately 200 wetlands per year using a stratified random site selection process. Through SOLEC, the Great Lakes Coastal Wetlands Consortium developed indices of biological integrity (IBIs) for each of the groups (hereinafter 'sub-indicators') in 2002 and protocols were finalized in 2008 (GLCWC 2008); the invertebrate and fish sub-indicators in particular have been developed and tested via peer-reviewed scientific literature as well. Monitoring of Great Lakes coastal wetlands is currently being conducted using GLRI funds and will continue for at least five years (current funding through 2015). Upon completion of the fifth year, every Great Lakes coastal wetland in the basin greater than 4 hectares in size with a surface water connection to the Great Lakes will be sampled and a baseline will be established. The stratified random design does have a re-sampling component in place to ensure that wetland by year interaction, or temporal variation, is captured. The number of sites sampled per year after the completion of the baseline is yet to be determined, but will likely fall between 100 and 200 sites. Several Great Lakes coastal wetland types, like dune and swale complexes, forested swamps, and barrier beaches, do not fall within the scope of the current monitoring plan, but these wetland types will also eventually have to be addressed. The five sub-indicators being used in the current monitoring project are existing individual SOLEC indicators. Individual IBIs are derived for each of the sub-indicators which can be used independently as a measure of Great Lakes coastal wetland ecosystem health based on a percentage of points possible reflected as 'reference conditions' to 'extremely degraded'. However, an overall view of wetland health can be derived by considering these sub-indicators in combination, because they function and indicate anthropogenic disturbance at different spatial and temporal scales and have varying resolution of detection. For example, the vegetation sub-indicator tends to indicate coarse scale regional variation while invertebrates detect much more local disturbance within regions. Fish tend to detect disturbance somewhere between the local and regional scale. The geographic scale of disturbance for birds and amphibians is not yet determined, nor is the resolution for detecting ecosystem health. Landscape measures are used to determine loss, transformation and restoration of wetland types experiencing varying degrees of anthropogenic disturbance. However, landscape measures have been challenging due to data gaps and because coastal wetlands are extremely dynamic systems; they migrate, disappear, and appear with changing water levels not necessarily related to anthropogenic disturbance.

Indicator Relevance
Recognition and appreciation of the importance of coastal wetlands in the Great Lakes ecosystem has grown markedly in recent decades as numerous important ecosystem functions have been ascribed to these habitats. For example, coastal wetlands provide critical breeding and migratory habitat for wildlife such as birds, mammals, reptiles, and amphibians (Austen et al. 1994, Hanowski et al. 2007a, Hecnar 2004, Mitsch and Gosselink 1993). These habitats are also critical spawning and nursery areas for many fish species of ecologic and economic importance (Jude et al. 2005, Chubb and Liston 1986, Klarer and Millie 1992). Additionally, coastal wetlands trap, process, and remove nutrients and sediment from Great Lakes nearshore waters; and recharge groundwater supplies (Burton 1985, Heath 1992). Accordingly, broad consensus has emerged among scientists, resource managers, and policy-makers on the importance of coastal wetland functions to the entire Great Lakes ecosystem. However, over half of all Great Lakes coastal wetlands have been destroyed by human activities and many remaining coastal wetlands suffer from anthropogenic stressors such as nutrient and sediment loading, fragmentation,

invasive species, shoreline alteration, and water level control (Burton 1985, Krieger et al. 1992, SOLEC 2007), as documented by a bi-national Great Lakes-wide mapping and attribution project (Albert and Simonson 2004, Ingram and Potter 2004). Therefore, conservation of remaining coastal wetlands and restoration of previously destroyed wetlands are vital components of restoring the Great Lakes ecosystem. Indicators of Great Lakes coastal wetland health must be monitored to accomplish this. Several essential measures of coastal wetland health are listed below.

<u>Measures</u>

Macroinvertebrates

Macroinvertebrate samples should be collected annually from the dominant plant zones in each wetland (Uzarski et al. 2004) using dip nets in accordance with standard SOLEC protocols. Plant zones are defined as patches of vegetation in which a particular plant type or growth form dominates the plant community based on visual coverage estimates. Numerous replicate samples are collected from each plant zone within each wetland. Sampling should begin in mid-June in the most southerly regions of the Great Lakes and continue into early September, moving north with annual development of the vegetation and macroinvertebrates. Sampling should be conducted when emergent plant communities generally achieve maximum annual biomass. Macroinvertebrates collected in the field are then identified in the laboratory using standard taxonomic keys. This information is then used to calculate an IBI score in accordance with Great Lakes Coastal Wetlands Consortium (GLCWC) protocols. Great Lakes coastal wetland ecosystem health is then quantified based on a percentage of points possible reflected as ‘reference conditions’ to ‘extremely degraded’ from the perspective of the invertebrate community.

