SOLEC 2000

Implementing Indicators

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State of the Lakes Ecosystem Conference 2000
Implementing Indicators

Draft for Discussion at SOLEC 2000

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State of the Lakes Ecosystem Conference 2000 - Implementing Indicators

Introduction

This report is a collection of summary reports on [25] Great Lakes environmental indicators. Its purpose is to provide SOLEC participants an advanced look at the status of Great Lakes ecosystem components based on the suite of 80 indicators proposed at SOLEC 1998.

Each indicator report was authored by one or more people who are familiar with the subject area and data sources. Acknowledgments are included in each report. SOLEC organizers provided the authors with guidelines for the preparation of the report. The indicator reports have been reformatted to a common page layout style, but the content has not been edited. **These indicator reports should be considered DRAFT - for SOLEC Review**.

These indicators will be presented and discussed at SOLEC 2000. Participants will have opportunities to provide additional data or data sources, contribute overall assessments about the status of the Great Lakes, and debate implications of the indicators and assessments for environmental management. Based on the information in these indicators, on feedback and analyses received at SOLEC 2000, and on additional information obtained after SOLEC 2000, a State of the Great Lakes 2001 report will be prepared which will contain both the final indicator summary reports and assessments of Great Lakes ecosystem components based on the indicators.

The indicators in this report are grouped according to the SOLEC categories of nearshore and offshore open waters, coastal wetlands, nearshore terrestrial (including land use), human health, and unbounded. Other groupings are equally valid, depending on the perspective of the user. A table is included in Appendix A of this report that lists all the SOLEC indicators and identifies to which of several alternate groupings each indicator is relevant. Previous versions of this table have appeared in the **State of the Great Lakes 1999** report and in the **Selection of Indicators for Great Lakes Basin Ecosystem Health - Version 4**.

This is the first attempt to assemble data and to present summary assessments for the SOLEC indicators. Not all the SOLEC indicators are included in this report. Several reasons are possible for SOLEC indicators to be absent from this report:

C The data exist but they were not retrieved and summarized by the time this report was assembled and printed. These indicator summaries should be available for distribution at SOLEC 2000.

C The data exist, but they were not accessible to indicator authors within the constraints of time and personnel available. The information might be available for the State of the Great Lakes 2001 report, but not for consideration at SOLEC 2000.

C The required data have not been collected. Changes to existing monitoring programs or the initiation of new monitoring programs are needed to collect and analyze the data.

C The indicator is still under development. More research and/or testing is needed before the indicator can be implemented.

Also, not all indicators presented here are complete. Some have data for selected geographic areas, but not for all the Great Lakes. Some present only part of the data that are proposed for a complete indicator.

Over the next several years, more of the SOLEC indicators will be phased in. Monitoring programs will be adjusted, information management systems put into place, and research and testing completed to refine the indicators. Meanwhile, readers are encouraged to assist in the biennial assessment of the Great Lakes by reading the indicator reports and providing constructive feedback on their content, format, data, conclusions and implications for management.

For further details of the indicator development process and of previous SOLEC conferences can be found on the web at: http://www.on.ec.gc.ca/solec/ and http://www.epa.gov/glnpo/solec/

Walleye [and Hexagenia]

SOLEC Indicator #9

Purpose

Trends in walleye fishery yields indicate changes in overall fish community structure, the health of percids, and the stability and resiliency of the Great Lakes aquatic ecosystem.

Ecosystem Objective

Protection, enhancement, and restoration of historically important, mesotrophic habitats that support walleye as the top fish predator are necessary for stable, balanced, and productive elements of the Great Lakes ecosystem.

State of the Ecosystem

Reductions in phosphorus loadings during the 1970s substantially improved spawning and nursery habitat for many fish species in the Great Lakes. Improved mesotrophic habitats (i.e., western Lake Erie, Bay of Quinte, Saginaw Bay, and Green Bay), along with interagency fishery management programs that increased adult survival, led to a dramatic recovery of walleyes in many areas of the Great Lakes, especially in Lake Erie. High water levels also may have played a major role in the recovery. Fishery endpoints, established for these areas by Lake Committees within the Great Lakes Fishery Commission, were attained or exceeded in nearly all areas by the mid-1980s and then declined during the 1990s. Total yields were highest in Lake Erie (averaged nearly 4,800 kilotons, 1975-1999), intermediate in Lakes Huron and Ontario (<300 kilotons in all years), and lowest in Lakes Michigan and Superior (<10 kilotons). Declines in the 1990s were likely related to shifts in environmental states (i.e., from mesotrophic to less favorable oligotrophic conditions), changing fisheries, and, perhaps in the case of Lake Erie, a population naturally coming into balance with its prey base. The effects of exotic species on the food web or on walleye behavior (increased water clarity can limit daytime feeding) also may have been a contributing factor. In general, walleye yields tended to peak during periods of ideal environmental conditions (mid-1980s) and remain substantially improved from levels of the 1970s.

Future Pressures

Natural, self-sustaining walleye populations require adequate spawning and nursery habitats. In the Great Lakes, these habitats lie in tributary streams and nearshore reefs, wetlands, and embayments. Loss of these habitats is the primary concern for future health of walleye populations. Environmental factors that alter water level, water temperature, water clarity, and flow (currents) can substantially affect nearshore habitats. Thus, global warming and its subsequent effects on temperature and precipitation in the Great Lakes basin may become increasingly important determinants of walleye health. Exotic species, like zebra mussels, ruffe, and round gobies may disrupt the efficiency of energy transfer through the food web, potentially affecting growth and survival of walleye. Moreover, alterations in the food web can affect environmental characteristics (like water clarity), which can in turn affect fishery catches of walleye. Human disturbance of tributary and nearshore habitats through activities like dredging, diking, farming, and filling of wetlands will continue to pose threats to all fish species that require these habitats for reproduction.

Future Activities

Research is needed to further identify critical reproductive habitats and how they are being affected by environmental and anthropogenic disturbances. This information is crucial to develop management plans that carefully balance human demands with ecosystem health. Annual harvest assessments should be continued for walleye fisheries in all areas and should be reported in a standard unit (pounds).

Further Work Necessary

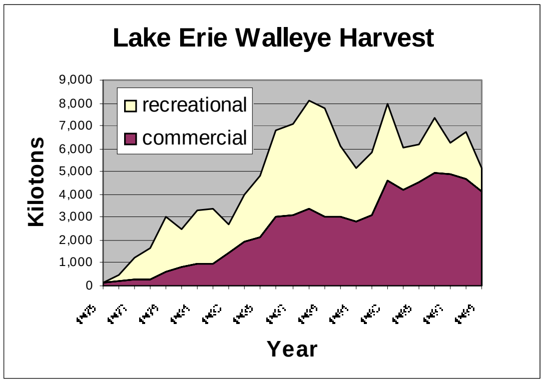
Fishery yields can serve as appropriate indicators of walleye health but need to include all types of fisheries (i.e., recreational, commercial, tribal) in the areas of interest. Yield assessments are lacking for some fisheries or in some years for most of the areas. Moreover, measurement units are not standardized among fishery types (i.e., commercial fisheries are measured in pounds while recreational fisheries are measured in numbers), which means additional conversions are necessary and may introduce errors. Therefore, trends in yields across time (years) are probably better indicators than absolute values within any year, assuming that any introduced bias is relatively constant over time. It may be useful to also compile index net survey estimates of relative abundance from all areas (where available) to augment the yield data.

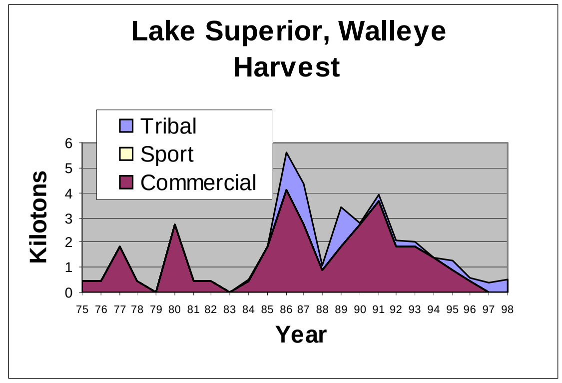
Sources

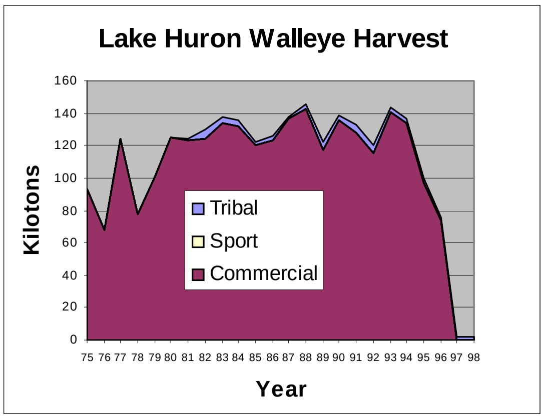
Fishery harvest data were obtained from Tom Stewart (Lake Ontario-OMNR), Tom Eckhart (Lake Ontario - NYDEC), Karen Wright (Upper Lakes tribal data-

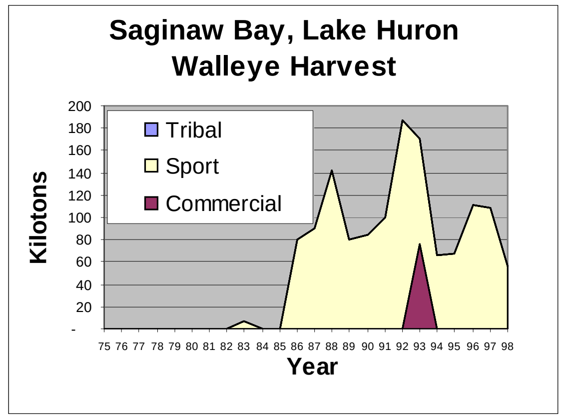
COTFMA), Dave Fielder (Lake Huron-MDNR), Terry Lychwyck (Green Bay-WDNR), various annual OMNR and ODNR Lake Erie fisheries reports, and the GLFC commercial fishery data base. Gene Emond (ODNR) collated data into a standardized form. Fishery data should not be used for purposes outside of this document without first contacting the agencies that collected them.

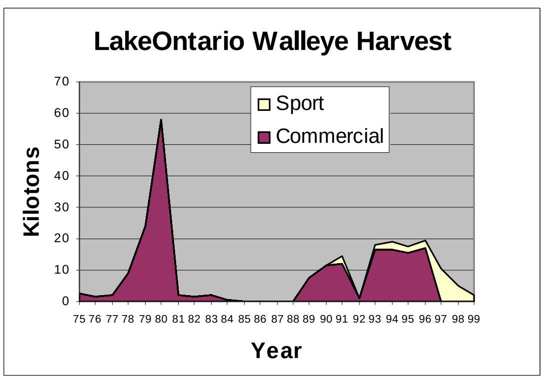
Acknowledgments
Author: Roger Knight, Ohio Department of Natural Resources, OH.

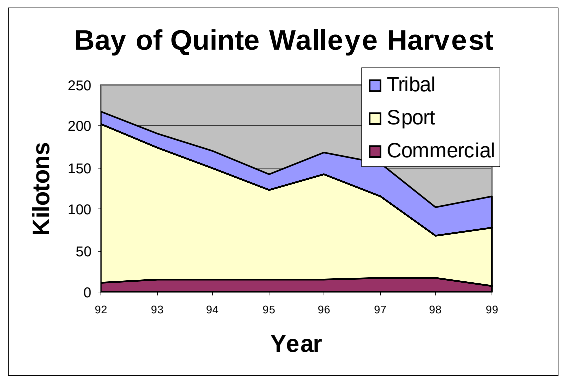


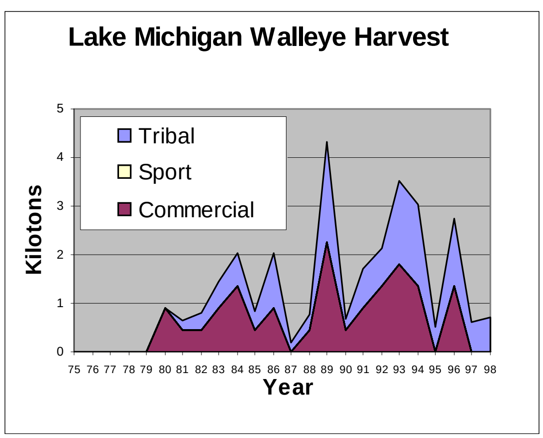


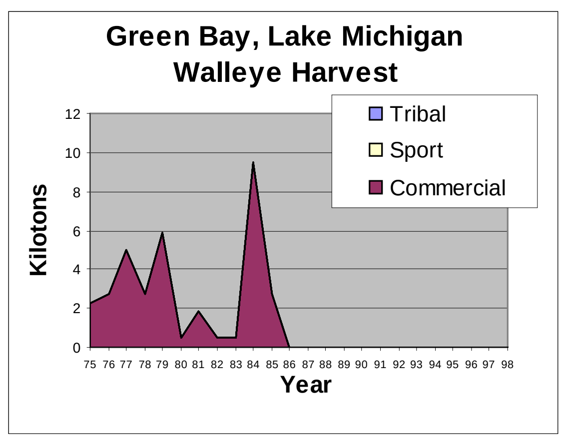












FCGOs
Lake Huron: 0.7 million kg
Lake Michigan: 0.1 to 0.2 million kg
Lake Erie: sustainable harvests in all basins
Achievement of these targets will require healthy walleye stocks in each lake.

[Walleye and] Hexagenia
SOLEC Indicator #9

Purpose
The distribution, abundance, and annual production of the burrowing mayfly *Hexagenia* in mesotrophic Great Lakes habitat is measured directly and used as the indicator. *Hexagenia* is proposed for use as an indicator of ecosystem health because it is intolerant of pollution and is thus a good reflection of water and lakebed sediment quality in mesotrophic Great Lakes habitats, where it was historically the dominant, large, benthic invertebrate and an important item on the diets of many valuable fishes.

Ecosystem Objective
Historically productive Great Lakes mesotrophic habitats like western Lake Erie; the Bay of Quinte, Lake Ontario; Saginaw Bay, Lake Huron; and Green Bay, Lake Michigan, should be restored and maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with *Hexagenia* as the dominant, large, benthic invertebrate.

State of the Ecosystem
Major declines in the abundance of *Hexagenia* and low abundance or absence in some Great Lakes habitats where they were historically abundant have been linked to eutrophication and low dissolved oxygen in bottom waters and to pollution of sediments by metals and petroleum products. For example, *Hexagenia* was abundant in the western and central basins basins of Lake Erie in the 1930s and 1940s but an extensive mortality occurred in 1953 in the eastern portion of the western basin. The population there recovered in 1954, but extinction followed throughout the western and central basins by the early 1960s. Improvements in water and sediment quality in historical *Hexagenia* habitat following the imposition of pollution controls in the 1960s were not immediately followed by the recovery of *Hexagenia* populations. However, there is now evidence of the beginnings of recovery of *Hexagenia* in Green Bay, Lake Michigan, and full recovery of the population in western Lake Erie is predicted to occur in 2000, indicating the health of these mesotrophic habitats is improving substantially. Most of Lake St. Clair and portions of the Upper Great Lakes Connecting Channels support populations of *Hexagenia* with the highest biomass and production measured anywhere in North America (Fig. 1). In sharp contrast, *Hexagenia* has been extirpated in polluted portions of these same Great Lakes waters and no recovery is presently evident.

The recovery of *Hexagenia* in western Lake Erie is a signal event, which shows clearly that properly implemented pollution controls can bring about the recovery of a major Great Lakes mesotrophic ecosystem. With its full recovery, the *Hexagenia* population in western Lake

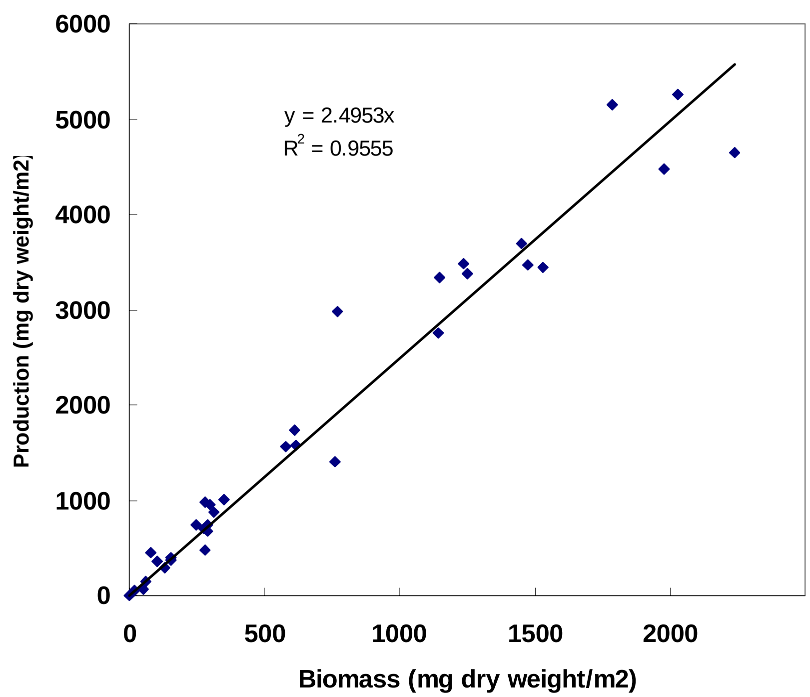


Figure 1. Mean annual biomass and production of *Hexagenia* populations in North America.
Biomass values >500 (production values > about 1000) represent populations from unpolluted portions of Lake St. Clair, the St. Marys River, and eastern Lake Superior. Lower values represent populations from polluted areas elsewhere in the Upper Great Lakes Connecting Channels and populations from polluted and clean habitats elsewhere in North America.
(Source: T. A. Edsall, unpublished data.)

Erie will probably reclaim its functional status as a primary agent in sediment bioturbation and as a trophic integrator directly linking the detrital energy resource to fish, and particularly the economically valuable percid community. The recovery of the *Hexagenia* population in western Lake Erie also helps remind us of one outstanding public outreach feature associated with using *Hexagenia* as an indicator of ecosystem health—the massive swarms of winged adults that are typical of healthy, productive *Hexagenia* populations in areas of historical abundance in the Great Lakes. These swarms will be highly visible to the public who can use them to judge the success of water pollution control programs and the health of Great Lakes mesotrophic ecosystems.

Future Pressures on the Ecosystem

The virtual extinction and delayed recovery of the *Hexagenia* population in western Lake Erie was attributed to the widespread, periodic occurrence of anoxic bottom waters resulting from nutrient inputs in sewage and runoff from agricultural lands, and to toxic pollutants, including oil and heavy metals, which accumulated and persisted in the lakebed sediments. Most point source inputs are now controlled, but in-place pollutants in lakebed sediments appear to be a problem in some areas. Paved surface runoff and combined sewer overflows also pose a major problem in some urban areas. Phosphorus loadings still exceed guideline levels in some portions of the Great Lakes and loadings may increase as the human population in the Great Lakes basin grows.

The effects of exotic species on *Hexagenia* and its usefulness as an indicator of ecosystem health are unknown and may be problematic. It has been postulated that the colonization of the western basin by the zebra mussel (*Dreissena polymorpha*) and the recovery of *Hexagenia* are linked causally, but no specific mechanism has yet been proposed. Support for zebra mussel as a major factor in the recovery of *Hexagenia* in the western basin is perhaps eroded by the fact that Saginaw Bay, Lake Huron, is also heavily colonized by the zebra mussel, but the *Hexageni*a population there, which collapsed in 1955-1956, still has not shown signs of recovery.

Future Actions

Regulate point sources and non-point sources of pollution in the basin to improve and maintain Great Lakes water and sediment quality consistent with the environmental requirements of healthy, productive populations of *Hexagenia*. Continue development and application of technology and practices designed to remediate lakebed and riverbed sediments in AOCs and critical *Hexagenia* habitat areas that have problem levels of persistent, in-place pollutants.

Further Work Needed

Develop a monitoring program and baseline data for *Hexagenia* populations in all major, historical, Great Lakes mesotrophic habitats so that changes in ecosystem health can be monitored and reported, management strategies evaluated and improved, and corrective actions taken to improve ecosystem health and to judge progress toward reaching interim and long term targets and goals. Conduct studies needed to describe the interactions between *Hexagenia* and introduced aquatic species and the effect of those species, if any, on the utility of *Hexagenia* as an indicator of ecosystem health.

Acknowledgments

Author: Thomas Edsall, US Geological Survey, Biological Resources Division, Ann Arbor, MI.

Preyfish Populations

SOLEC Indicator #17

Purpose

To directly measure the abundance and diversity of preyfish populations, especially in relation to the stability of predator species necessary to maintain the biological integrity of each lake.

Ecosystem Objective

The importance of preyfish populations to support healthy, productive populations of predator fishes is recognized in the FCGOs for each lake. As example, the fish community objectives for Lake Michigan specify that in order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. This indicator also relates to the 1997 Strategic Great Lakes Fisheries Management Plan Common Goal Statement for Great Lakes fisheries agencies.

This assemblage of fishes form important trophic links in the aquatic ecosystem and constitute the majority of the fish production in the Great Lakes. Preyfish populations in each of the lakes is currently monitored on an annual basis in order to quantify the population dynamics of these important fish stocks leading to a better understanding of the processes that shape the fish community and to identify those characteristics critical to each species. Populations of lake trout, Pacific salmon, and other salmonids in have been established as part of intensive programs designed to rehabilitate (or develop new) game fish populations. These valuable predator species sustain an increasingly demanding and highly valued fisheries and information on their status is crucial. In turn, these apex predators are sustained by forage fish populations. In addition, the bloater and the lake herring, native species, and the rainbow smelt are also directly important to the commercial fishing industry. Therefore, it is very important, based on (1) lake trout restoration goals, (2) stocking projections, (3), present levels of salmonid abundance and (4) commercial fishing interests, that the current status and estimated carrying capacity of the fish populations be fully understood.

State of the Ecosystem

The segment of the Great Lakes' fish communities that we classify as preyfish comprises species that, as mature adults, prey essentially on zooplankton. Those species that depend on diets of invertebrates, typically crustacean zooplankton, for their entire life history are those fish considered in this section – including both pelagic and benthic species. This convention also supports the recognition of particle-size distribution theory and size-dependent ecological processes. Based on size-spectra theory, body size is an indicator of trophic level and the smaller, short-lived fish that constitute the planktivorous fish assemblage discussed here are a discernable trophic group of the food web. At present, bloaters (*Coregonus hoyi*), lake herring (*Coregonus artedi*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and deepwater sculpins (*Myoxocephalus thompsoni*), and to a lesser degree species like ninespine sticklebacks (*Pungitius pungitius*) and slimy sculpins (*Cottus cognatus*) constitute the bulk of the preyfish communities.

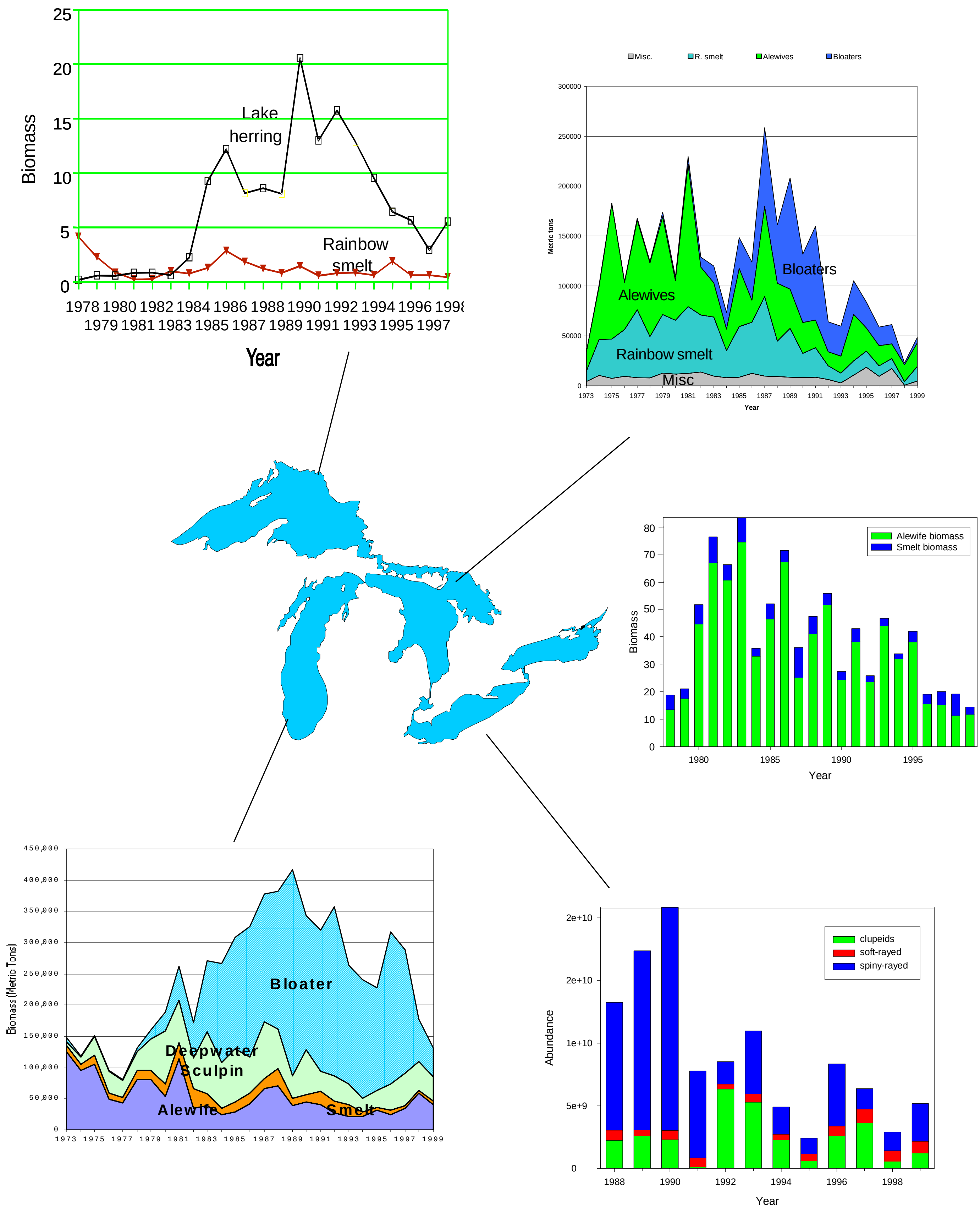
In Lake Erie, the prey fish community is unique among the Great Lakes in that it is characterized by relatively high species diversity. The prey fish community comprises primarily gizzard shad (*Dorosoma cepedianum*) and alewife (clupeids), emerald (*Notropis atherinoides*) and spottail shiners (*N. hudsonius*), silver chubs (*Hybopsis storeriana*), trout-perch (*Percopsis omiscomaycus*), round gobies (*Neogobius melanostomus*), and rainbow smelt (soft-rayed), and age-0 yellow (*Perca flavescens*) and white perch (*Morone americana*), and white bass (*M. chrysops*)(spiny-rayed).

Lake Michigan –

Alewives remain at consistently lower levels as compared to previous years. Some increase in abundance is noted with strong 1995 and 1998 year classes, but the current low population levels appear to be driven in large part by predation pressure. Rainbow smelt have declined and remain at lower levels, possibly due to predation. Bloater biomass continues to decline due to lack of recruitment and slow growth. Bloaters are expected to decline further, but may rebound as part of an anticipated natural cycle in abundance. Sculpins remain at the same level of abundance and continue to contribute a significant portion of the preyfish biomass.

Lake Huron –

Similar to Lake Michigan, the decline in bloater abundance has resulted in shift in an increased proportion of alewives in the preyfish community. The changes in the abundance and age structure of the prey for salmon and trout to predominantly younger, smaller fish suggests that


25
20
15
10
5
0
Biomass
Lake
herring
Rainbow
smelt
1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 199
1979 1981 1983 1985 1987 1989 1991 1993 1995 1997
Year
Misc.
R. smelt
Alewives
Bloaters
300000
250000
200000
150000
100000
50000
0
Metric tons
Alewives
Bloaters
Rainbow smelt
Misc
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year
80
70
60
50
40
30
20
10
0
Biomass
Alewife biomass
Smelt biomass
1980 1985 1990 1995
Year
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Biomass (Metric Tons)
Bloater
Deepwater
Sculpin
Alewife
Smelt
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
2e+10
2e+10
1e+10
5e+9
0
Abundance
clupeids
soft-rayed
spiny-rayed
1988 1990 1992 1994 1996 1998
Year

predation pressure is an important force in both alewife and rainbow smelt populations. Sculpin populations have varied, but have been at lower levels in recent years.

Lake Ontario –
Alewives and to a lesser degree rainbow smelt dominate the preyfish population. Alewives remain at same low level; though this species has exhibited a strong 1998 year class. Rainbow smelt show some increase due to influence of 1996 year class, but the paucity of large individuals indicates heavy predation. Overall, shifts to deeper water have been noted in fish distributions and may be related to establishment of Dreissena. Sculpin populations have declined and remained at low levels in since 1990.

Lake Superior –
Lake herring populations have declined recently to be less dominant in the preyfish community. Lake herring biomass is controlled by production of young, which is mediated by environment rather than parental stock size. In contrast, rainbow smelt biomass has remained low and is likely controlled by predation from trout and salmon. Continued low forage biomass will result in declining growth and survival rates of trout and salmon. Sculpins remain at low but consistent levels of abundance.

Lake Erie –
Recently, the prey fish community in all three basins of Lake Erie has shown declining trends. In the eastern basin, rainbow smelt have shown significant declines in abundance coupled with alternate year high abundance pattern, as well as declines in growth rate over the past several years. These declines have been attributed to lack of recruitment associated with Driessenid colonization and reductions in productivity. The western and central basins also have shown declines in forage fish abundance associated with declines in abundance of age-0 white perch and rainbow smelt. The clupeid component of the forage fish community has shown no overall trend in the past decade, although gizzard shad and alewife abundance has been quite variable across the survey period.

Future Pressures
The influences of predation by salmon and trout on preyfish populations appear to be common across all lakes. Additional pressures from Dreissena populations are apparent in Lake Ontario and Lake Erie, and "bottom up" effects on the prey fishes may be expected from a dramatic decline recently observed in Diporeia populations in Lake Michigan as well as newly expanded populations of Dreissena in this lake.

Future Activities
Recognition of significant predation effects on preyfish populations has resulted in recent salmon stocking cutbacks in Lakes Michigan, Huron, and Ontario. However, even at lower populations, alewives have exhibited the ability to produce strong year classes such that the continued judicious use of artificially propagated predators seems necessary to avoid domination by the alewife. It should be noted that this is not an option in Lake Superior since lake trout and salmon are largely lake-produced. Potential "bottom up" effects on prey fishes would be difficult in any attempt to mitigate owing to our inability to affect changes – this scenario only reinforces the need to avoid further introductions of exotics into the Great Lake ecosystems.

Further Work Necessary
It has been advanced that in order to restore an ecologically balanced fish community, a diversity of prey species at population levels matched to primary production and predator demands must be maintained. However, the current mix of native and naturalized prey and predator species, and the contributions of artificially propagated predator species into the system confounds any sense of balance. The metrics of ecological balance as the consequence of fish community structure are best defined through food-web interactions. It is through understanding the exchanges of trophic supply and demand that the fish community can be described quantitatively and ecological attributes such as balance be better defined and the limits inherent to the ecosystem realized.

Continued monitoring of the fish communities and regular assessments of food habits of predators and prey fishes will be required to quantify the food-web dynamics in the Great Lakes. This recommendation is especially supported by continued changes that are occurring not only in the upper but also in the lower trophic levels. Recognized sampling limitations of traditional capture techniques has prompted the application of acoustic techniques as another means to estimate absolute abundance of prey fishes in the Great Lakes. Though not an assessment panacea, acoustics has provided additional insights and has demonstrated utility in the estimates of preyfish biomass.

It is obvious that protecting or reestablishing rare or extirpated members of the once prominent native prey fishes, most notably the various members of the whitefish family (*Coregonus* spp), should be a priority in all the Great Lakes. This recommendation would include the deepwater cisco species and should be reflected in future indicator reports.

With the continuous nature of changes that seems to characterize the prey fishes, the appropriate frequency to review this indicator is on a 5-year basis.

Acknowledgements
Author: Guy W. Fleischer, USGS Great Lakes Science Center, Ann Arbor, MI.
Contributions from Robert O'Gorman and Randy W. Owens, USGS Great Lakes Science Center, Lake Ontario Biological Station, Oswego NY, Charles Madenjian, Gary Curtis, Ray Argyle and Jeff Schaeffer, USGS Great Lakes Science Center, Ann Arbor, MI, and Charles Bronte and Mike Hoff, USGS Great Lakes Science Center, Lake Superior Biological Station, Ashland, WI., and Jeffrey Tyson, Ohio Div. of Wildlife Sandusky Fish Research Unit, Sandusky, OH.

All preyfish trend figures are based on annual bottom trawl surveys performed by USGS Great Lakes Science Center, except Lake Erie, which is from surveys conducted by the Ohio Division of Wildlife.

Spawning-Phase Sea Lamprey Abundance

SOLEC Indicator #18

Purpose

This indicator estimates the abundance of sea lampreys in the Great Lakes, which has a direct impact on the structure of the fish community and health of the aquatic ecosystem. In particular, populations of large, native, predatory fishes are negatively affected by mortality caused by sea lampreys.

Ecosystem Objective

The 1955 Convention of Great Lakes Fisheries created the Great Lakes Fishery Commission (GLFC) "*to formulate and implement a comprehensive program for the purpose of eradicating or minimizing the sea lamprey populations in the Convention area*". Under the Joint Strategic Plan for Great Lakes Fisheries, lake committees, consisting of all fishery management agencies, have established Fish Community Objectives (FCOs) for each of the lakes. These FCOs cite the need for sea lamprey control to support objectives for the fish community, in particular, objectives for lake trout, the native top predator. The FCOs include endpoints for sea lampreys of varying specificity:

Superior (1990) - *50% reduction in parasitic-phase sea lamprey abundance by 2000, and a 90% reduction by 2010*;

Michigan (1995) - *Suppress the sea lamprey to allow the achievement of other fish-community objectives*;

Huron (1995) - *75% reduction in parasitic sea lamprey by the year 2000 and a 90% reduction by the year 2010 from present levels*;

Erie (1999 draft) - *Sea lamprey are a pest species requiring control;*

Ontario (1999) - *Suppress sea lamprey to early-1990s levels, and maintaining marking rates at <.02 marks/lake trout.*

State of the Ecosystem

The first complete round of stream treatments with the lampricide TFM resulted in early success in most all of the Great Lakes. Measures of spawning-phase populations showed a reduction to less than 10% of their pre-control abundance in Lakes Superior, Michigan, Huron, Erie, and Ontario.

