THE DEVELOPMENT AND IMPLEMENTATION OF INDICATORS OF ECOSYSTEM HEALTH IN THE GREAT LAKES BASIN

HARVEY. SHEAR[1]*, NANCY STADLER-SALT[2], PAUL BERTRAM[3] and PAUL HORVATIN[4]

[1] *Environment Canada - Ontario Region, Office of the Regional Science Advisor, 4905 Dufferin Street, Downsview, ON, Canada M3H 5T4;* [2] *Environment Canada – Ontario Region, Office of the Regional Science Advisor, 867 Lakeshore Rd., Burlington, ON, Canada L7R 4A6;* [3] *U.S. Environmental Protection Agency, Great Lakes National Program Office, 77 West Jackson Blvd., Chicago, IL USA 60604;* [4] *U.S. Environmental Protection Agency, Great Lakes National Program Office, 77 West Jackson Blvd., Chicago, IL USA 60604 (*author for correspondence, e-mail harvey.shear@ec.gc.ca)*

Abstract. This paper describes a process for the selection of a suite of ecosystem health indicators for the Great Lakes, as called for in the Great Lakes Water Quality Agreement. The paper also presents some preliminary data on status and trends in ecosystem components based on those indicators. The indicator selection process was carried out by over 150 scientists and managers from both Canada and the USA, and involved the presentation of the proposed indicators at the State of the Lakes Ecosystem Conferences (SOLECs). An open period for comment followed the conferences where input from scientists involved in Great Lakes programs was received. The suite of indicators will, over time, present information in an understandable format that will allow for more informed management decisions.

1. Introduction

The purpose of the Great Lakes Water Quality Agreement (GLWQA) between the United States and Canada is 'to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem' (United States and Canada, 1987). The Agreement also calls for the development of ecosystem health indicators. The two countries have spent billions of dollars and hundreds of thousands of hours attempting to reverse the effects of cultural eutrophication, toxic chemical pollution, bacterial pollution, over-fishing, habitat destruction, and introduced species, and trying to prevent future problems from arising. Environmental and natural resource management agencies are now trying to demonstrate that past remediation programs have been successful, and that the results of future or continuing programs will be positive and proportionate to the resources expended (financial and personnel time).

Assessing the health of the Great Lakes basin ecosystem is a significant challenge. The Lakes themselves contain one-fifth of the world's fresh surface water with over 17,000 km of shoreline. The basin consists of over 520,000 km^2 of land with about 33.5 million people living there. The basin is governed by two

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nations, eight states, one province, and hundreds of municipal and local governments. A set of Great Lakes basin ecosystem indicators will enable the Great Lakes community to work together within a consistent framework to assess and monitor changes in the state of the ecosystem. Data collected through various government and non-government programs can be analysed, interpreted, and ecosystem health information characterized within a series of such indicators. A consensus by environmental management agencies and other interested stakeholders about what information is necessary, sufficient and feasible to characterize the state of Great Lakes ecosystem health, and to measure progress toward ecosystem goals and objectives, will facilitate more efficient monitoring and reporting programs.

Concepts of human health are fairly well defined and familiar to most people. The World Health Organization revised the definition to include elements beyond mere absence of disease, or physical well-being, including elements such as mental and social well-being (cited in Rapport, 1995). It is possible to apply these same definitions to ecosystems. Ecosystem health can be measured to some degree and characterized as having 7 key properties. They are:

(1) free from ecosystem distress syndrome; (2) resilient; (3) self-sustaining; (4) do not impair adjacent ecosystems; (5) free from risk factors; (6) economically viable; and (7) capable of sustaining healthy human populations (Rapport, 1995). This raises a more basic question, however, about the nature of ecosystems.

Callicott (1995) questioned the very concept of the ecosystem health. Do ecosystems exist as self-regulating entities with a particular species composition, and inherent measures of health? Are there spatial bounds that define ecosystems? Is there integrity to these systems? Callicott (1995) concludes that ecosystems do exist as sets of process functions within temporal boundaries, and that ecosystem health is an objective condition that can be measured, albeit with an overlay of societal values. In the context of the Great Lakes, ecosystem health has been accepted as a concept (Governments of the United States of America and of Canada, 1987). Society is beginning to recognize that to achieve that health, socio-economic trade-offs will be necessary, and the natural history of the resource must be recognized (Steedman, 1994).

In the context of the Great Lakes, the ecosystem is given a spatial boundary, namely the watershed of the Great Lakes. The temporal component to the definition is any arbitrary time chosen for management action or investigation. More importantly, the ecosystem approach is the defining mechanism by which management agencies are to carry out their research and deliver their regulatory programs (Governments of the United States and of Canada, 1987; Vallentyne and Beeton, 1988; Hartig and Vallentyne, 1989; Hartig and Zarull, 1992; International Joint Commission, 1995). In real terms, the ecosystem approach has come to mean a comprehensive approach to environmental issues, considering the interacting living (including humans) and non-living components of the Great Lakes basin.

In terms of health, animal populations can be measured as to age, size, reproductive success, incidence of disease, and rate of death. Alternatively, the health of individual organisms can be measured by biochemical, cellular, physiological or behavioural characteristics. These measures are discontinuous in the sense that they do not represent ecosystem health so much as they do individuals' health. With respect to the health of the Great Lakes, scientists and non-scientists have engaged in the development of appropriate ecosystem indicators for some time (Ryder and Edwards, 1985; Edwards and Ryder, 1990; Bertram and Reynoldson, 1992; Bertram and Stadler-Salt, 1999; Bertram *et al.*, 2002). Scientists have become what Lincoln (1995) has called for, namely the 'thinking arm of the broad ecosystem health partnership' of scientists and general public. At present, there is a continuum of proposed indicators from ones that are most easily understood by the non-scientific public to those understood by the scientific community. The indicators developed and explained in this paper fall into the former category.

One expression of ecosystem health is ecosystem integrity, the term used in the Great Lakes Water Quality Agreement (GLWQA) (Governments of the United States of America and of Canada, 1978). The Agreement's stated purpose, as noted, is '*to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem*'. While not precisely defined in the Agreement, integrity is understood by the agencies working under the aegis of the Agreement, to include the health of the constituent populations of the ecosystem, the ability of systems to self-organize, and also the physical and chemical environment needed to support good health, and the biological diversity of the ecological communities, and the ecosystem's ability to withstand stress or adapt to it. This definition is not too dissimilar to that of Angermeir and Karr (1994) and applies to the Great Lakes.

In measuring ecosystem health, one must bear in mind that ecosystems and ecological communities are dynamic and reflect the various perturbations that occur in nature even without human activities, for example, climate variability (Kelly *et al.*, 1994). They exist in balance with these natural perturbations, and their composition changes over time, tending towards stability and increasingly complex inter-relationships (Wilson, 1992). Mature and relatively stable communities tend to contain proportionately more organisms that are longer lived and have specialized and demanding habitat requirements. In contrast to these natural stresses, the physical, chemical and biological stresses that act to disrupt integrity are usually the result of human activity.

To measure ecosystem health in the Great Lakes, one has to define indicators against which to measure that health. One of the most important features of such an assessment is the recognition by environment and natural resource managers, and more recently by the informed Great Lakes public, of the changes that have occurred in the ecosystem, many of which are irreversible. The valuation given to a particular indicator, say lake trout population status as an indicator of aquatic ecosystem health, could be negative based on historical species composition. In terms of ecosystem function, however, the other top predators such as stocked Pacific salmon, that have replaced lake trout, may be functioning in a similar way to lake trout, and may result in a similar functioning of the ecosystem (Allen and Hoekstra, 1992). The long-term sustainability of such an ecosystem, as determined by societal goals and measured by science, is questionable, given the need to artificially stock Pacific salmon.

It has become a choice for society whether, for example, lake trout and Atlantic salmon, or pacific salmon should be the top predators in Lake Ontario. Science provides the information upon which to make this choice (Lackey, 1995), but economics (commercial and sport fishing interests), politics, and the natural history of the resource (Steedman, 1994) also are major influences over the final decision. In the degraded ecosystem of Lake Ontario, human design will have a great influence over the composition of the fishery (Steedman, 1994). Once that decision is made, the end point for assessment of ecosystem health becomes the species of choice, and not the historical species assemblage.

A schematic of the hierarchy of vision, goals and objectives, and where indicators fit into this scheme for the Great Lakes, is shown in Figure 1. In the Great Lakes context, a *vision* is developed through an agreed upon public consensus regarding the kind of ecosystem, society and economy that the public wants for a particular geographic area. For example, for Lake Superior (LaMP, 2002), a Public Forum developed a broad vision for the Lake and its basin. The Public Forum includes people from industry, academia, government, environmental groups, and aboriginal communities. A *goal* is more specific, and refers to a particular component of the ecosystem, but the goal is still generic in nature. The ecosystem *objective* is more specific, and has numerical endpoints, so that it is quantifiable. For the Great Lakes, there are objectives for the fish community, for example Lake Superior (GLFC, 2001), for phosphorus loadings and in-lake concentrations (Nielsen, 2002), and for some contaminants in fish tissue (GLIN, 2002). In working towards these ecosystem objectives, there may be interim *targets* established over a defined time frame. For example in Lake Superior, there is an objective of reducing mercury sources within the basin to zero by 2020, with interim targets of 60% in 2000 and 80% by 2010 (LaMP, 2002).