Fish

Fish sampling should be conducted using three replicate fyke nets in each major plant zones in each wetland for one net-night (Uzarski *et al*. 2005). The method of determining locations at which to set nets is identical to that for invertebrate sampling described above. Locations should correspond with those for macroinvertebrate and water quality sampling. Nets should be placed perpendicular to the vegetation zone of interest, and therefore, fishes within or moving along the edge of the plant zone are likely to be caught. The timing of sampling should correspond with the maturity of the vegetation in each system. Fish should be identified to species, counted, and measured before being released. Data should be used to calculate the GLCWC (2008) IBI to provide a score based on a percentage of points possible reflected as ‘reference conditions’ to ‘extremely degraded’ from the perspective of the fish community.

Plants

Identification and quantification of all wetland plant species occurring in a specified number of sampling quadrants at each wetland are required so sampling should take place in July and August on an annual basis. Within each wetland, sampling should occur along three transects perpendicular to depth contours crossing wetland vegetation zones present; the number of vegetation zones will vary depending on each particular wetland. Operationally-defined vegetation zones are wet meadow, emergent vegetation, and submergent vegetation. If a distinct submergent zone is present, it should also be sampled. Data should be used to calculate wetland ecosystem health according to GLCWC (2008). The score derived for ecosystem health based on plants relies heavily on the Floristic Quality Index (FQI) and the occurrence of invasive species.

Amphibia (Frogs and Toads)

Amphibian species (both presence-absence and semi-quantitative) within each wetland are based on listening and counting frog and toad (anuran) vocalizations in accordance with SOLEC procedures. Sites should be visited up to three times per breeding season during peak vocalization periods. Surveys should be conducted from one-half hour before sunset to four and one-half hours after sunset and only during acceptable weather conditions (GLCWC 2008). Dates of sampling should be dependent on the timing of amphibian development for a given year and general weather conditions. In southern regions, amphibian counts can generally be initiated in early April, but should be later in the northern regions. This sub-indicator is still in the developmental phase and it is not known if it can eventually be used alone as an indicator of ecosystem health. It is currently being used to indicate temporal variation in anuran communities.

Birds
The composition and density of bird species within each wetland are measured annually by counting the number of species and individuals at predetermined sampling locations in each wetland. The number of bird counting points will be dependent on wetland size, but generally are the same locations used for the amphibians. To get a good representation of the bird community, both shoreline (i.e., approximate upland/wetland interface) and interior stations should be sampled.

Point count surveys should be conducted either from one-half hour before sunrise to four hours after sunrise or four hours before sunset. The number of birds seen or heard should be recorded during 15-minute observation periods (5 minutes of passive observation, 5 minutes of broadcast calling, 5 minutes of passive observation) at each point count station (GLCWC 2008). Wetlands should be surveyed twice per breeding season, with a minimum of 10 days between visits. One count should be in the morning and one count in the evening. This sub-indicator is still in the developmental phase and it is unknown if it can eventually be used alone as an indicator of ecosystem health. It is currently being used to indicate temporal variation in bird communities.

Chemical/Physical
Basic chemical and physical data should be collected concurrently with invertebrate and fish samples in accordance with the GLCWC Monitoring Plan (GLCWC 2008). These covariate data represent important measures of wetland condition and are used to account for variability in biotic indicators. These data are critical for adaptive management. As more data accumulate these data allow for IBI testing and refining.

Water quality should be determined for single composite samples collected from the sampling locations within each vegetation zone and associated with invertebrate and/or fish sampling. The following measurements should be made in the field: temperature, dissolved oxygen, pH, specific conductivity, transparency tube clarity, oxidation-reduction potential (redox), and in situ chlorophyll fluorescence. Alkalinity, turbidity, soluble reactive phosphorus (SRP), [nitrate+nitrite]-nitrogen, ammonium-nitrogen, chlorophyll-a, total nitrogen (TN), total phosphorus (TP), chloride, color, and sediment percent organic matter should be measured in the lab according to APHA.

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

losses of wetland area, land cover/land use adjacent to each wetland, changes in land use/land cover across the basin, and area dominated by invasive vegetation.