The numbers of sea lamprey migrating up rivers to spawn provides an indicator of the abundance of parasites feeding in the lakes during the previous year. Estimates of individual spawning runs are used to estimate lake-wide abundance from a new regression model that relates run size to stream characteristics. Figure 1 presents these lake-wide estimates for the past 20 years.

Lake Superior: During the past 20 years, populations have fluctuated but remain at levels less than 10% of peak abundance. The FCO for sea lampreys was met in 1994 and 1995, but abundance has increased since 1995. Recent increased abundance estimates have raised concern in all waters. Marking rates have not shown the same relatively large increase except in some areas of Canadian waters. Survival objectives for lake trout continue to be met but may be threatened if these increases persist.

Lake Michigan: Over the majority of the lake, populations have been relatively stable. Marking rates on lake trout have remained low for the period and the general FCOs are being met. However, a gradual increase in the lake population is continuing through the present. This change is due to increases in the north caused by an expansion of the large population in Lake Huron into Lake Michigan.

Lake Huron: Following the success of the first full round of stream treatments during the late 1960s, sea lamprey populations were suppressed to low levels (<10%) through the 1970s. During the early 1980s, populations increased in Lake Huron, particularly the north. This increase continued through to a peak in abundance during 1993. Through the 1990s Lake Huron contained more sea lamprey than all the other lakes combined. FCOs were not being achieved. The Lake Huron Committee had to abandon its lake trout restoration objective in the northern portion of the lake during 1995 because so few lake trout were surviving attacks by sea lamprey to survive to maturity. The St. Marys River was identified as the source of this increase. The size of this connecting channel made traditional treatment with the lampricide TFM impractical. A new integrated control strategy including targeted application of a new bottom-release lampricide, enhanced trapping of spawning animals, and sterile-male release was initiated in 1997. A decline in spawning-phase abundance is predicted for 2001 as a result of the completion of the first full round of lampricide spot treatments during 1999.

Lake Erie: Following the completion of the first full round of stream treatments in 1987, sea lamprey populations collapsed. Lake trout survival wounding

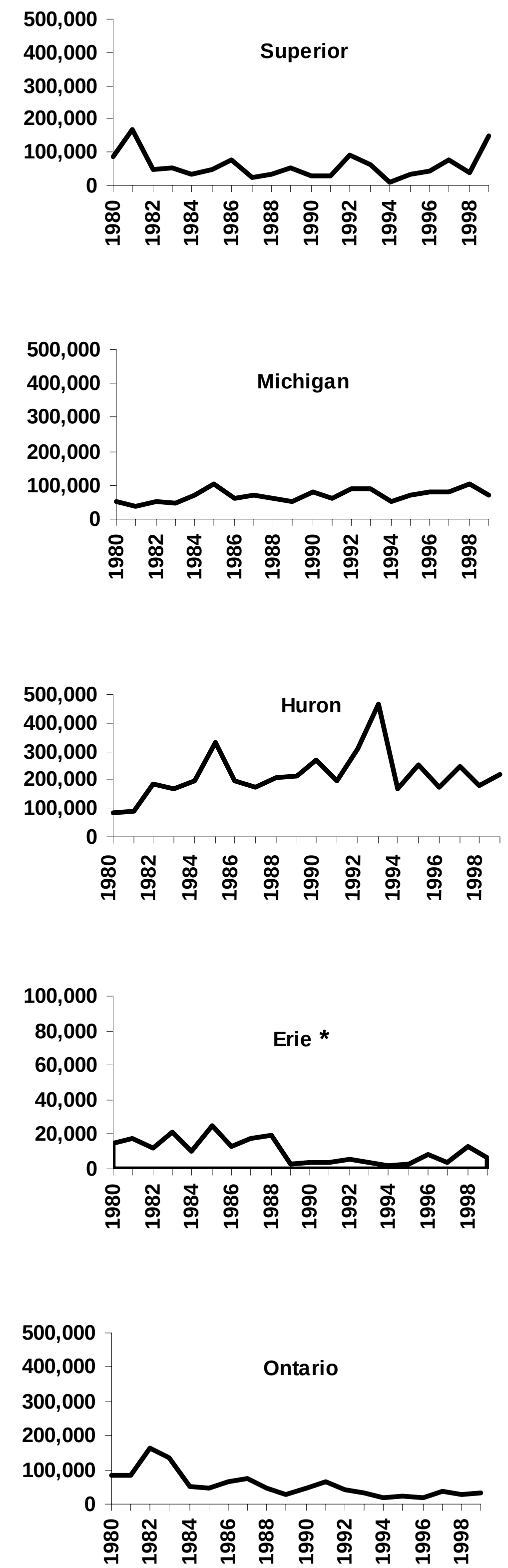


Figure 1. Total annual abundance of sea lamprey estimated during the spawning migration. Note the scale for Lake Erie is 1/5 larger than the other lakes.

rates declined and survival increased to levels sufficient to meet the rehabilitation objectives in the eastern basin. However lamprey abundance has increased since the early 1990's to levels that threaten the lake trout success. A major assessment effort during 1998 indicated that the source of this increase were several streams in which treatments had been deferred due to low water flows or concerns for non-target organisms. These critical streams have been treated during 1999 and 2000 and sea lamprey abundance is predicted to decline by 2002.

Lake Ontario: Abundance of spawning-phase sea lampreys has continued to decline to low levels through the 1990s. The FCOs for both sea lamprey abundance and lake trout marking continue to be achieved.

Future Pressures on the Ecosystem

Since parasitic-phase sea lampreys are at the top of the aquatic food chain and inflict high mortality on large piscivores, population control is essential for healthy fish communities. As water quality improves so does the potential for sea lampreys to colonize new locations. Increasing abundance in Lake Erie demonstrates how short lapses in control can result in rapid increases of abundance and that continued effective stream treatments are necessary to overcome the reproductive potential of this invading species.

As fish communities recover from the effects of lamprey predation or overfishing, there is evidence that the survival of parasitic sea lampreys increases due to prey availability. Better survival means that there are more residual sea lamprey to cause harm. Significant additional control efforts, like those on the St. Marys River, may be necessary to maintain suppression.

The GLFC has a goal of reducing reliance on lampricides and increasing efforts to integrate other control techniques, such as the sterile-male-release-technique or the installation of barriers to stop the upstream migration of adults. This philosophy is consistent with sound practices of integrated pest management, but can put additional pressures on the ecosystem such as limiting the passage of fish upstream of barriers. Care must be taken in applying new alternatives or in reducing lampricide use to not allow sea lamprey abundance to increase.

Future Actions

The GLFC continues to focus on research and development of alternative control strategies including new methods like the use of pheromones to disrupt migration and *spawning. Computer models, driven by empirical data, are being used to best allocate treatment resources, and research is being conducted to better understand the variability in sea lamprey population.*

Further Work Necessary

Targeted lampricide treatments are predicted to reduce sea lamprey to acceptable levels in Lakes Huron and Erie. The sources of increases in Lake Superior need to be identified and dealt with. Continuing improvements in monitoring sea lamprey populations will ensure control is applied where it is most needed. In addition, research to better understand lamprey/prey interactions, the population dynamics of lampreys that survive control actions, and refinement alternative methods are all key to maintaining sea lamprey at tolerable levels.

Acknowledgments

Author: Gavin Christie, Great Lakes Fishery Commission, Ann Arbor, MI.

Native Unionid Mussels

SOLEC Indicator #68

Purpose

Unionids are of unique ecological value, functioning as natural biological filters, providing food for fish and wildlife, and indicators of good water quality. As our largest freshwater invertebrate, they are key players in the movement of organic and inorganic particulate matter between the water column and the sediment. Unionid mussels are long-lived, relatively sedentary animals, which are highly sensitive to habitat degradation, organic, inorganic, and metal pollutants, and biofouling by zebra mussels. Thus, unionid distribution and abundance patterns provide a rapid assessment tool indicating the general health of the aquatic ecosystem. Since native mussel shell have historically formed the backbone of museum invertebrate collections, more historical data exists for freshwater unionids than for any other group of aquatic invertebrates, with many records available from even before the 1860's.

Ecosystem Objective

The ultimate goal is to identify, protect and enhance critical unionid populations and key habitats to ensure the future survival of these animals, particularly the endangered and threatened species in the Great Lakes, their tributaries and connecting channels. This goal relates to the IJC Desired Outcome 6: Biological community integrity and diversity. The diversity of native invertebrate fauna should be maintained in order to stabilize ecosystem habitats throughout the Great Lakes drainage basin.

A number of federal-and state/province listed species are found in the Great Lakes within both Canadian and United States jurisdictions. In Canada, the northern riffleshell (*Epioblasma torulosa rangiana*), rayed bean (*Villosa fabalis*), and the wavy-rayed lampmussel (*Lampsilis fasciola*) have been designated as federally endangered and the first two species are provincially endangered (*L. fasciola* was designated as threatened in Ontario). The mudpuppy mussel (*Simpsonaias ambigua*)and the snuffbox (*Epioblasma triquetra*)are under evaluation and will likely be designated as endangered in 2001. In the United States, a number of mussels are state and federally listed within the Great Lakes watershed, including the clubshell (*Pleurobema clava*), fat pocketbook (*Potamilus capax*), northern riffleshell (*E. torulosa rangiana*), and the white catspaw (*Epioblasma obliquata perobliqua*).

State of the Ecosystem

Unionid mussels are the most endangered animals in North America. Approximately 70% of all North American species are state/province or federally listed as endangered or threatened. Most unionid populations in the Great Lakes and associated watersheds have declined as a result of decades of habitat alteration such as dredging, urbanization, increased sedimentation, shoreline armoring, changes in fish distribution, and the in action of chemical pollutants in the water column and sediments.

The introduction of zebra mussels into the Great Lakes has led to the rapid extirpation of unionids in many areas. Unionid species diversity and density has severely declined in the open waters of Lake Erie, the Detroit River, and Lake St. Clair since the arrival of zebra mussels in the mid-1980s. Densities have dropped from an average of 16 individuals/square meter to less than 1 (Figure 1). Many sites contain no live unionids at all. Unionid mortality results both from biofouling and food resource competition and drastic declines in populations often occur within two years of the initial dreissenid invasion.

While unionids have been extirpated in many areas due to zebra mussel induced mortality, some remnant populations have survived in certain habitats. Healthy and diverse communities were recently discovered in lake Erie in nearshore areas with firm substrates (Schloesser et al. 1997), in soft sediments associated with coastal marshes (Nichols and Amberg 1999), and in a coastal marsh in the St. Clair River delta (Mackie et al. 2000). The protective mechanisms in these shallow lake zones vary. In wetland areas, unionids often escape extirpation by burrowing in the soft sediments and suffocating biofouling zebra mussels. Wave action may also play a key role in preventing permanent zebra mussel colonization.

Since zebra mussels have a planktonic larval stage (veliger) which requires an average of 20-30 days to develop into a benthic stage, rivers and streams have limited colonization potential. Such areas can provide natural refugia to unionid populations. Regulated streams and rivers, those containing reservoirs, may not provide refugia. Reservoirs with water retention times great than 20-30 days will allow veligers to develop and settle, after which the impounded populations will seed downstream reaches on

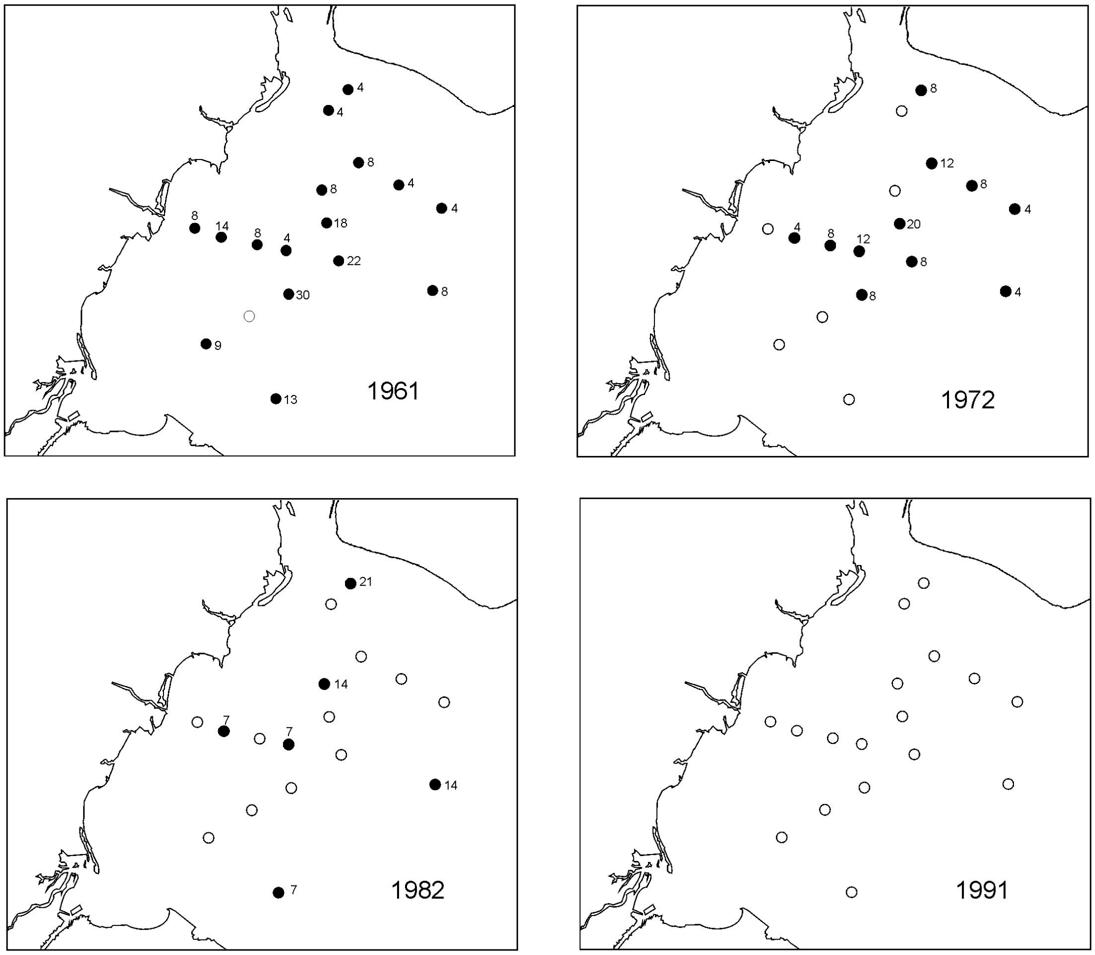


Figure 1. Abundance of freshwater mussels (numbers/m2) collected in 1961, 1972, 1982 and 1991 from 17 sites in the western basin of Lake Erie.
Source: Nalepa et al. (1991) and Schloesser and Nalepa (1994).

an annual basis. It is vital to prevent the introduction of zebra mussels into these reservoirs.

Future Pressures

Zebra mussel expansion is the main threat facing unionids in the Great Lakes drainage basin. Zebra mussels are now found in all the Great Lakes, and in many associated water bodies. As of the year 2000, 180 inland lakes in the region were known to be colonized by zebra mussels. Most of these infested lakes, 130,are located in Michigan. Other exotics may also negatively affect unionid survival through the reduction of native fish fauna. Unionid reproductive cycles contain a parasitic larval stage requiring specific fish hosts. Exotic fish such as the European ruffe and the round goby are known to totally displace native fish, thus causing the functional extinction of local unionid populations.

Continuing changes in land-use, with increasing urban sprawl, development of factory farms, and elevated use of herbicides to remove aquatic vegetation from lakes for recreational purposes will continue to have a negative impact on unionid populations in the future.

Future Activities

Unionid populations need to be self-sustaining wherever practical throughout their historic range in the Great Lakes, and associated major riverine habitats, including the connecting channels.

1. The first activity needed is to prevent the further introduction of exotic species into the Great Lakes.

2. The second critical activity is to prevent the further inland expansion of exotic species such as zebra

mussels, European ruffe, and round gobies. Overland expansion of these exotics can be minimized through greater emphasis on education of water user groups.

Future Work Necessary

1. Review and compile information on existing surveys of all watersheds.
2. Determine the present distribution and abundance of unionid populations in key watersheds using standardized sampling techniques.
3. Target known populations of endangered and threatened species for inventory, habitat analysis, and yearly monitoring of habitat changes.
4. Existing unionid refugia found in zebra mussel areas need to be documented and protected from future disturbance.
5. Legislative and educational efforts throughout Canada and the United States need to be implemented to protect river systems from zebra mussel colonization in order to protect critical unionid populations that might be key to future restoration efforts. Without self-sustaining river populations, reestablishing lake populations will not be possible.
6. Consolidate in an easily accessible format databases on unionid distribution and abundance. Such information can be gleaned from various museum collections as demonstrated by the work done on the Canadian side of the lower Great Lakes basin. This data needs to be centralized, electronically accessible, and GPS integrated to maximize its usability as a management and environmental assessment tool to resource managers and regulatory agencies. Once the database has been collated, habitat-specific population models can be developed to determine population health, reproductive output, and species-richness within various watersheds leading to the development of criteria to assess habitat and population status.
7. Standardize sampling efforts and measures. Several different methods are used for surveying unionid populations. These methods need to be standardized and a consistent protocol developed. Such standardization is already under discussion by the Freshwater Mollusk Conservation Society. Their protocols should be considered for recommendation and implementation. Use of non-lethal methods for determining the health status of unionids, such as the use of glycogen levels, or other physiological analyses, needs to be recommended.

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Acknowledgements

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Lake Trout [and Scud (*Diporeia hoyi*)]

SOLEC Indicator #93

Purpose

This indicator will track the status and trends in lake trout and it will be used to infer the basic structure of cold water predator and prey communities, and the general health of the ecosystem. Lake trout historically were the principal salmonine predator in all the Great Lakes, and maintained predatory control on native and introduced prey fishes. Populations in all the Great Lakes, with the exception of Lake Erie, supported large food- and sport fisheries, that were integral to the economies of lake-shore communities. By the late 1950s, sea lamprey predation and overfishing extirpated lake trout throughout most of the Great Lakes with remnant stocks in Lake Superior, and a few sites in Lake Huron surviving. Intensive management through control of fisheries, reductions in sea lamprey, and stocking of hatchery-reared fish have restored standing stocks in all the Great Lakes. Full restoration will not be achieved until natural reproduction is established and maintained, and to date only Lake Superior has that distinction.

Ecosystem Objective

Self-sustainability through the establishment of naturally reproducing populations the goal of the lake trout restoration program in all the Great Lakes. Target fishery yields based on natural reproduction are articulated for each lake, except Lake Ontario. These approximate historical production or lower yields that recognize and accommodate stocked and naturalized non-native salmonines. These targets are 4 million pounds from Lake Superior, 2.5 million pounds from Lake Michigan, 2 millions pounds from Lake Huron, and 110,000 lbs from Lake Erie. Lake Ontario has no specified fishery yield, but instead states an interim objective of 0.5-1.0 million adult fish with females 7.5 years old and able to produce 100,000 yearling recruits annually through natural reproduction. Regulatory controls on the fisheries generally preclude measures to attainment yield objectives, even in Lake Superior were self-sustaining populations predominate. Interagency cooperative stock assessment programs are carried out annually in each lake to measure changes in relative abundance, size and age structure, survival, and extent of natural reproduction. The measures are just now being compared to historical surrogate measures were possible to gauge the extent of restoration, especially in Lakes Michigan and Superior.

State of the Ecosystem

Lake trout stock sizes have dramatically increased in all the Great Lakes shortly after the initiation of sea lamprey control, stocking, and harvest control. Natural reproduction is now wide spread in Lake Superior, for both nearshore and offshore stocks, and stocking has been discontinued throughout most of the lake. Densities of wild fish have exceeded that of hatchery-reared fish since the mid 1980s. Recent comparisons with historical data indicate that lake trout densities are now at or exceed those measured during 1929-43 (the pre-lamprey period). Unfortunately natural reproduction is at very low levels or non-existent in the rest of the Great Lakes, therefore populations in these waters are maintained solely by stocking. Populations there are large enough to support tightly regulated sport and commercial fisheries.

Potential Limitations to Restoration

Several potential causes for the lack of natural reproduction have been proposed. Predation on newly hatched lake trout larvae by native and non-native predators is thought to prevent significant recruitment, especially in Lakes Michigan, Erie, and Ontario. In Lake Huron, excessive sea lamprey predation results in few fish reaching sexual maturity, hence there are inadequate parental stock sizes. Hatchery-reared fish appear unable to select suitable substrate for egg deposition, and recent evidence from Lake Superior suggests that these fish are 50% less reproductively efficient compared to wild lake trout. Historically, many morphotypes were present that were uniquely adapted to specific habitats. That genetic diversity is lacking in the strains of hatchery-reared fish stocked, and may be contributing to the lack of colonization of certain areas. Early mortality syndrome (EMS) has been identified as a significant bottleneck to lake trout restoration. EMS of larvae though to be due to thiamine deficiencies as the result of the parental diet of alewives, which contain thaiminase, a thiamine-degrading enzyme.

Future Actions

Because of the uncertainty of the bottlenecks to reproduction, several research priorities have been identified (Eshenroder et al. 1999). These include 1) Evaluate the performance of stocking early-life history stages of lake trout as imprinting to natal areas likely occurs sometime between the egg and fry stage; 2)

Promote the reintroduction of a full range of Great Lakes phenotypes (principally found only in Lake Superior), and assess their reproductive performance; 3) Develop a predictive model for thiamine/thiaminase transfer between forage fishes and lake trout; 4) Determine how fetch, water depth, and interstitial depth interact to limit survival of lake trout embryos; and 5) Assess biotic effects of predation in fish communities altered by exotics, and unbalanced predator/prey ratios.

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Acknowledgments

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Contributions by James Bence, Michigan State University, East Lansing, MI, Donald Einhouse, New York Department of Environmental Conservation, Dunkirk, NY, and Robert O'Gorman, U.S. Geological Survey, Oswego, NY.

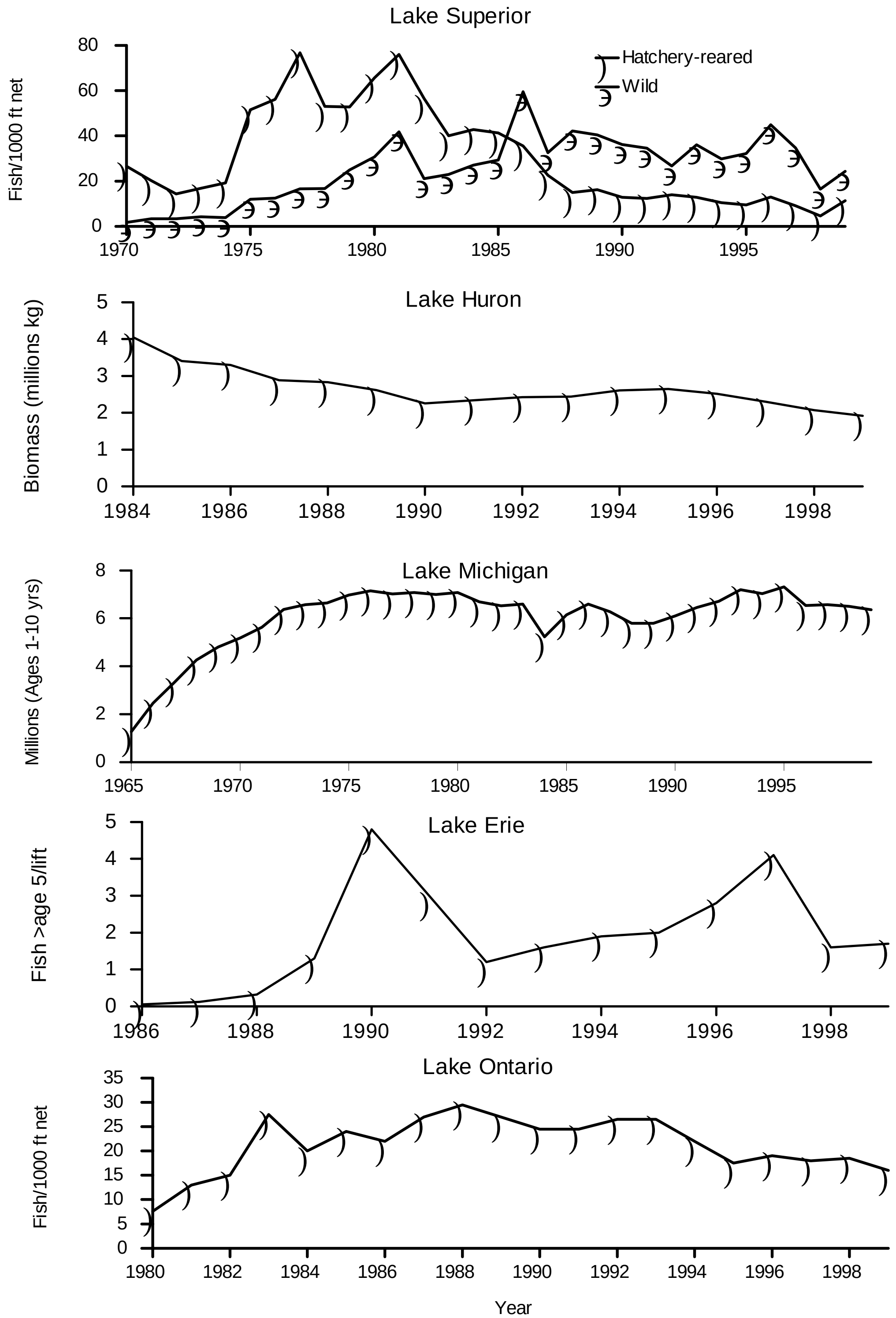

Figure 1.

[Lake Trout and] Scud (*Diporeia hoyi*)

SOLEC Indicator #93

Purpose

This indicator provides a measure of the biological integrity of the offshore regions of the Great Lakes and consists of assessing the abundance of the benthic macroinvertebrate *Diporeia*. This glacial-marine relict is the most abundant benthic organism in cold, offshore regions (> 30 m) of each of the lakes. It is present, but less abundant in nearshore regions of the open lake basins, and is naturally absent from shallow, warm bays, basins, and river mouths. *Diporeia* occurs in the upper few centimeters of bottom sediment and feeds on algal material that freshly settles to the bottom from the water column (i.e. mostly diatoms). In turn, it is fed upon by most all species of fish. In particular, *Diporeia* is fed upon by many forage fish species, and these species serve as prey for the larger piscivores such as trout and salmon. For example, sculpin feed almost exclusively upon *Diporeia*, and sculpin are fed upon by lake trout. Thus, *Diporeia* is an important pathway by which energy is cycled through the ecosystem, and a key component in the food web of offshore regions. The importance of this organism is recognized in the Great Lakes Water Quality Agreement (Supplement to Annex 1 – Specific Objectives).

Ecosystem Objective

The ecosystem goal is to maintain a healthy, stable population of *Diporeia* in offshore regions of the main basins of the Great Lakes, and to maintain at least a presence in nearshore regions. On a broad scale, abundances are directly related to the amount of food settling to the bottom, and population trends reflect the overall productivity of the ecosystem. Abundances can also vary somewhat relative to shifts in predation pressure from changing fish populations. In nearshore regions, this species is sensitive to local sources of pollution.

State of the Ecosystem

Populations of *Diporeia* are currently in the state of dramatic decline in portions of Lakes Michigan, Ontario, and eastern Lake Erie. Populations appear to be stable in Lake Superior, while data are currently not available to assess long-term trends in Lake Huron. In the first three Lakes, abundances have decreased in both nearshore and offshore areas over the past 10 years, and large areas are now nearly devoid of this organism. Areas where *Diporeia* is known to be rare or absent include the southeastern portion of Lake Michigan from Chicago to Grand Haven at water depths < 70 m (Figure 1), all of Lake Ontario at depths < 70 m except for some areas along the northern shoreline, and all of the eastern basin of Lake Erie. In other areas of Lakes Michigan and Ontario, *Diporeia* is still present, but abundances have decreased by one-half or more. Spatial patterns of these declines coincided with the introduction and rapid spread of the zebra mussel, *Dreissena polymorpha*, and the quagga mussel, *Dreissena bugensis*. These species were introduced into the Great Lakes in the late 1980s via the ballast water of ocean-going ships. Reasons for the negative response of *Diporeia* to these mussel species are not entirely clear. At least one initial hypothesis was that dreissenid mussels were outcompeting *Diporeia* for available food. That is, large mussel populations were filtering food material before it reached the bottom, thereby decreasing amounts available to *Diporeia*. More recent evidence suggests that the reason for the decline is more complex than a simple decline in food: 1*) Diporeia* is completely absent from areas where food is still settling to the bottom and there are no local populations of mussels; 2) the physiological condition of individual animals show no sign of food deprivation even though population numbers are decreasing; 3) rates of decline are greatest in depositional areas; these are areas with the highest amounts of settling food.

Future Pressures on the Ecosystem

As populations of dreissenid mussels continue to expand, it may be expected that populations of *Diporeia* will continue to decline. In the open lakes, mussels tend to be most abundant at water depths of 30-50 m. This is the same depth interval where *Diporeia* has historically been most abundant, and forage fish populations are at their highest.

Future Actions

Because of its key role in the food web of offshore regions of the Great Lakes, trends in *Diporeia* populations should be closely monitored. In particular, efforts should be made to document the continued decline in Lakes Michigan and Ontario, and to assess the status of the population in Lake Huron. Continued monitoring will not only provide information on the extent of the decline, but also provide a better understanding of linkages to dreissenid populations. In addition, impacts on the offshore food web need to be further examined. While recent evidence suggests that fish species most dependent upon *Diporeia* as a food source are affected directly, secondary impacts on other, alternate prey items and other fish species are a real possibility.

Further Work Necessary
Because of the rapid rate at which *Diporeia* is declining and its significance to the food web, agencies committed to documenting trends should report data in a timely manner. The population decline has a defined natural pattern, and studies of food web impacts should be spatially well coordinated.

Acknowledgments
Author: Thomas Nalepa, National Oceanic and Atmospheric Administration, GLERL, Ann Arbor, MI.

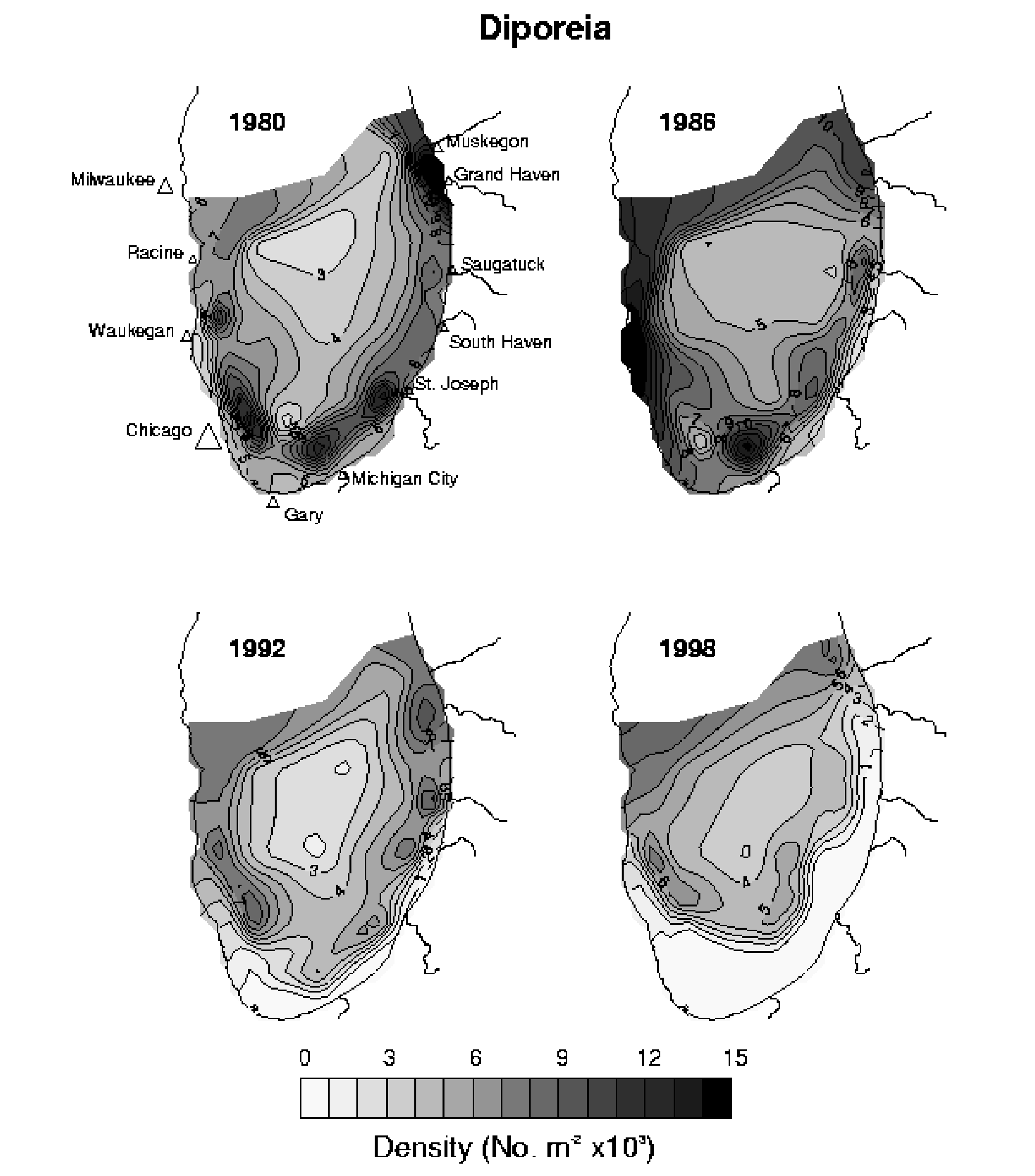

Figure 1. Density (no. m^{-2} x 10^3) of *Diporeia* in the southern basin of Lake Michigan between 1980 and 1998. Note recent declines in the southeastern portion of the basin. (Source: Great Lakes Environmental Research Laboratory, NOAA)

Deformities, Eroded Fins, Lesions and Tumours (DELT) in Nearshore Fish

SOLEC Indicator #101

Purpose

This indicator (101) will assess the prevalence of external anomalies in nearshore fish. It will be used to infer areas where fish are exposed to contaminated sediments within the Great Lakes. The presence of contaminated sediments at Areas of Concern (AOCs) has been correlated with an increased incidence of anomalies in benthic fish species (brown bullhead and white suckers), that may be associated with specific families of chemicals.