An *indicator* is a parameter or value that reflects the condition of an environmental (or human health) component, usually with a significance that extends beyond the measurement or value itself (Canada and United States, 1999). Used alone or in combination, indicators provide the means to assess progress toward one or more objectives: are conditions improving so that the objective is closer to being met, or are conditions deteriorating? The achievement of these objectives leads towards achievement of higher order goals and vision for the ecosystem.

The State of the Lakes Ecosystem Conferences (SOLECs) were established by the governments of Canada and the United States in 1992 in response to reporting requirements of the GLWQA. The objectives of the biennial SOLECs are to:

(1) assess the state of the Great Lakes ecosystem based on accepted indicators;
(2) strengthen decision-making and management;

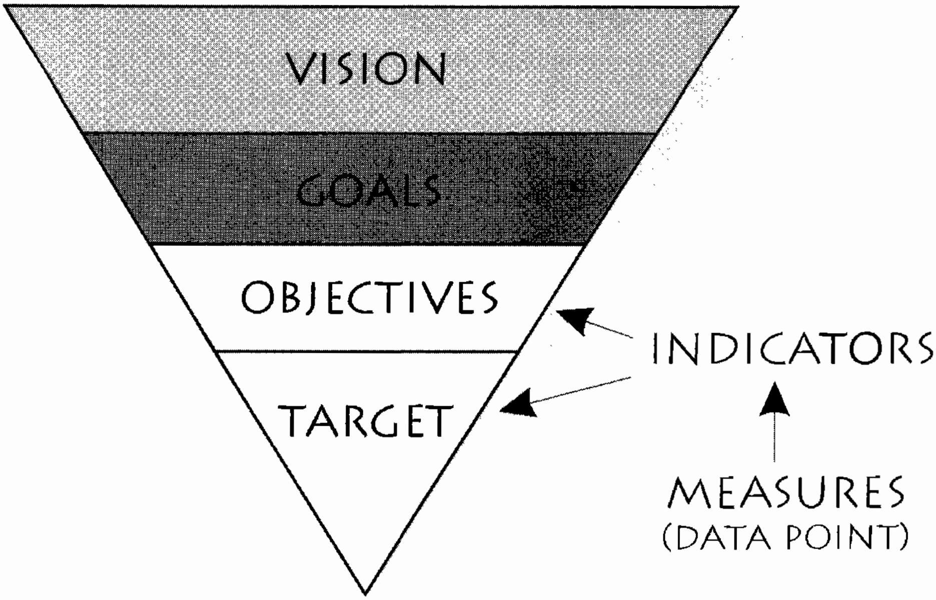

Figure 1. Conceptual Model of the Relationships between Indicators, Measures, Targets, Objectives, Goals and Visions.

(3) inform local decision makers of Great Lakes environmental issues; and
(4) provide a forum for communication and networking amongst all stakeholders

To accomplish objectives 1, 2 and 3, the information presented at SOLEC, and subsequently in the State of the Great Lakes reports (Canada and the United States 1995, 1997, 1999, 2001), has to be in a form that is clear, concise and easily understood by decision-makers and the public at large throughout the basin. The development and implementation of indicators are called for in the Great Lakes Water Quality Agreement (United States and Canada, 1987) and are important tools in meeting the SOLEC objectives.

At the first SOLEC in 1994, the governments reported on basin-wide conditions relating to aquatic ecosystem health, human health, aquatic habitat and wetlands, nutrients, contaminants, and the economy. These categories ensured that major components of the ecosystem were assessed, as well as a major component of human activity (the economy). A series of *ad hoc* indicators was developed to provide an assessment of the state of these components, and to assess progress toward the goals of the GLWQA. The indicators selected were based on the opinions of the authors of the background papers, and their assessments were based on the best professional judgement of these authors (United States and Canada, 1995). A similar process was followed for SOLEC 96, in which the focus was on the nearshore aquatic and terrestrial environments (Canada and United States, 1997). The SOLEC organizers recognized that this approach was not scientifically rigorous. In order to provide better consistency in the type and scope of information provided at future conferences, for SOLEC 98, the organizers developed a set of indicators that were easily understood, and that objectively represented the condition of the Great Lakes basin ecosystem, the stresses on the ecosystem, and the human responses to those stresses.

The purpose of this paper is to present initial data on a subset of the indicators. The subset was selected to illustrate the types of information available for various ecosystem components or societal responses to environmental degradation. Over time, as the data sets become more complete as a time series, we will be able to draw conclusions regarding the trends in ecosystem components illustrated by the indicators, and relate them to ecosystem goals and objectives.

2. Indicator Selection Process

To guide the development of a suite of indicators for the Great Lakes basin ecosystem, the SOLEC organizers employed a series of organizing principles:

Build upon the work of others. Much work has already been done both in the Great Lakes basin and throughout the world on indicators of ecosystem health.

Focus on broad spatial scales reflecting conditions on the scale of the whole Great Lakes basin, whole lake watersheds, and sub-basins of the larger Lakes.

Select a framework for subdividing the Great Lakes basin ecosystem based on geographic zones (offshore, nearshore, coastal wetlands, nearshore terrestrial) and non-geographic issues (human health, land use and societal).

Select a system for types of indicators. There are several classification schemes or models for indicators (GMIED 1998; IJC 1991, 1996; Messer 1992; Regier 1992), one of which is the State-Pressure-Human Activity (Response (OECD, 1993). The S-P-A model is simple and broadly applicable and was selected as the system for Great Lakes indicators.

Identify criteria for indicator selection. The primary criteria that were used for the selection of the suite of indicators were: *necessary*, *sufficient* and *feasible*. In addition, a set of 21 secondary criteria was identified. For any given indicator, the more criteria that were met, the stronger the case for including that indicator on the proposed list (Bertram and Stadler-Salt, 1999).

A group of experts was assembled to review, select, and refine Great Lakes indicators. Experts participated either directly with hands-on selection and development of indicators, or by reviewing draft products throughout the process. Over 150 people were involved in some way in this project. More than 850 indicators were identified through this process. The indicators were then screened according to the criteria, and the list was shortened. In some cases, indicators from the existing list were modified or combined, or new indicators were developed to create the proposed suite of 80 Great Lakes indicators.

A full description of the 80 indicators can be found in Bertram and Stadler-Salt, 1999.

3. Implementing SOLEC Indicators

At SOLEC 2000, reports were presented on 33 of the 80 indicators. These 33 were selected because data were readily available. The qualitative assessments for the 33 indicators are included in Table I. The indicators and their assessments were discussed at SOLEC 2000 in workshop sessions, and comments, criticisms, and suggestions for improvements were noted. After SOLEC 2000, the indicator reports and assessments were posted on the SOLEC websites (www.on.ec.gc.ca/solec and www.epa.gov/glnpo/solec) for several months to solicit additional input. Refinements were made to some of the indicators, and to the subjective assessments before the State of the Great Lakes, 2001 report was released (Canada and the United States, 2001). The SOLEC organizers have accepted this process of open review as equivalent to a peer review. The SOLEC review process has been described in Bertram *et al.*, 2002.

These indicators were used to develop a qualitative assessment of the status and trends of the Great Lakes ecosystem components. Indicators were rated in five broad categories:

- *poor*, (significant negative impact in one or more of the Lakes with not even minimally acceptable conditions);
- *mixed/deteriorating* (the ecosystem component displays both good and degraded features, but the trend is towards greater deterioration from acceptable conditions);
- *mixed* (some features of the basin were degraded and some were good, perhaps differing by Lake basin)
- *mixed/improving* (the ecosystem component shows both good and degraded features, but overall conditions are improving towards an acceptable state); and
- *good/restored* (the state of the ecosystem component is meeting presently accepted objectives).

The overall status of the Great Lakes basin ecosystem has been determined to be 'mixed' based on the data available for these 33 indicators, however, it must be stressed that the assessment is incomplete. Data for a few of the 33 indicators are not yet basin-wide, in other cases only part of the data proposed for the complete indicator have been presented. The remaining 47 indicators have yet to be reported and in some cases, the required data have not been collected. Changes to existing monitoring programs or the initiation of new monitoring programs may be necessary. Additionally, some indicators are still in the development stage (Canada and the United States, 2001).

The examples presented in this paper, represent major ecosystem components or issues except open and nearshore waters. A discussion of those indicators can be found elsewhere in this volume (Neilson, 2002). For each ecosystem component or issue, a short overview is followed by a description of the indicators, with examples of the data available for that indicator.