Overall Index of Wetland Health

While the individual indices of biological integrity (IBIs) derived for each of the sub-indicators can be used independently as a measure of Great Lakes coastal wetland ecosystem health, an overall index of wetland health can potentially be derived by combining these individual scores, and therefore, providing the most reliable and complete measure of the extent, composition and quality of coastal wetlands in the basin. An attempt to combine sub-indicators into an overall measure of wetland health is currently underway.

References

Albert, D.A., and L. Simonson. 2004. *Coastal wetland inventory of the Great Lakes region* (GIS coverage of U.S. Great Lakes: www.glc.org/wtlands/inventory.html), Great Lakes Consortium, Great Lakes Commission, Ann Arbor, MI.

Anderson, P. and R.D. Davic. 2004. Use of transparency tubes for rapid assessment of TSS and turbidity in streams. *Lake and Reservoir Management* 20:110-120.

APHA. 2005. *Standard Methods for the Examination of Water and Wastewater.* 25^{th} Edition. American Public Health Association.

Austen, M.J.W., M.D. Cadman, and R.D. James. 1994. *Ontario Birds at Risk: Status and Conservation Needs.* Federation of Ontario Naturalists and Long Point Bird Observatory. 165 pp.

Burton, T.M. 1985. Effects of water level fluctuations on Great Lakes coastal marshes. In: *Coastal Wetlands*, Lewis Publishers, Chelsea Michigan. Pp. 3-13.

Chubb, S.L., and C.W. Liston. 1986. Density and distribution of larval fishes in Pentwater Marsh, a coastal wetland on Lake Michigan. *Journal of Great Lakes Research* 12: 332-343.

GLCWLC 2008. Great Lakes Coastal Wetlands Monitoring Plan. Great Lakes Coastal Wetlands Consortium, March 2008. www.glc.org/wetlands/final-report.html.

Hanowski, J.M., N. Danz, R. Howe, G. Niemi, and R. Regal. 2007a. Consideration of geography and wetland geomorphic type in the development of Great Lakes coastal wetland bird indicators. *Ecohealth* 4:194-205.

Heath, R.T. 1992. Nutrient dynamics in Great Lakes coastal wetlands: future directions. *Journal of Great Lakes Research* 18: 590-602.

Hecnar, S.J. 2004. Great Lakes wetlands as amphibian habitats: a review. Aquatic *Ecosystem Health and Management*. 7(2): 289-303.

Ingram, J. W., and B. Potter. 2004. Development of a Coastal Wetlands Database for the Great Lakes Canadian Shoreline. http://www.glc.org/wetlands/inventory.html Great Lakes Consortium, Great Lakes Commission, Ann Arbor, MI.

Jude, D., D.A. Albert, J. Brazner, and D.G. Uzarski. 2005. Lake Michigan's Coastal Wetlands: Distribution and Fish Utilization. Pages 439-477. *In* M. Munawar and T. Edsall (eds.), *The State of Lake Michigan*, Ecovision World Monograph Series, S. P. B. Academic Publishing, The Netherlands.

Klarer, D. and D.F. Millie. 1992. Aquatic macrophytes and algae at Old Woman Creek estuary and other Great Lakes coastal wetlands. *Journal of Great Lakes Research* 18: 622-633.

Krieger, K.A., D.M. Klarer, R.T. Heath, and C.E. Herdendorf. 1992. Coastal wetlands of the Laurentian Great Lakes: current knowledge and research needs. Preface: a call for research on Great Lake coastal wetlands. *Journal Great Lakes Research* 18: 525-528.

Merritt, R.W., K.W. Cummins, and M.B. Berg. 2008. *An Introduction to the Aquatic Insects of North America*, fourth ed. Kendall/Hunt Publishing Co., Dubuque, IA. 1158 pp.

Minnesota Pollution Control Agency (MPCA). 2007. Guidance manual for assessing the quality of Minnesota surface waters for the determination of impairment 305(b) Report and 303(d) List. September 2007. Minnesota Pollution Control Agency, Environmental Outcomes Division, St. Paul, MN, 55155.

Minnesota Pollution Control Agency (MPCA). 2006. Turbidity TMDL Protocols and Submittal Requirements. Minnesota Pollution Control Agency, St. Paul MN, December 2006. 100 p. www.pca.state.mn.us/publications/wq-iw1-07.pdf

Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands.* Van Nostrand Reinhold, New York.
SOLEC. 2007. State of the Great Lakes. Environment Canada and United States Environmental Protection Agency. ISBN 978-0-662-47328-2. EPA 905-R-07-003. Cat No. En161-3/1-2007E-PDF. http://www.epa.gov/solec/sogl2007/SOGL2007.pdf

Thorp, J.H., and A.P. Covich. 2010. *Ecology and Classification of North American Freshwater Invertebrates*. 3rd Edition. Academic Press, San Diego, CA. 911 pp.