Ecosystem Objective

As a result of clean-up efforts some AOCs that historically have had a high incidence of fish with external anomalies currently, now show fewer abnormalities. Using an index based on prevalence of external anomalies will help identify nearshore areas that have populations of benthic fish exposed to contaminated sediments, and will help assess the recovery of AOCs following remediation. Thus the objective is to help restoration and protection of beneficial uses in Areas of Concern or in open lake waters, including beneficial use (iv) *Fish tumors or other deformities* (GLWQA, Annex 2). This indicator also supports Annex 12 of the GLWQA.

State of the Ecosystem

Elevated incidence of liver tumors (histopathologically verified neoplastic growths) were frequently identified during the past two decades. These elevated frequencies of liver tumors have been shown to be useful indicators of beneficial use impairment of Great Lakes aquatic habitat. External raised growths (sometime as histopathologicaly verified tumors on the body or lips), such as papillomas, may also be useful as an indicator. Field and laboratory studies have correlated chemical carcinogens found in sediments at some AOCs in Lakes Erie, Michigan, and Huron with an elevated incidence of liver and external tumors. Other external anomalies may also be used to assess beneficial use impairment; however, they must be carefully evaluated. An external lesion index will provide a tool for following trends in fish population health that can be easily used by resource managers or by community-based monitoring programs.

DELT Index — The deformities, eroded fins, lesions, and tumors (DELT) index (Ohio EPA) was developed as a metric for the Index of Biological Integrity (IBI) and has been successfully used for inland waters (Sanders et al 1999). All species of fish are used to compile the DELT index, not just benthic species or mature fish. Although the DELT index looks at the entire fish community, its inclusion of all species and age groups lessens its discriminatory power in distinguishing among levels of contaminant exposure in fish from various tributaries .

ELF Index — The external lesion frequency (ELF) index is being developed as a single species, mature fish estimate of contaminant exposure. Brown bullhead have been used to develop the index, since they are the most frequently used benthic indicator species in the southern Great Lakes and they have been recommended by the IJC as the key indicator species (IJC 1989). The most common external anomalies found in bullhead over the last twenty years (Figure 1) are raised Growths (RG on the body (B) or lips (L) — often called tumors), focal discoloration (FD, called melanistic spots), and stubbed or shortened/ missing barbels (SB).

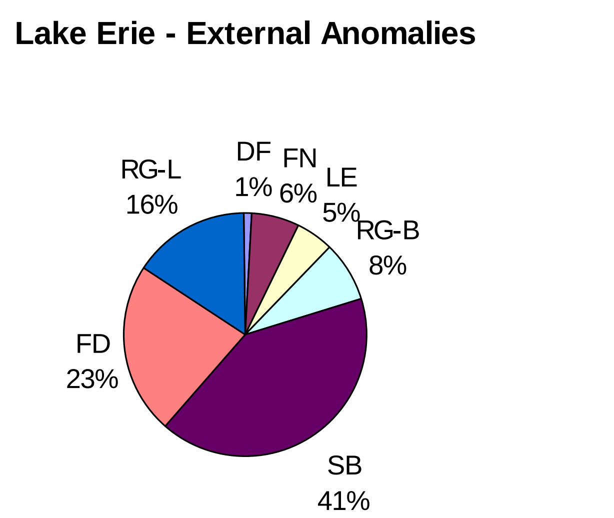

Figure 1. External anomalies on brown bullhead collected from 1980s through 2000. DF- deformities, FN-fin erosion, LE-lesions, RG-B-raised growth-body, SB-stubbed barbell, FD-focal discoloration, and RG-L – raised growth-lip.

Using some of these external anomalies we have recently examined bullhead populations in several Lake Erie contaminated tributaries and a reference site. Knobbed barbels have not been as consistently reported in the historical database, but also appears to be a useful parameter. Preliminary findings indicate that single anomalies occurring at ≥0.4 per fish or multiple anomalies occurring at greater than O.8 per fish would indicate possible impairment (Figure 2). More research is needed to define this index and demonstrate correlation to the exposure levels of fish populations to contaminants.

Future Pressures

As the Great Lakes AOCs and the tributaries may continue to remain in a degraded condition, exposure of the fish populations to contaminated sediments will continue to cause elevated incidence of external anomalies.

Future Activities

Additional remediation to clean-up contaminated sediments will help to reduce rates of external anomalies. The external anomalies index, particularly for bullheads and white suckers, will help follow trends in fish health to help address any current AOCs that may be eligible for delisting. (IJC Delisting criteria, see IJC 1996)

Future Work Necessary

The single benthic species indicator has the potential in defining habitats that are heavily polluted. Joint U.S.-Canada studies over a gradient of polluted to pristine Great Lakes habitats using standardized methodology to design an external survey for both bullhead and white sucker would help create a common index useful as an indicator of ecosystem health.

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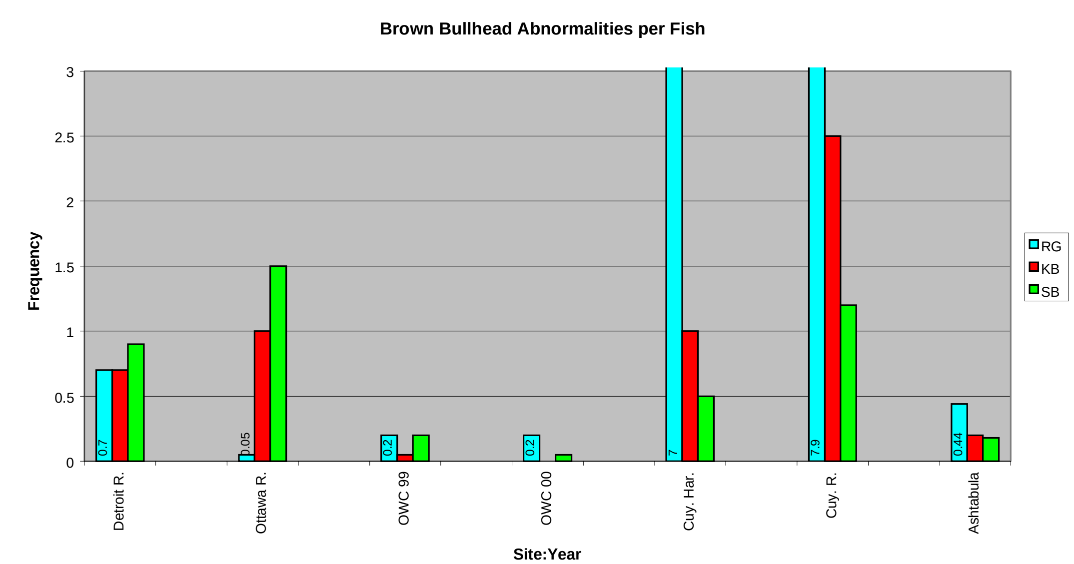


Figure 2. External lesion frequency for brown bullheads in Lake Erie, 1999-2000. OWC-Old Woman Creek-reference, Cuy- Cuyahoga River. RG-raised growth, KB-knobbed barbells, SB-stubbed barbels.

Phytoplankton Populations

SOLEC Indicator #109

Purpose

This indicator involves the direct measurement of phytoplankton species composition, biomass, and primary productivity in the Great Lakes, and indirectly assesses the impact of nutrient/contaminant enrichment and invasive exotic predators on the microbial food-web of the Great Lakes. It assumes that phytoplankton populations respond in tractable, quantifiable ways to anthropogenic inputs of both nutrients and contaminants. Therefore, inferences can be made about system perturbations through the assessment of phytoplankton community size and structure and productivity.

Ecosystem Objective

Desired objectives are phytoplankton biomass size and structure indicative of oligotrophic conditions (i.e. a state of low biological productivity, as is generally found in the cold open waters of large lakes) for Lakes Superior, Huron and Michigan; and of mesotrophic conditions for Lakes Erie and Ontario. In addition, algal biomass should be maintained below that of a nuisance condition in Lakes Erie and Ontario, and in bays and in other areas wherever they occur. There are currently no guidelines in place to define what criteria should be used to assess whether or not these desired states have been achieved.

State of the Ecosystem

Given the substantial gaps in existing data, trends in phytoplankton biomass and community composition can only be assessed with caution. Records for the three basins of Lake Erie suggest that substantial reductions in summer phytoplankton standing crops occurred in the late 1980's in the eastern basin, and in the early 1990's for the central and western basins. The considerable variability of the data, however, preclude assessments of potential changes in community composition. In general, phytoplankton biovolume in Lake Michigan was lower in the 1990's than in the 1980's, though again considerable interannual variability and gaps in the data preclude definitive conclusions. The timing of these declines in phytoplankton biomass suggest the possible impact of zebra mussles in Lake Erie, and perhaps also Lake Michigan. No trends are apparent in phytoplankton biovolume in Lakes Huron or Ontario; while only a single year of data exists for Lake Superior. Data on primary productivity is no longer being collected.

No assessment of "ecosystem health" is currently possible on the basis of phytoplankton community data, since reference criteria and endpoints have yet to be developed.

Future Pressures on the Ecosystem

The two most important potential sources of future pressures on the phytoplankton community are changes in nutrient loadings and continued introductions/expansions of exotic species. Increases in nutrients can be expected to result in increases in primary productivity, which is not currently being measured, and possibly also in increases in phytoplankton biomass. In addition, increases in phosphorus concentrations might result in shifts in phytoplankton community composition away from diatoms and towards other taxa. Continued expansion of zebra mussel populations might be expected to result in reductions in overall phytoplankton biomass, and perhaps also in a shift in species composition, although these potential effects are not clearly understood. It is unclear what effects, if any, might be brought about by changes in the zooplankton community.

Future Actions

The effects of increases in nutrient concentrations tend to become apparent in nearshore areas before offshore areas. The addition of nearshore monitoring to the existing offshore monitoring program might therefore be advisable. Given the greater heterogeneity of the nearshore environment, any such sampling program would need to be carefully thought out, and an adequate number of sampling stations included to enable trends to be discerned.

Further Work Necessary

A highly detailed record of phytoplankton biomass and community structure has accumulated, and continues to be generated, through regular monitoring efforts. However, a substantial amount of this data is either inaccessible or unusable due to problems with data storage and processing. It is essential that current gaps in the data be filled where in fact that data exists.

In spite of this database, the interpretation of this data currently remains problematical. While the use of phytoplankton data to assess "ecosystem health" is conceptually attractive, there is currently no objective, quantitative mechanism for doing so. Reliance upon literature values for nutrient tolerances or indicator status of individual species is not recommended, since the unusual physical regime of the Great Lakes makes it likely that responses of individual species to their chemical environment in the Great Lakes will vary in fundamental ways from those in other lakes. Therefore, there is an urgent need for the development of an objective, quantifiable index specific to the Great Lakes to permit use of phytoplankton data in the assessment of "ecosystem health".

Acknowledgements
Authors: Richard P. Barbiero, DynCorp I&ET, Alexandria, VA, and Marc L. Tuchman, US Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL.

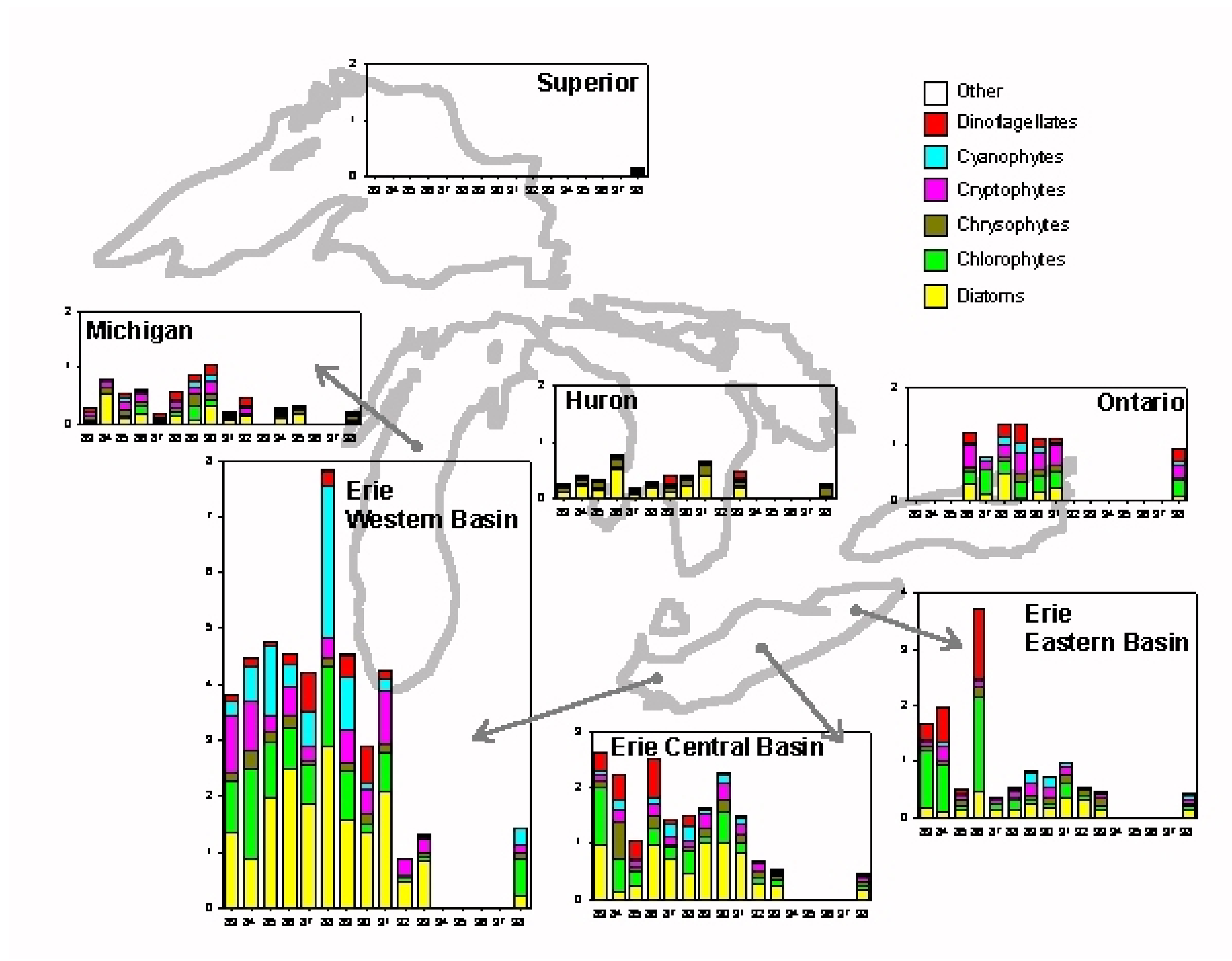


Figure 1. Trends in phytoplankton biovolume (gm/m^3) and community composition in the Great Lakes 1983-1998 (Summer, Open Lake, Epilimnion) (Blank indicates no data).
(Source: Great Lakes National Program Office, U.S. Environmental Protection Agency)

Phosphorus Concentrations and Loadings

SOLEC Indicator #111

Purpose

This indicator assesses total phosphorus levels in the Great Lakes, and it is used to support the evaluation of trophic status and food web dynamics in the Great Lakes. Phosphorus is an essential element for all organisms and is often the limiting factor for aquatic plant growth in the Great Lakes. Although phosphorus occurs naturally, the historical problems caused by elevated levels have originated from man-made sources. Phosphate detergent use, sewage treatment plant effluent, agricultural and industrial sources have released large amounts into the Lakes.

Ecosystem Objective

The goals of phosphorus control are to maintain an oligotrophic state in Lakes Superior, Huron and Michigan; to maintain algal biomass below that of a nuisance condition in Lakes Erie and Ontario; and to eliminate algal nuisance in bays and in other areas wherever they occur (GLWQA Annex 3). Maximum annual phosphorus loadings to the Great Lakes that would allow achievement of these objectives are listed in the GLWQA.

The expected concentration of total phosphorus in the open waters of each lake, if the maximum annual loads are maintained, are listed in the following table:

Lake	Phosphorus Guideline μg/L
Superior	5
Huron	5
Michigan	7
Erie - Western Basin	15
Erie - Central Basin	10
Erie - Eastern Basin	10
Ontario	10

State of the Ecosystem

Strong efforts begun in the 1970s to reduce phosphorus loadings have been successful in maintaining or reducing nutrient concentrations in the Lakes, although high concentrations still occur locally in some embayments and harbours. Phosphorus loads have decreased in part due to changes in agricultural practices (e.g., conservation tillage and integrated crop management), promotion of phosphorus-free detergents, and improvements made to sewage treatment plants and sewer systems.

Average concentrations in the open waters of Lakes Superior, Michigan, Huron, and Ontario are at or below expected levels. Concentrations in all three basins of Lake Erie exceed phosphorus guidelines and recent data suggest an increasing trend (Figure 1). In Lake Erie, approximately 75% of the stations sampled exceeded the recommended guideline. In Lakes Ontario and Huron, although almost all offshore waters meet the desired guideline, some offshore and nearshore areas and embayments experience elevated levels (Figure 2) which could promote nuisance algae growths such as the attached green algae, Cladophora.

Summarizing the information into an indicator is too subjective until the specifics regarding the metric have been defined.

Future Pressures on the Ecosystem

The trend toward increasing phosphorus concentrations in Lake Erie may be an early warning that the current control measures are no longer sufficient. Even if current phosphorus controls are maintained, additional loadings can be expected. Increasing numbers of people living along the Lakes will exert increasing demands on existing sewage treatment facilities, possibly contributing to increasing phosphorus loads.

Future Actions

Because of its key role in productivity and food web dynamics of the Great Lakes, phosphorus concentrations continue to be watched by environmental and fishery agencies. Future activities that are likely to be needed include assessing the capacity and operation of present and future sewage treatment plants in the context of increasing human populations being served. Additional upgrades in construction or operations may be required.

Further Work Necessary

The analysis of phosphorus concentrations in the Great Lakes is ongoing and reliable. However, a coordinated enhanced Great Lakes monitoring program is required with agreement on specifics such as analytical and field methodologies, sampling locations, inclusion of nearshore and embayment sites, determination of the indicator metric and its complimentary subjective index.

A binationally coordinated effort to compute phosphorus loads to the Great Lakes, or at least Lake Erie, is also required. Loading estimates for the Great Lakes have not been computed since 1991in all lakes except Erie, which has loadings information up to 1994. An evaluation of non-point and point source monitoring programs and the adequacy of the resulting data to calculate annual loads by source category will be required. Otherwise, the loadings component of this SOLEC indicator will remain unreported, and changes in the different sources of phosphorus to the Lakes may go undetected.

Acknowledgments
Authors: Scott Painter, Environment Canada, Environmental Conservation Branch, Burlington, ON, and Glenn Warren, US Environmental Protection Agency, Great Lakes National Programs Office, Chicago, IL

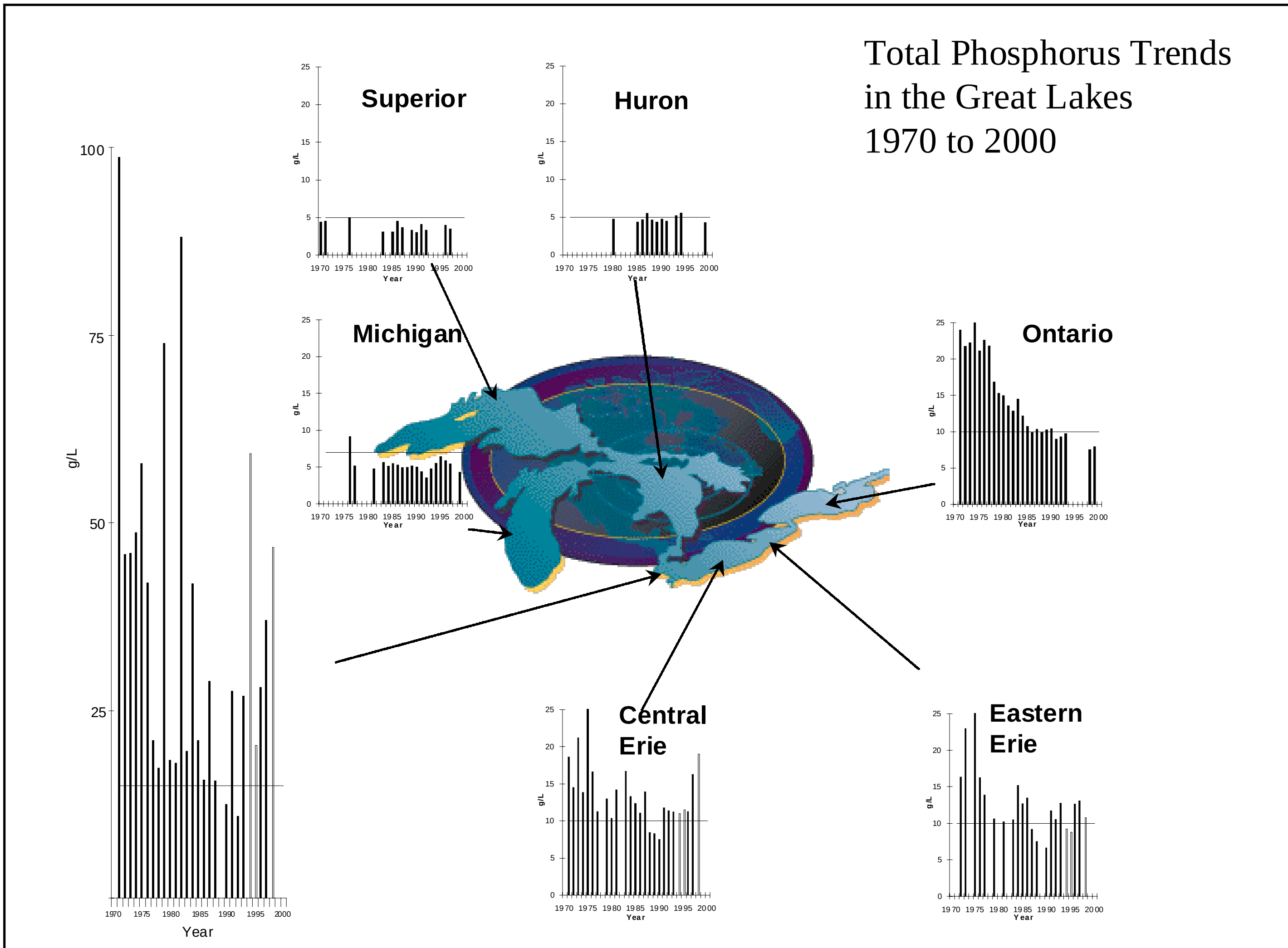


Figure 1. Total Phosphorus Trends in the Great Lakes 1971-2000 (Spring, Open Lake, Surface) (Blank indicates No Sampling).
(Source: Environmental Conservation Branch, Environment Canada and Great Lakes National Program Office, U.S. Environmental Protection Agency)

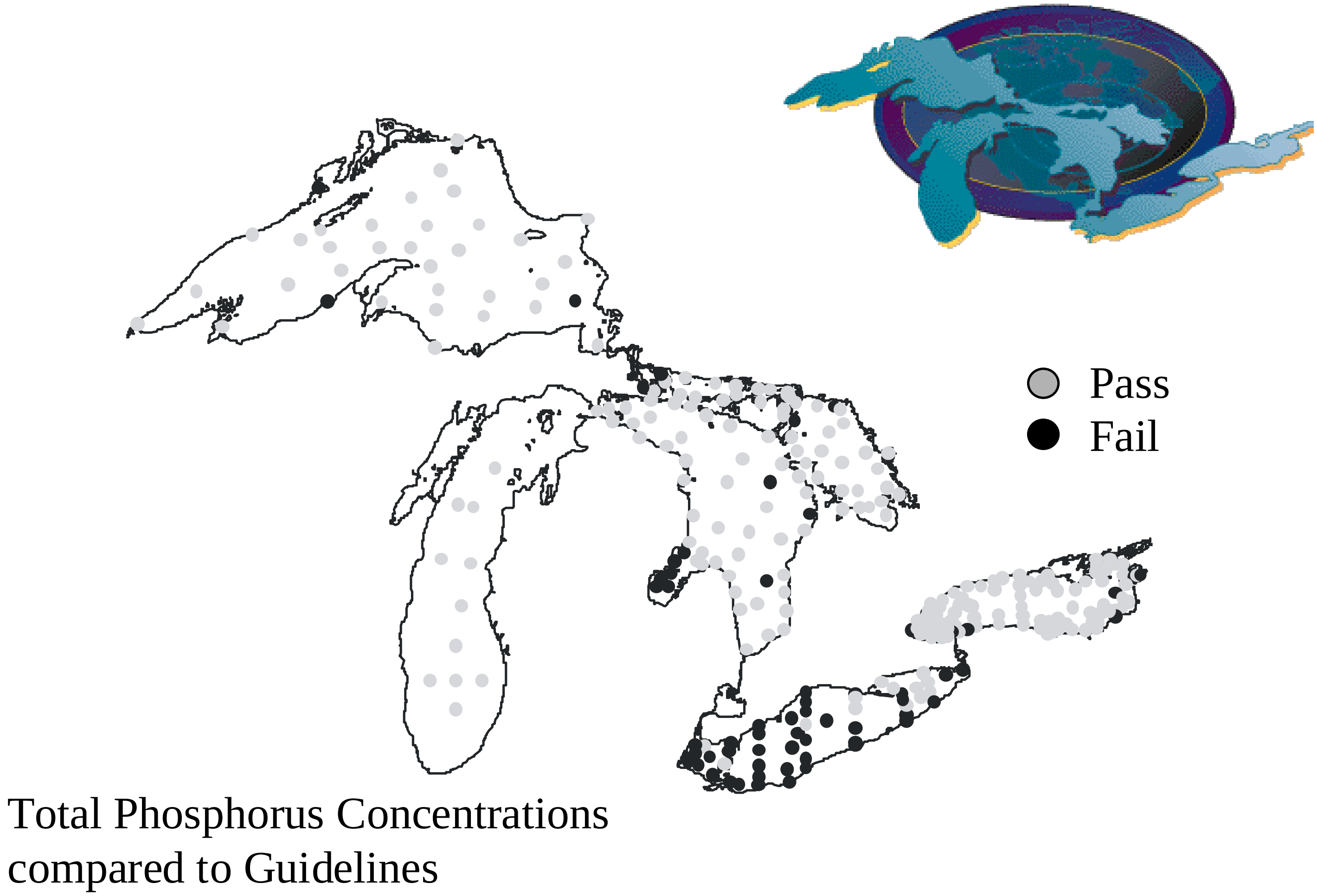


Figure 2. Total phosphorus concentrations in the Great Lakes for the most recent year data were available in each lake. (Source: Environmental Conservation Branch, Environment Canada)

Contaminants in Colonial Nesting Waterbirds

SOLEC Indicator #115

Purpose

This indicator will assess current chemical concentration levels and trends as well as ecological and physiological endpoints in representative colonial waterbirds (gulls, terns, cormorants and/or herons). These features will be used to infer and measure the impact of contaminants on the health, i.e. the physiology and breeding characteristics, of the waterbird populations. This indicator is important because colonial waterbirds are the top of the aquatic food web predators in the Great Lakes ecosystem and they are very visible and well known to the public. They bioaccumulate contaminants to the greatest concentration of any trophic level organism and they breed on all the Great Lakes. Thus, they are a very cost efficient monitoring system and allow easy inter-lake comparisons. The current Herring Gull Egg Monitoring program is the longest continuous-running annual wildlife contaminants monitoring program in the world (1974-present). It determines concentrations of up to 20 organochlorines, 65 PCB congeners and 53 PCDD and PCDF congeners.

Ecosystem Objective

The objective of monitoring colonial waterbirds on the Great Lakes is to discover the point when there is no difference in contaminant levels and related biological endpoints between birds on and off the Great Lakes. When colonial waterbirds from the Great Lakes do not differ in chemical and biological parameters from birds off the Great Lakes, e.g. birds in northern Saskatchewan or the Maritimes, then our clean-up objective will have been reached.

State of the Ecosystem

The Herring Gull Egg Monitoring Program has provided researchers and managers with a powerful tool to evaluate change in contaminant concentrations in Great Lakes wildlife for more than 25 years. The extreme longevity of the egg database makes it possible to calculate temporal trends in contaminant concentration in wildlife and to look for significant changes within those trends. Contaminant "hot spots" for wildlife have been identified by testing for spatial patterns. The database shows that most contaminants in gull eggs have declined a minimum of 50% and many have declined more than 90% since the program began in 1974. Presently it shows that in more than 70% of cases, contaminants levels are decreasing as fast or faster than they did in the past. In less than 20% of cases, the rate of decline has slowed in recent years. Spatially, gull eggs from Lake Ontario and the St. Lawrence River continue to have the greatest levels of mirex and dioxin (2,3,7,8 TCDD), those from the upper lakes have the greatest levels of dieldrin and heptachlor epoxide, those from Lake Michigan have the greatest levels of DDE and those from Lake Michigan and the Detroit River-Western Lake Erie area have the greatest levels of PCBs.

In terms of gross ecological effects of contaminants on colonial waterbirds, e.g. eggshell thinning, failed reproductive success and population declines, most species seem to have recovered. Populations of most species have increased over what they were 25-30 years ago. Interestingly, Double-crested Cormorants, whose population levels have increased more than 400-fold, have been shown to still be exhibiting some shell thinning. Although the gross effects appear to have subsided, there are many other subtle, mostly physiological and genetic endpoints that are being measured now that were not in earlier years. For example, porphyrins, retinoids and germline minisatellite DNA mutations have been found to correlate with contaminant levels in Herring Gulls. However, the bottom line is that the colonial waterbirds of the Great Lakes are much healthier than they were during the 1970s.

Future Pressures

Future pressures for this indicator include all sources of contaminants which reach the Great Lakes. This includes those that are already well known, e.g. re-suspension of sediments, as in western Lake Erie, and atmospheric inputs, such as PCBs in Lake Superior as well as less known ones, e.g. underground leaks from landfill sites.

Future Activities

The annual collection and analysis of Herring Gull eggs from 15 sites on both sides of the Great Lakes and the assessment of that species' reproductive success is a permanent part of the CWS Great Lakes surveillance activities. Likewise, so is the regular monitoring of population levels of most of the colonial waterbird species.; the plan is to continue these procedures. Research work on improving and expanding the Herring Gull Egg Monitoring program is done on a more opportunistic, less predictable basis (see below, Further Work Necessary).

Further Work Necessary

We have learned much about interpreting the Herring Gull egg contaminants data from associated research studies. However, much of this work is done on an opportunistic basis, when funds are available. Several research activities should be incorporated into routine monitoring, e.g. tracking of porphyria, vitamin A deficiencies and evaluation of the avian immune system. Likewise, more research should focus on new areas, e.g. the impact of endocrine disrupting substances and factors regulating chemically-induced genetic mutations.

Acknowledgements

Author: D.V. Chip Weseloh, Canadian Wildlife Service, Environment Canada, Downsview, ON. Thanks to other past and present staff at CWS-Ontario Region (Burlington and Downsview), as well as staff at the CWS National Wildlife Research Centre (Hull, Que.) and wildlife biologists Ray Faber, Ralph Morris, Jim Quinn, Jihn Ryder, Brian Ratcliff and Keith Grasman for egg collections, preparation, analysis and data management over the 27 years of this project.

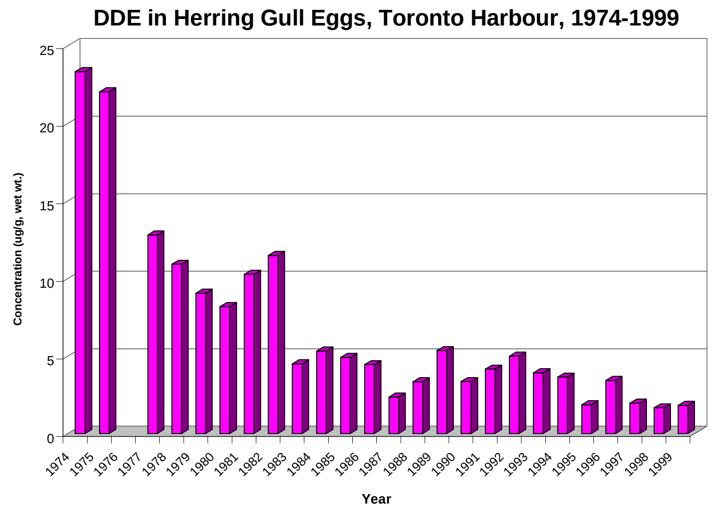


Figure 1. Temporal trends.

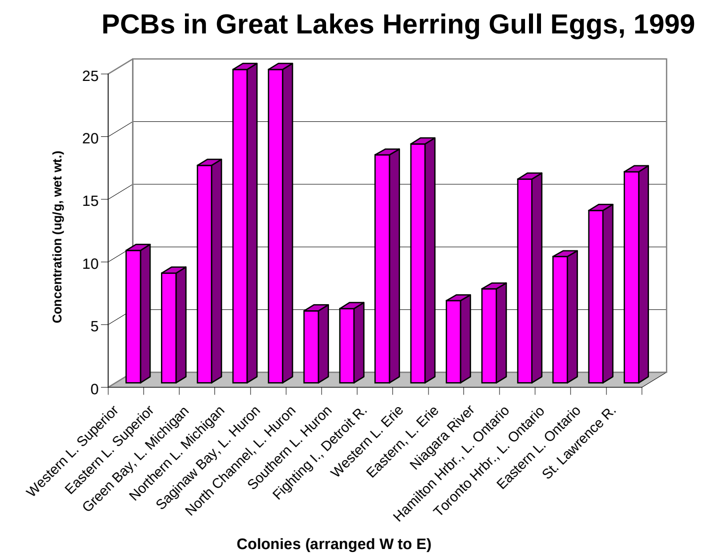


Figure 2. Spatial trends.

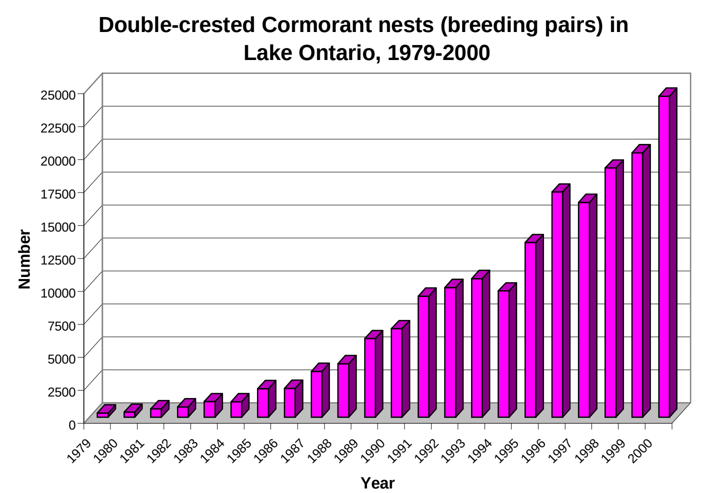


Figure 3. Population trends.