TABLE I
Assessments of the 33 Great Lakes indicators

Indicator Name	Unit of Measure*	Assessment
Deformities, Eroded Fins, Lesions and Tumors (DELT) in Nearshore Fish	Numbers & percent	Poor (Lake Erie)
Exotic Species Introduced into the Great Lakes (aquatic only)	Number of introductions	Poor
Native Unionid Mussels	Distribution & abundance	Mixed, deteriorating
Scud (*Diporeia hoyi*)	Abundance, yield, or biomass	Mixed, deteriorating
Amphibian Diversity & Abundance	Species composition & relative abundance	Mixed, deteriorating
Wetland-dependent Bird Diversity & Abundance	Species composition & relative abundance	Mixed, deteriorating
Coastal Wetland Area by Type	Hectares	Mixed, deteriorating
Effect of Water Level Fluctuations	Metres above sea level	Mixed, deteriorating
Extent of Hardened Shoreline	Kilometres	Mixed, deteriorating
Preyfish Populations	Abundance, diversity, age & size of distributionMixed	
Spawning-Phase Sea Lamprey Abundance	Number of spawning run adult sea lampreys; wounding rates on large salmonids	Mixed
Lake Trout	Abundance, yield, or biomass	Mixed
Phosphorus Concentrations & Loadings	Total phosphorus levels (μg/l) & annual total phosphorus loads (tonnes/year)	Mixed
Toxic Chemical Concentrations in Offshore Waters	μg/l	Mixed
Contaminants in Snapping Turtle Eggs	μg/g	Mixed
Area, Quality & Protection of Alvar par Communities	Hectares	Mixed
Sustainable Agricultural Practices	Number of Environmental and Conservation farm plans in place	Mixed
E. coli and Fecal Coliform in Recreational Waters	Colonies/100 ml Mixed	
Air Quality	$\mu g/m^3$	Mixed
Economic Prosperity	Unemployment rates	Mixed
Acid Rain	Kg/ha/year	Mixed
Hexagenia	Abundance, biomass or annual production	Mixed, improving
Atmospheric Deposition of Toxic Chemicals	Kg/year	Mixed, improving
Contaminants Affecting Productivity of Bald Eagles	μg/g; number of fledged young produced; number of developmental deformities	Mixed, improving

TABLE I
Continued

Indicator Name	Unit of Measure*	Assessment
Brownfields Redevelopment	Hectares	Mixed, improving
Chemical Contaminants in Edible Fish Tissue	μg/g	Mixed, improving
Walleye	Abundance, biomass or annual production	Good
Contaminants in Colonial Nesting Waterbirds	μg/g	Good
Drinking Water Quality	μg/l	Good
Population Monitoring & Contaminants Affecting the American Otter	μg/g Insufficient data to assess indicator	
Phytoplankton Populations	Numbers/ml & size-fractionated primary productivity	Unable to assess status until targets are determined
Zooplankton Populations	Community composition; mean individual size; & biomass and production	Unable to assess status until targets are determined
Urban Density	Human population/km^2 of existing & proposed development areas	Unable to assess status until targets are determined
Mass Transportation	% of commuters using public transit	Unable to assess status until targets are determined
Water Use	Litres/cap/year	Unable to assess status until targets are determined

*Full descriptions of each indicator and units of measure can be found in the Selection of Indicators for Great Lakes Ecosystem Health, version 4, March 2000.

Over time, as monitoring and reporting on the full suite of indicators is implemented, we will have a clearer, more complete picture of the health of the Great Lakes basin ecosystem. For example, in the long term, by analysing the monitoring data for coastal wetlands indicators, and assessing the results, the health of the wetlands of the Great Lakes will become apparent. There may still be gaps in information, possibly requiring an adjustment in the number of indicators needed for that environmental compartment or issue, as well as a refinement of the indicators, in order to describe more fully the state of the component.

3.1. Coastal Wetland Ecosystems

Wetlands have important ecological, social, and economic values, and are some of the most productive ecosystems in the world (Maynard and Wilcox, 1997). However, since European settlement, draining and filling have resulted in a loss of more than 50% of the wetlands in several states in the Great Lakes basin (Dahl, 1990) and more than 80% of the wetlands have been lost from several counties in Ontario (Snell, 1987). Threats include regulation of lake water levels, upland land use changes, dredging and filling, non-native invasive plants and animals, and toxic chemicals.

There are few existing monitoring programs for Great Lakes coastal wetlands, although plans are underway to develop such a network (GLCWC, 2002). Efforts are being made to select indicators for which there are existing data and monitoring programs, although many of the indicators will require new or improved monitoring programs.

3.1.1. *Wetland-Dependent Bird Diversity and Abundance*

This indicator assesses the diversity and abundance of wetland-dependent birds in the Great Lakes basin and is indirectly used to evaluate the health and function of wetlands. Breeding birds are valuable components of Great Lakes wetlands and rely on the physical, chemical and biological health of their habitats. Because these relationships are particularly strong during the breeding season, the presence and abundance of breeding individuals can provide a source of information on wetland status and trends. When long-term monitoring data are combined with an analysis of habitat characteristics, trends in species abundance and diversity can contribute to an assessment of the ability of Great Lakes coastal wetlands to support birds and other wetland-dependent wildlife. Populations of several wetland-dependent birds are at risk due to the continuing loss and degradation of their habitats.

From 1995 through 1999, 53 species of birds that use marshes (wetlands dominated by non-woody emergent plants) for feeding and/or nesting were recorded by Marsh Monitoring Program (MMP) volunteers at 322 routes throughout the Great Lakes basin (Weeber and Vallianatos, 2000). Among the bird species that typically feed in the air above marshes, tree swallow *(Tachycineta bicolour)* and barn swallow (Hirundo rustica) were the two most common. Red-winged blackbird *(Agelaius phoeniceus)* was the most commonly recorded marsh nesting species, followed by swamp sparrow *(Melospiza georgiana)*, common yellowthroat *(Geothlypis trichas)* and marsh wren *(Cistothorus palustris)*. Individual bird species varied considerably in their distribution among lake basins; patterns likely influenced by differences in species geographic range and variation among basins in sampled wetland habitat characteristics such as permanency, size, and dominant vegetation type.

The mmP analyzed five years of data across the Great Lakes basin from 1995–1999. Bird species occurrence and numbers, and their activity and likelihood of being observed, vary naturally amongst years and within seasons. Although results are still preliminary, based on the 5 years of data, trends are shown for several birds recorded on Great Lakes mmP routes (Figures 2a and b). Population indices and trends (i.e. average annual percent change in population index) are presented for species with statistically significant trends between 1995 and 1999. Species with significant basin-wide declines are shown in Figure 2a. Each of the declining species depends upon wetlands for breeding but, because they use wetland habitats almost exclusively, the pied-billed grebe *(Podilymbus podiceps)*, American coot *(Fulica americana)*, common moorhen *(Gallinula chloropus)*, and black tern *(Chlidonias niger)* are particularly dependent on the availability of healthy wetlands. Although declines for tree swallow and red-winged blackbird were not quite statistically significant, trends for these species are also presented because they are particularly widespread and common marsh nesting birds. Statistically significant basin-wide increases are shown in Figure 2b.

3.1.2. *Amphibian Diversity and Abundance*

This indicator assesses the species composition and relative abundance of calling frogs and toads to infer the condition of Great Lakes basin marshes. A high proportion of the Great Lakes basin's amphibian species inhabit wetlands during part of their life cycle, and many of the species at risk in the basin are associated with wetlands. Similarly, there is growing international concern about declines of amphibian populations and an apparent increase in rates of deformities. (Heyer *et al.*, 1994; Stebbins and Cohen, 1995). Because frogs and toads are relatively sedentary, have semi-permeable skin, and breed in and adjacent to aquatic systems, they are likely to be more sensitive to, and indicative of, local sources of contamination to wetlands than most other vertebrates.

From 1995 through 1999, 11 frog and two toad species were recorded by Marsh Monitoring Program (MMP) participants surveying 354 routes across the Great Lakes basin. Spring peeper *(Pseudacris crucifer)* was the most frequently detected species (69% of the stations monitored). Green frog *(Rana clamitans)* was detected in more than half of station years. Gray tree frog *(Hyla versicolor)*, American toad *(Bufo americanus)* and northern leopard frog *(Rana pipiens)* were also common, being recorded in more than one-third of all station years. Gray tree frog was recorded with the second highest average frequency. Bullfrog *(Rana catesbeiana)*, chorus frog *(Pseudacris triseriata)* and wood frog *(Rana sylvatica)* were detected in approximately one-quarter of station years. Five species were detected infrequently by mmP surveyors, and were recorded in less than three percent of station years.

Trends in amphibian occurrence were assessed for the eight species commonly detected on mmP routes. For each species, a trend was assessed first on a route-by-route basis in terms of the annual proportion of stations with each species present. These route level trends were then combined for an overall assessment of trend for each species. Although some trends were suggested for species such as American

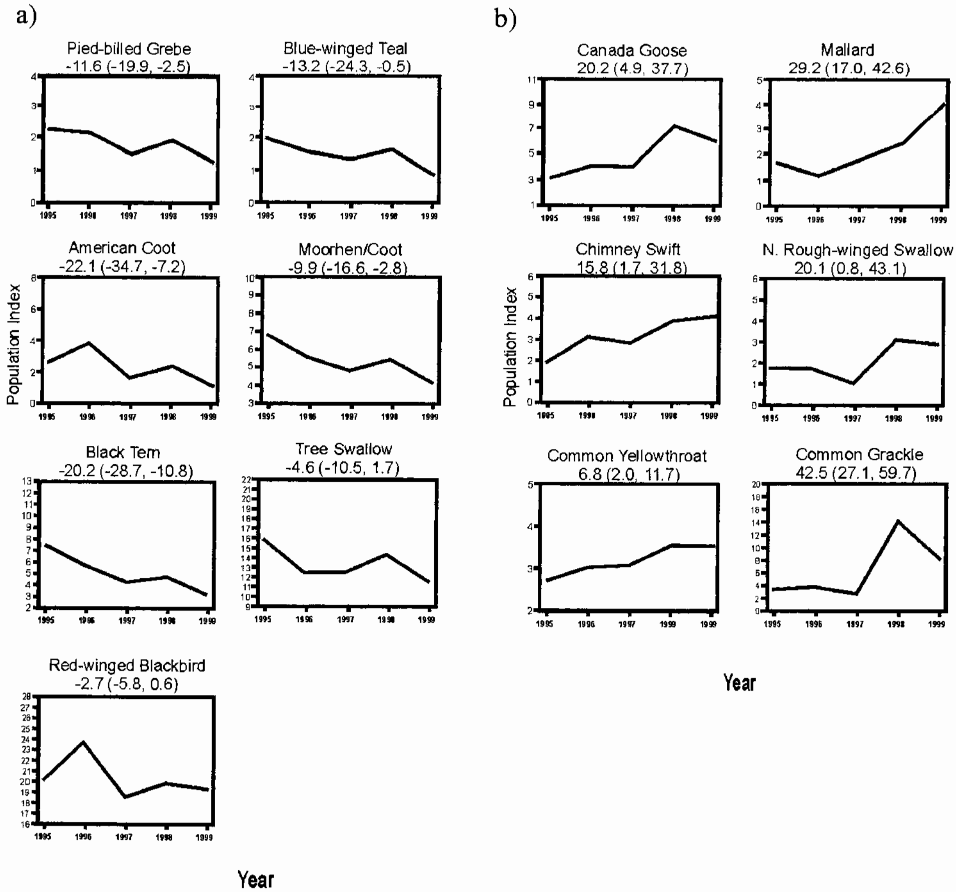

Figure 2. Annual population indices of a) declining and b) increasing marsh nesting and aerial foraging bird species detected on Great Lakes basin mmP routes, 1995 through 1999. Population indices are based on counts of individuals inside the mmP station boundary and are defined relative to 1999 values. The estimated annual percent change (trend) is indicated for each species and the associated lower and upper extremes of 95% confidence limits are enclosed in parentheses. *Source: Marsh Monitoring Program (Weeber and Vallianatos, 2000).*