Uzarski, D.G., T.M. Burton, and J.A. Genet. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. *Aquatic Ecosystem Health and Management*. 7:269-288.

Uzarski, D.G., T.M. Burton, M.J. Cooper, J. Ingram, and S. Timmermans. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: Development of a fish-based Index of Biotic Integrity. *Journal of Great Lakes Research* 31(supplement 1): 171-187.

Weeber, R.C., and M. Vallianatos (eds.). 2000. *The Marsh Monitoring Program 1995-1999. Monitoring Great Lakes wetlands and their amphibians and bird inhabitants.* Bird Studies Canada in cooperation with Environment Canada and U.S. Environmental Protection Agency.

<u>Aquatic Invasive Species: invasion rates and impact</u>
Prepared by: Bill Taylor

Aquatic Invasive Species, sub-indicator 1: rate of invasion

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

<u>Indicator Relevance</u>
The purpose of this indicator is to measure the success of management actions to reduce the rate of new species arriving in the Great Lakes. It will not deal with severity or extent of impact and be as inclusive as possible in terms of the species used in the indicator.

<u>Measures</u>
This indicator depends on the timely detection of new AIS. To support rapid response programs being planned and implemented, sites that are high risk invasion points (harbours, marinas, city waterfronts, city parks connected to Great Lakes) should be selected and monitored. The selection of sites and the type of monitoring to be conducted at those sites should be based on risk assessment. A pilot program that is widely considered to be state of the art has been implemented at Duluth (USGS 2007, Dupré 2011). The current state of AIS monitoring activity in the Great Lakes was reviewed by Dupré (2011), and data on AIS are currently maintained at the Great Lakes Aquatic Non-Indigenous Species Information System (GLANSIS).

A challenge with this indicator is that invasions are low frequency, stochastic events. Therefore, it is hard to detect signal from noise. Plotting cumulative numbers of invasions may be appropriate, as will analyses that can detect changes in slope of cumulative numbers versus time (e.g., Ricciardi 2001; Holeck et al. 2004).

Aquatic Invasive Species, sub-indicator 2: status and impact of AIS (number, and distribution)

<u>Definition</u>
This is defined as status and impact of aquatic invasive species having detrimental effects. It specifically excludes species that are benign or perceived to be desirable species. Status will be generally measured as biomass of AIS relative to native species of equivalent trophic position (e.g., zooplankton, planktivorous fishes). Impact may be anything that prevents the achievement of any of the General Objectives (Article 3) of the WQA, or that contributes to a Beneficial Use Impairment (Annex 1, WQA) and may be quantified differently for different AIS, e.g., impact of sea lampreys may be quantified as wounding rates on a species of interest and/or contribution to mortality.

<u>Indicator Relevance</u>
The purpose of this indicator is to measure the extent to which Great Lakes are populated by AIS, to quantify their detrimental impact, and to evaluate the success of mitigation measures.

<u>Measures</u>
AIS information requires broad-spectrum biological sampling, including plankton sampling, benthic sampling (nearshore and offshore), wetland sampling for plants and fauna, zooplankton sampling, and

trawling for fish. Secondary processing of samples beyond simple counting and measuring would be required to identify alien pathogens. Therefore, operational definition of this indicator should build on monitoring activities put in place for other reasons, rather than require new and redundant sampling efforts. For example, this indicator should capitalize on data collected for:

- Indicator 2, fish species of interest. Trawl, gillnetting, and other sampling activities should be used to record the fraction of AIS relative to native species
- Indicator 5, lower food web productivity/health. The contribution of AIS and NIS to total phytoplankton, zooplankton, and benthos should be recorded.
- Indicator 6, coastal wetlands. The contribution of AIS and NIS to biological sampling of fish, plants, and invertebrates should be recorded.

Other sampling programs that should contribute to this effort include:

- the proposed special monitoring for new AIS in high risk areas (see sub-indicator-1 on new AIS).
- data currently collected on larval lamprey abundance and wounding rates (available from http://www.glfc.org/sealamp/status.php)
- five-yearly sampling conducted as part of the Cooperative Science Monitoring Initiative (CSMI)

In the future, it may also be possible to integrate molecular methods into monitoring for AIS relative abundance in the future (Darling and Mahon 2011; Dejean et al. 2011).