Zooplankton Populations

SOLEC Indicator #116

Purpose

This indicator directly measures changes in community composition, mean individual size and biomass of zooplankton populations in the Great Lakes basin, and indirectly measures zooplankton production as well as changes in food-web dynamics due to changes in vertebrate or invertebrate predation; changes in system productivity, and changes in the type and intensity of predation and in the energy transfer within a system. Suggested metrics include zooplankton mean length, the ratio of calanoid to cladoceran and cyclopoid curstaceans, and zooplankton biomass.

Ecosystem Objective

Ultimately, analysis of this indicator should provide information on the biological integrity of the Great Lakes, and lead to the support of a healthy and diverse fishery. However, the relationship between these objectives and the suggested metrics have not been fully worked out, and no specific criteria have yet been identified for these metrics.

A mean individual size of 0.8 mm has been suggested as "optimal" for zooplankton communities sampled with a 153 µm mesh net, although the meaning of deviations from this objective, and the universality of this objective remain unclear. In particular, questions regarding its applicability to dreissenid impacted systems have been raised.

In general, calanoid/cladoceran+cyclopoid ratios tend to increase with decreasing nutrient enrichment. Therefore high ratios are desirable. As with individual mean size, though, clear objectives have not presently been defined.

State of the Ecosystem

The most recent available data (1998) suggests that mean individual lengths of offshore zooplankton populations in the three upper lakes and the central basin of Lake Erie exceed the objective of 0.8 (Fig. 1), suggesting a fish community characterized by a high piscivore/planktivore ratio. Mean individual lengths of zooplankton populations in the western and eastern basins of Lake Erie, as well as most sites in Lake Ontario, were substantially below this objective. Interquartile ranges for most lakes (considering the three basins of Lake Erie separately) were generally on the order of 0.1 - 0.2 mm, although Lake Ontario was substantially greater. Historical data from the eastern basin of Lake Erie, from 1985 to 1998, indicate a fair amount of interannual variability, with values from offshore sites ranging from about 0.5 to 0.85 (Fig. 2). As noted above, interpretation of these data are currently problematic.

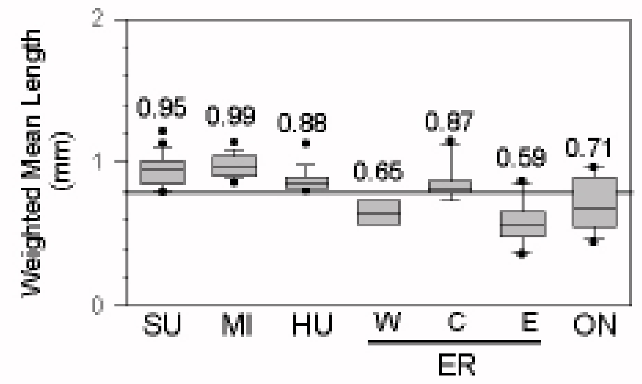


Figure 1. Average individual mean length of zooplankton for the five Great Lakes. Lake Erie is divided into western, central and eastern basins. Length estimates were generated from data collected with 153µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower. Numbers indicates arithmetic averages.
(Source: US Environmental Protection Agency, Great Lakes National Program Office, August, 1998.)

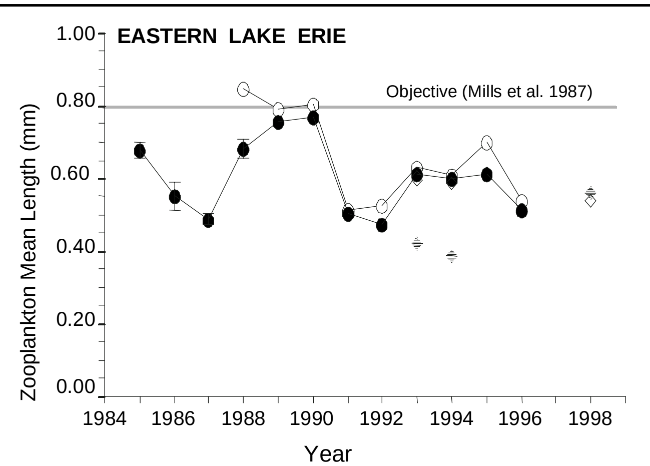


Figure 2. Trend in Jun27-Sep30 mean zooplankton length: NYDEC data (circles) collected with 153-um mesh net, DFO data (diamonds) converted from 64-um to 153-um mesh equivalent. Open symbols = offshore, solid symbols = nearshore (<12 m). 1985-1988 are means+/- 1 S.E.
(Source: Johannsson et al. 1999)

The ratio of calanoids to cladocerans and cyclopoids showed a clear relationship with trophic state. The average value for the oligotrophic Lake Superior was at least four times as high as that for any other lake, while Lakes Michigan and Huron and the eastern basin of Lake Erie were also high (Fig. 3). The western basin of Lake Erie and Lake Ontario were identically low, while the central basin of Lake Erie had an intermediate value. Historical comparisons of this metric are difficult to make because most historical data on zooplankton populations in the Great Lakes seems to have been generated using shallow (20 m) tows. Calanoid copepods tend to be deep living organisms; therefore the use of data generated from shallow tows would tend to contribute a strong bias to this metric. This problem is largely avoided in Lake Erie, particularly in the western and central basins, where most sites are shallower than 20 m. Comparisons in those two basins have shown a statistically significant increase in the ratio of calanoids to cladocerans and cyclopoids between 1970 and 1983-1987, with this increase sustained throughout the 1990's, and in fact up to the present. A similar increase was seen in the eastern basin, although some of these data were generated from shallow tows, and are therefore subject to doubt.

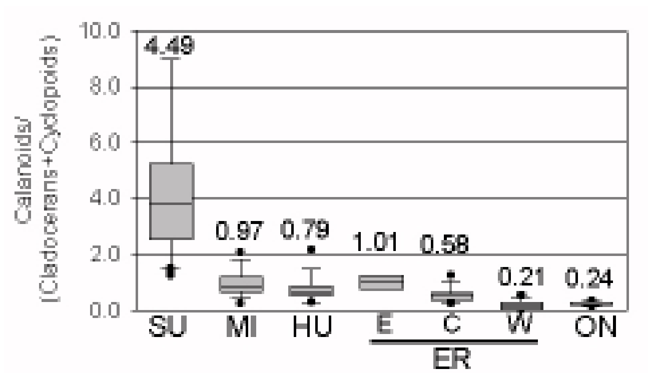


Figure 3. Ratio of biomass of calanoid copepods to that of cladocerans and cyclopoid copepods for the five Great Lakes. Data as in Fig. 1; Boxes as in Fig. 1. Numbers indicates arithmetic averages

Future Pressures on the Ecosystem

The zooplankton community might be expected to respond to changes in nutrient concentrations in the lakes, although the potential magnitude of such "bottom up" effects are not well understood. The most immediate potential threat to the zooplankton communities of the Great Lakes is posed by invasive species. An exotic predatory cladoceran, *Bythotrephes cedarstroemii*, has already been in the lakes for over ten years, and is suspected to have had a major impact on zooplankton community structure. A second predatory cladoceran, *Cercopagis pengoi*, was first noted in Lake Ontario in 1998, and is expected to spread to the other lakes. In addition, the continued proliferation of dreissenid populations can be expected to impact zooplankton communities both directly through the alteration of the structure of the phytoplankton community, upon which many zooplankton depend for food.

Future Actions

Continued monitoring of the off shore zooplankton communities of the Great Lakes is critical, particularly considering the current expansion of the range of the exotic cladoceran *Cercopagis* and the probability of future invasive zooplankton and fish species.

Further Work Necessary

Currently the most critical need is for the development of quantitative, objective criteria that can be applied to the zooplankton indicator. The applicability of current metrics to the Great Lakes is largely unknown, as are the limits that would correspond to acceptable ecosystem health.

The implementation of a long term monitoring program on the Canadian side is also desirable, to expand both the spatial and the temporal coverage currently provided by American efforts. Since the use of various indices is dependent to a large extent upon the sampling methods employed, coordination between of these two programs, both with regard to sampling dates and locations, and especially with regard to methods, would be highly recommended.

Sources

Johannsson, O.E., C. Dumitru, and D.M. Graham. 1999. Examination of zooplankton mean length for use in an index of fish community structure and its application in Lake Erie. J. Great Lakes Res. 25:179-186).

Acknowledgements

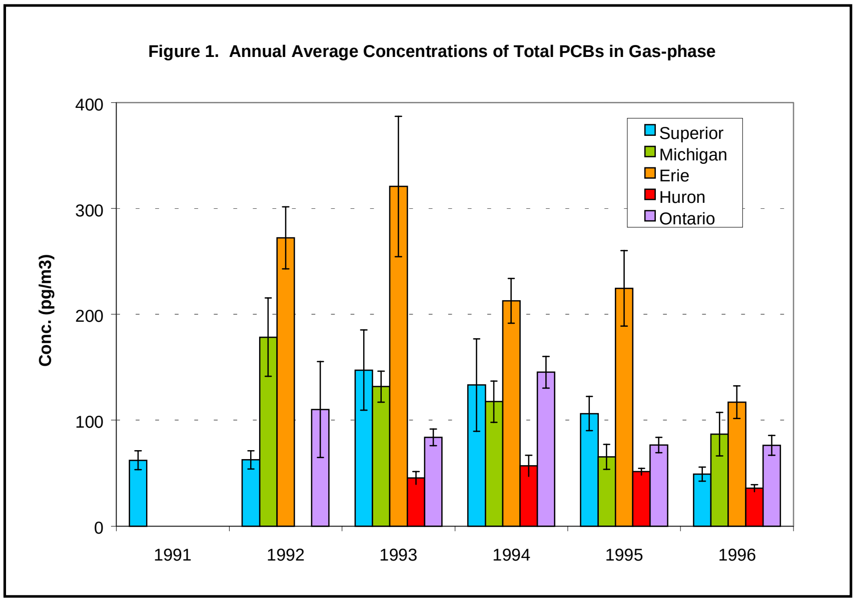
Authors: Richard P. Barbiero, DynCorp I&ET, Alexandria, VA USA, Marc L. Tuchman, US Environmental Protection Agency, Great Lakes National Program Office, Chicago IL, and Ora Johannsson, Fisheries and Oceans Canada, Burlington, ON.

Atmospheric Deposition of Toxic Chemicals

SOLEC Indicator #117

Purpose

To estimate the annual average loadings of priority toxic chemicals from the atmosphere to the Great Lakes and to determine temporal trends in contaminant concentrations. This information will be used to aid in the assessment of potential impacts of toxic chemicals from atmospheric deposition on human health and the Great Lakes aquatic ecosystem, as well as to track the progress of various Great Lakes programs toward virtual elimination of toxics from the Great Lakes.



Ecosystem Objective

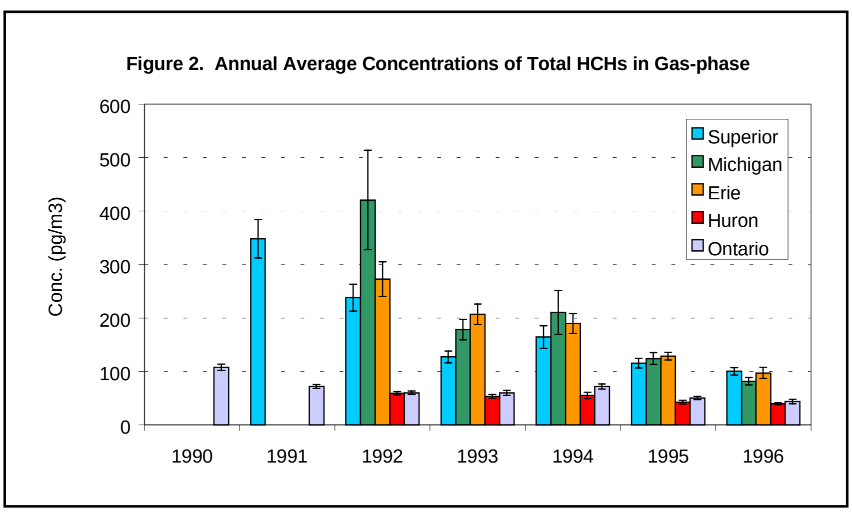
The Great Lakes Water Quality Agreement (GLWQA) and the Binational Strategy both state the virtual elimination of toxic substances to the Great Lakes as an objective. Additionally, GLWQA General Objective (d) states that the Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic to human, animal, or aquatic life.

State of the Ecosystem

The Integrated Atmospheric Deposition Network (IADN) consists of five master sampling sites, one near each of the Great Lakes, and several satellite stations. This joint United States-Canadian project has been in operation since 1990, and since that time, thousands of measurements of the concentrations of polychlorinated biphenyls (PCBs), pesticides, trace metals, and polycyclic aromatic hydrocarbons (PAHs) have been made at these sites. These concentrations cover the atmospheric gas and particle phases and precipitation. These data have been interpreted in terms of temporal trends and in terms of loadings to the Lakes. The data set is large, and thus, only selected data will be presented here.

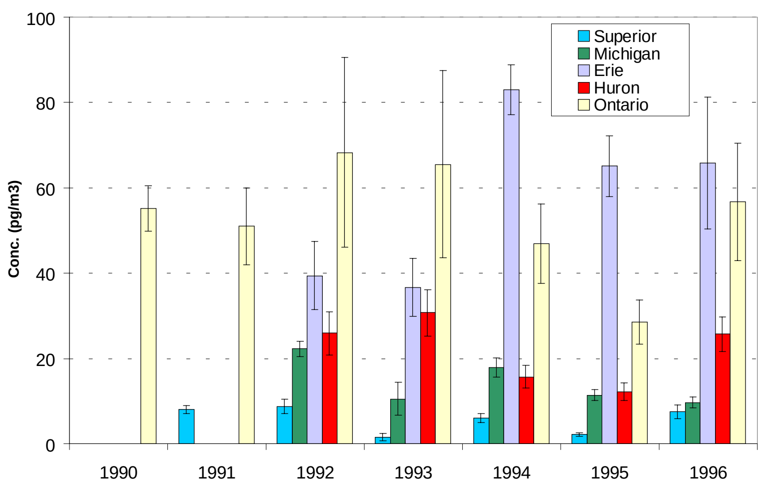
For gas-phase total PCBs (ΣPCB), the Lake Erie site consistently shows relatively elevated concentrations compared to the other Lakes; see Figure 1. For all sites, the trend over time is generally down with half-lives on the order of 3-6 years. The relatively elevated concentrations for Lake Erie are not surprising given the proximity of the sampling site to the city of Buffalo, New York. Although not shown, it is interesting to point out that ΣPCB concentrations at a satellite site in downtown Chicago are about a factor of 10 higher that at the other more remote sites.

For gas-phase α- and γ-HCH (ΣHCH), the concentration trend is uniformly down at all sites, and the concentration of ΣHCH seems to have reached a new steady value of about 50-100 pg/m^3; see Figure 2. It is important to remember that γ-HCH (lindane) is a pesticide, and it is still used as a seed treatment in the United States and Canada. Thus, these atmospheric concentrations may represent this current source, and they may not decrease further until this source is eliminated.



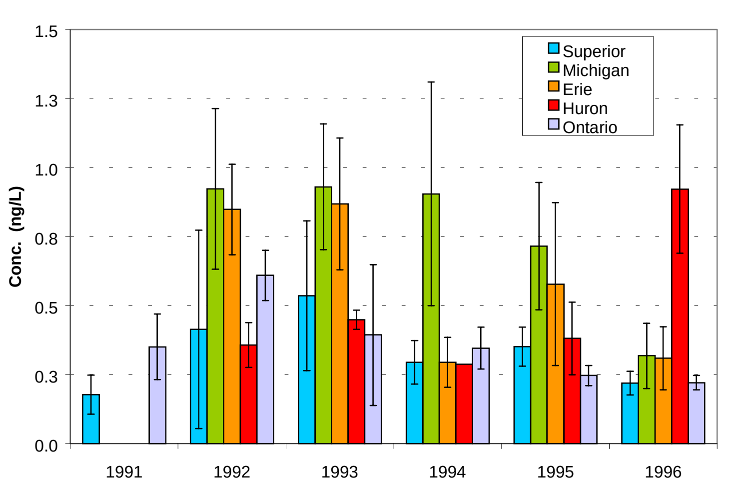
Benzo[*a*]pyrene is produced by the incomplete combustion of almost any fuel and is carcinogenic. Figure 3 shows the annual average particle-phase concentrations of BaP. The concentrations of BaP are relatively high at Lakes Erie and Ontario, sites near major population centers, and the concentrations are relatively unchanged as a function of time at all sites.

Figure 3. Annual Average Concentrations of B[a]P in Particle-phase



As an example of the precipitation data, Figure 4 shows the concentrations of dieldrin from 1991 to 1996. Historically, the concentrations at Lakes Michigan and Erie were higher than at the other sites, possibly because of agricultural uses near these two locations. With the exception of Lake Huron in 1996, the concentrations are generally unchanged or decreasing slightly.

Figure 4. Annual Average Concentrations of Dieldrin in Precipitation



The concentrations of lead in the particle-phase are shown in Figure 5. Historically, the concentration of lead at Lake Erie was higher than at the other sites, possibly because of urban effects at this location, which is near Buffalo. The concentrations are generally unchanged at most of the other sites.

The loadings from the atmosphere for ΣPCB, ΣHCH, and BaP are given in Figure 6; a negative-going bar indicates that the lake is vaporizing the compound to the atmosphere. A missing bar in Figure 6 indicates that the loading could not be calculated – not that the loading was zero. The most important message from these data is that the absolute values of the loadings are generally getting smaller, which indicates that the lake water and the air above it are getting closer to being in equilibrium. A report on the atmospheric loadings of these compounds to the Great Lakes has recently been published. To receive a copy, please contact one of the agencies listed at the end of this report.

Future Pressures on the Ecosystem

Pressure on the Lakes from atmospheric loadings of toxic compounds is likely to continue for some unknown time into the future. Possible exceptions are pesticides that are no longer in use; these compounds are likely to become virtually undetectable by the middle of this century. Because the sources of PCBs and PAHs are likely to continue, the concentrations of these compounds in the atmosphere near the Great Lakes will decrease slowly, if at all.

Future activities

In terms of the agricultural chemicals, such as HCH, further restrictions on the use of these compounds may be warranted. In terms of the PAH, further controls on the emissions of large- and small-scale combustion systems may induce a decline in the input of these compounds to the Great Lakes' atmosphere. In terms of the PCBs, most of the controllable sources of these compounds have been eliminated. The remaining sources are likely to be diffuse terrestrial sources located in urban areas. Regulatory mechanisms to control these sources do not exist. Voluntary pollution prevention activities, such as those advocated by the Binational Strategy, and technology-based pollution controls can aid in reducing the amounts of toxic chemicals deposited to the Great Lakes. Efforts to achieve reductions in use and emissions of toxics worldwide through international assistance and negotiations should also be supported.

Future work necessary

The Integrated Atmospheric Deposition Network (IADN) should continue. Only through the repetitive, long-term monitoring of the atmosphere will it become clear if regulations aimed at reducing the input of these toxic organic compounds into the Great Lakes have been effective.

For additional information

(or for a copy of the latest IADN loadings report) contact:

Air Quality Research Branch
Environment Canada
4905 Dufferin Street,
Toronto, ON M3H 5T4
Canada

Atmospheric Programs Manager
Great Lakes National Program Office
U.S. Environmental Protection Agency
77 West Jackson Boulevard, G-17J
Chicago, IL 60604
U.S.A.

Acknowledgements

Ron Hites and Ilora Basu at Indiana University prepared this report on behalf of the IADN Steering Committee.

Figure 5. Annual Average Concentrations of Lead in Particle-phase

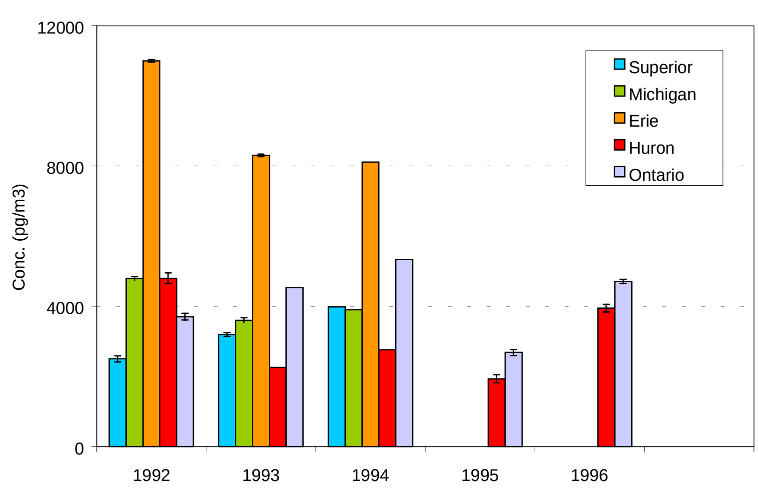
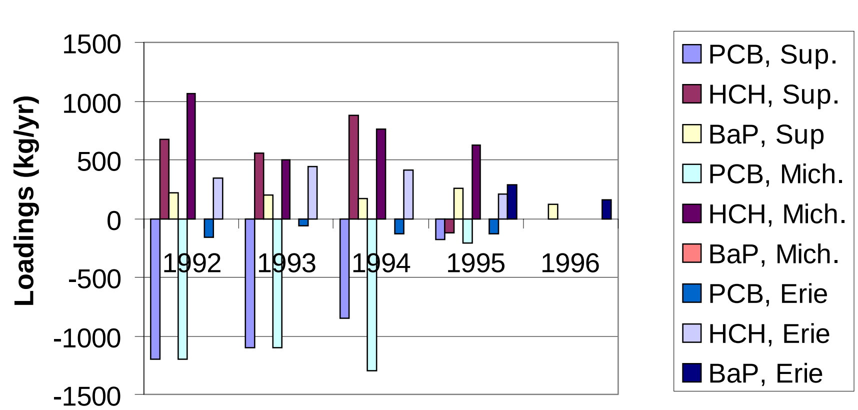


Figure 6. Loadings of Total PCBs, Total HCHs, and BaP to the Great Lakes



Toxic Chemical Concentrations in Offshore Waters

SOLEC Indicator #118

Purpose

This indicator reports the concentration of priority toxic chemicals in offshore waters, and by comparison to protection for aquatic life and human health criteria infer the potential for impacts on the health of the Great Lakes aquatic ecosystem. As well, the indicator can be used to infer the progress of virtual elimination programs.

Ecosystem Objective

The Great Lakes should be free from materials entering the water as a result of human activity that will produce conditions that are toxic or harmful to human, animal, or aquatic life (GLWQA, Article III(d)).

State of the Ecosystem

Many toxic chemicals are present in the Great Lakes. As a result of various ecosystem health assessments, a comparatively small number have been identified as "critical pollutants". Even so, it is impractical to summarize the spatial and temporal trends of them all within the current context. Examples of only a few have been provided for illustration. In collating the available information, what became apparent were the difficulties in attempting to summarize different sources of information collected using different sampling and analytical methods at different locations at different times. Differences were impossible to resolve. For the parties to report on an on-going basis, a monitoring program with consistent protocols would have to be the primary source of the historically available information as well as a commitment to maintain such a program. For these reasons, a single source of information was used to illustrate spatial and temporal trends: Environment Canada's open lake and interconnecting channels monitoring program, on-going since 1986 using consistent methodologies throughout the various programs.

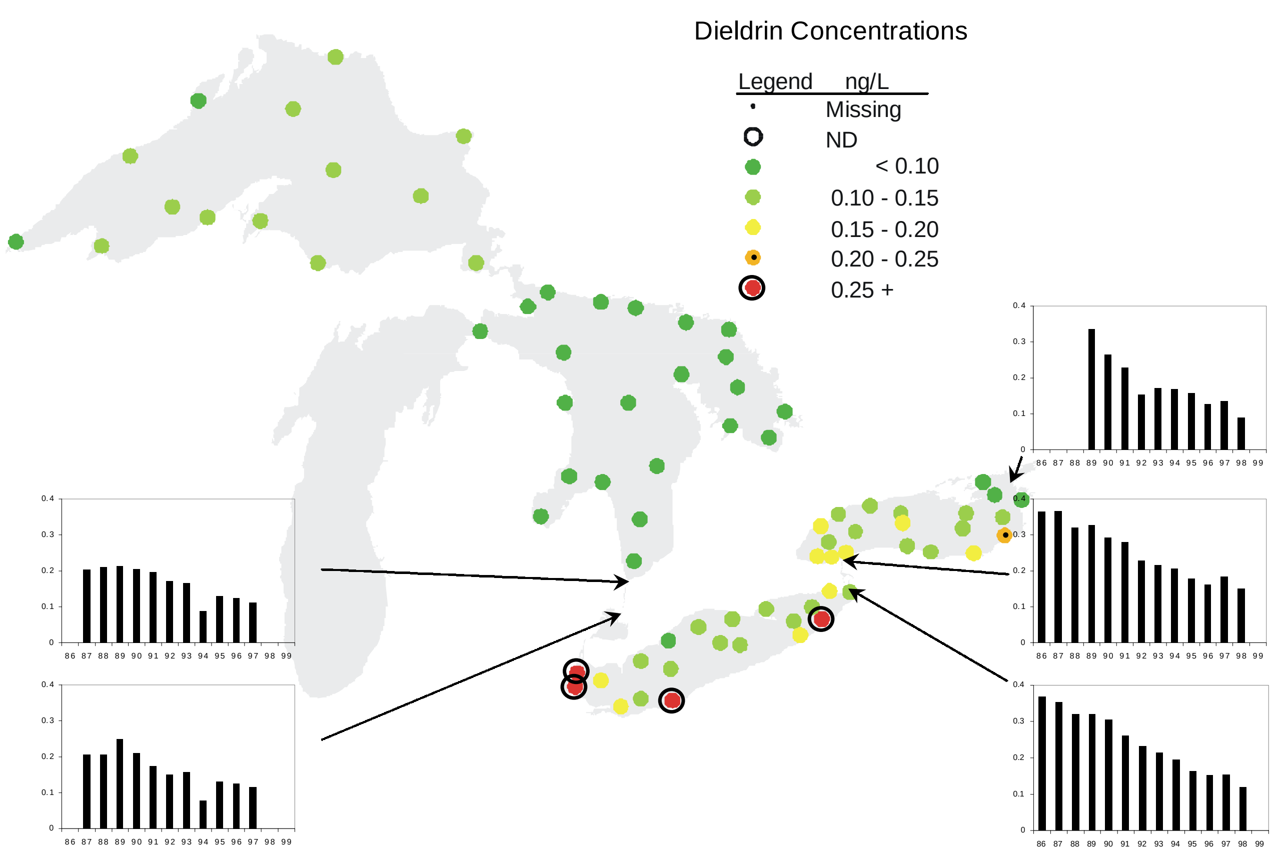


Figure 1. Spatial Dieldrin patterns in the Great Lakes (Spring 1997 or 1998, Surface) and annual most likely estimated averages for the interconnecting channels from 1986 to 1998. Units = ng/L
(Source: Environmental Conservation Branch, Environment Canada)

Organochlorines, several of which are on various "critical pollutant" lists, have and are still declining in the Great Lakes in response to management efforts. Spatial concentration patterns illustrate the ubiquitous nature for some, meanwhile, the influence of localized source(s) for others.

Organochlorine pesticides such as Lindane and Dieldrin (Figure 1) are observed at all open lake stations and connecting channels sites at relatively similar concentrations, although the lower lakes still appear to have local influences, probably historically contaminated soils or sediments. Concentrations throughout the Great Lakes have decreased by ~ 50% between 1986 and 1996 and are still declining. Dieldrin exceeds the most sensitive water quality criterion for the protection of human consumers of fish by a factor of 250 times.
Hexachlorobenzene, octachlorostyrene, and mirex exemplify organochlorines whose presence is due to historical localized sources. Consequently, their occurrence in the environment is isolated to specific locations in the Great Lakes basin. Concentrations of all three in the Niagara River have decreased by more than 50% between 1986 and 1996. Both HCB and mirex continue to exceed their most stringent criteria for the protection of human consumers of fish by a factor of 2 and 7, respectively.

Polycyclic aromatic hydrocarbons (PAHs) are another class of critical pollutants. Some PAHs appear to be increasing in concentration and spatial patterns suggest localized sources. For example, comparisons of upstream/downstream concentrations over time suggest increasing inputs from localized sources in the Niagara River (Figure 2). In contrast decreasing concentrations are observed at the outflow of Lake Ontario.

Future Pressures on the Ecosystem
Management efforts to control inputs of organochlorines have resulted in decreasing concentrations in the Great Lakes, however, sources for some still exist.

The increase in some PAH concentrations in localized areas should be reviewed and analyzed in more detail. The ecosystem impact is unknown.

Chemicals such as endocrine disrupting chemicals, in-use pesticides, and pharmaceuticals are emerging issues.

Future Actions
Efforts such as those underway in the Great Lakes Binational Toxics Strategy need to be maintained to identify and control the remaining sources.

Targeted monitoring to identify and trackdown local sources should be considered for those chemicals whose ambient environmental distribution suggests localized influences.

The research community in the Great Lakes basin is actively pursuing the emerging chemicals issue. The monitoring community will need to incorporate the results of these activities in planning future monitoring programs in the Great Lakes basin.

Further Work Necessary
Environment Canada conducts routine toxic contaminant monitoring in the Great Lakes. However, a coordinated binational enhanced monitoring program is required with agreement on specifics such as analytical and field methodologies, sampling locations, inclusion of connecting channel, nearshore and embayment sites. An agreed upon approach for summarizing and reporting the indicator will also be required given that many chemicals and locations have unique stories to tell.

Acknowledgments
Author: Scott Painter, Environment Canada, Environmental Conservation Branch, Burlington, ON.

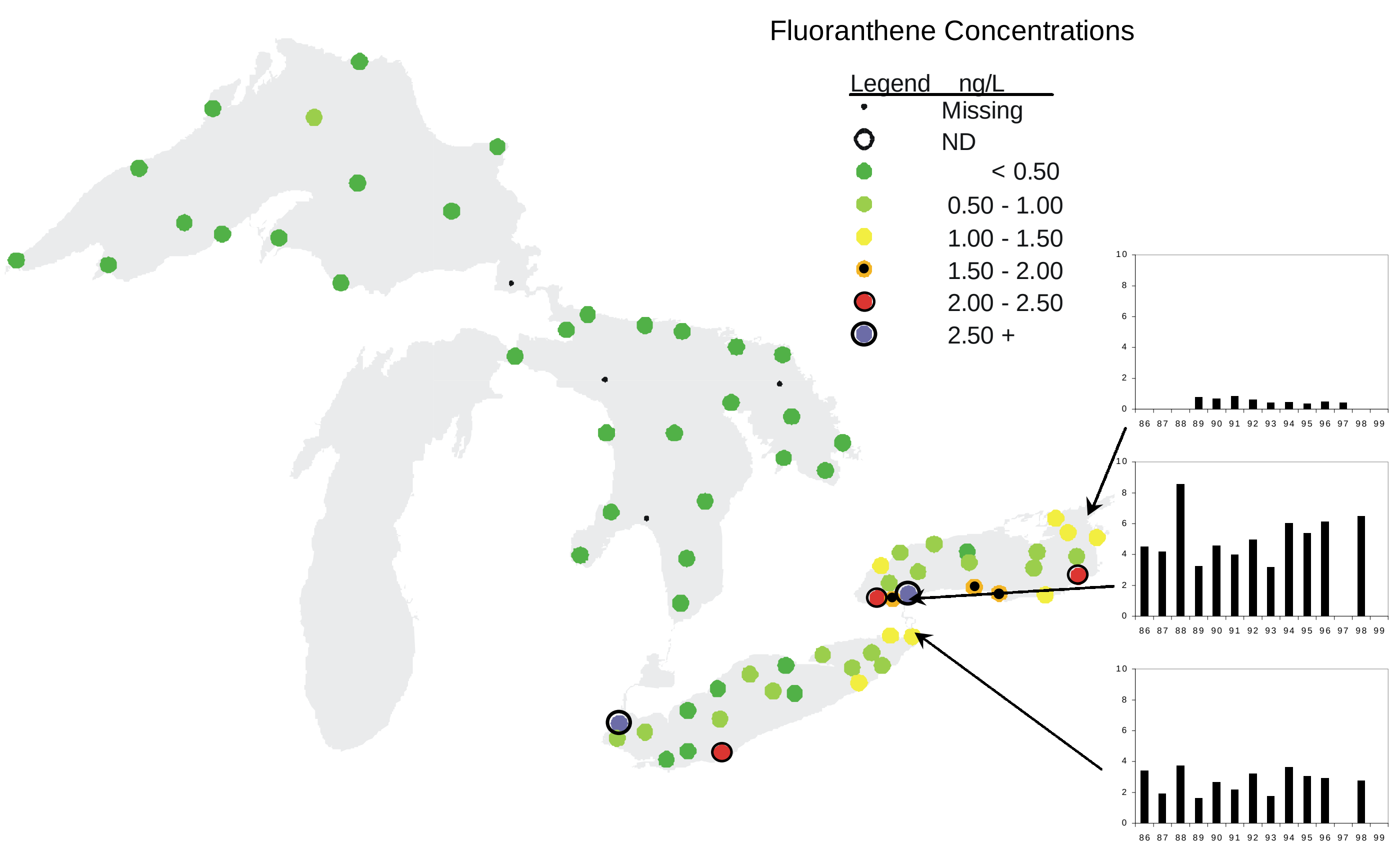


Figure 2. Spatial fluoranthene patterns in the Great Lakes (Spring 1997 or 1998, Surface) and annual most likely estimated averages for the interconnecting channels from 1986 to 1998. Units = ng/L
(Source: Environmental Conservation Branch, Environment Canada)

Amphibian Diversity and Abundance

SOLEC Indicator #4504

Purpose

Assessments of the species composition and relative abundance of calling frogs and toads are used to help infer the condition of Great Lakes basin marshes (i.e. wetlands dominated by non-woody emergent plants). 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. 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.

Ecosystem Objective

The objective is to ensure healthy breeding populations of Great Lakes wetland amphibians by sustaining the necessary quantity and quality of wetland habitat.