toad and bullfrog, only the declining trend for chorus frog could be resolved with sufficient statistical confidence (Figure 3). Although long-term (1950s to 1990s) losses of chorus frog have been recorded in the St. Lawrence River valley, this species is known to have population fluctuations, and even regional extinctions, over short time periods due to natural factors such as differences in annual weather conditions (Diagle, 1997).

3.1.3. *Contaminants in Snapping Turtle Eggs*

This indicator measures the concentrations of persistent contaminants in the eggs of Common Snapping Turtles living in wetlands of the Great Lakes basin in order

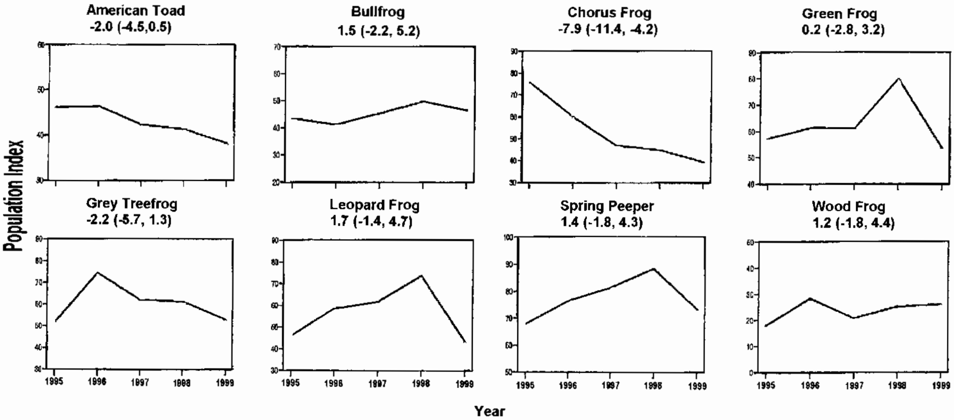

Figure 3. Annual indices of calling amphibian occurrence on mmP routes within the Great Lakes basin, 1995 to 1999. Indices are based on the annual proportion of survey stations with each species present and are defined relative to 1999 values. The estimated annual percent change (trend) is indicated for each species and the associated lower and upper extremes of 95% confidence limits are enclosed in parentheses. Source: Marsh Monitoring Program (Weeber and Vallianatos, 2000).

to provide an indirect measure of foodweb contamination and its effects on wetland wildlife.

Snapping turtles *(Chelydra serpentina)* are ideal candidates as indicators of wetland health due to their sedentary nature, their ability to accumulate high levels of contaminants over their long life-span and their position as top predators in the food chain (Bishop *et al.*, 1991; Bishop *et al.*, 1994; Bishop *et al.*, 1996). Contaminant levels measured in Snapping turtle eggs are indicative of contaminant levels found in the turtle's diet (about 1/3 fish, 1/3 plants and 1/3 other items including invertebrates and to a lesser degree smaller turtles, birds and snakes). Snapping turtle eggs collected at two Lake Ontario sites (Cootes Paradise and Lynde Creek) had the highest PCDD concentrations (notably 2,3,7,8-TCDD; Figure 4) and number of detectable PCDF congeners (twenty versus six at all other sites). Eggs from Cranberry Marsh (Lake Ontario) had similar levels of PCBs (Figure 5) compared to Lake Erie sites, but higher concentrations and a greater number of PCDD and PCDF congeners were detected at this site relative to Lake Erie sites (Figure 4). Eggs from Akwesasne contained the highest level of PCBs relative to all other sites as shown in Figure 5 (Bishop and Gendron, 1998). Details on site selection, sample size and statistical treatment of these data may be found in Bishop and Gendron, 1998.

Temporal trends for contaminants indicate that at two Lake Ontario sites (Cootes Paradise and Lynde Creek), levels of PCBs increased significantly from 1984 to 1990/91 (Figure 5). Alternatively, levels of PCDDs (including 2,3,7,8-TCDD) and PCDFs decreased significantly at Cootes Paradise from 1984 to 1989 (Figure 4). At Lake Erie and the reference lake sites, decreasing or stable levels of contaminants in eggs were reported from 1984 to 1991.

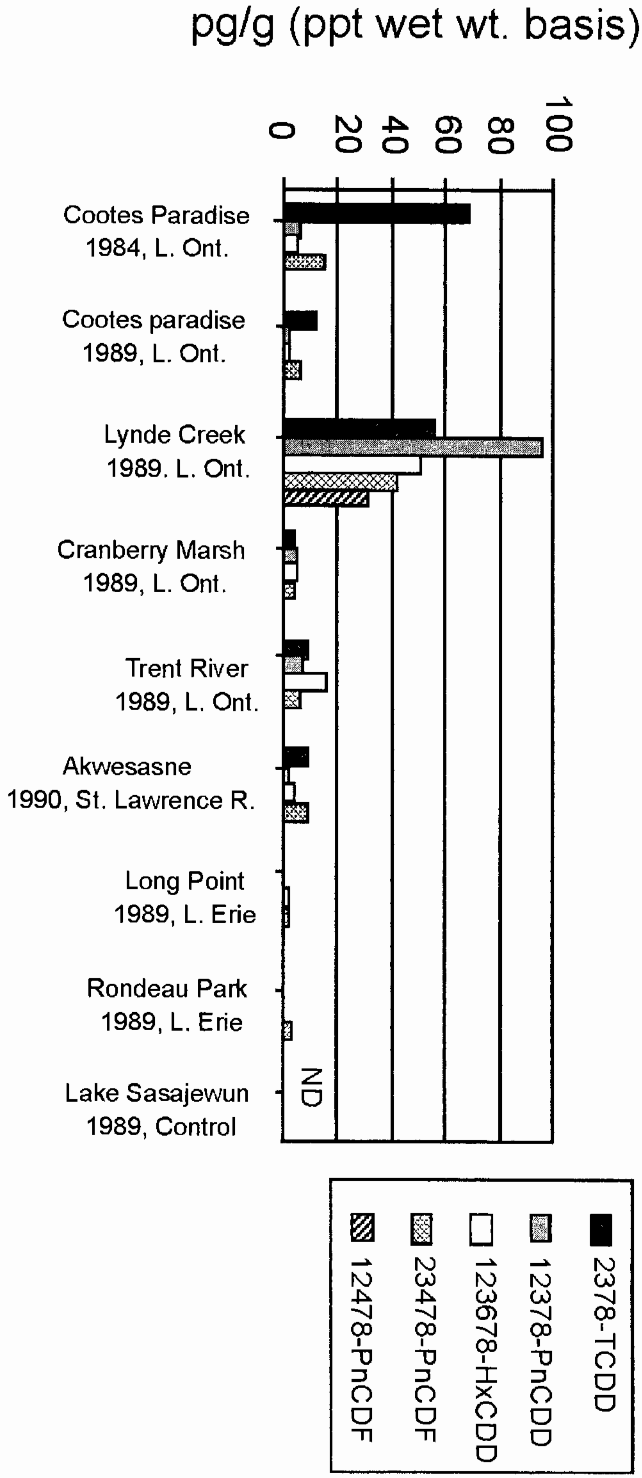

Figure 4. Dioxin and furan concentrations (1984; 1989/90) in Snapping turtle eggs at Canadian Great Lakes study sites. Source: C. Bishop and Gendron, 1998.

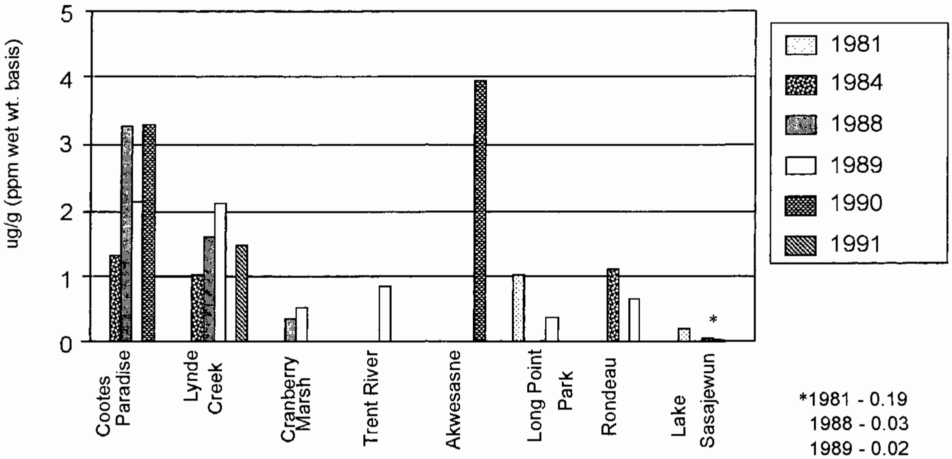

Figure 5. Mean sum PCB concentrations (1981–1991) in Snapping turtle eggs at Canadian Great Lakes study sites and one inland reference site. Source: C. Bishop and Gendron, 1998.