References

Darling, J.A. and A.R. Mahon. 2011. From molecules to management: adopting DNA-based methods for monitoring biological invasions in aquatic environments. Environmental Research. 111(7): 978-988.

Dejean T, Valentini A, Duparc A, Pellier-Cuit S, Pompanon F, et al. 2011. Persistence of environmental DNA in freshwater ecosystems. PLoS ONE 6(8): e23398.

Dupré, S. 2011. An assessment of early detection monitoring and risk assessments for aquatic invasive species in the Great-Lakes St. Lawrence Basin. IJC.

Holeck, K.T., E.L. Mills, H.J. MacIsaac, M.R. Dochoda, R.I. Colautti, A. Ricciardi. 2004. Bridging troubled waters: biological invasions, transoceanic shipping, and the Laurentian Great Lakes. BioScience 54: 919 - 929.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an “invasion meltdown” occurring in the Great Lakes? Can. J. Fish. Aquat. Sci. 58: 2513-2525.

USGS. 2007. Field notes, available at http://www.fws.gov/fieldnotes/regmap.cfm?arskey=22338

Abundance and Distribution of Fish-Eating and Colonial Nesting Birds

Prepared by: Bill Bowerman

Definition

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

Indicator Relevance

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

Measures

This indicator includes the following measures of biological, physical and chemical integrity. Measures for biological integrity include reproductive output, rate of developmental deformities, distribution and number of nesting pairs, and physiological biomarkers. Measures reflecting physical integrity include nesting habitat, and effects of climate change on nesting chronology. Fish-eating birds are also excellent measures of chemical integrity. Herring gull eggs have been collected annually on all 5 lakes and connecting channels since 1973 (Weseloh and Moore 2011). The locations and sizes of colonies for all species of colonial waterbirds are documented every 10 years along all Great Lakes and connecting channels. Fish-eating birds are indicators in many of the AOCs, and are used for delisting criteria. While Herring Gull eggs provide a consistent, annual trend of contaminant trends, they fail to assess direct biological effects.

Bald Eagle population surveys have been conducted along most Great Lakes shorelines and interior areas since 1961. These surveys continue along the US shorelines of all 5 lakes, and along Lakes Erie and Ontario in Canada, and statewide in Michigan and New York. All Great Lakes shoreline habitat was quantified in 1992 (Bowerman et al. 2005). Blood, feathers, eggs and tissues are collected annually (Bowerman et al. 1995; Stromberg et al. 2007; Best and Wilke 2009; Route et al. 2011).

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

Relationships for contaminant concentrations among species and among tissues allow us to utilize the guild of fish-eating birds as the indicator (Weseloh and Moore 2011). Cause-effect relationships between biological outcomes and chemical, biological, and physical stressors for each species allow for direct comparison of health across spatial and temporal scales.

References

Best, D., E. Wilke. 2009. Detroit River-Western Lake Erie Indicator Project: Bald eagle indicator of reproductive success, accessed at http://www.epa.gov/medatwrk/grosseile_site/indicators/eagles.html

Bowerman, W.W., J.P. Giesy, D.A. Best, and V.J. Kramer. 1995. A review of factors affecting productivity of bald eagles in the Great Lakes region: Implications for recovery. *Environmental Health Perspectives* 103 (Suppl. 4):51-59

Bowerman, W.W., T. G. Grubb, A.J. Bath, J.P. Giesy, D.V.C. Weseloh. 2005. A survey of potential bald eagle nesting habitat along the Great Lakes shoreline. Res. Pap. RMRS-RP-56WWW access at http://www.fs.fed.us/rm/pubs/rmrs_rp056.pdf

Route, B., P. Rasmussen, R. Key, S. Hennes, M. Meyer, M. Martell. 2011. Emerging contaminants in nestling bald eagles at three National Parks in the Upper Midwest, Poster at IAGLR 2011, accessed at http://science.nature.nps.gov/im/monitor/meetings/GWS_2011/docs/GWS_IAGLR%202011.pdf

Stromberg, K., D. Best, P. Martin, W. Bowerman. 2007. Contaminants affecting productivity of bald eagles, Indicator 8135, SOLEC 2007, accessed at www.epa.gov/solec/sogl2007/8135_bald_eagles_contaminants.pdf

Weseloh, D.V.C., D. Moore. 2011. Contaminants in fish-eating waterbirds, draft SOLEC report accessed at http://www.solecregistration.ca/documents/Contaminants%20in%20Waterbirds%20DRAFT%20Oct2011.pdf

APPENDICES

Appendix A

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