State of the Ecosystem

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 was the most frequently detected species (Table 1) and, as indicated by an average calling code of 2.5, was frequently recorded in full chorus (Call Level Code 3) where it was encountered. Green Frog was detected in more than half of station years and the average calling code indicates this species was usually recorded as Call Level 1. Gray Treefrog, American Toad and Northern Leopard Frog were also common, being recorded in more than one-third of all station years. Gray Treefrog was recorded with the second highest average calling code (1.9), indicating that MMP observers usually heard several individuals with some overlapping calls. Bullfrog, Chorus Frog and Wood Frog 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.

With only five years of data collected across the Great Lakes basin, the MMP is still quite young as a monitoring program. 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 Toad and Bullfrog, only the declining trend for Chorus Frog could be resolved with sufficient statistical confidence (i.e. confidence limits do not encompass zero) (Figure 1). Although long-term (1950s to 1990s) losses of Chorus Frog have been recorded in the St. Lawrence River valley

Species Name	% station-years present*	Average calling code
Spring Peeper	69.0	2.5
Green Frog	56.6	1.3
Gray Treefrog	37.9	1.9
American Toad	36.9	1.5
N. Leopard Frog	32.6	1.3
Bullfrog	26.6	1.3
Chorus Frog	25.4	1.7
Wood Frog	18.7	1.5
Pickerel Frog	2.4	1.1
Fowler's Frog	1.4	1.2
Mink Frog	1.3	1.2
Blanchard's Cricket Frog	0.9	1.2
Cope's Gray Treefrog	0.9	1.3

*MMP survey stations monitored for multiple years considered as individual samples

Table 1. Frequency of occurrence and average Call Level Code for amphibian species detected inside Great Lakes basin MMP stations, 1995 through 1999. Average calling codes are based upon the three level call code standard for all MMP amphibian surveys; surveyors record Code 1 (little overlap among calls, numbers of individuals can be determined), Code 2 (some overlap, numbers can be estimated) or Code 3 (much overlap, too numerous to be estimated).

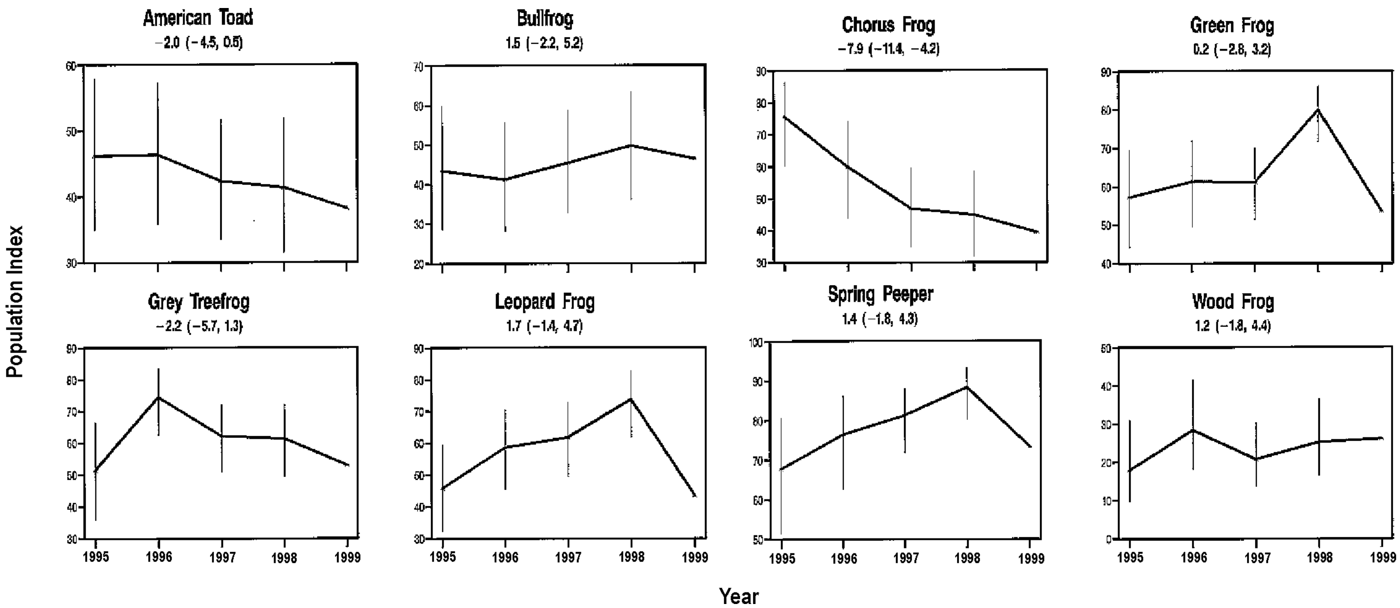


Figure 1. Annual indices of calling amphibian occurrence on MMP routes within the Great Lakes basin, 1995 to 1999. Indices are based on the annual proportion of survey stations with each species present and are defined relative to 1999 values; vertical bars indicate 95% confidence limits around annual indices. 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.

just outside the Great Lakes basin, 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). Additional survey and other (e.g. remote sensing) data and detailed analyses will be required to understand how the trends observed for Chorus Frog and other amphibian species relate to changes in Great Lakes wetland habitat conditions.

These data will serve as baseline data with which to compare future survey results and will help provide an understanding of the status and distribution of calling frogs and toads in Great Lakes' wetlands. Anecdotal and research evidence suggests that wide variations in the occurrence of many amphibian species at a given site is a natural and ongoing phenomenon. These variations are apparent for many of the amphibian species recorded by MMP volunteers during the past five years. Additional years of data will help reveal whether these observed patterns (e.g. decline in Chorus Frog station occupancy) continue. Further data are required to conclude whether Great Lakes wetlands are successfully sustaining amphibian populations.

Future Pressures

Current pressures on wetland amphibians will likely continue. Many coastal and inland Great Lakes wetlands are at the lowest elevations in watersheds that support very intensive industrial, agricultural and residential development. Habitat loss and deterioration remain the predominant threat to Great Lakes amphibian populations. More subtle impacts such as water level stabilization, sedimentation, contaminant and nutrient inputs, and the invasion of exotic plants and animals continue to degrade wetlands across the region.

Future Activities

Because of the sensitivity of amphibians to their surrounding environment and the growing international concern about their populations, amphibians in the Great Lakes basin and elsewhere continue to be the focus of monitoring activities. Wherever possible, efforts should be made to maintain wetland habitats and adjacent uplands. Apart from habitat loss, there is also a need to address impacts that are detrimental to wetland health such as inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made in this area, further wetland conservation and restoration efforts are needed.

Further Work Necessary

Monitoring of amphibian species will continue in marshes across the Great Lakes basin through the MMP. Continued monitoring of at least 100 routes through 2006 is projected to provide good resolution for several of the amphibians recorded by the MMP. Recruitment and retention of program participants will therefore continue to be a high priority, especially in coastal wetlands. Further work is necessary to establish endpoints for amphibian diversity and abundance. Additional monitoring and other (e.g. remote sensing) data and more detailed analyses are required to examine trends in relation to wetland habitat characteristics and at basinwide, lake basin and other spatial scales. Current monitoring is adapted for large geographic scales, work is currently underway to help refine assessments of bird communities at single sites; additional amphibian work may follow. Assessments of the relationships among station occupancy, calling codes and relative abundance estimates, amphibian population parameters, and critical environmental factors are needed.

Although more frequent updates are possible, reporting trend estimates every five or six years is most appropriate for this indicator. A variety of efforts are underway to enhance reporting breadth and efficiency.

Sources

Diagle, C. 1997. Distribution and Abundance of the Chorus Frog, *Pseudacris triseriata*, in Quebec. In Amphibians in Decline: Canadian Studies of a Global Problem (D. M. Green, ed.). The Society for the Study of Amphibians and Reptiles, Saint Louis, Missouri.

Acknowledgements

Author: Russ Weeber, Bird Studies Canada, Port Rowen, ON.
The Marsh Monitoring Program is delivered by Bird Studies Canada in partnership with Environment Canada's Canadian Wildlife Service and with significant support from the U.S. Environmental Protection Agency's Great Lakes National Program Office and Lake Erie Team. The contributions of all Marsh Monitoring Program staff and volunteers are gratefully acknowledged.

Contaminants in Snapping Turtle Eggs

SOLEC Indicator #4506

Purpose

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

Methods

The persistent contaminants measured in Snapping Turtle eggs include 59 non-ortho polychlorinated biphenyl (PCB) congeners, six ortho PCB congeners (ortho PCB congeners are more toxic than non-ortho PCB congeners), 20 organochlorine pesticides (including DDT and mirex) and their metabolites, 14 polychlorinated dioxins (PCDD) and 22 furans (PCDF) and mercury. Eggs were collected from the nest and either analyzed for contaminants or incubated artificially to determine hatching success, deformity rates of hatched turtles, and rates of unhatched eggs. Generally, eggs were collected from 1981 to 1991 on the Canadian side of the Lakes at four sites on Lake Ontario (Cootes Paradise/Hamilton Harbour, Lynde Creek, Cranberry Marsh and Trent River), two sites on Lake Erie (Big Creek Marsh/Long Point and Rondeau Provincial Park), one site on the St. Lawrence River (Akwesasne) and one reference site at Lake Sasajewun, an inland lake at Algonquin Provincial Park.

Snapping Turtle eggs have also been collected for contaminant analyses for most years from 1992 to 1999 at most of the study sites listed above. However, these data have not yet been statistically analyzed and will not be discussed at this time.

Ecosystem Objective

The ecosystem objective is to protect wetland wildlife, especially long-lived species like the Snapping Turtle, from the effects of contamination which may include impaired embryonic development.

The mean wet weight concentrations in Snapping Turtle eggs suggested as endpoints are concentrations found in eggs from Big Creek Marsh, Lake Erie which showed no significant difference in hatching rates and deformity rates as compared to the reference site, Lake Sasajewun, Algonquin Park. The following endpoints for mean wet weight concentrations in Snapping Turtle eggs should not be exceeded:

Toxic Equivalents = 158.3 ug/g
Total polychlorinated biphenyls (PCB) = 0.338 ug/g
Total polychlorinated dibenzo dioxins (PCDD) = 1.0 pg/g
Total polychlorinated dibenzo furans (PCDF) = 3.0 pg/g
pp'DDE (metabolite of DDT) = 0.05 ug/g
mirex = 0.0014 ug/g

State of the Ecosystem

Snapping Turtles 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. 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 1) and number of

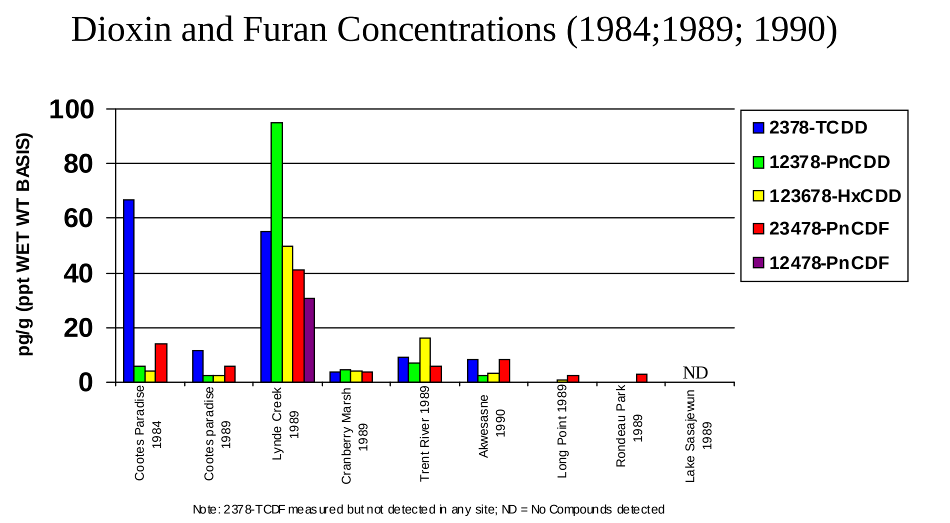


Figure 1. Dioxin and furan concentrations (1984; 1989/90) in Snapping Turtle eggs at Canadian Great Lakes study sites
(Source: Bishop and Gendron, 1998).

detectable PCDF congeners (twenty versus six at all other sites). Eggs from Cranberry Marsh (Lake Ontario) had similar levels of PCBs (Figure 2) and organochlorines (not shown) 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 1). Eggs from Akwesasne contained the highest level of PCBs relative to all other sites (Figure 2).

Temporal trends for contaminants indicate that for eggs at two Lake Ontario sites (Cootes Paradise and Lynde Creek), levels of PCBs and DDE (not shown) increased significantly from 1984 to 1990/91 (Figure 2). Importantly, levels of PCDDs (including 2,3,7,8-TCDD) and PCDFs decreased significantly at Cootes Paradise from 1984 to 1989 (Figure 1). At Lake Erie and the reference lake sites, decreasing or stable levels of contaminants in eggs were reported from 1984 to 1991.

Future Pressures
High contaminant levels associated with eggs of Lake Ontario turtles may be due, in part, to a diet of migratory Lake Ontario fish, including carp and other large long-lived fish species. Similarly, low contaminant levels observed in Lake Erie eggs may be due to a more diversified diet of less contaminated smaller fish and other local diet items. Continuing contaminant exposures in Lake Ontario and St. Lawrence River Snapping Turtles will likely only be alleviated through natural biological loss of persistent chemicals from the environment (e.g. sedimentation) and further reductions of atmospheric, point and non-point source loadings into the Lake Ontario and St. Lawrence River ecosystems.

Future Activities
Similar to other SOLEC coastal wetland indicators, this indicator is currently being reviewed by the Canadian Wildlife Service (CWS) and the SOLEC coastal wetlands core group. For CWS, this program is still in its experimental stages and further analyses of the data are required to determine whether this indicator will be adopted as part of ongoing wildlife monitoring activities. A new binational Great Lakes coastal wetland indicator consortium, supported by the U.S. Environmental Protection Agency, will also evaluate the suitability of this indicator in assessing coastal wetland health. Pending further consideration, analyses of contaminant levels in Snapping Turtle eggs at selected study sites and studies of rates of abnormal development may continue in future years as part of a long-term strategy for monitoring foodweb contamination and its effects on wetland wildlife.

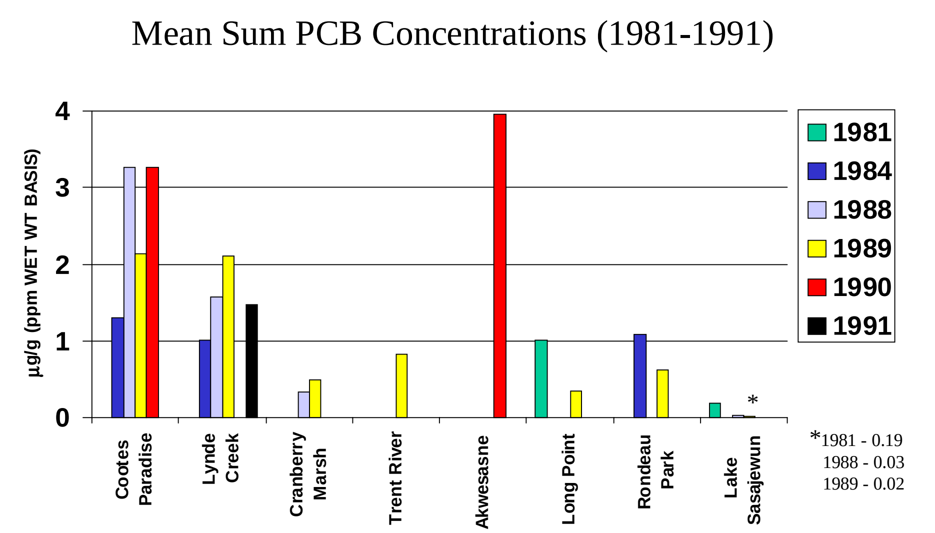


Figure 2. Mean sum PCB concentrations (1981-1991) in Snapping Turtle eggs at Canadian Great Lakes study sites and one inland reference site.
(Source: Bishop and Gendron, 1998).

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 3). Rates were similar between the one Lake Erie site sampled (Long Point) and the reference inland lake.

Further Work Necessary
In order to use this indicator at a basin-wide scale, additional monitoring sites need to be established at representative sites in the United States and the upper Great Lakes. Evaluation of other biological endpoints such as disruption of hormone levels and development of secondary sexual characteristics in Snapping Turtles would also be of value.

The effects of contaminants on the Great Lakes ecosystem, including wetlands, have been studied for many years. The parties to the Great Lakes Water Quality Agreement (U.S. and Canada) are committed to the virtual elimination of discharge associated with any or all persistent toxic substances.

Sources

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Bishop, C.A. and Gendron, A.D. 1998. Reptiles and amphibians: shy and sensitive vertebrates of the Great Lakes basin and St. Lawrence River. Environ. Monit. Assess. 53: 225-244.

Acknowledgments

Author: Kim Hughes, Canadian Wildlife Service, Environment Canada, Downsview, ON.
Contributions from Christine Bishop, Ph.D., Canadian Wildlife Service, Environment Canada, R.J. Brooks, Ph.D., University of Guelph, Canadian Wildlife Service - National Wildlife Research Centre and Peggy Ng, York University.

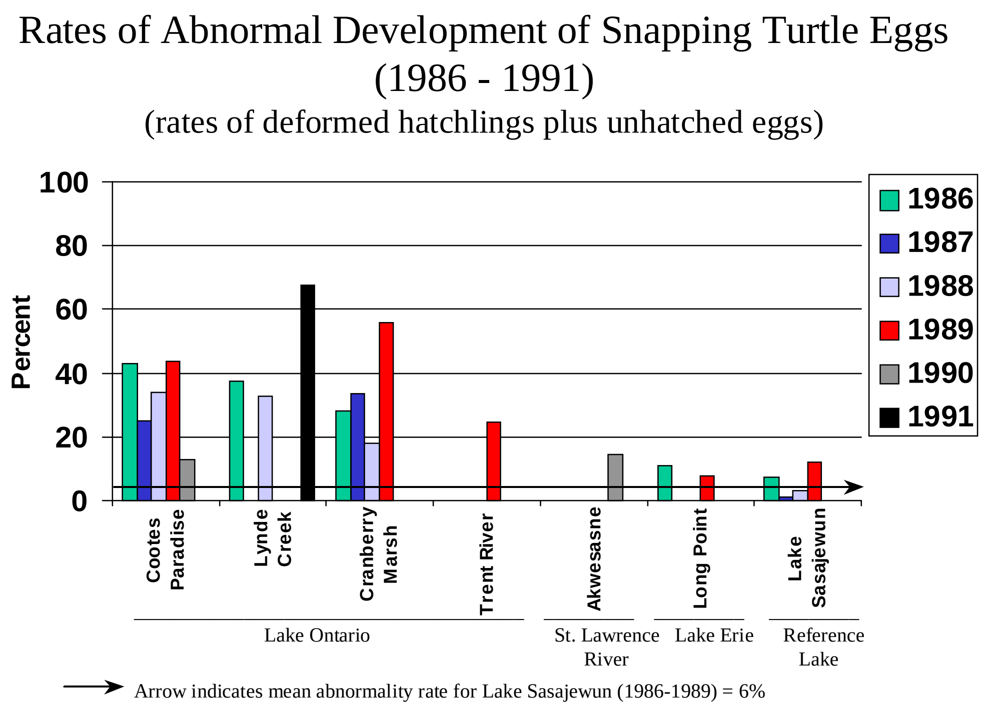


Figure 3. Rates of abnormal development (i.e., rates of deformed hatchlings plus unhatched eggs) of Snapping Turtle eggs (1986-1991) at Canadian Great Lakes study sites and one inland reference site.
(Source: Bishop and Gendron, 1998)

Wetland-Dependent Bird Diversity and Abundance

SOLEC Indicator #4507

Purpose

Assessments of the diversity and abundance of wetland-dependent birds in the Great Lakes basin are 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.

Geographically extensive and long-term surveys of wetland-dependent birds are possible through the coordination of skilled volunteer naturalists in the application of standardized monitoring protocols. Information on the abundance, distribution and diversity of marsh birds provides needed measures of their population trends, and with their habitat associations, can contribute to more effective, long-term conservation strategies.

Ecosystem Objective

The objective is to ensure healthy breeding populations of Great Lakes wetland-dependent birds by sustaining the necessary quantity and quality of wetland habitat.

State of the Ecosystem

From 1995 through 1999, 53 species of birds that use marshes (wetlands dominated by non-woody emergent plants) for feeding, nesting or both were recorded by Marsh Monitoring Program (MMP) volunteers at 322 routes throughout the Great Lakes basin. Among the bird species that typically feed in the air above marshes, Tree Swallow and Barn Swallow were the two most common. Red-winged Blackbird was the most commonly recorded marsh nesting species, followed by Swamp Sparrow, Common Yellowthroat and Marsh Wren. 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.

With only five years of data collected across the Great Lakes basin, the MMP is still quite young as a monitoring program. Bird species occurrence and numbers, and their activity and likelihood of being observed, vary naturally among years and within seasons. Although results are still preliminary, trends are presented for several birds recorded on Great Lakes MMP routes (Figure 1a,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 were Pied-billed Grebe, Blue-winged Teal, American Coot, undifferentiated Common Moorhen/ American Coot, and Black Tern (Figure 1a). 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 were observed for Canada Goose, Mallard, Chimney Swift, Northern Rough-winged Swallow, Common Yellowthroat and Common Grackle (Figure 1b). Each of the declining species depends upon wetlands for breeding but, because they use wetland habitats almost exclusively, the Pied-billed Grebe, American Coot, Common Moorhen, and Black Tern are particularly dependent on the availability of healthy wetlands. Although declines in these wetland specialists and increases in some wetland edge and generalist species (e.g. Common Yellowthroat and Canada Goose) suggest trends in wetland habitat conditions, additional years of data and more detailed analyses are required to understand how these patterns relate to trends in Great Lakes wetland functions.

Future Pressures

Future pressures on wetland-dependent birds will likely include continuing loss and degradation of important breeding habitats through wetland loss, water level stabilization, sedimentation, contaminant and nutrient inputs, and the invasion of exotic plants and animals.

Future Activities

Wherever possible, efforts should be made to maintain high quality wetland habitats and adjacent upland areas. In addition to loss, there is a need to address impacts that are detrimental to wetland health such as water level stabilization, invasive species and inputs of toxic chemicals, nutrients and sediments. Restoration programs are underway for many degraded wetland areas through the work of local citizens, organizations and governments. Although significant progress has been made, further conservation and restoration work is needed.

Further Work Necessary

Monitoring of wetland-dependent bird species will continue across the Great Lakes basin through the MMP. Continued monitoring of at least 100 routes through 2006 is projected to provide good resolution for most of the wetland-dependent birds recorded by the MMP. Recruitment and retention of program participants will therefore continue to be a high priority, particularly in coastal wetlands. Further work is necessary to establish endpoints for bird diversity and abundance. Additional monitoring and other (e.g. remote sensing) data and more detailed analyses are required to examine trends in relation to wetland habitat characteristics at basinwide, lake basin and other spatial scales. Current monitoring is adapted for large geographic scales, work is currently underway to help refine assessments of bird communities at single sites. Assessments of the relationships among count indices, bird population parameters, and critical environmental factors are needed.

Although more frequent updates are possible, reporting trend estimates every five or six years is most appropriate for this indicator. A variety of efforts are underway to enhance reporting breadth and efficiency.

Acknowledgements

Author: Russ Weeber, Bird Studies Canada, Port Rowen, ON. The Marsh Monitoring Program is delivered by Bird Studies in partnership with Environment Canada's Canadian Wildlife Service and with significant support from the U.S. Environmental Protection Agency's Great Lakes National Program Office and Lake Erie Team. The contributions of all Marsh Monitoring Program staff and volunteers are gratefully acknowledged.

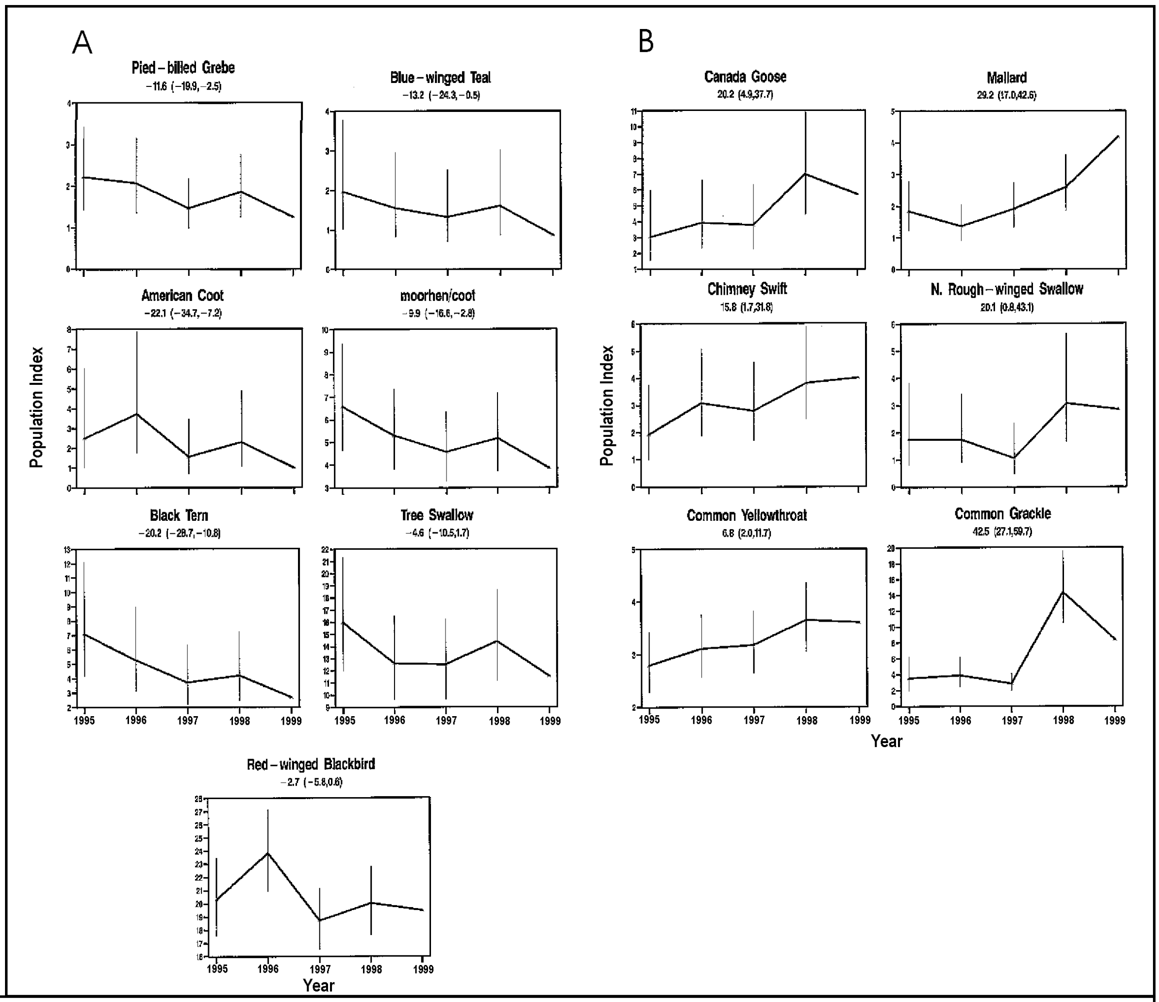


Figure 1: Annual population indices of a) declining and b) increasing marsh nesting and aerial foraging bird species detected on Great Lakes basin MMP routes, 1995 through 1999. Population indices are based on counts of individuals inside the MMP station boundary and are defined relative to 1999 values; vertical bars indicate 95% confidence limits around annual indices. The estimated annual percent change (trend) are indicated for each species and the associated lower and upper extremes of 95% confidence limits are enclosed in parentheses.

Coastal Wetland Area by Type

SOLEC Indicator #4510

Please note - figures 2 & 3 for this indicator are unavailable at this time

Purpose

The purpose of this indicator is to examine and better understand periodic changes in area of coastal wetland types, taking into account natural variations. The area indicator needs to be evaluated in terms of wetland quality by looking at both change in areal extent and change within wetlands, in concert with other indicators.

Coastal wetlands include a range of habitats from bogs and treed swamps to emergent marshes. They also have many configurations. Being open to the lake, some are more susceptible to the influence of lake level changes than others which may be behind barrier beaches. Given the tremendous natural variation that can occur in both quality and area as a result of fluctuating water levels (e.g., Lake St. Clair wetlands change in size by up to 300 percent depending on water levels), this factor is paramount in the interpretation of trends in wetland area. For example, recent low water levels have moved wetland vegetation lakeward (where bottom topography is suitable), shrinking some and increasing others in addition to exposing many mudflats. Yet when the waters rise again, through exposure during the low water period, the seedbank may result in a reinvigoration of wetland vegetation.

Ecosystem Objective

The ecosystem objective is to reverse the trend toward loss and degradation of Great Lakes coastal wetlands, ensuring adequate representation of wetland types across their historical range.

State of the Ecosystem

Wetlands continue to be lost and degraded, yet the ability to track and determine the extent and rate of this loss in a standardized way is not yet feasible. The need to know the location, type and area of Great Lakes coastal wetlands has been identified by a number of individuals, groups and agencies for many years in order to understand the rate and distribution of the changes and track conservation efforts. For example, in preparation for SOLEC '96, the possibility of pulling together a map of Great Lakes coastal wetlands was thoroughly investigated and was determined to be unfeasible at that time. In addition to distribution, the health and status of remaining Great Lakes coastal wetlands, continues to be unknown.

A number of approaches to establish a baseline and determine trends in wetland area have been and will continue to be considered. Unfortunately, none of these exactly match the method outlined for this indicator at SOLEC '98. It is hoped that a new Great Lakes wetlands indicators consortium, which is supported by the US Environmental Protection Agency, will debate the merits of various indicators and approaches, including wetland area.

In the meantime, many efforts have been initiated to estimate wetland area. For example, on the Canadian side of the basin, development of the Ontario Coastal Wetland Atlas provides the most comprehensive and current data base of Ontario Great Lakes wetlands. It includes a relatively complete, spatially referenced map and data base of Canada's Great Lakes coastal wetlands present as of the mid-1980s. It consolidates and enhances information from a variety of sources including: Ontario Ministry of Natural Resources' (OMNR) wetland evaluations, Environment Canada's Environmental Sensitivity Atlases, Natural Heritage Information Centre, OMNR's Natural Areas Database and other site specific studies.

Adding up the area of individual wetlands from the Ontario Atlas will provide an initial estimate of total Canadian Great Lakes coastal wetland area. Unfortunately, this is unlikely to be a method which is repeated since it is labour intensive, expensive, and covers a very large geographic area. Therefore, it does not represent the baseline for a trend, rather it provides a very useful point-in-time reference which aids in the selection of representative sites for monitoring area and other indicators, and improves understanding of wetland change.

The Wetland Inventory for Research and Education Network (WIRENET), which was based on a similar, but less extensive process than the Atlas, including mid-1980s wetland evaluations, provides an on-line map of Ontario coastal wetlands at:

www.on.ec.gc.ca/glimr/wirenet/. WIRENET was used in the work on coastal wetland biodiversity investment areas for SOLEC '98.

Other methods to look at trends in coastal wetland area rely on remotely sensed data. For example, the U.S. Fish and Wildlife Service published the National Wetland Inventory (NWI) in 1982, based on the analysis of aerial photographs with ground-truthing. The NWI includes delineated wetland types using the system of Cowardin et al. (1979). Updates are to be prepared every 10 years with the first one in 1990 and the 2000 update due soon. Updates are based on a statistical sampling of wetlands, not on a full set of aerial photos. The NWI, although very useful, does not specifically identify coastal wetlands.

In Canada, trends in wetland area, vegetation communities and adjacent land uses have been mapped and digitized for eight coastal wetlands for seven different years between 1934 and 1995. These data are based on air photo interpretation and include the following wetlands: Lake St. Clair marshes, Big Creek-Holiday Beach, Rondeau Bay North Shore, Turkey Point, Oshawa Second Marsh, Presqu'ile Marsh, Dunnville Marsh and Long Point (see Fig. 1). There are plans to add additional wetlands to this "Trends Through Time" database in order to increase the representativeness of the sites selected for the basin. Plans are also underway to investigate the potential to use these sites to indicate and interpret change (Fig. 2) and status of coastal wetlands at a basinwide scale (Fig. 3).

Numerous research efforts are underway to assess the use of remote sensing technologies, and in some cases combine the results of satellite remote sensing, aerial photography and field work to document recent wetland loss. It is hoped that in the future, remote sensing will be used to provide an overview and facilitate a binational map of Great Lakes coastal wetlands as well as to establish a consistent methodology for tracking and anticipating change and facilitate faster updates and better tracking of wetland change in areas of high land-use change.

Future Pressures

There are many stressors which have and continue to contribute to the loss and degradation of coastal wetland area. These include: filling, dredging and draining for conversion to other uses such as urban, agricultural, marina, and cottage development; shoreline modification; water level regulation; sediment and nutrient loading from watersheds; adjacent landuse; invasive species, particularly exotics; and climate variability and change.

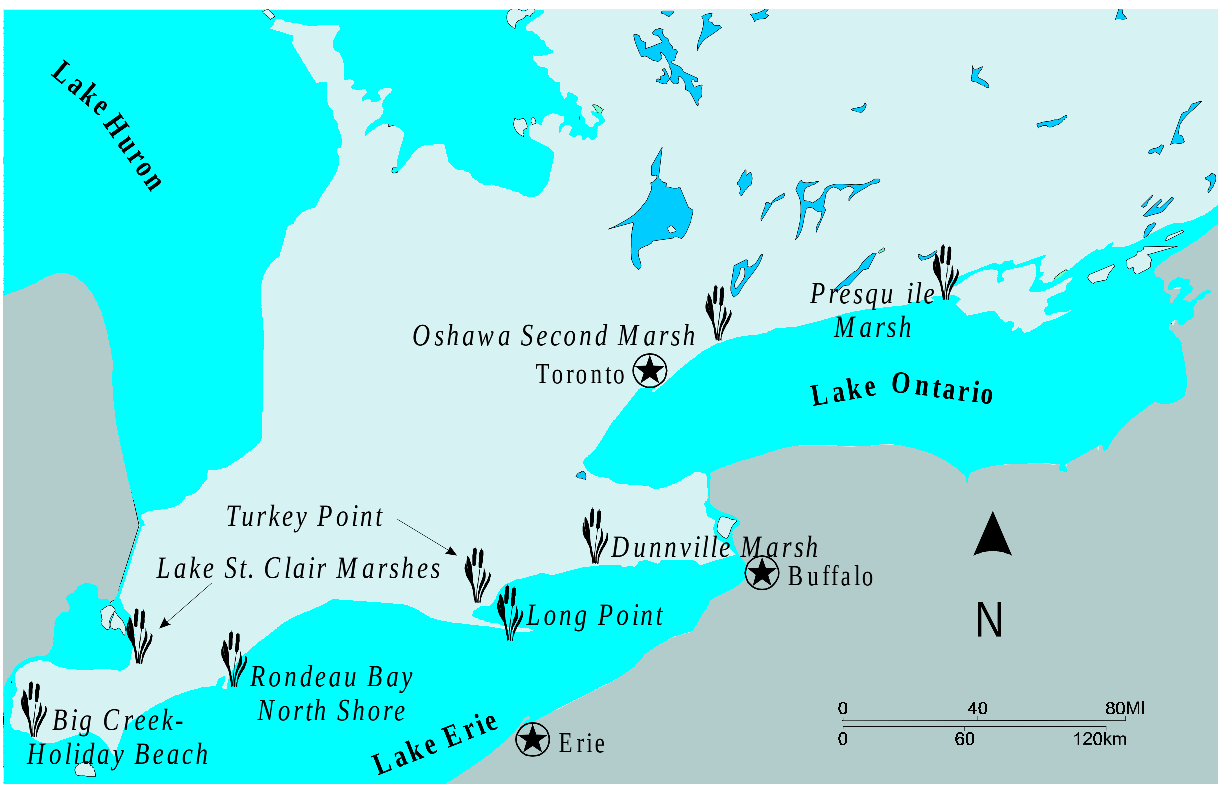


Figure 1. Location of eight coastal wetlands for "Trends Through Time" database.