Bishop *et al.*, 1991, have demonstrated that eggs with the highest contaminant levels also show the poorest developmental success. Rates of abnormal development of Snapping turtle eggs from 1986–1991 were highest at all four Lake Ontario sites compared to all other sites studied (Figure 6). Rates were similar between the one Lake Erie site sampled (Long Point) and the reference inland lake, Lake Sasajewun.

3.2. NEARSHORE TERRESTRIAL ECOSYSTEMS

The nearshore terrestrial environment is an integral part of the Great Lakes basin ecosystem, the extent of which is defined by the Lakes themselves. The nearshore terrestrial environment is defined as that part of the land (climate, vegetation) directly influenced by the Lakes. A description of these areas and major stresses on these natural communities was described in *State of the Great Lakes 1997* (Canada and United States, 1997) and The Land by the Lakes: Nearshore Terrestrial Ecosystems (Reid *et al.*, 1997).

Thirteen indicators of nearshore terrestrial ecosystem health have been developed. Three of these indicators are illustrated here.

3.2.1. *Extent of Hardened Shoreline*

This indicator assesses the extent of hardened shoreline through construction of sheet piling, rip rap, or other erosion control structures. Anthropogenic hardening of the shorelines not only directly destroys natural features and biological communities, it also has a more subtle impact (Maynard *et al.*, 1997). Many of the biological communities along the Great Lakes are dependent upon the transport of shoreline sediment by lake currents. Altering the transport of sediment disrupts the balance of accretion and erosion of materials carried along the shoreline by wave

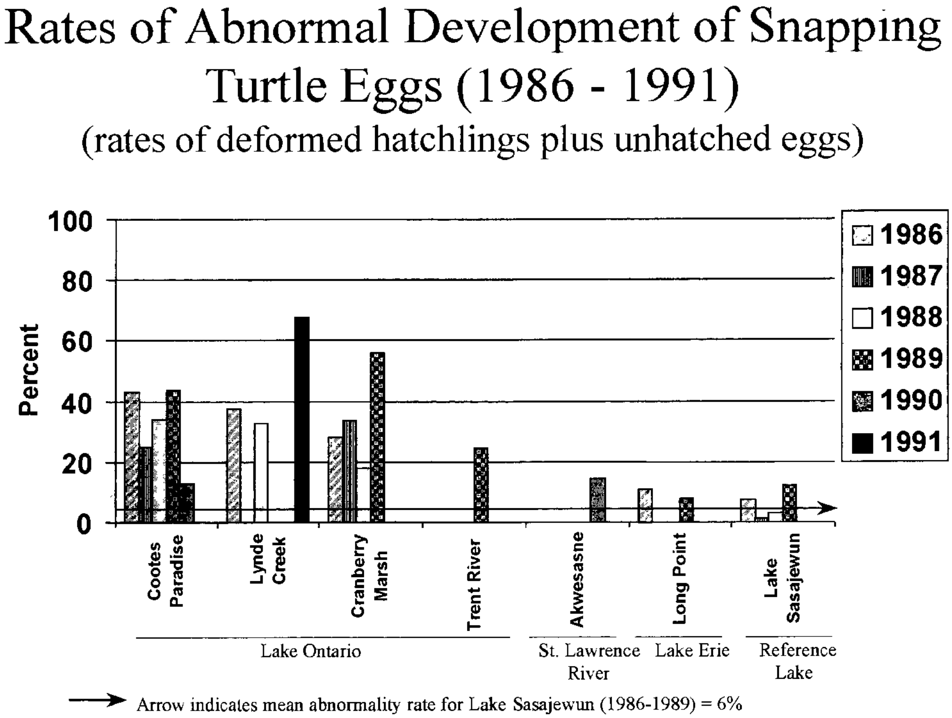

Figure 6. Rates of abnormal development (i.e. rates of deformed hatchlings plus unhatched eggs) of Snapping turtle eggs (1986–1991) at Canadian Great Lakes study sites and one inland reference site. Source: C. Bishop and Gendron, 1998.

action and lake currents (Maynard *et al.*, 1997). The resulting loss of sediment replenishment can intensify the effects of erosion, causing ecological and economic impacts. Erosion of sand spits and other barriers allows increased exposure and loss of coastal wetlands. Dune formations can be lost or reduced due to lack of adequate nourishment of new sand to replace sand that is carried away. Increased erosion also causes property damage to shoreline properties.

The National Oceanic and Atmospheric Administration (NOAA) Medium Resolution Digital Shorelines dataset was compiled between 1988 and 1992 (NOAA, 1997). It contains data on both the Canadian and U.S. shorelines, using aerial photography from 1979 for the state of Michigan and from 1987–1989 for the rest of the basin.

From this dataset, shoreline hardening has been categorized for each Lake and connecting channel. Figure 7 indicates the percentages of shorelines in each of these categories. The St. Clair, Detroit and Niagara Rivers have a higher percentage of their shorelines hardened than anywhere else in the basin. Of the Lakes themselves, Lake Erie has the highest percentage of its shoreline hardened, and Lakes Huron and Superior have the lowest.

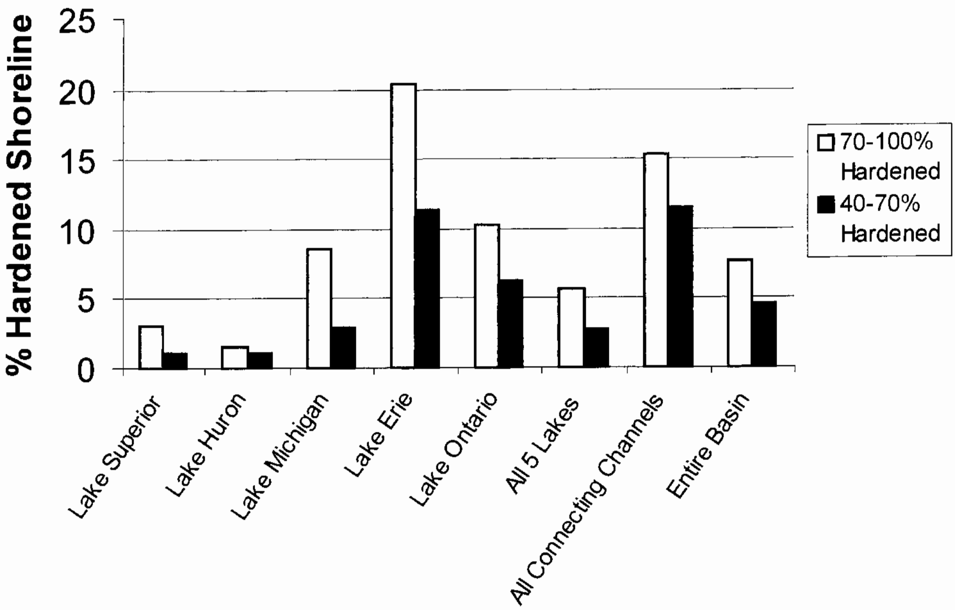

Figure 7. Shoreline hardening in the Great Lakes (compiled from 1979 data for the state of Michigan and 1987–1989 data for rest of the basin). Source: Environment Canada and U.S. Environmental Protection Agency, (unpublished).

In 1999, Environment Canada assessed change in the extent of shoreline hardening along about 22 kilometres of the Canadian side of the St. Clair River from 1991–1992 to 1999. Over the 8-year period, an additional 5.5 kilometres (32 percent) of the shoreline had been hardened (Leadlay and Read, personal communication). This is clearly not representative of the overall basin, as the St. Clair River is a narrow shipping channel with high volumes of Great Lakes traffic. This area also has experienced significant development along its shorelines, and many property owners are hardening the shoreline to reduce the impacts of erosion.

3.2.2. *Contaminants Affecting Productivity of Bald Eagles*

The indicator assesses the number of fledged young, number of developmental deformities, and the concentrations of organic and heavy metal contamination in bald eagle eggs, blood, and feathers. The data will be used to infer the potential for harm to other wildlife and human health through the consumption of contaminated fish.

Bald eagle *(Haliaeetus leucocephalus)* populations may be slowly recovering, based on the current measures used for the bald eagle. These measures are: 1) Concentrations of DDT Complex, PCB, PCDD, PCDF and other organic contaminants and mercury and other heavy metals in Bald Eagle eggs, blood, and feathers; 2) number of fledged young produced; and 3) number of developmental deformities.

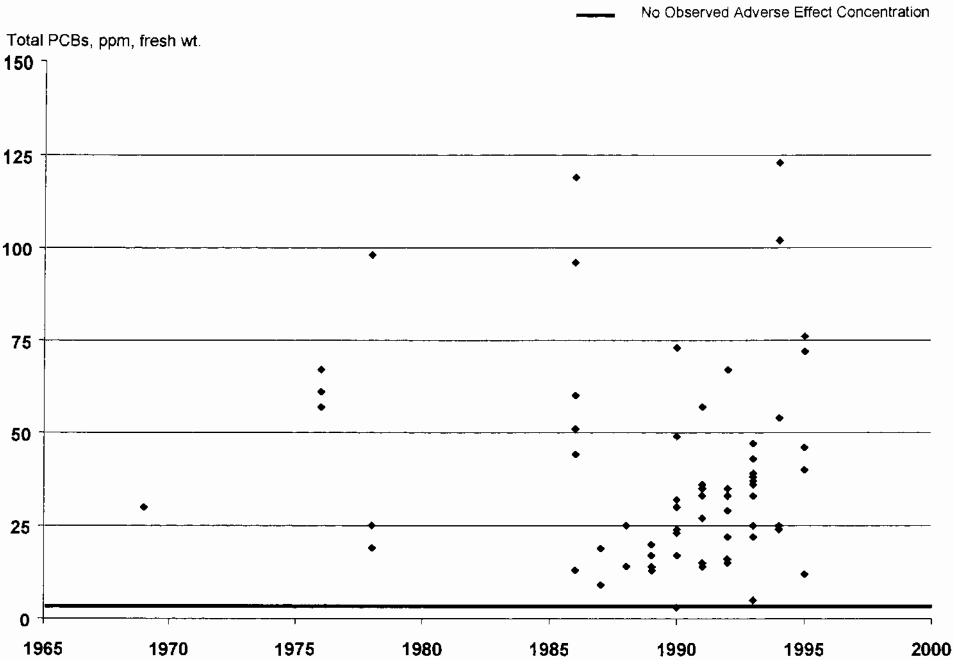

Figure 8. Concentrations of Total PCBs, mg/kg, fresh wet weight in unhatched bald eagle eggs collected in the Great Lakes, 1968–1995. Source: W. Bowerman, D.A. Best, T.G. Grubb, G.M. Zimmerman and J.P. Giesy, 1998.

Based on the first year of the Michigan Biosentinel Eagle Project (Bowerman *et al.*, 2002), the concentrations of p,p-DDE, Total PCBs, and mercury in blood plasma and feathers of nestling bald eagles are either stable, or declining from concentrations observed in the late 1980s and early 1990s. While the majority (>95%) of egg concentrations are still greater than the No Observed Adverse Effects Concentrations (NOAECs) for PCBs and p,p'-DDE, in a few, isolated shorelines, they have been below the NOAECs (Figures 8 and 9). No trends are apparent for the entire Great Lakes population of bald eagles in either analysis. The NOAECs for PCBs were 4.0 mg/kg and 2.7 mg/kg for p,p'-DDE.

The number of nestling eagles fledged from nests along the shorelines of the Great Lakes has steadily increased from 6 in 1977 to over 200 in 2000. Eagles nesting along Lake Erie and along the Wisconsin shoreline of Lake Superior have been consistently above the 1.0 young per occupied nest criteria for the past few years. Other areas of Lakes Superior, and the entirety of Lakes Michigan and Huron, have not attained this level. In 2000, the first record of a nesting pair of bald eagles along the shoreline of Lake Ontario was observed. The approximate areas of the Great Lakes shorelines that have nesting eagles is shown in Figure 10. Areas with no confirmed nesting locations likely reflect a combination of lack of habitat and the time needed to recolonize where there is adequate habitat.

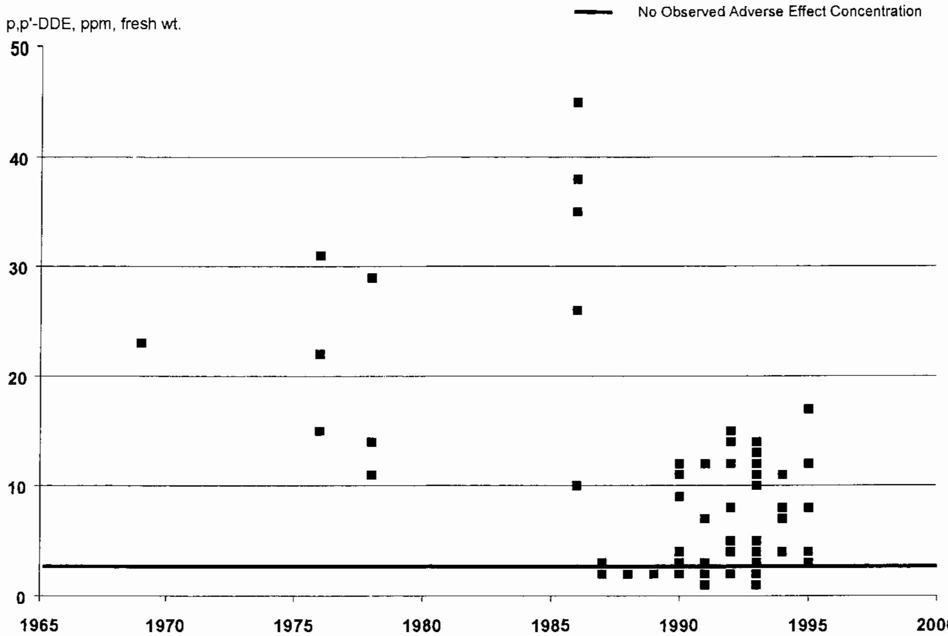

Figure 9. Concentrations of p,p′-DDE, mg/kg, fresh wet weight in unhatched bald eagle eggs collected from the Great Lakes, 1968–1995. Source: W. Bowerman, D.A. Best, T.G. Grubb, G.M. Zimmerman and J.P. Giesy, 1998.

3.2.3. *Area, Quality and Protection of Alvar Communities*

This indicator assesses the status of one of the 12 special lakeshore communities identified within the nearshore terrestrial area (Reid *et al.*, 1999). Alvar communities are naturally open habitats occurring on flat limestone bedrock. They have a distinctive set of plant species and vegetative associations, and include many species of plants, molluscs, and invertebrates that are rare elsewhere in the basin. All 15 types of alvars and associated habitats occurring in the Great Lakes – St. Lawrence River basin are globally imperiled or rare. Data from the International Alvar Conservation Initiative and state/provincial alvar studies were screened and updated to identify viable community occurrences (Reschke et al, 1999). Just over 66% of known Great Lakes alvars occur close to the shoreline, with all or a substantial portion of their area within 1 kilometre of the shore (Table II).

Alvar habitats have likely always been sparsely distributed, but more than 90% of their original extent has been destroyed or substantially degraded by agriculture and other human uses (Reschke *et al.*, 1999). Approximately 64% of the remaining alvar area occurs within Ontario, with about 16% in New York, 15% in Michigan, 4% in Ohio, and smaller areas in Wisconsin and Quebec.

The current status of all remaining nearshore alvar communities was evaluated by considering current land ownership and the type and severity of threats to their

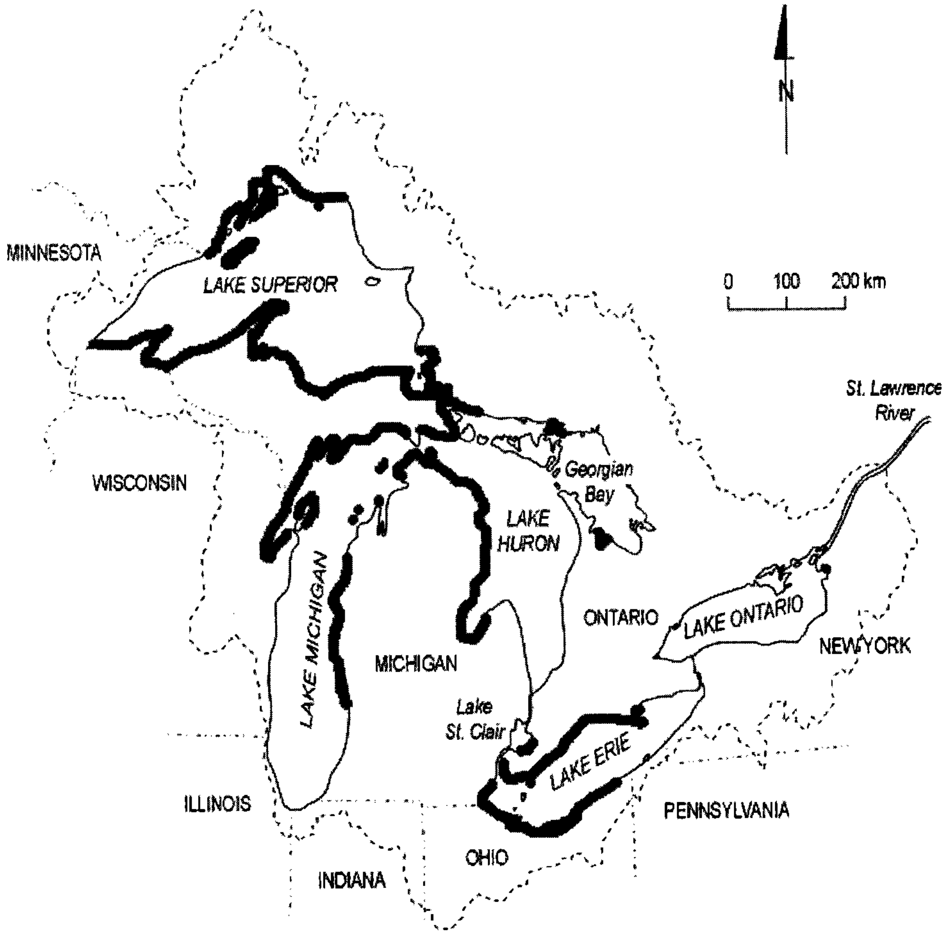

Figure 10. Approximate nesting locations of bald eagles along the Great Lakes shorelines, 2000. Source: W. Bowerman, Clemson University, Lake Erie and Lake Superior LaMPs, and for Lake Ontario, Peter Nye, New York State Department of Environmental Conservation, (unpublished).