Many of these stressors require direct human action to implement, and thus, with proper consideration of the impacts, can be reduced. The natural dynamics of wetlands must be understood. Global climate variability and change have the potential to amplify the dynamics by reducing water levels in the Lakes in addition to changing seasonal storm intensity and frequency, water level fluctuations and temperature.

Because of growing concerns around water quality and supply, which are key Great Lakes conservation issues, and the role of wetlands in flood attenuation, nutrient cycling and sediment trapping, wetland changes will continue to be monitored closely.

Future Activities

There are activities underway on many fronts and at many scales to conserve remaining wetlands. These include: improving legislation, policies and permitting processes; communication and outreach activities to promote good stewardship; habitat and biodiversity protection programs; habitat rehabilitation programs; watershed stewardship; and research. One example includes the current review of the Water Level Regulation Plan for Lake Ontario. In determining revisions to the plan, this review will consider wetlands, fisheries and other environmental and emerging issues along with the traditional interests of hydropower, commercial navigation and shoreline property owners.

Being able to track, document and anticipate changes in coastal wetland area, distribution and diversity will direct wetland conservation to prevent the loss of key areas and maintain and sustain hydrologic function in the Great Lakes basin.

Further Work Necessary

The difficult decisions on how to address human-induced stressors causing wetlands loss have been considered for some time. A better understanding of wetland function will help to assess exactly what is being lost. An educated public is critical to ensuring that wise decisions about the stewardship of the Great Lakes basin ecosystem are made. Better platforms for getting understandable information to the public are needed.

As mentioned previously, it is hoped that a new binational Great Lakes coastal wetland indicator consortium will wrestle with all of the difficult issues with respect to the most appropriate, implementable method for tracking trends in area as well as the frequency with which it is monitored and reported, in order to establish the best technique.

Acknowledgments

Authors: Lesley Dunn, Canadian Wildlife Service, Environment Canada, Downsview, ON and Laurie Maynard, Canadian Wildlife Service, Environment Canada, Guelph, ON.

Contributions from Doug Forder, Canadian Wildlife Service, Environment Canada, Duane Heaton, U.S. Environmental Protection Agency, Linda Mortsch, Meteorological Service of Canada, Environment Canada, Nancy Patterson, Canadian Wildlife Service, Environment Canada and Brian Potter, Ontario Ministry of Natural Resources.

Effect of Water Level Fluctuations

SOLEC Indicator #4861

Purpose

The purpose of this indicator is to examine the historic water levels in all of the Great Lakes, and compare these levels and their effects on wetlands with post-regulated levels in Lakes Superior and Ontario, where water levels have been regulated since about 1914 and 1959, respectively. Naturally fluctuating water levels are known to be essential for maintaining the ecological health of Great Lakes shoreline ecosystems, especially coastal wetlands. Thus, comparing the hydrology of the Lakes serves as an indicator of degradation caused by the artificial alteration of the naturally fluctuating hydrological cycle. Furthermore, water level fluctuations can be used to examine effects on wetland vegetation communities over time as well as aid in interpreting estimates of coastal wetland area, especially in those Great Lakes for which water levels are not regulated.

Ecosystem Objective

The ecosystem objective is to maintain the diverse array of Great Lakes coastal wetlands by allowing, as closely as is possible, the natural seasonal and long-term fluctuations of Great Lakes water levels. Great Lakes shoreline ecosystems are dependent upon natural disturbance processes, such as water level fluctuations, if they are to function as dynamic systems. Naturally fluctuating water levels create ever-changing conditions along the Great Lakes shoreline, and the biological communities that populate these coastal wetlands have responded to these dynamic changes with rich and diverse assemblages of species.

State of the Ecosystem

Water levels in the Great Lakes have been measured since 1860, but even 140 years is a relatively short period of time when assessing the hydrological history of the Lakes. Sediment investigations conducted recently by Thompson and Baedke on the Lake Michigan-Huron system indicate quasi-periodic lake level fluctuations (Figure 1), both in period and amplitude, on an average of about 160 years, but ranging from 120 - 200 years.

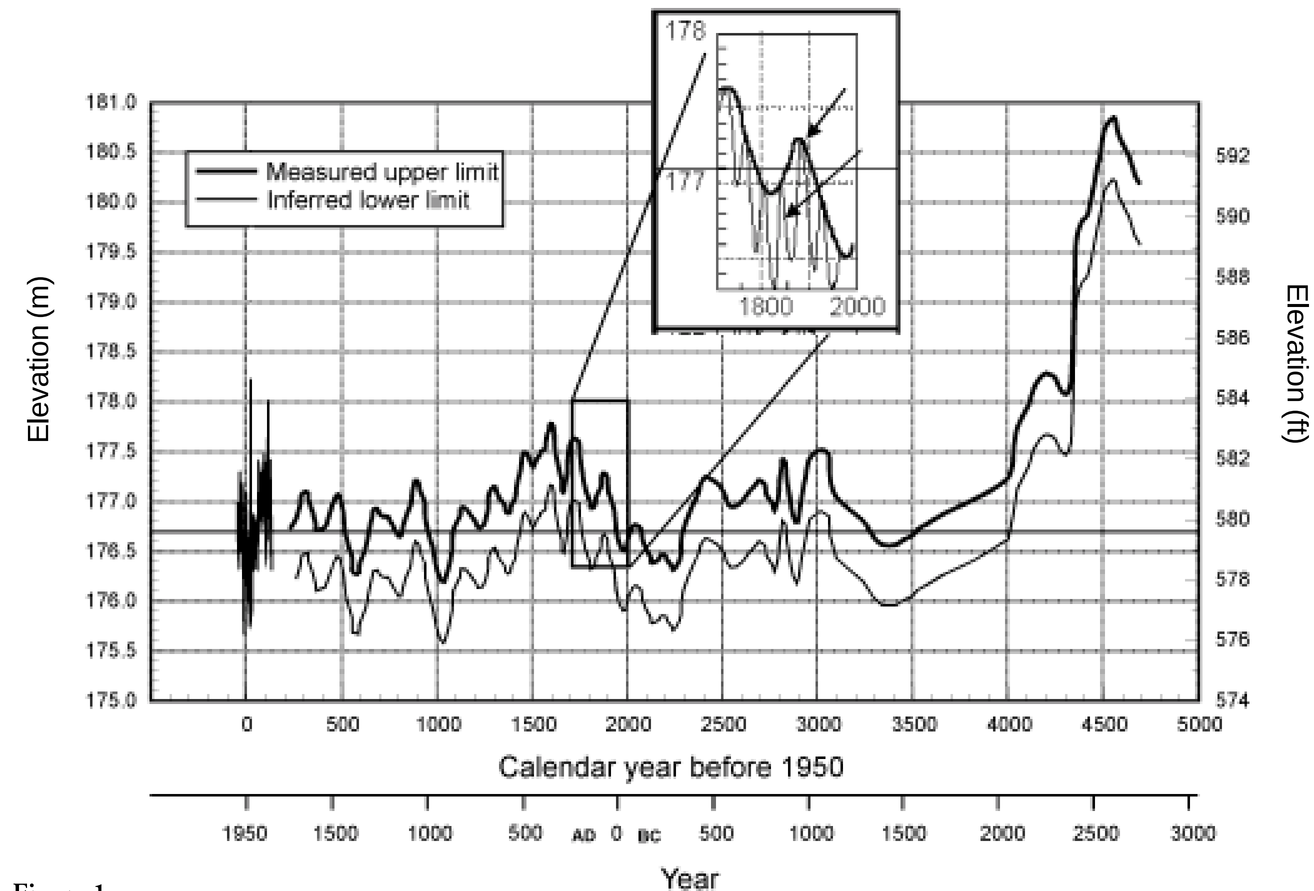


Figure 1.

Within this 160-year period, there also appear to be sub-fluctuations of approximately 33 years. Therefore, to assess water level fluctuations and wetland trends, it is necessary to look at long-term data.

Because Lake Superior is at the upper end of the watershed, the fluctuations have less amplitude than the other Lakes. Lake Ontario (Figure 2), at the lower end of the watershed, more clearly shows these quasi-periodic fluctuations and the almost complete elimination of the high and low levels since the Lake level began to be regulated in 1959, and more rigorously since 1976. For example, the 1986 high level that was observed in the other Lakes was eliminated from Lake Ontario. The level in Lake Ontario after 1959 contrasts that Lake Michigan-Huron (Figure 3), which shows the more characteristic high and low water levels.

Seasonal water level fluctuations result in higher summer water levels and lower winter levels. Additionally, the often unstable summer water levels ensure a varied hydrology for the diverse plants species inhabiting coastal wetlands. Without the seasonal variation, the wetland zone would be much narrower and less diverse. Even very short-term fluctuations resulting from changes in wind direction and barometric pressure can substantially alter the area inundated, and thus, the coastal wetland community.

Long-term water level fluctuations, of course, have an impact over a longer period of time. During periods of high water, there is a die-off of shrubs, cattails, and other woody or emergent species that cannot tolerate long periods of increased depth of inundation. At the same time, there is an expansion of aquatic communities,

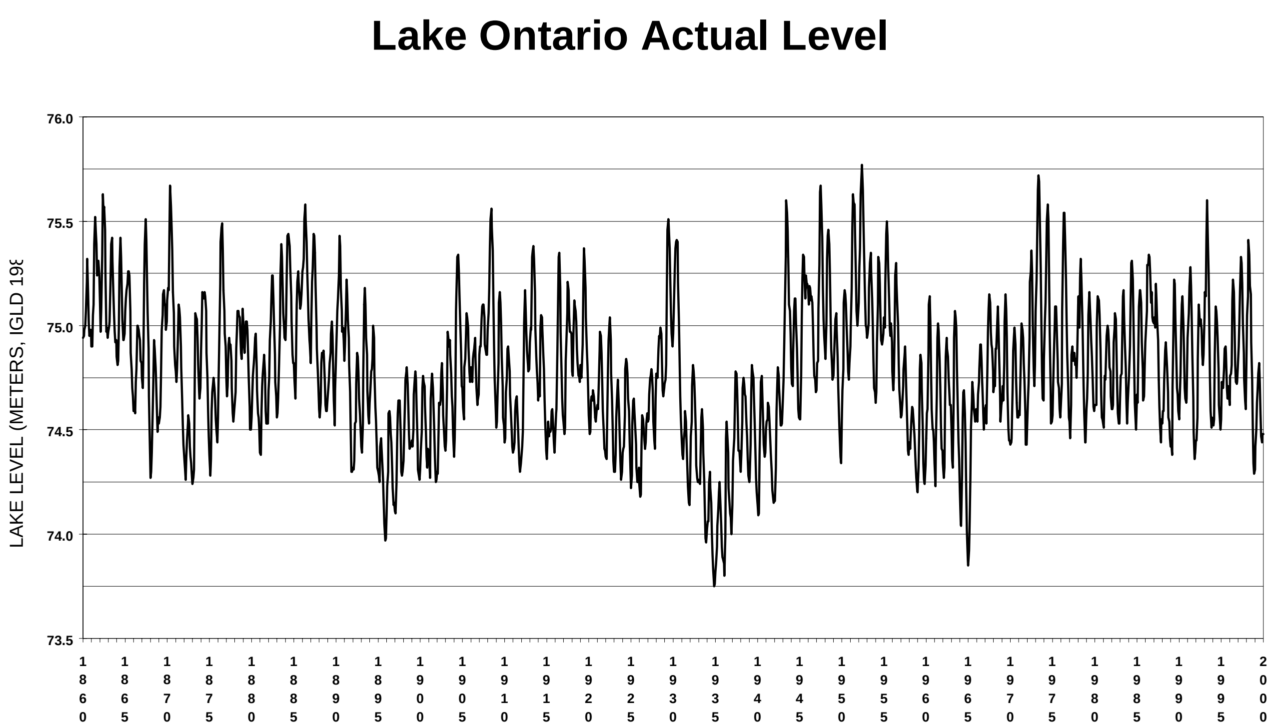


Figure 2.

The significance of seasonal and long-term water level fluctuations on coastal wetlands is perhaps best explained in terms of the vegetation, which, in addition to its own diverse composition, provides the substrate, food, cover, and habitat for many other species dependent on coastal wetlands.

notably submergents, into the newly inundated area. As the water levels recede, seeds buried in the sediments germinate and vegetate this newly exposed zone, while the aquatic communities recede outward back into the Lake. During periods of low water, woody plants and emergents expand again to reclaim their former area as aquatic communities establish themselves further outward into the Lake.

The long-term high-low fluctuation puts natural stress on coastal wetlands, but is vital in maintaining wetland diversity. It is the mid-zone of coastal wetlands that harbours the greatest biodiversity. Under more stable water levels, coastal wetlands occupy narrower zones along the Lakes and are considerably less diverse, as the more dominant species, such as cattails, take over to the detriment of those less able to compete under a stable water regime. This is characteristic of many of the coastal wetlands of Lake Ontario, where water levels are regulated.

Future Pressures
Future pressures on the ecosystem include additional withdrawals or diversions of water from the Lakes, or additional regulation or smoothing of the high and low water levels. These potential future pressures will require direct human intervention to implement, and thus, with proper consideration of the impacts,
can be prevented. The more insidious impact could be due to global climate variability and change. The quasi-periodic fluctuations of water levels are the result of climatic effects, and global climate change has the potential to greatly alter the water levels in the Lakes.

Future Activities
A new reference study is planned for Lake Ontario to develop a more ecologically compatible plan for water level regulation. With this work, there is hope that Lake Ontario's coastal wetlands will benefit from a better plan for managing Lake water levels.

Continued monitoring of water levels in all of the Great Lakes is vital to understanding coastal wetland dynamics and the ability to assess wetland health on a large scale. Fluctuations in water levels are the driving force behind coastal wetland biodiversity and overall wetland health. Their effects on wetland ecosystems must be recognized and monitored throughout the Great Lakes basin in both regulated and unregulated Lakes.

Further Work Necessary
The difficult decisions on how to address human-induced global climate change extend far beyond the bounds of Great Lakes coastal wetlands, but this could be a major cause of lowered water levels in the Lakes in future years.

Also, an educated public is critical to ensuring wise decisions about the stewardship of the Great Lakes Basin ecosystem, and better platforms to getting understandable information to the public are needed.

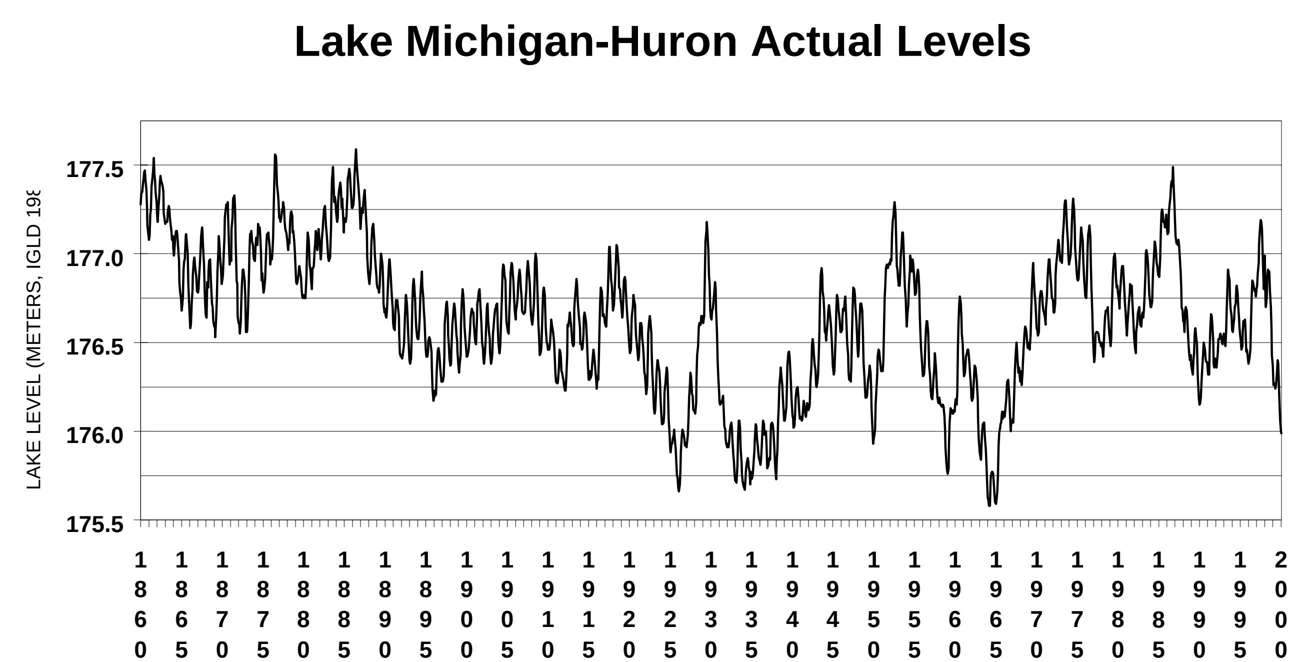


Figure 3.

Because Lake level fluctuations occur over long quasi-periodic fluctuations, modification of this indicator is necessary from that presented at SOLEC in 1998.

Acknowledgments
Author: Duane Heaton, U.S. Environmental Protection Agency, Chicago, IL.
Contributions from Douglas A. Wilcox, Ph.D., U.S. Geological Survey, Biological Resources Division, Todd A. Thompson, Ph.D., Indiana Geological Survey, and Steve J. Baedke, Ph.D., James Madison University.

Area, Quality and Protection of Alvar Communities

SOLEC Indicator #8129 (in part)

Purpose

This indicator assesses the status of one of the 12 special lakeshore communities identified within the nearshore terrestrial area. 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 basin are globally imperiled or rare.

Ecosystem Objective

Conservation of alvar communities relates to IJC Desired Outcome 6: Biological Community Integrity and Diversity. A four-year study of Great Lakes alvars completed in 1998 (the International Alvar Conservation Initiative - IACI) evaluated conservation targets for alvar communities, and concluded that essentially all of the existing viable occurrences should be maintained, since all types are below the minimum threshold of 30-60 viable examples. As well as conserving these ecologically distinct communities, this target would protect populations of dozens of globally significant and disjunct species. A few species, such as Lakeside Daisy (*Hymenoxis herbacea*) and the beetle *Chlaenius p. purpuricollis*, have nearly all of their global occurrences within Great Lakes alvar sites.

State of the Ecosystem

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. Approximately 64% of the remaining alvar area occurs within Ontario, with about 16% in New York State, 15% in Michigan, 4% in Ohio, and smaller areas in Wisconsin and Quebec.

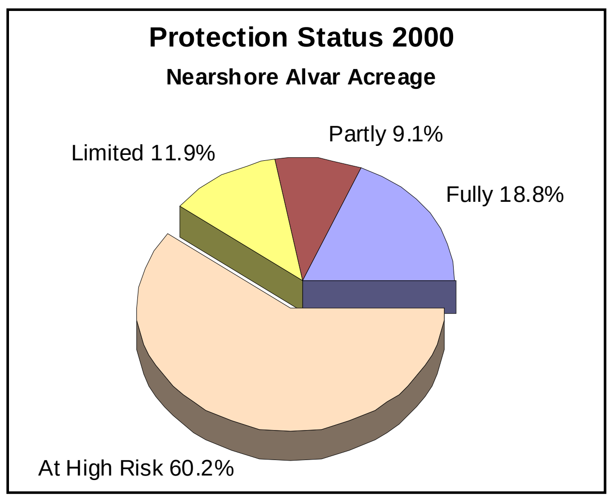
Data from the IACI and state/provincial alvar studies was screened and updated to identify viable community occurrences. Just over 2/3 of known Great Lakes alvars occur close to the shoreline, with all or a substantial portion of their area within 1 km of the shore.

Note that typically several different community types occur within each alvar site.

	Total in Basin	Nearshore
No. of alvar sites	82	52
No. of community occurrences	204	138
Alvar acreage	28,475	20,009

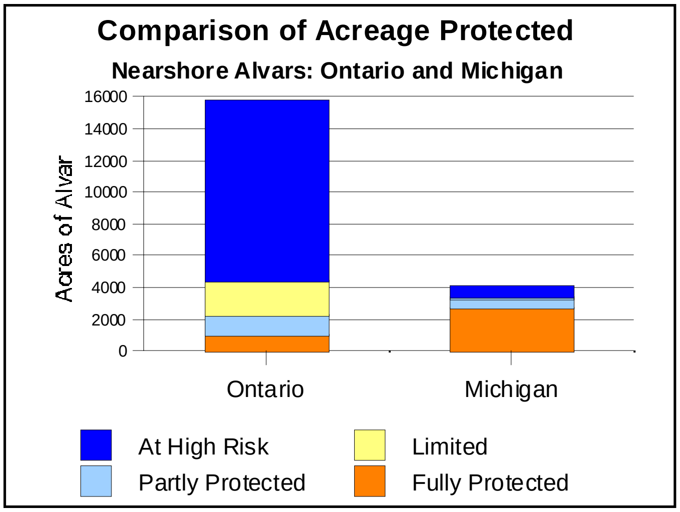
Among the 15 community types documented, six types show a strong association (over 80% of their acreage) with nearshore settings. Four types have less than half of their occurrences in nearshore settings.

The current status of all nearshore alvar communities was evaluated by considering current land ownership and the type and severity of threats to their integrity. As shown in the figure, less than 1/5th of the nearshore alvar acreage is currently fully protected, while over 3/5th is at high risk.

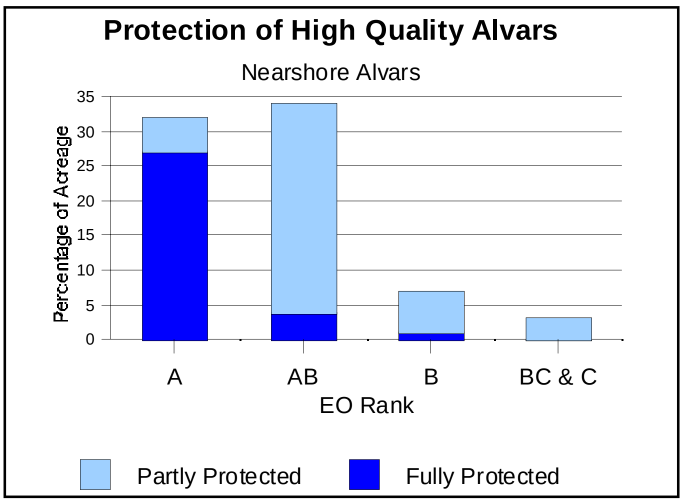


The degree of protection for nearshore alvar communities varies considerably among jurisdictions. For example, Michigan has 66% of its nearshore alvar acreage in the Fully Protected category, while Ontario has only 7%. In part, this is a reflection of the much larger total shoreline acreage in Ontario, as shown in the following figure. (Other states have too few nearshore sites to allow comparison).

Each alvar community occurrence has been assigned an "EO rank" to reflect its relative quality and condition. A



and B-ranks are considered viable, while C-ranks are marginal. As shown in the following figure, protection efforts to secure alvars have clearly focused on the best quality sites.

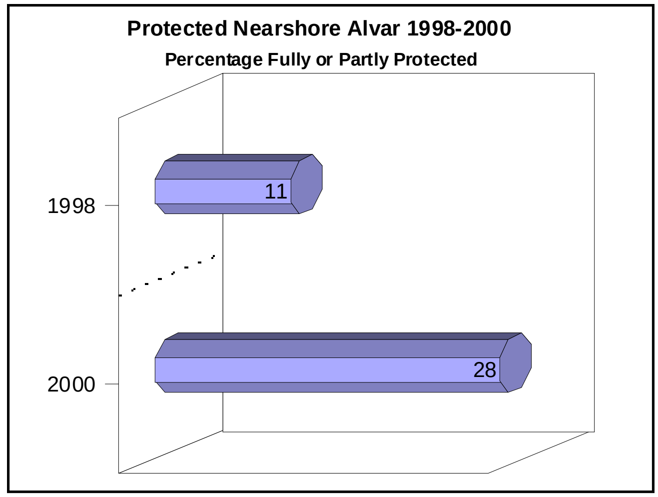


Pressure on the Ecosystem

Nearshore alvar communities are most frequently threatened by habitat fragmentation and loss, trails and off-road vehicles, resource extraction uses such as quarrying or logging, and adjacent land uses such as residential subdivisions. Less frequent threats include grazing or deer browsing, plant collecting for bonsai or other hobbies, and invasion by exotic plants such as European Buckthorn and Dog-strangling Vine.

Recent Progress

Documentation of the extent and quality of alvars through the IACI has been a major step forward, and has stimulated much greater public awareness and conservation activity for these habitats. Over the past two years, a total of 10 securement projects has resulted in protection of at least 5289.5 acres of alvars across the Great Lakes basin, with 3344.5 acres of that within the nearshore area. Most of the secured nearshore area is through land acquisition, but 56 acres on Pelee Island (ON) are through a conservation easement, and 1.5 acres on Kelleys Island (OH) are through State dedication of a nature reserve. These projects have increased the area of protected alvar dramatically in a short time.



Future Actions

Because of the large number of significant alvar communities at risk, particularly in Ontario, their status should be closely watched to ensure that they are not lost. A re-assessment of their status every 2-3 years would be appropriate. Major bi-national projects hold great promise for further progress, since alvars are a Great Lakes resource, but most of the unprotected area is within Ontario. Projects could usefully be modelled after the 1999 Manitoulin Island (ON) acquisition of 17,000 acres, which took place through a cooperative project of The Nature Conservancy of Canada, The Nature Conservancy, Federation of Ontario Naturalists, and Ontario Ministry of Natural Resources.

For Further Information

A baseline database of both nearshore and basin-wide alvar occurrences has been developed, along with an analysis report: *Status of Great Lakes Alvars 2000*. Results from the IACI are summarized in *Conserving Great Lakes Alvars* (1999), available from The Nature Conservancy Great Lakes Program Office in Chicago.

Acknowledgments

Authors: Ron Reid, Bobolink Enterprises, Washago, ON, and Heather Potter, The Nature Conservancy, Chicago, IL

Extent of Hardened Shoreline

SOLEC Indicator #8131

Purpose

This indicator assesses the extent of hardened shoreline through construction of sheet piling, rip rap, or other erosion control structures.

Ecosystem Objective

Shoreline conditions should be healthy to support aquatic and terrestrial plant and animal life, including the rarest species.

Anthropogenic hardening of the shorelines not only directly destroys natural features and biological communities, it also has a more subtle but still devastating impact. 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 action and lake currents. 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.

State of the Ecosystem

The National Oceanic and Atmospheric Administration (NOAA) Medium Resolution digital Shorelines dataset was compiled between 1988 and 1992. 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. Table 1indicates 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.

In 1999, Environment Canada assessed change in the extent of shoreline hardening along about 22 kilometers of the Canadian side of the St. Clair River from 1991-1992 to 1999. Over the 8-year period, an additional 5.5 kilometers (32 percent) of the shoreline had been hardened. 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.

Future Pressures on the Ecosystem

Shoreline hardening is not generally reversible, so once a section of shoreline has been hardened, it can be considered a permanent feature. As such, the current state of shoreline hardening likely represents the best condition that can be expected in the future.

Pressure will continue to harden additional stretches of shoreline, especially during periods of high lake levels. This additional hardening in turn will starve the downcurrent areas of sediment to replenish that which eroded away, causing further erosion and further incentive for additional hardening. Thus, a cycle of shoreline hardening can progress along the shoreline.

The future pressures on the ecosystem resulting from existing hardening will almost certainly continue, and additional hardening is likely in the future. The uncertainly is whether the rate can be reduced and ultimately halted. In addition to the economic costs, the ecological costs are of concern, particularly the further lost or degradation of coastal wetlands and sand dunes.

Future Actions

Shoreline hardening can be controversial, even litigious, when one property owner hardens a stretch of shoreline that may increase erosion of an adjacent property. The ecological impacts are not only difficult to quantify as a monetary equivalent, but difficult to perceive without an understanding of sediment transport along the lakeshores. The importance of the ecological process of sediment transport needs to be better understood as an incentive to reduce new shoreline hardening. An educated public is critical to ensuring wise decisions about the stewardship of the

Great Lakes basin ecosystem, and better platforms for getting understandable information to the public is needed.

Further Work Necessary

It is possible that more recent aerial photography of the shoreline will be interpreted to show more recently hardened shorelines. Once more recent data provides information on hardened areas, updates may only be necessary basinwide every 10 years, with monitoring of high-risk areas every 5 years.

Acknowledgments

Authors: John Schneider, US Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL, Duane Heaton, US Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL, and Harold Leadlay, Environment Canada, Environmental Emergencies Section, Downsview, ON

Lake/Connecting Channel	**70-100%** Hardened (%)	**40-70%** Hardened (%)	**15-40%** Hardened (%)	**0-15%** Hardened (%)	**Non-**structural Modifications (%)	**Unclassified** (%)	**Total** Shoreline (km)
Lake Superior	3.1	1.1	3.0	89.4	0.03	3.4	5,080
St. Marys River	2.9	1.6	7.5	81.3	1.6	5.1	707
Lake Huron	1.5	1.0	4.5	91.6	1.1	0.3	6,366
Lake Michigan	8.6	2.9	30.3	57.5	0.1	0.5	2,713
St. Clair River	69.3	24.9	2.1	3.6	0.0	0.0	100
Lake St. Clair	11.3	25.8	11.8	50.7	0.2	0.1	629
Detroit River	47.2	22.6	8.0	22.2	0.0	0.0	244
Lake Erie	20.4	11.3	16.9	49.1	1.9	0.4	1,608
Niagara River	44.3	8.8	16.7	29.3	0.0	0.9	184
Lake Ontario	10.2	6.3	18.6	57.2	0.0	7.7	1,772
St. Lawrence Seaway	12.6	9.3	17.2	54.7	0.0	6.2	2,571
All 5 Lakes	5.7	2.8	10.6	78.3	0.6	2.0	17,539
All Connecting Channels	15.4	11.5	14.0	54.4	0.3	4.4	4,436
Entire Basin	7.6	4.6	11.3	73.5	0.5	2.5	21,974

Contaminants Affecting Productivity of Bald Eagles

SOLEC Indicator #8135

Purpose

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.

Ecosystem Objective

This indicator supports monitoring of progress under the Great Lakes Water Quality Agreement for several of the Annexes. Under Annex 2, it will track progress under the Remedial Action Plans (RAPs) and Lakewide Management Plans (LaMPs) for several of the beneficial use impairments including effects on wildlife habitat, presence of developmental deformities, and degradation of wildlife populations. Under Annex 12, concentrations of persistent toxic substances within the tissues of a top-level predator of the Great Lakes will be tracked, and trends can be drawn. Under Annex 13, pollution from non-point sources will also be tracked since many pairs of eagles nest in areas away from point sources of pollution.

State of the Ecosystem

The Great Lakes ecosystem may be slowly recovering, based on the current measures used for the bald eagle. These 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.

Based on the first year of the Michigan Biosentinel Eagle Project, 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 NOAECs for PCBs and p,p'-DDE, in a few, isolated shorelines, they have been below the NOAECs (Figures 1 and 2). No trends are apparent for the entire Great Lakes population of bald eagles in either analysis. The NOAEC concentrations for PCBs were 4.0 mg/kg and 2.7 mg/kg for p,p'-DDE.

The number of developmental deformities observed has increased over time. This may be due to the lesser importance of the egg shell thinning related to p,p-DDE as a negative impact to the ability of eagles to reproduce.

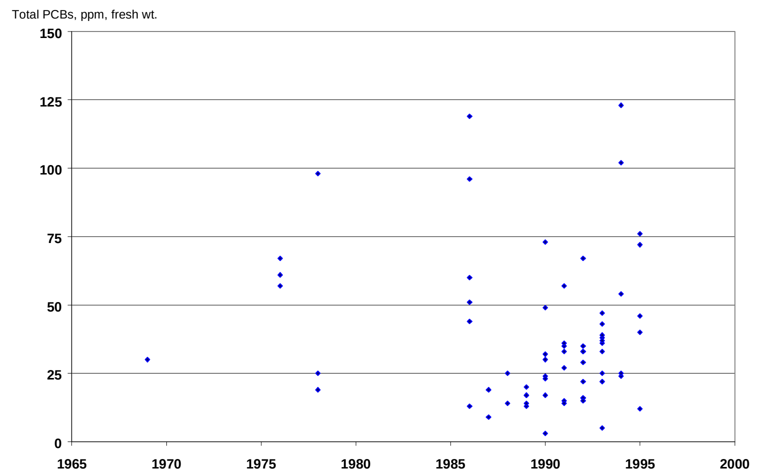


Figure 1. Concentrations of Total PCBs, mg/kg, fresh wet weight in unhatched bald eagle eggs collected from the Great Lakes, 1968-1995.
(Source: Bowerman *et al.* 1998)

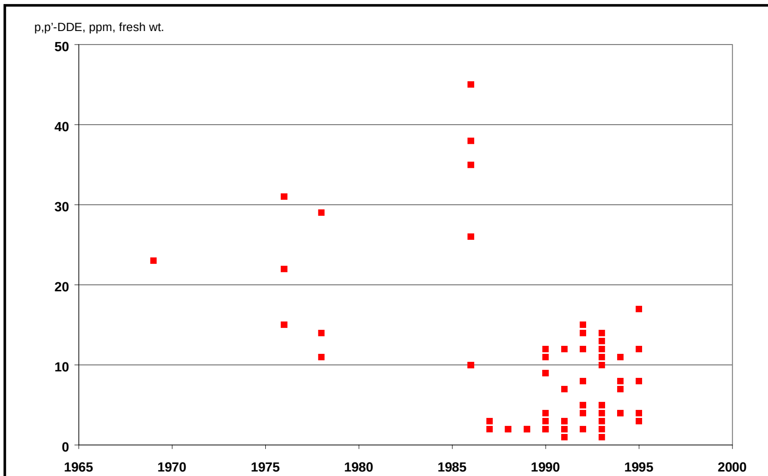


Figure 2. Concentrations of p,p'-DDE, mg/kg, fresh wet weight in unhatched bald eagle eggs collected from the Great Lakes, 1968-1995.
(Source: Bowerman *et al.* 1998).