TABLE II

Alvar locations within the Great Lakes basin

	Total in Basin	Nearshore
No. of alvar sites	82	52
No. of community occurrences	204	138
Alvar acreage	28475	20009

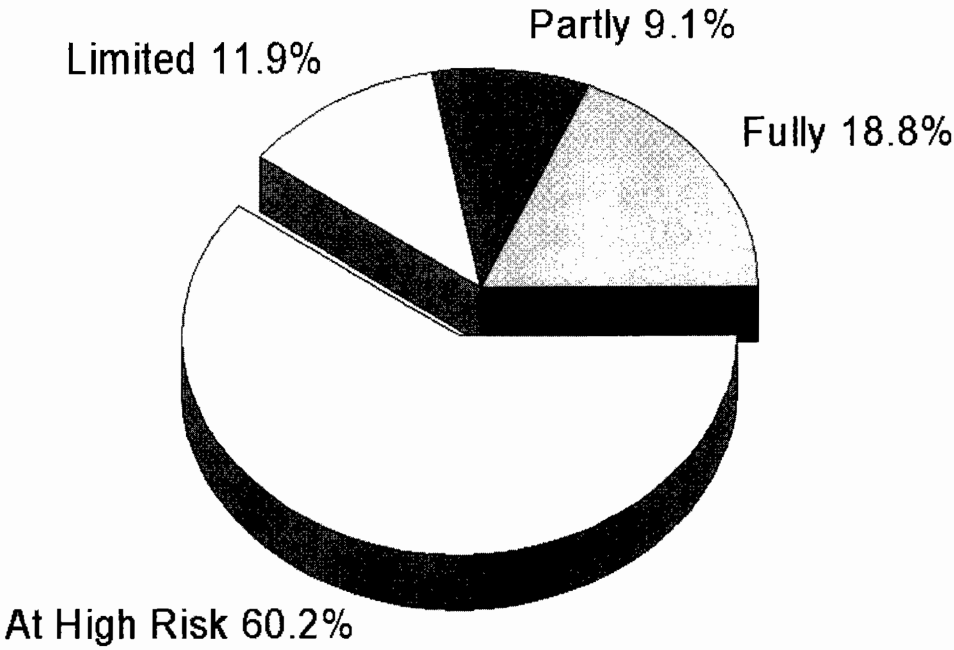

Figure 11. Protection Status 2000. Nearshore Alvar Acreage. Source: Ron Reid, (unpublished).

integrity. As shown in Figure 11, less than 20% of the nearshore alvar acreage is currently fully protected, while over 60% is at high risk.

The degree of protection for nearshore alvar communities varies considerably among jurisdictions. For example, Michigan has 66% of its nearshore alvar acreage in the Fully Protected category, while Ontario has only 7% in this category. In part, this is a reflection of the much larger total shoreline acreage in Ontario.

3.3. Land Use

The *State of the Great Lakes 1997* identified changing patterns of land use as a major ecosystem stressor for the Great Lakes basin and its nearshore areas (Canada and the United States, 1997). Industrial, commercial, residential, agricultural, and transportation-related development, result in significant, and cumulative impacts for native species and their habitats as well as for Great Lakes water quality. Land use activities take place throughout the basin, but their most immediate and direct impact on the Great Lakes appears to be on lands proximate to the Lakes themselves and their tributary waters. These nearshore areas suffer from a particular and disproportionate environmental burden because of their unique and sensitive environments and proximity to development (Canada and the United States, 1997).

3.3.1. *Brownfields Redevelopment*

This indicator assesses the acreage of redeveloped brownfields, and can be used to evaluate over time the rate at which society rehabilitates and reuses former developed sites that have been degraded or abandoned.

All eight Great Lakes states, Ontario and Quebec have programs to promote remediation or 'cleanup' and redevelopment of brownfields sites (ROBIN, 2002). Several of the brownfields cleanup programs have been in place since the mid to late 1980s, but establishment of more comprehensive brownfields programs that focus on remediation and redevelopment has occurred during the 1990s. Today, each of the Great Lake states has a voluntary cleanup or environmental response program that offers a range of risk-based, site specific background and health cleanup standards that are applied based on the specifics of the contaminated property (ROBIN, 2002).

Information on acres of brownfields remediated from Illinois, Minnesota, New York, and Pennsylvania indicates that a total of 28,789 acres (11,651 hectares) of brownfields have been remediated in these jurisdictions alone. Available data from six Great Lakes states indicate that more than 8,662 brownfield sites have participated in brownfields cleanup programs (V. Pebbles, personal communication). Redevelopment is a criterion for eligibility under many state brownfields cleanup programs. Where local brownfields clean up and redevelopment efforts are independent of state/provincial funding or oversight, redevelopment activities may go underreported at the state/provincial level. Though there is inconsistent and inadequate data on acres of brownfields remediated and/or redeveloped, available data indicate that both brownfields cleanup and redevelopment efforts have risen dramatically since the mid 1990s with the new wave of risk-based cleanup standards and widespread use of state liability relief mechanisms that allow private parties to redevelop, buy or sell property without being held liable for contamination they did not cause. Data also indicates that the majority of cleanups in Great Lakes states and provinces are occurring in older urbanized areas, many of which are located on the Great Lakes and in the basin. Based on this information, the state of brownfields redevelopment is good and improving.

3.3.2. *Sustainable Agriculture Practices*

This indicator assesses the number of environmental and conservation farm plans and environmentally friendly practices in place, such as integrated pest management to reduce the potential adverse impacts of pesticides, conservation tillage and other soil preservation practices to reduce energy consumption, prevent ground and surface water contamination, and achieve sustainable natural resources.

Agriculture accounts for 35 percent of the land area of the Great Lakes basin and dominates the southern portion of the basin (U.S. EPA and Canada, 1995). In the past, excessive tillage and intensive crop rotations led to soil erosion and resulting sedimentation of major tributaries (IJC, 1978). Agriculture is a major user of pesticides with an annual use of 26,000 tons. These practices led to a decline

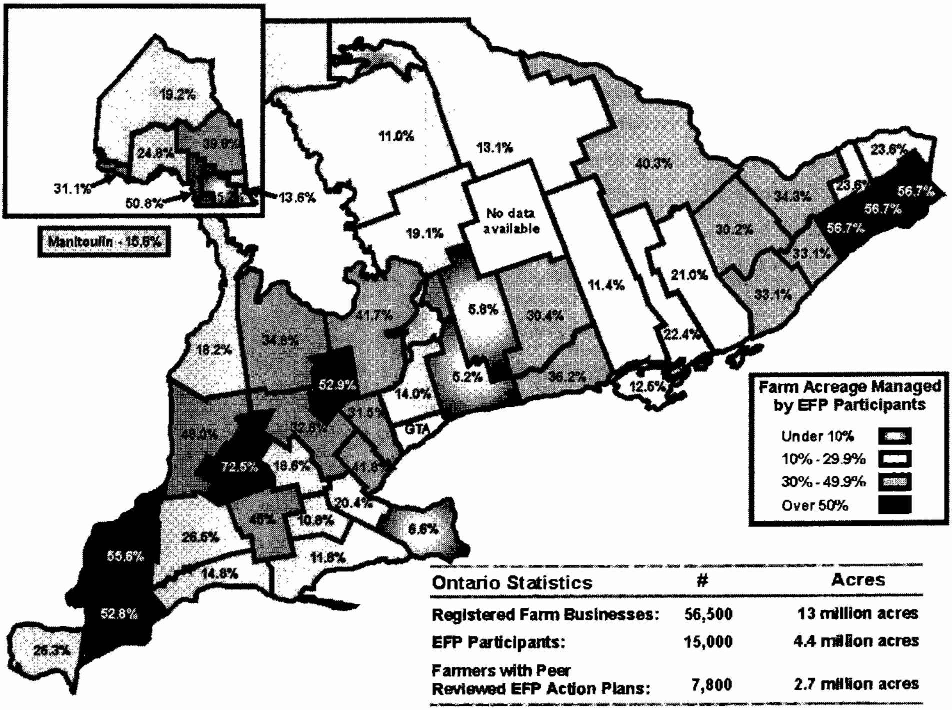

Figure 12. All Ontario Statistics as of April 1999. Environmental Farm Plan (EFP). Source: Ontario Soil and Crop Improvement Association, April 1999; 1997 Ontario farm registration database; 1996 Census of Agriculture.

of soil organic matter. Recently, there has been increasing cooperation between government and the farm community on Great Lakes water quality management programs. The adoption of more environmentally responsible practices has helped to replenish carbon in the soils back to 60 percent of turn-of-the-century levels.

Both the Ontario Ministry of Agriculture and Food (OMAF) and the USDA's Natural Resources Conservation Service (NRCS) provide conservation planning advice, technical assistance and incentives to farm clients and rural landowners. Clients develop and implement conservation plans to protect, conserve, and enhance natural resources that harmonize productivity, business objectives and the environment. Successful implementation of conservation planning depends upon the voluntary participation of clients.

The Ontario Environmental Farm Plan (EFP) encourages farmers to develop action plans and adopt environmentally responsible technologies through the Ontario Farm Environmental Coalition (OFEC) workshops delivered in partnership with OMAF. Recently, with the technical assistance of OMAF, OFEC released a Nutrient Management Planning Strategy and accompanying software to enable farmers to develop individualized nutrient management plans. Figure 13 shows the degree of implementation of Environmental Farm Plans in Ontario.

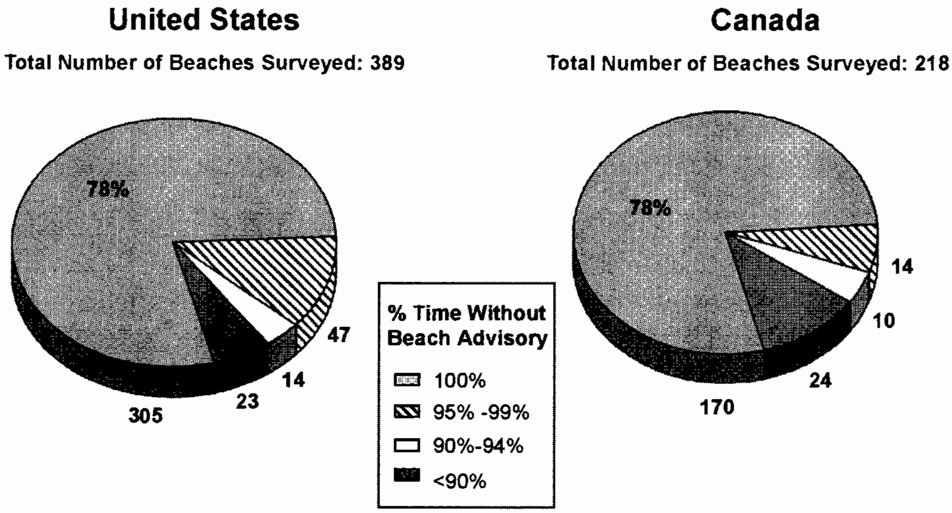

Figure 14. Comparison of U.S. and Canadian beach advisories for Great Lakes beaches, 1998. Source: U.S. Environmental Protection Agency Beach Watch Program, National Health Protection Survey of Beaches for Swimming (1998) and Ontario Ministry of Environment.

TABLE III

Contaminants that fish advisories are based on in Canada and the United States

Lake	Contaminants that Fish Advisories are based on in Canada and the United States
Superior	PCBs, mercury, toxaphene, chlordane, dioxin
Huron	PCBs, mercury, dioxin, chlordane, toxaphene
Michigan	PCBs, mercury, chlordane, dioxin
Erie	PCBs, dioxin, mercury
Ontario	PCBs, mercury, mirex, toxaphene, dioxin

Historical levels of PCBs in coho salmon, with corresponding meal advice, from each of the Great Lakes are shown in Figure 15. Currently, Lake Superior is the only lake with no consumption advisories on coho salmon due to PCBs, while in Lake Ontario only one meal of coho salmon every two months is advised.

3.5. Societal

Human society is part of the ecosystem, and integrated environmental management requires human activities to be respectful of other ecosystem components. For example, the creation and discharge of waste materials by humans may have an impact on both the habitat and the health of plant and animal species. A responsible society will recognize its collective impact on the surrounding environment, and it will seek to sustain ecosystem integrity indefinitely.

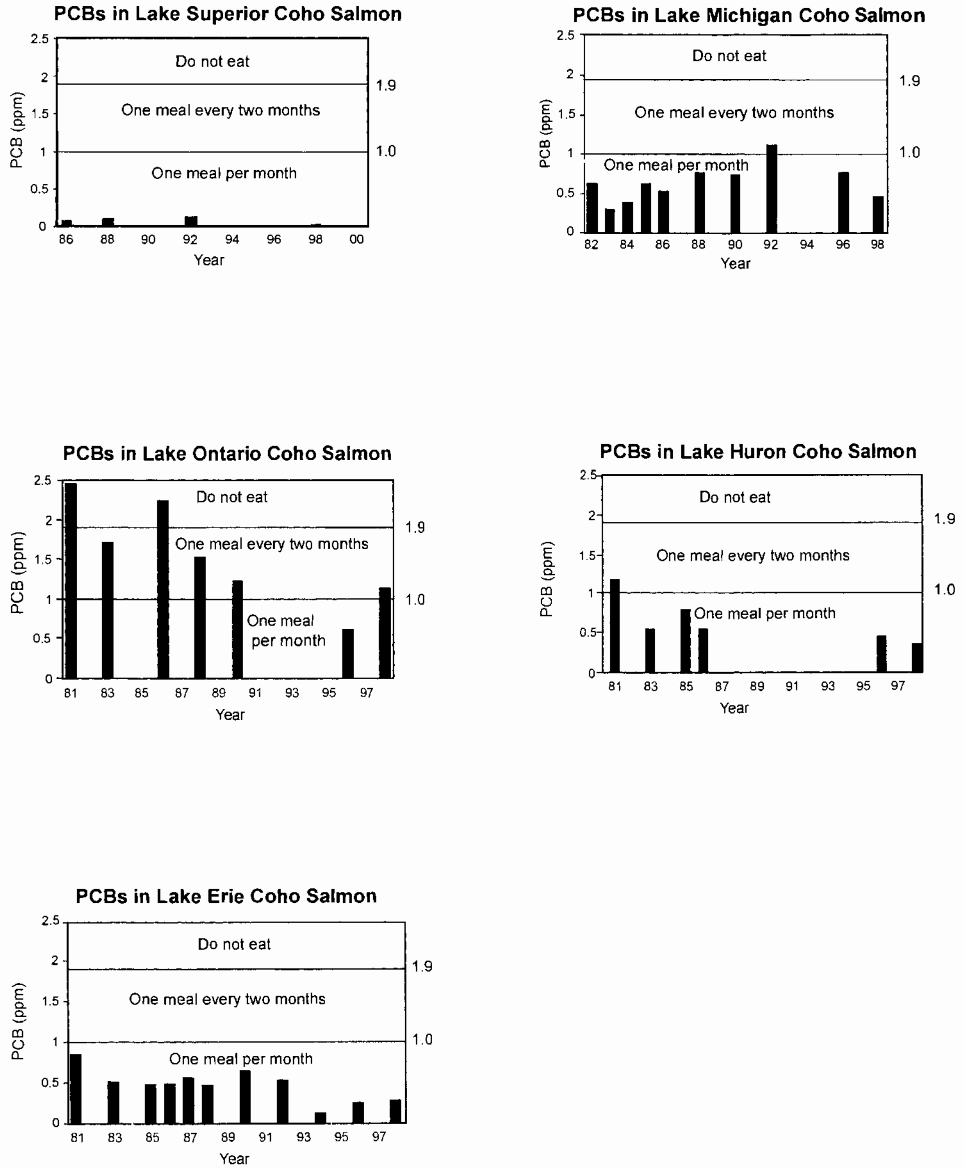

Figure 15. Results of a uniform fish advisory protocol applied to historical data (PCBs, coho salmon) in the Great Lakes. Source: Sandy Hellman, U.S. Environmental Protection Agency, Great Lakes National Program Office (unpublished).

Some of the main entry mechanisms include ship ballast water, the deliberate release of fish and other faunal species, and releases from hobby aquaria. Some plant species have escaped from cultivation. Even with voluntary and mandatory ballast exchange programs recently implemented in Canada and the U.S., newly introduced species associated with shipping activities have been identified.

Introductions of non-native species are expected to continue because of increased global trade; new diversions of water into the Great Lakes; aquaculture industries; and changes in water quality and/or temperature. Even the presence of some key non-native species could make the Great Lakes more hospitable for other nuisance species.

4. Summary

The process for selecting and developing indicators of the health of the Great Lakes basin ecosystem has been open, engaging the participation of a wide variety of stakeholders. Informal consensus on the suite of indicators has been actively sought, and continues to be important, as the indicators are refined. The indicators have been extensively reviewed, but the list continues to be dynamic, and individual indicators are subject to testing and further revision.

Based on the overall criteria of *necessary* and *sufficient*, the suite of indicators addresses most of the Great Lakes ecosystem components. Some additional indicators may be added as information gaps or other managerial needs for data are identified. Some indicators may also be removed from the list if they no longer provide useful information.

Monitoring and reporting on the state of ecosystem components is not a new concept to Great Lakes programs. The value added by this process is the deliberate selection of information requirements and the translation of those requirements into a comprehensive suite of indicators for multiple users. The data collected from collaborative monitoring efforts and the subsequent interpretation of the data should be useful for environmental managers at all levels of government as well as for researchers, industry, and private citizens. The suite of indicators can also be used by the governments of Canada and the U.S. not only as a basis for reporting on progress toward the goals of the GLWQA, but also as a basis for engaging additional monitoring and research.

Several challenges remain to fully implement the indicators. They include the following:

- Periodically reviewing and refining the indicator list;
- Gaining acceptance of the list by federal, state, provincial, and municipal partners who have the potential to monitor these indicators;
- Nesting local and lake-wide indicators within basin-wide indicators;

- Building appropriate monitoring and reporting activities into Great Lakes programs at the federal, provincial, state, Tribes/First Nations, and industry levels, including agencies that have not traditionally provided monitoring data; and
- Reporting on indicators in a format that will meet the needs of multiple users.

As more of the underlying data supporting the indicators become available, more audiences can be served, including the general public, local decision-makers, and the scientific and engineering communities. Using indices is another way to make information available to specific audiences. A well- informed public should facilitate the management decisions and actions that are needed to continue progress toward the goals of the Great Lakes Water Quality Agreement.

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