No developmental deformities have been observed since 1995 in nestling eagles, however, the effort to visit nests along the shorelines of the Great Lakes has also declined with the state of Michigan being the sole exception.

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. One young fledged and an unhatched egg was collected by Peter Nye of New York DEC. The approximate areas of the Great Lakes shorelines that have nesting eagles is shown in Figure 3.

Future Pressures
The current and future pressures on nesting eagles of the Great Lakes ecosystem are: 1) the continued exposure, through food chain mechanisms, to environmental pollutants and their detrimental effects on reproduction; 2) other human related pressures on nesting eagles due to disturbances near nest sites; 3) in some areas of the Great Lakes, food availability plays some role in productivity; 4) loss of habitat due to development; 5) for eagles nesting above barrier dams, the potential for fish passage of contaminated Great Lakes fishes; and, 6) potential increases in mortality due to loss of protection after delisting from the U.S. Endangered Species list.

Future Activities
Progress toward elimination of sources and inputs to the lakes of persistent toxic substances would mitigate the first pressure. Management plans for nesting, roosting, and perching habitat for eagles along the lakeshores is important for mitigation of the other stressors. Education of the public on how to interact with eagles during the critical periods of their reproductive cycle, when solitude is necessary, is another, continuing means of mitigation. Use of risk assessment and environmental impact analysis is critical prior to loss of barrier dams along Great Lakes tributaries, to ensure that fish-dependent wildlife are not negatively impacted should fish passage be implemented.

Further Work Necessary
Under the Clean Michigan Initiative, Michigan DEQ has increased its surveillance and monitoring of bald eagles, to determine trends in concentrations of persistent toxic substances. Michigan, will therefore, maintain a statewide eagle survey which can also be used for a baseline for other regions of the Great Lakes. The state of Ohio and the Province of Ontario have stopped banding nestling eagles along Lake Erie in recent years,

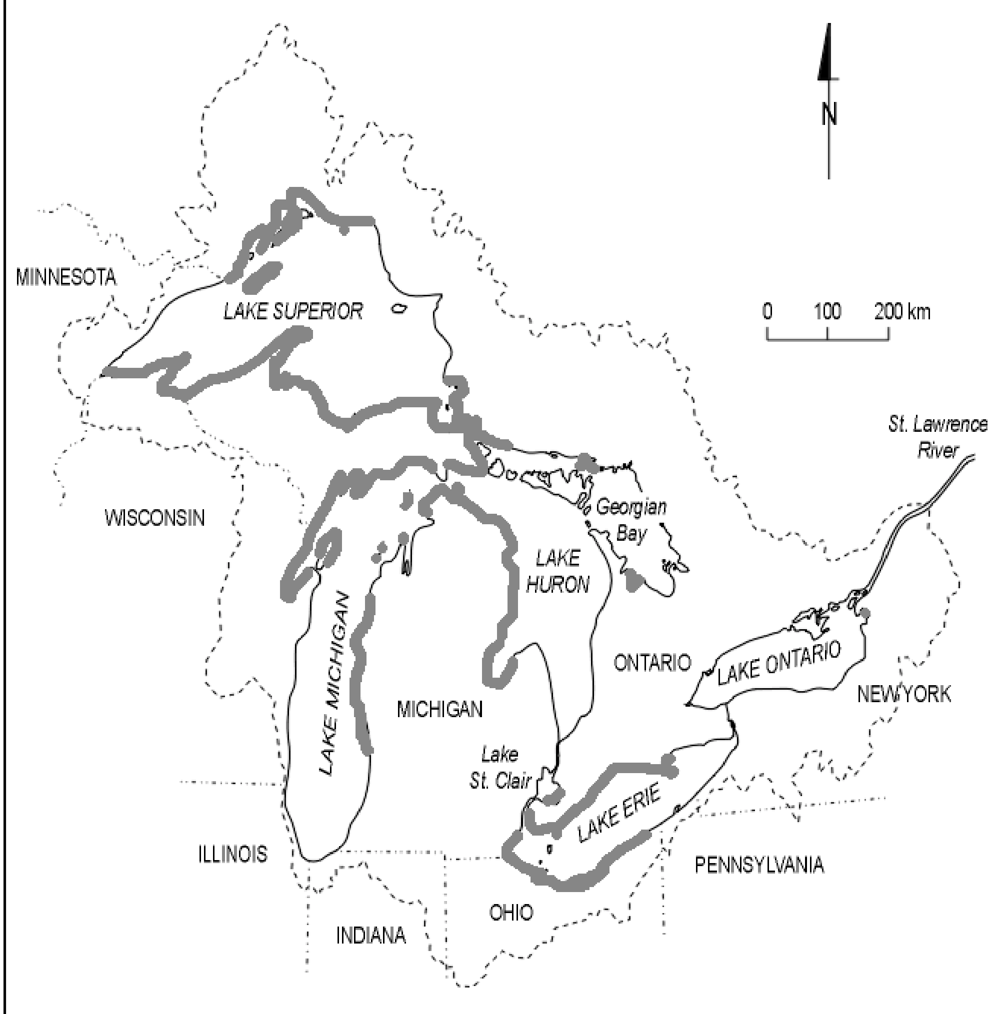


Figure 3. Approximate nesting locations of bald eagles along the Great Lakes shorelines, 2000.

but they have both maintained their eagle nesting surveys. A periodic sampling for contaminant trends should be undertaken specifically for reporting under this Indicator. To improve monitoring under this indicator we need to cover the Canadian regions of Lakes Huron and Superior better and include them in monitoring activities. Wisconsin maintains its eagle surveys and banding activities, however, decreased funding may threaten their program. A comprehensive, Basin-wide database of bald eagle nesting, contaminant, and productivity data designed for this Indicator needs to be completed. This will both improve access to data and allow for better interpretation of these data. In addition, the early 1990s survey of the entire Great Lakes shoreline to determine the amount and locations of potential nesting habitat should be repeated to document the state of this habitat and potential threats. The appropriate reporting frequency for SOLEC should be biannually.

Sources

Data for Figures 1 and 2 from Bowerman, W.W., D.A. Best, T.G. Grubb, G.M. Zimmerman, and J.P. Giesy. 1998. Trends of contaminants and effects for bald eagles of the Great Lakes Basin. Environmental Monitoring and Assessment 53(1):197-212.
Data regarding bald eagle locations (Figure 3) from Bowerman 1993, Lake Erie and Lake Superior LaMPs, and for Lake Ontario, Peter Nye, NYDEC.

Acknowledgments

Authors: William Bowerman, Clemson University, David Best, U.S. Fish & Wildlife Service, and Michael Gilbertson, International Joint Commission.

Population Monitoring and Contaminants affecting the American Otter

SOLEC Indicator #8147

Purpose

To directly measure the contaminant concentrations found in American otter populations within the Great Lakes basin and to indirectly measure the health of Great Lakes habitat, progress in Great Lakes ecosystem management, and/or concentrations of contaminants present in the Great Lakes. Importantly, as a society we have a moral responsibility to sustain healthy populations of American otter in the Great Lakes/St. Lawrence basin.

Ecosystem Objective

The importance of the American otter as a bio-sentinel is related to IJC Desired Outcomes 6: Biological Community Integrity and Diversity, and 7: Virtual Elimination of Inputs of Persistent Toxic Chemicals. Secondly, American otter populations in the upper Great Lakes should be maintained, and restored as sustainable populations in all Great Lakes coastal zones, lower Lake Michigan, western Lake Ontario, and Lake Erie watersheds and shorelines. Lastly, Great Lakes shoreline and watershed populations of American otter should have an annual mean production of > 2 young/adult female; and concentrations of heavy metal and organic contaminants should be less than the NOAEL found in tissue sample from mink as compared to otter tissue samples.

State of Great Lakes Otter

In a review of general population indices of State and Provincial otter population data indicates primary areas of population suppression still exist in western Lake Ontario watersheds, southern Lake Huron watersheds, lower Lake Michigan and most Lake Erie watersheds. Most coastal shoreline areas have more suppressed populations than interior zones and Great Lakes drainage populations.

Data provided from New York DEC and Ontario MNR suggests that otter are almost absent in western Lake Ontario. Areas of otter population suppression are directly related with human population centers and subsequent habitat loss, except for some coastal areas. Little statistically viable population data exists for the Great Lakes populations, and all suggested population levels were determined from coarse population assessment methods (see table below).

State/Province	Spatial data that includes Great Lakes drainages (method)	Visible Coastal Data	Minimum Spatial Scale	Reproductive Data	Minimum Spatial Scale Data Linked to Reproductive Data	Restoration
Minnesota	yes (registration, aerial surveys)	limited	30 mi2	yes, limited	no	no
Wisconsin	yes (registration, research)	limited	variable, Deer Management Unit	yes, mandatory, every three years	no	no
Michigan	yes (registration, research)	yes	1 mi2	yes, voluntary about 100 carcasses annually	no	no
Illinois	yes, minimal (presence/absence, surveys, model)	no	variable, watershed	yes, limited	no	recent
Indiana	yes (presence/absence, surveys, model)	no	variable, watershed	yes, limited	no	recent
Ohio	yes (presence/absence, surveys, model)	no	variable, watershed	yes, limited	no	recent
Pennsylvania	yes (minimal)	no	variable	yes, limited	no	recent
New York	yes (registration, research)	no	variable, town, county, wildlife management unit, watershed	yes (historic), limited, voluntary	no	occurring
Ontario	yes, trapper surveys	no	variable	yes, limited	no	no

Future Pressures

American otters are a direct link to organic and heavy metal concentrations in the food chain. It is a more sedentary species and subsequently synthesizes contaminants from smaller areas. Contaminants are a potential and existing problem for many otter populations on the Great Lakes. Globally indications of contaminant problems have been noted by decreased population levels, morphological abnormalities (i.e decreased baculum length) and decline in fecundity. Changes in the species population and range are also representative of anthropogenic riverine and lacustrine habitat alterations.

Future Actions

Michigan and Wisconsin have indicated a need for an independent survey using aerial survey methods to index otter populations in their respective jurisdictions. Minnesota has already started aerial population surveys for otter. Subsequently, some presence absence data may be available for Great Lakes watersheds and coastal populations. In addition, if the surveys are conducted annually the trend data may become useful.

There was agreement among resource managers on the merits of aerial surveys methods to index otter populations. The method is appropriate in areas with adequate snow cover. However, the need for habitat suitability studies in advance of such surveys is necessary prior to conducting useful aerial surveys.
New York DEC, Ohio DNR, Federal jurisdictions and Tribes on Great Lakes coasts indicated strong needs for future contaminant work on American otter.

Funding is needed by all jurisdictions to do habitat, contaminant and aerial survey work.

Further Work Necessary

All state and provincial jurisdictions use different population assessment methods making comparisons difficult. Most jurisdictions use survey methods to determine populations on a large regional scale. Most coarse methods were developed to assure that trapping is not limiting populations and that otter are adequately surviving and reproducing in their jurisdiction. There is little work done on finer spatial scales for using otter a barometer of ecosystem heath.

All State and Provincial jurisdictions only marginally index Great Lakes watershed populations by presence absence surveys, track surveys, observations, trapper surveys, population models, aerial surveys, and trapper registration data.

Michigan has the most useful spatial data that can index their Great Lakes coastal populations due to registration of trapped animals to a point of kill accuracy of 1 mi^2. However, other population measures of health such as reproductive rates, age and morphological measures are not tied to spatial data in any jurisdiction, but are pooled together for the entire areas. If carcasses are collected for necropsy the samples are usually too small to accurately define health of Great Lakes otter. Subsequently, there is a large need to encourage resource management agencies to stream line data for targeted population and contaminant research on Great Lakes otter populations, especially in coastal zones.

Acknowledgments

Author: Thomas C.J. Doolittle, Bad River Tribe of Lake Superior Chippewa Indians, Odanah, WI.

Urban Density

SOLEC Indicator #7000

Purpose

This indicator measures human population density and indirectly measures the degree of inefficient land use and urban sprawl for communities in the Great Lakes Basin. The number of people that inhabit a community relative to its size is an indicator of the economic efficiency of that community based on the existence of 'economies of scale' associated with high density development.

Ecosystem Objective

Increasing urban density promotes economic viability and the pursuit of sustainable development, which are generally accepted goals for society. These objectives are threatened when population growth is concentrated such that urban development does not occur at the expense of wetland and other natural resources, through expansions of urban sprawl. High density growth is an alternative to urban sprawl.

State of the Ecosystem

There are marked differences around the Great Lakes Basin is communities' urban densities. Initial research results indicates that there appears to be differences between Canadian and US communities, although other factors, such as ongoing 'rust belt' US population declines, may be partly responsible for the statistical differences in urban densities.

Figure 1 below illustrates the urban densities among the larger more established urban cities of Toronto, Ontario and Cuyahoga County, Ohio (which includes Cleveland) and the two smaller communities of the Regional Municipality of Niagara, Ontario and Niagara County, New York.

In addition, there are significant differences in the sizes of these municipalities. The two Toronto and the Regional Municipality of Niagara in Ontario are, respectively, twice the size in population than Cuyahoga County, Ohio and Niagara County, New York. Further, Toronto is part of a larger urban developed area, known as the Greater Toronto Area which in total has an urban density that is closer to Cuyahoga County.

The Canadian Province of Ontario, unlike most Great Lakes US states, has influenced urban growth with a highly centralized planning system, which employs clear provincial planning policies, guidelines and performance indicators. However, those policies have shifted over the last decade towards encouraging greater suburban expansion through urban sprawl, including provisions for expansion into 'prime' agricultural lands.

Trends over the last ten years indicate that population densities are increasing in both of the Canadian communities sampled and stable to declining in the US communities. Increased new suburban low-density development in the US communities, simultaneous with declining populations is exacerbating the fall in densities. While the Canadian communities are experiencing increasing densities, there is on-going low-density suburban pressure, particularly for the Greater Toronto Area.

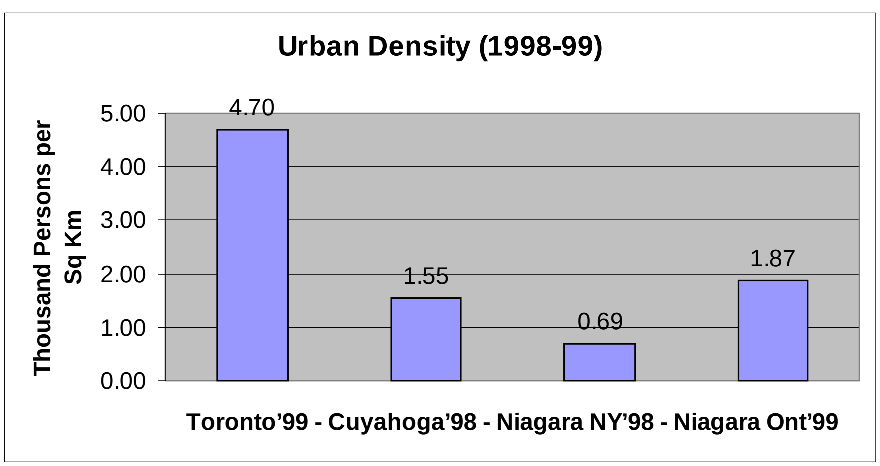


Figure 1. Urban densities in four Great Lakes urban communities.

There are corresponding significant relationships between urban density and other indicators of land use, such as urban transit. This indicates that urban efficiency and the development of sustainable communities may be causally linked to the degree of urban population concentration.

Future Pressures on the Ecosystem

Apparent trends toward increasing urban densities in Ontario, notwithstanding, urban sprawl continues to place pressure on economic as well as environmental resources in Great Lakes basin communities. Continued low density development throughout the basin may have significant irreversible negative implications for the Great Lakes ecosystem.

Future Action

There exists, in most Great Lakes communities, the potential for increased use of brownfields and other underutilized areas within the existing developed sections of urban communities. Road, water and sewer and other infrastructure, typically is already in place to make this (re-) development economically viable and to conserve resources from being expended to clear land and install new infrastructure. Urban concentration policies at all levels of government that promote increased urban density are essential for this to happen.

Further Work Necessary

Additional research is required to survey other communities around the Great Lakes basin to determine the extent of current knowledge on community urban densities. Also, there is a need to further understand the broader economic and environmental significance of different urban densities around the basin and the fuller implications of declining and increasing densities. There is also a need to set standards for collecting and reporting on land use data, including urban density. Finally, governments at all levels should join public interest groups and academic institutions in this research to broaden its appeal and understanding.

Sources

Rivers Consulting and J. Barr Consulting. "State of the Lakes Ecosystem Conference – Land Use Indicators Project". Unpublished report Environment Canada. July 30, 2000.

Acknowledgments

Authors: Ray River, Rivers Consulting, Campbellville, ON, and John Barr, Burlington, ON.

Brownfields Redevelopment

SOLEC Indicator #7006

Purpose
To assess the acreage of redeveloped brownfields, and to evaluate over time the rate at which society rehabilitates and reuses former developed sites that have been degraded or abandoned.

Ecosystem Objective
The goal of brownfields redevelopment is to remove threats of contamination associated with these properties and bring them back into productive use. Remediation and redevelopment of brownfields results in two types of ecosystem improvements: 1) reduction or elimination of environmental risks from contamination associated with these properties; and 2) reduction in pressure for open space conversion as previously developed properties are reused.

State of the Ecosystem
All eight Great Lakes states, Ontario and Quebec have programs to promote remediation or "cleanup" and redevelopment of brownfields sites. 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.

Efforts to track brownfields redevelopment are uneven among Great Lakes jurisdictions. Not all jurisdictions track brownfields activities and methods vary where tracking does take place. More fundamentally, there is no single definition for brownfields. Most states track the number sites remediated through the state brownfields or cleanup program and some also track the number sites that have been redeveloped. However, the size of brownfields varies greatly so the number of sites is not an effective indicator for assessing land renewal efforts. The overall number of sites being addressed does say something about the level of cleanup activity, but this becomes problematic when there are several different programs that address brownfields, but not brownfields alone. Where cleanups do not have formal reporting requirements, so there is no information base for tracking brownfield cleanups or redevelopment. No Great Lakes state or province tracks acres of brownfields *redeveloped*, though several are beginning to track acres of brownfields *remediated*.

Remediation is a necessary precursor to redevelopment. Remediation is often used interchangeably with "clean-up," though brownfields remediation does not always involve removing all contaminants from the sites. Remediation includes, *removal*, *treatment* and *exposure controls*. In many cases, the cost of truly cleaning up (i.e., treating) or removing the contaminants would prohibit redevelopment or reuse. To address this obstacle to brownfields reuse, all Great Lakes states and provinces allow some contaminants to remain on site as long as the risks of being exposed to those contaminants are eliminated or reduced to acceptable levels. Capping a site with clean soil, or restricting the use of groundwater are examples of these "exposure controls" and their use has been a major factor in advancing brownfields redevelopment.

Information on acres of brownfields remediated from Illinois, Minnesota, New York, and Pennsylvania indicates that a total of 28,789 acres of brownfields have been remediated in these jurisdictions alone. Available data from six Great Lakes states indicates that more than 8,662 brownfield sites have participated in brownfields cleanup programs. Redevelopment is a criteria for eligibility under many state brownfields cleanup programs. Where local brownfields cleaned 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 1990's 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.

Future Pressures

Some debate has occurred regarding the long-term effectiveness of exposure controls. One could conclude that as long as the controls are monitored and enforced, there will be no unacceptable risks to human health or the environment from their use. However, there are no Great Lakes state or federal programs in place to ensure long-term monitoring and enforcement of exposure controls. Also, cleanup standards based on risks to human health may not be appropriate for brownfields cleanup that results in habitat creation/ enhancement.

Several Great Lakes states allow brownfields redevelopment to proceed without cleaning up contaminated groundwater as long as no one is going to use or come into contact with that water. However, where migrating groundwater plumes ultimately interface with surface waters, some surface water quality may continue to be at risk from brownfields contamination even where brownfields have been pronounced "clean."

Land use and economic policies that encourage new development to occur outside already developed areas over urban brownfields is an ongoing pressure that can be expected to continue.

Future Activities

Exposure controls need to be monitored and enforced over the medium and long-term. Federal and state agencies need to agree as to which level of government is best-suited for this task. More research may be needed to determine the relationship between groundwater supplies and Great Lakes surface waters and their tributaries. Because brownfields redevelopment results in both elimination of environmental risks from past contamination and reduction in pressure for open space conversion, data should be collected that will enable an evaluation of each of these activities.

Future Work Necessary

Great Lakes states and provinces have begun to track brownfields remediation and/or redevelopment, but the data is generally not available or searchable in ways that are helpful to assess progress toward meeting the terms of the Great Lakes Water Quality Agreement.

Consistency in data gathering also presents challenges for assessing progress in the basin overall. States and provinces should share ideas and work with local jurisdictions to develop consistent tracking mechanisms and build shared online data bases on brownfields redevelopment that can be searched by: 1) environmental remediation (acres remediated or mass (i.e., pounds) of contamination remediated); 2) mass of contamination removed or treated (i.e., not requiring an exposure control); 3) geographic location; 4) level of urbanization; and 5) type of reuse (i.e., commercial, residential, open space, none, etc).

Sources

Personal communication: Great Lakes State Brownfield/Voluntary Cleanup Program Managers; Publications: *Evaluation of Effectiveness: Pennsylvania Land Recycling and Environmental Remediation Standards Act*, January, 2000; Indiana Voluntary Remediation Program Statistics Web Page; *Illinois, Site Remediation Program 1999 Annual Report*; *Wisconsin Remediation and Redevelopment Biennial Reports, 1997 and 1999*; Wisconsin Bureau of Remediation and Redevelopment Tracking System (online).

Acknowledgments

Author: Victoria Pebbles, Great Lakes Commission, Ann Arbour, MI

Mass Transportation

SOLEC Indicator #7012

Purpose

This indicator directly measures the percentage of daily commuters that use public transportation or other alternatives to the private car and indirectly measures the stress to the Great Lakes ecosystem caused by the use of the private motor vehicle and its resulting high resource utilization and creation of pollution.

Ecosystem Objective

Current use of the private automobile for commuting in the largely low density urban sprawl communities of the Great Lakes basin is very inefficient. Reliance on the private automobile has encouraged the development of expansive roadways and parking areas to accommodate the automobile. Extensive use of the automobile has led to significant ecosystem problems including air pollution, high personal and public costs associated with the automobile, and loss of leisure, work or other time due to traffic congestion. The ecosystem objective involves responding to Annex 1, 3 and 15 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

There are marked differences among the Great Lakes Basin communities' in automobile usage for commuting. Initial research results indicates that there also appear to be differences between Canadian and US communities. Figure 1 below illustrates the percentage of daily commuters (for all purposes over 24 hours a day) that use alternatives to the private automobile to commute to work, play, etc. in four communities surveyed in the basin. Among the larger more established urban cities of Toronto, Ontario and Cuyahoga County, Ohio (which includes Cleveland) alternatives are higher than in the more lightly populated and smaller communities of the Regional Municipality of Niagara, Ontario and Niagara County, New York.

There is a direct relationship between public transportation and the degree of urban density. The community with the highest concentration of population also had the highest rate of non-auto commuting and public transit usage. This relationship was pronounced in Toronto where higher density also facilitated greater use of bicycling and walking among urban commuters.

However, the biggest differences are with public transportation. Figure 2 illustrates how the densely populated community of Toronto has by far the greatest urban commuting rates In addition, there are significant differences in the sizes of these municipalities.

Trends for non-automobile urban commuting in Toronto have been relatively static over the last decade.

Future Pressures on the Ecosystem

Population has been increasing on the Canadian portion of the Great Lakes basin, although urban transportation has been relatively constant over the last decade. The result has been increasing traffic gridlock and increasing air pollution. Recent development pressure has been towards low density urban sprawl making public transportation use more difficult, since low density development in not conducive to mass transportation.

Future Action

There exists, in most Great Lakes communities, the potential for increased use of public transportation and other means of non-auto commuting. Development of the urban form, urban density and an effective and cost-effective public transportation infrastructure are the keys to improving transit rates throughout the basin.

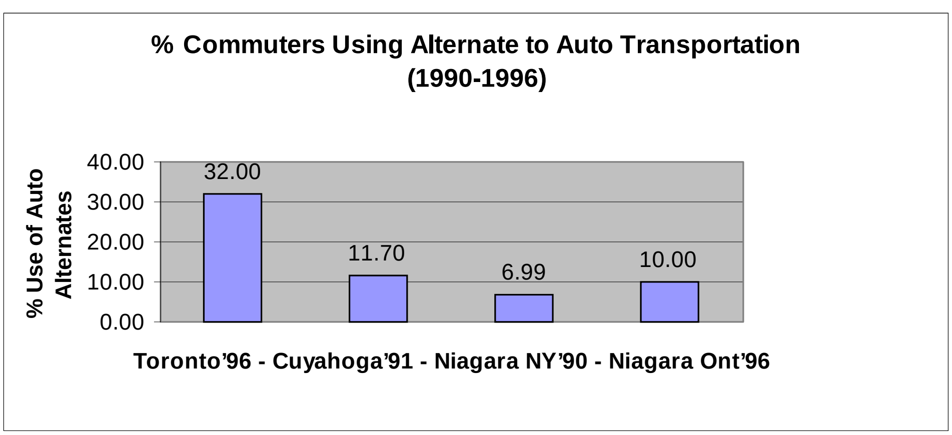


Figure 1. Percentage of Commuters using Alternatives to Automobiles in Selected Communities

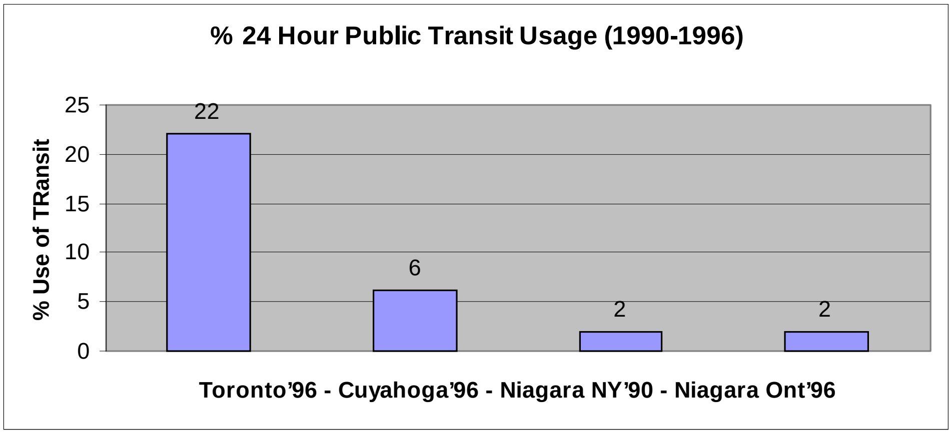


Figure 2. Percentage of Commuters Using Public Transit

Further Work Necessary

Additional research is required to survey other communities around the Great Lakes basin to better understand the relationship between rates of non-auto commuting and urban density, the effectiveness and cost effectiveness of public transportation, and the impact of alternate types of urban form. There is also a need to set standards for collecting and reporting on land use data, including urban density. Finally, governments at all levels should join public interest groups and academic institutions in this research to broaden its appeal and understanding.

Sources

Rivers Consulting and J. Barr Consulting. "State of the Lakes Ecosystem Conference – Land Use Indicators Project". Unpublished report Environment Canada. July 30, 2000.

Acknowledgments

Authors: Ray Rivers, Rivers Consulting, Campbellville, ON, and John Barr, Burlington, ON.

Sustainable Agricultural Practices

SOLEC Indicator #7028

Purpose

To assess 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.

Ecosystem Objective

This indicator supports Annex 2, 3, 12 and 13 of the GLWQA. The objective is the sound use and management of soil, water, air, plant, and animal resources to prevent degradation. The process integrates natural resource, economic, and social considerations to meet private and public needs. The goals are to create a healthy and productive land base that sustains food and fiber, functioning watersheds and natural systems, enhances the environment and improves the rural landscape.

State of the Ecosystem

Agriculture accounts for 35 present of the land area of the Great Lakes basin and dominates the southern portion of the basin. In the past excessive tillage and intensive crop rotations led to soil erosion and resulting sedimentation of major tributaries. Inadequate land management practices contributed to 63 million tons of soil eroded annually by the 1980's. Ontario estimated it's costs of soil erosion and nutrient/ pesticide losses at $68 million annually. Agriculture is a major user of pesticides with an annual use of 26,000 tons. These practices led to a decline of soil organic matter. Recently there has been increasing cooperation with the farm community on Great Lakes water quality management programs. Today's conservation systems have reduced the rates of U.S. soil erosion by 38 percent in the last few decades. 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, Food and Rural Affairs (OMAFRA) 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 OMAFRA. Recently, with the technical assistance of OMAFRA, OFEC released a Nutrient Management Planning Strategy and accompanying software to enable farmers to develop individualized nutrient management plans.

USDA's voluntary Environmental Quality Incentives Program provides technical, educational, and financial assistance to landowners that install conservation systems. The Conservation Reserve Program allows landowners to converts environmentally sensitive acreage to vegetative cover. States may add funds to target critical areas under the Conservation Reserve Enhancement Program and the Wetlands Reserve Program is a voluntary program to restore wetlands.

Future Pressures

The trend towards increasing farm size and concentration of livestock will change the face of agriculture in the basin. Development pressure from the urban areas may increase the conflict between rural and urban landowners. This can include higher taxes, traffic congestion, flooding and pollution. By urbanizing farmland we may limit future options to deal with social, economic, food security and environmental problems.

Future Actions

Ontario is developing a Best Management Practices (BMP) book on Riparian Buffers, and a Livestock Operations Standards Act. Food Systems 2000, started in 1987, set a target of reducing agricultural pesticides by 50 percent while maintaining effective pest control, and competitive, sustainable farms. Partnerships between agriculture and municipalities include incentives for BMP's to reduce phosphorus loading and protect rural water quality.

The US Clean Water Action Plan of 1998 calls for USDA and the Environmental Protection Agency to cooperate further on soil erosion control, wetland restoration, and reduction of pollution from farm animal operations. National goals are to install 2 million miles of buffers along riparian corridors by 2002 and increase wetlands by 100,000 acres annually by 2005. Under the 1999 EPA/USDA Unified National Strategy for Animal Feeding Operation (AFO) all AFO's will have nutrient management plans implemented by 2009.

Sources

This indicator was prepared using information from:

Great Lakes Commission. 1996. An Agricultural Profile of the Great Lakes Basin.

International Joint Commission. 1998. Ninth Biennial Report on the Great Lakes.

Natural Resources Conservation Service. 1999. NRCS Performance and Results Measurement System.

Acknowledgments

Authors: Roger Nanney, US Natural Resources Conservation Service, Chicago, IL, and Peter Roberts, Ontario Ministry of Agriculture, Food and Rural Affairs, Guelph, ON.

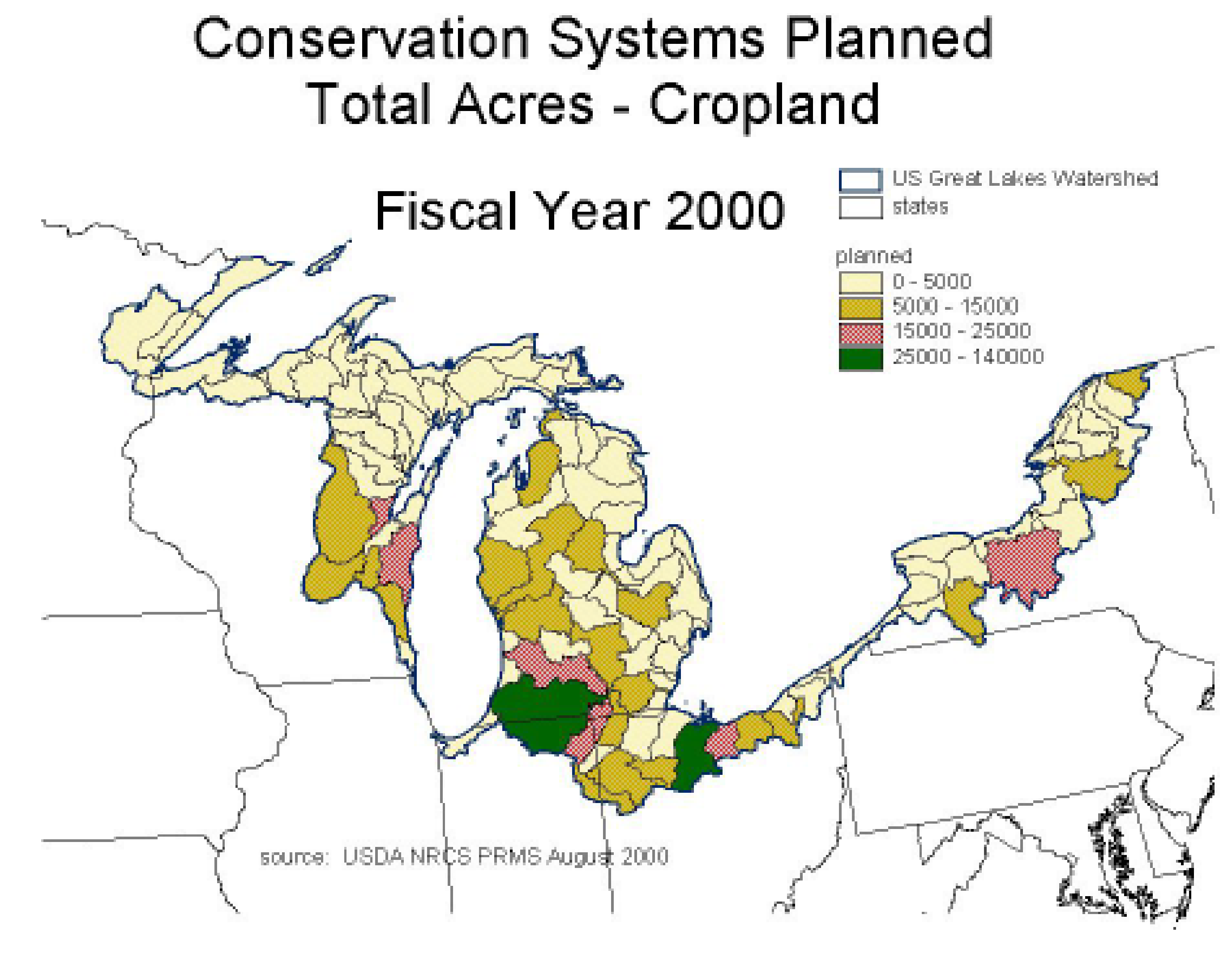
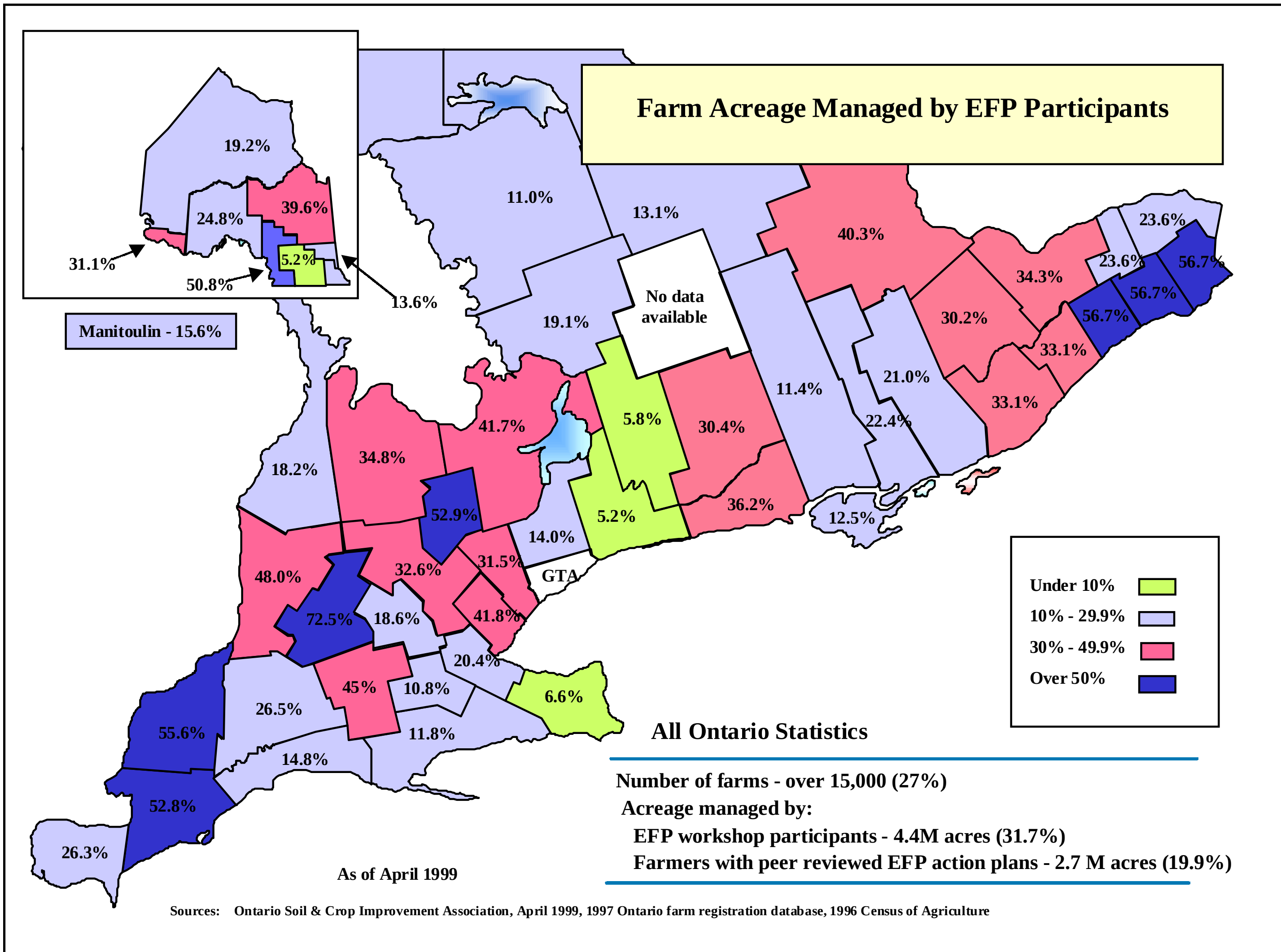


Figure 1. Annual U.S. Conservation Systems Planned for FY 2000.
(Source: USDA, NRCS, Performance and Results Measurement System)



Farm Acreage Managed by EFP Participants
19.2%
39.6%
24.8%
31.1%
5.2%
50.8%
13.6%
Manitoulin - 15.6%
11.0%
13.1%
40.3%
23.6%
34.3%
23.6%
56.7%
56.7%
56.7%
No data available
19.1%
30.2%
33.1%
21.0%
33.1%
11.4%
22.4%
5.8%
30.4%
41.7%
34.8%
18.2%
52.9%
36.2%
5.2%
12.5%
14.0%
31.5%
GTA
48.0%
32.6%
72.5%
18.6%
41.8%
20.4%
45%
10.8%
6.6%
26.5%
55.6%
11.8%
14.8%
52.8%
26.3%
Under 10%
10% - 29.9%
30% - 49.9%
Over 50%
All Ontario Statistics
Number of farms - over 15,000 (27%)
Acreage managed by:
EFP workshop participants - 4.4M acres (31.7%)
Farmers with peer reviewed EFP action plans - 2.7 M acres (19.9%)
As of April 1999
Sources: Ontario Soil & Crop Improvement Association, April 1999, 1997 Ontario farm registration database, 1996 Census of Agriculture

Figure 2.

E. *coli* and Fecal Coliform in Recreational Waters

SOLEC Indicator #4081

Purpose

To assess E. *coli* and fecal coliform contamination levels in nearshore recreational waters, acting as a surrogate indicator for other pathogen types and to infer potential harm to human health through body contact with nearshore recreational waters.

Ecosystem Objective

Waters should be safe for recreational use. Waters used for recreational activities involving body contact should be substantially free from pathogens, including bacteria, parasites, and viruses, that may harm human health. This indicator supports Annexes 1, 2 and 13 of the GLWQA.

State of the Ecosystem

Beach water quality is monitored using two methods: counts of either E. *coli* and/or fecal coliforms (FC) in recreational waters measured as number of organisms per volume of water (e.g., FC/ml). When the bacteria standards are exceeded, local authorities may restrict swimming or issue advisories of unsafe water.

Frequency of beach postings at specific locations are reported annually and become the basis for determining the risk for safe recreational use, i.e., the percent of swim season individual beach waters have not been closed or restricted due to bacterial contamination and/or other environmental condition, including pre-emptive swimming closings based on past experience. Not all advisories, however, are due to bacterial contamination.

Survey reports of U.S. beach advisories during the 1998 swimming season (June, July, August) show that 81.2% of the respondents has some form of monitoring in use, and 78.4% were open for the entire 1998 season. Results were similar for Canadian beaches where 78% of the reported beaches were open the entire season (Figure 1). The distribution of the number of beaches for which advisories were issued for one, two, three, etc., days during the 1998 season shows that most beaches were open most of the season, and only a relatively few were closed 10 days or more (Figure 2).

Survey reports of U.S. breach closings or advisories during the 1999 season show that 76.7% of the respondents had some form of monitoring in use and that 65.2% were open for the entire 1999 season (Figure 3). Several factors may have influenced the apparent increase in percentage of beach closings in 1998 compared with 1998. 1) Fewer beach managers responded to survey questionnaires in 1999, and of those beaches that were reported, not all had been included in the 1998 data. Therefore, the underlying population of beaches were not exactly the same between years. 2) More beach managers were using E. *coli* testing in 1999 than in 1998. E *coli* is a more sensitive indicator of public health risks for swimmers, and it gives more consistent results. Its increased use as an indicator of bacterial contamination of swimming water is expected to result in more frequent swimming advisories to protect public health. 3). A change in accounting the number of beach advisory days in 1999 resulted in reports of beaches closed for two or three days in circumstances that would have been tallied as one or two days in 1998.

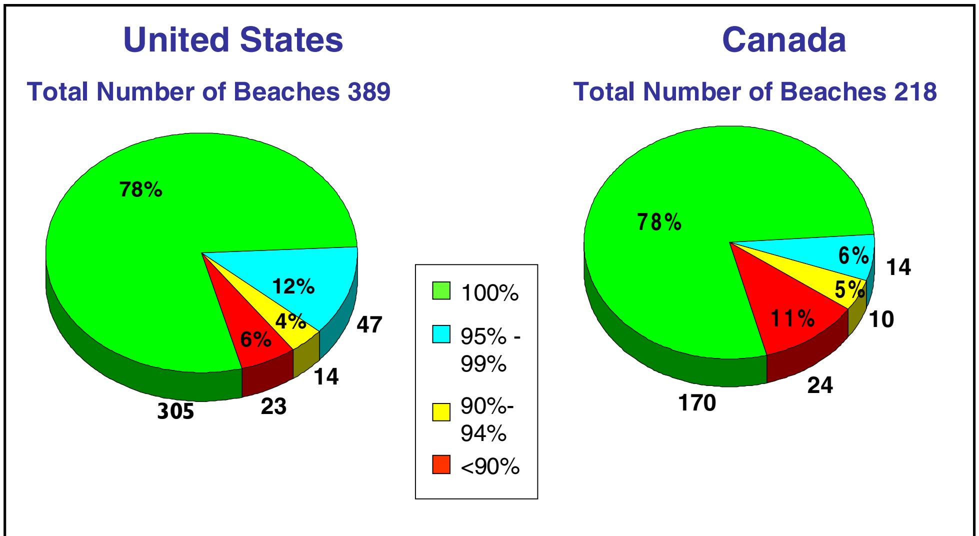


Figure 1. Percentage of Great Lakes beaches open for swimming (June-August 1998)

Future Pressures on the Ecosystem

Future growth of cities will increase the demands made on sewage treatment plant capacities, increasing the

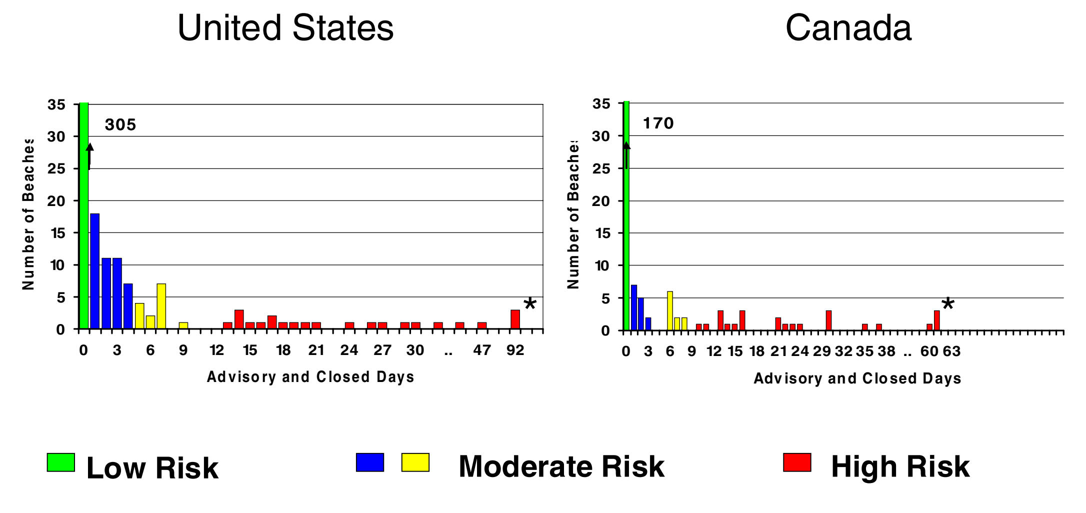


Figure 2. Great Lakes swimming advisories and closings 1998.

probability of release of untreated effluent. An increase in resort/vacation areas utilizing private systems, such as septic fields and cess pools, will likely increase undetected releases of inadequately treated waste. There is an uncertainty of available funding to carry-out beach monitoring and sanitary system capacity.

Future Activities

The experiences of the beach managers in the metropolitan areas of Chicago and Toronto have demonstrated two important elements to successful beach operations: active beach management, and communicating public health risks.

Beaches must be actively managed to provide benefits to the maximum number of users while minimizing potential risks to human health. Management may include infrastructure design such as groins, piers or revetments, and it may include daily (or more frequent) maintenance such as raking, trash pick-up, pet restrictions, and warnings to avoid the splash zone. Beaches may remain open for use even while under a swimming advisory.

Communicating public health risks may involve multiple forms of communication, including news media, telephone hot line, electronic web sites, posted notices at the beach, flags (such as used for storm warnings), and lifeguards. The message should be clear and consistent, i.e., "Swim" or "Don't Swim." Accurate information is needed, based on one objective standard, delivered by credible spokespersons.

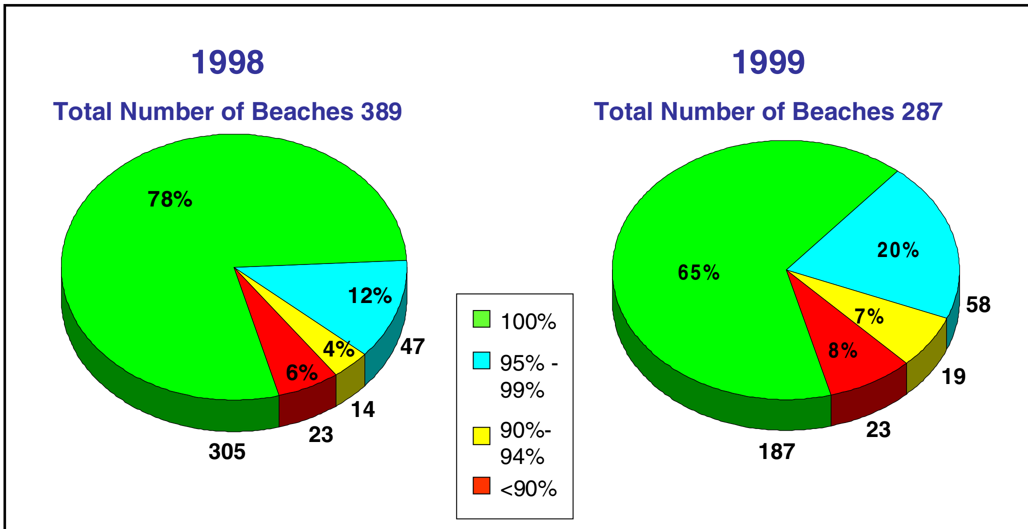


Figure 3. Percentage of U.S. Great Lakes beaches open for swimming (June-August).

Further Work Necessary

To fully implement this indicator, and to ensure the maximum enjoyment of Great Lakes beaches by the greatest number of people with the minimum risks to human health from exposure to bacterial contamination, the following elements are required:

- Universal adoption and application of E. *coli* testing and standards. All beaches should follow uniform protocols.

- C Development of rapid E. *coli* testing procedures that would allow beach managers to receive results within two hours of sampling water at beaches. Such data would facilitate real-time decisions concerning advisories to protect human health.
- C Frequent application of a rapid E. *coli* testing procedure. Because the procedure is quick, multiple testing can be performed during the swimming day, and swimming advisories adjusted as needed.
- C Universal reporting of beach advisories. All beaches on the Great Lakes shoreline should participate, and reporting should be timely and complete.

Acknowledgments
The following personnel contributed data, analysis, or reporting expertise to this indicator:
David Rockwell, Paul Bertram, and Wade Jacobson (SEE Program), U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Illinois.
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Duncan Boyd and Mary Wilson, Ontario Ministry of Environment, Environmental Monitoring and Reporting Branch, Toronto, Ontario.
Peter Gauthier, City of Toronto, Environmental Health Services, Toronto, Ontario.

Chemical Contaminants in Edible Fish Tissue

SOLEC Indicator #4083

Purpose

Assess the historical trends of the edibility of fish in the Great Lakes using fish contaminant data and a standardized fish advisory protocol. The approach is illustrated using the Great Lakes protocol for PCBs as the standardized fish advisory benchmark applied to historical data to track trends in fish consumption advice. US EPA GLNPO salmon fillet data and MOE data are used as a starting point to demonstrate the approach.

Ecosystem Objective

Overall Human Health Objective: The health of humans in the Great Lakes ecosystem should not be at risk from contaminants of human origin.
Fish and wildlife in the Great Lakes ecosystem should be safe to eat; consumption should not be limited by contaminants of human origin.

Annex 2 of the GLWQA requires LaMPs to define "…the threat to human health posed by critical pollutants…including beneficial use impairments."

State of the Ecosystem

Since the 1970's, there have been declines in many persistent bioaccumulative toxic (PBT) chemicals in the Great Lakes basin. However, PBT chemicals, because of their ability to bioaccumulate and persist in the environment, continue to be a significant concern.

Fish Consumption Programs are well established in the Great Lakes. States, tribes, and the province of Ontario have extensive fish contaminant monitoring programs and issue advice to their residents about how much fish and which fish are safe to eat. This advice ranges from recommendations to not eat any of a particular size of certain species from some water bodies, to recommending that people can eat unlimited quantities of other species and sizes. Advice from these agencies to limit consumption of fish is mainly due to levels of PCBs, mercury, chlordane, dioxin, and toxaphene in the fish. The contaminants are listed by lake, in the following table.

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

State, tribal and provincial governments provide information to consumers regarding consumption of sport-caught fish. This information is not regulatory - its guidance, or advice. Although some states use the Federal commercial-fish guidelines for the acceptable level of contaminants when giving advice for eating sport caught fish, consumption advice offered by most agencies is based on human health risk. This approach involves interpretation of studies on health effects from exposure to contaminants. Each state or province is responsible for developing fish advisories for protecting the public from pollutants in fish and tailoring this advice to meet the health needs of its citizens. As a result, the advice from state and provincial programs is sometimes different for the same lake and species within that lake.

Future Pressures

Organochlorine contaminants in fish in the Great Lakes are generally decreasing. As these contaminants decline mercury will become a more important contaminant of concern regarding the edibility of fish.

Screening studies on a larger suite of chemicals is needed. The health effects of multiple contaminants, including endocrine disruptors, need to be addressed.

Future Actions

To protect human health, actions must continue to be implemented on a number of levels. Reductions and monitoring of contaminant levels in environmental media and in human tissues is an activity in particular need of support. Health risk communication is also a crucial component to protecting and promoting human health in the Great Lakes.

There is a need for surveillance to evaluate how much fish people eat and carry out biomonitoring to determine actual tissue levels, particularly within sensitive populations.

Further Work Necessary

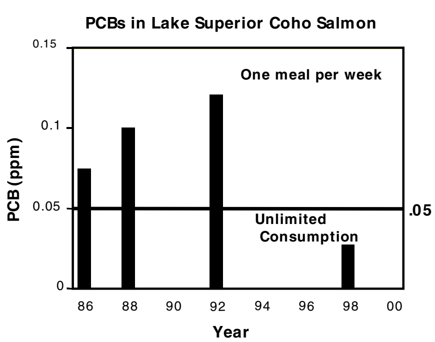
1) Evaluation of historical data: the long-term fish contaminant monitoring data sets that have been assembled by several jurisdictions for different purposes need to be more effectively utilized. Relationships need to be developed that allow for comparison and combined use of existing data from the various sampling programs. These data could be used in expanding this indicator to other contaminants and species and for supplementing the data used in this illustration.

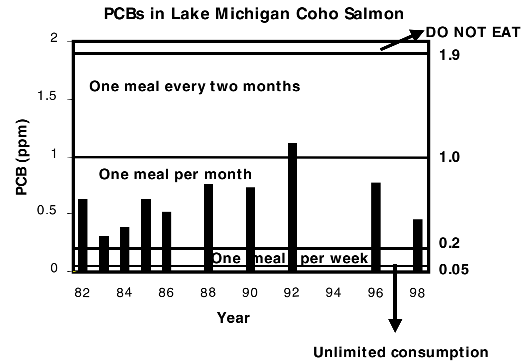
2) Coordination of future monitoring.

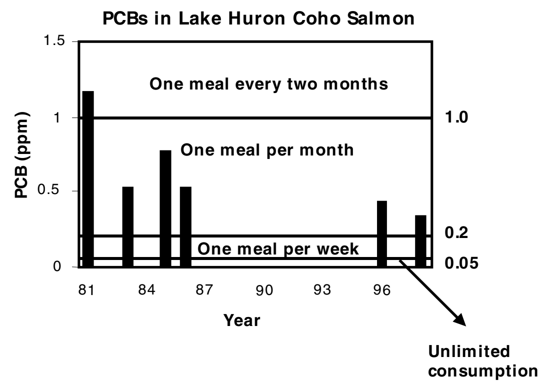
3) Agreement on fish advisory health benchmarks for the contaminants that cause fish advisories in the Great Lakes. Suggested starting points are: The Great Lakes Protocol for PCBs, US EPA IRIS RfD for mercury, and Health Canada's TDI for toxaphene.

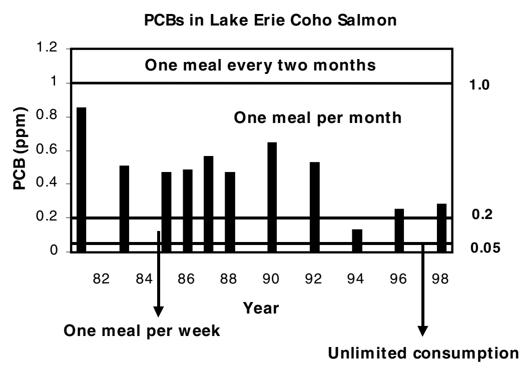
Acknowledgments

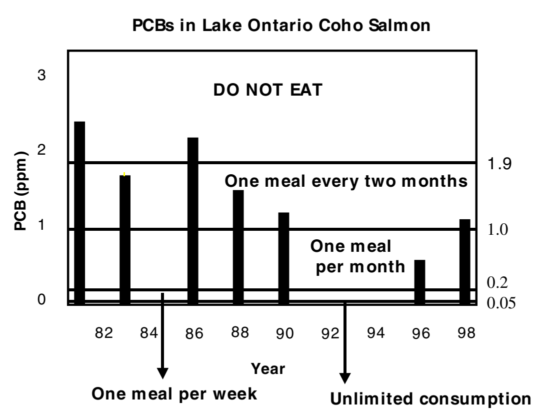
Authors: Patricia McCann, Minnesota Department of Health, and Sandy Hellman, U.S. EPA, Great Lakes National Program Office.











Drinking Water Quality

SOLEC Indicator #4175

Purpose

This indicator evaluates the chemical and microbiological contaminant levels in drinking water. It also assesses the potential for human exposure to drinking water contaminants and the efficacy of policies and technologies to ensure safe drinking water. Lastly, it evaluates the suitability of the Great Lakes as a source of drinking water. In order to effectively rate the health of the Lakes, this indicator focuses on the raw water as it flows into the water treatment plants, while also highlighting the concerns of the consumer by looking at such factors as exceeding the established drinking water standards of pathogens, taste and odor in treated water.

Ecosystem Objective

The desired objective for this indicator is that all treated drinking water should be safe to drink and free from chemical and microbiological contaminants (GLWQA Annexes 1,2,12 and 16). Water entering drinking water plants should be of high quality and have minimum levels of contaminants as is possible prior to treatment. Therefore, high quality source water is an integral part of this drinking water objective.

State of the Ecosystem

There are many facets of drinking water. This report will focus on six of those factors (Figure 1). The presence of pollutants in distributed water, as well as water from river and groundwater sources will not be examined in this report.

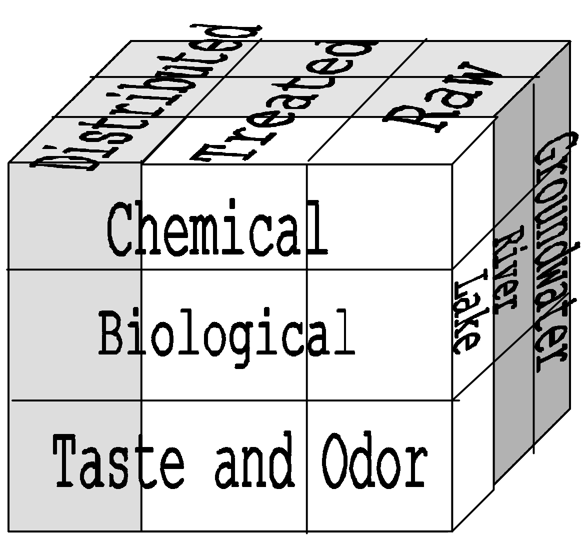


Figure 1. Drinking Water Cube, six factors are highlighted on the cube face

A focus on raw water will reflect the state of the lake waters at the treatment plant intakes, while an examination of exceeding the established drinking water standards of taste, odor and pathogens in treated water will address some concerns of the consumer. A market basket approach was used to select the water treatment plants that would represent the state of this indicator. At present there are 22 sites (Figure 2). While these sites are meant to be representative of the 5 Great Lakes, they cannot suggest a comprehensive state of the ecosystem. This year, the sites are focused on lake water intakes. In future years, the goal will be to incorporate tributaries and ground water sources of drinking water, as well as a greater number of water treatment plants for a more complete view of the status of treatable drinking water in the Great Lakes basin.

The parameters used to evaluate the state of drinking water in the Great Lakes encompass both microbiological and chemical contaminants. As was suggested at the 1999 Drinking Water Workshop sponsored jointly by SOLEC and the International Joint Commission, most of these parameters were examined in the raw water. Taste and odor, however, are most accurately measured in treated water. Additionally, there are no raw water regulations for these parameters. Therefore, methods of analysis vary.

The chemical parameters chosen were atrazine, nitrate and nitrite. These chemicals are seasonal and flow dependent. While minimal levels of atrazine, nitrate, and nitrite were detected in raw water, monthly averages and maximums fell below the federal regulations for treated water. Therefore, prior to treatment, contaminant levels in the Great Lakes water are less than maximum contaminant levels at these 22 sites as determined by plant monthly averages and maximums. However, it should be noted that although atrazine seasonally enters the lakes by way of tributaries, this pattern was not detected at the 22 intakes included here.

Figure 2. The 22 U.S. and Canadian water treatment plants.

The level of organic matter can be determined by examining Total Organic Carbon (TOC) or Total Dissolved Carbon (DOC). U.S. sites consistently test for TOC while Canadian sites test DOC. In the U.S., if TOC is less than 2.0 mg/L in both raw and treated water, water treatment plants can bypass certain additional treatments. The Canadian DOC for maximum level of DOC is 5.0 mg/L. The DOC concentrations in raw water at the Canadian sites were fairly low, as was TOC at the majority of U.S. sites. There were no treated water violations.

Turbidity was chosen as a parameter for its correlation with potential microbial problems. Turbidity itself is not an indication of possible health hazards. Incoming turbidity, however, can reveal trends about possible microbiological and other contaminants. High turbidity often coincides with a higher content of microbiological organisms. This trend, however, was not analyzed for this indicator report. Turbidity values vary depending on location and lake (Figure 3). There are no raw water maximum levels for turbidity because once in the filtration plant, it can be corrected. However, by being aware of seasonal fluctuations, the treatment plants can adjust treatment for optimal removal of microbial contaminants.

Taste and odor is a complex indicator. While it is an extremely important indicator to consumers, it is also difficult to quantitatively measure. There is no consistent test that is universally used among water treatment plants. Three possible ways to test taste and odor in treated water are the measurement of threshold odor, taste and odor panels, and the Geosmin and MIB methods that measure for the presence of odorous algae. Additionally, not all of the chosen water treatment sites had taste and odor data readily available. This indicator was evaluated for August 1999 at the six sites where data were available. Increased odor problems are usually associated with increased water temperatures. Therefore, August is usually the month of greatest odor problems. There were minimal problems with taste and odor at the six water treatment facilities that reported this parameter (Table 1).

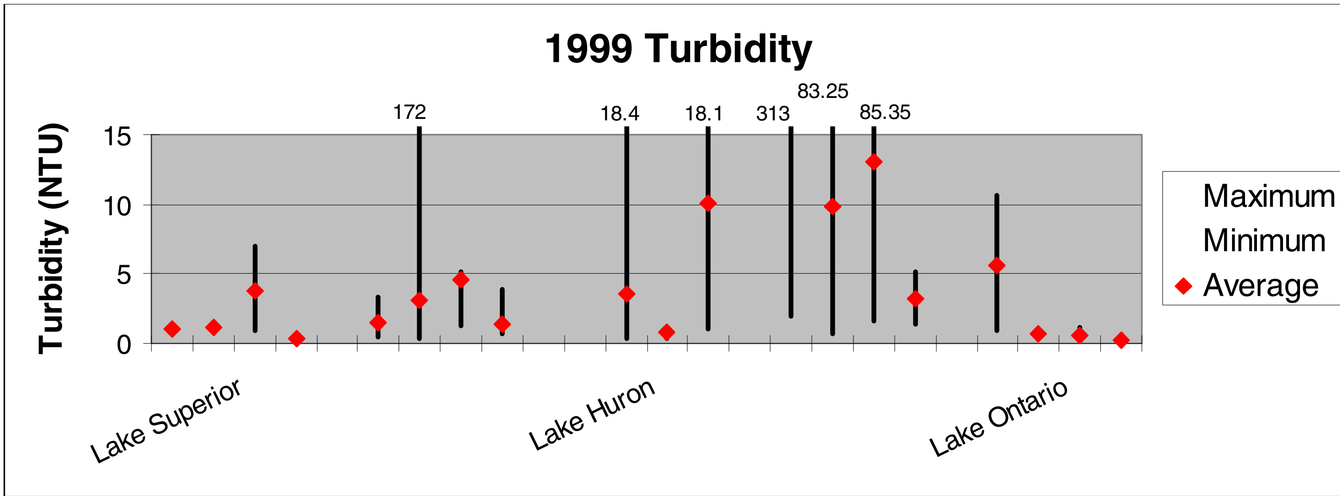


Figure 3. This graph represents the fluctuations that occur in raw water turbidity in the course of a single year. Values are based on monthly averages. Due to this, the graph is representative of possible fluctuation ranges but not conclusive of the exact turbidity for 1999.

Water Treatment Plant	August 1999 Taste and Odour
Belleville	Of the two August samples available, both had distinct odours, but not very strong
Chicago	100% taste/odour non-detected
Green Bay	100% taste/odour non-detected
London	90% taste/odour non-detected
Milwaukee	100% taste/odour non-detected
Thunder Bay	100% taste/odour non-detected

The microbiological indicators suggested are total coliform, *Escherischia coli, Giardia lambalia*, and *Cryptosporidium parvum*. The methods of analyzing water for *Giardia lambalia* and *Cryptosporidium parvum* are not the most reliable at this time but it is suggested that these remain indicators as better methods become available. *Escherischia coli* is only tested when distributed water tests positive for total coliform. Total coliform is probably the best choice for a microbial indicator at this time because it is the most uniformly tested of the pathogens. It is a required test in the U.S and Canada. An examination of the Safe Drinking Water Information System (SDWIS) of the U.S. Environmental Protection Agency and the consumer confidence reports for the U.S. sites indicate that there have been no total coliform exceedences for the last ten years. The maximum contaminant level exceedences reported by SDWIS were sampled after the treated water entered the distribution systems. If there are no exceedences in the distributed water, it can be inferred that there were no exceedences in the treated water. While the total coliform data were available for the Canadian sites, there presently is no user-friendly method for exceedence interpretation comparable to the U.S. consumer confidence reports. As of October 2000, however, Canadian treatment plants will also be required to produce this type of report. These reports are required for U.S. sites.

Use of the consumer confidence reports is extremely important. The data are presented in a more user-friendly method that is more appropriate for the needs of the SOLEC indicator. The reports are required to state if there have been any maximum contaminant levels or detections. They are not required to report on raw water data, with the exception of *Cryptosporidium parvum*.

The health of the Great Lakes, as determined by these drinking water parameters at these 22 sites, is fairly good. Chemical contaminants are consistently tested to be at minimal levels even prior to treatment. Additionally, violations of these chemical and microbial parameters are extremely rare. The risk of human exposure to contaminants is low. The quality of drinking water as it leaves the water treatment plants is good. The quality of water delivered, however, can vary due to the possibility of contaminants entering the distribution system.

Continuing Pressures

There are many pressures being placed on the sources of drinking water. Land use and agricultural runoff can negatively affect the raw water. Additionally, increases in both algal presence and water temperatures can produce "offensive" taste and odor. Byproducts of the drinking water disinfection process cause concern for some consumers. Lastly, aging distribution systems can affect the quality of already treated drinking water.

Future Activities

It is important to focus on protection of the source water. As an indicator of high quality drinking water, the state of raw water is pertinent. While the ability of the water treatment plants to treat drinking water is quite high, source water protection lowers the cost of treatment for the water plants. Analysis of raw water can reflect the actual health of the Great Lakes by using the methods already performed by the water systems.

Further Work Necessary

Unfortunately, analyzing drinking water trends basin-wide is a fairly daunting task. Due to unconformity in reporting and database management methods, it is difficult to create a cohesive report on this indicator. Additionally, the lack of electronic storage for historical data can hinder analysis of the basin-wider trends. As more treatment plants consistently report on similar tests and implement electronic data storage, these problems should be minimized.

The parameters chosen are actively used in some treatment plants while in others they currently are being worked into the system. The parameters for drinking water need to be based on water standards presently available so the data are possible to obtain and interpret as a SOLEC indicator. While consumer confidence reports can evaluate treated water detections and violations, a better method of data collection and interpretation for the extensive amount of raw water information should be established. Continual evaluation of these parameters and their relevance to both ecosystem and human health needs to be maintained. They should answer the concerns of both the water manager and the concerned consumer. The number of sites used to study the trends should be increased and these sites should be expanded to include both tributary sites and groundwater sites.

Acknowledgements

This report was assembled by Molly Madden (Environmental Careers Organization), with the assistance of Rod Holme (American Water Works Association), Pat Lachmaniuk (Ontario Ministry of Environment),Tom Murphy (U.S. EPA, Region 5), and Paul Bertram (U.S. EPA, GLNPO). Additional thanks is due to the water treatment plant operators and managers who submitted the requested data.

Air Quality

SOLEC Indicator #4176

Purpose

To monitor the air quality in the Great Lakes ecosystem, and to infer the potential impact of air quality on human health in the Great Lakes Basin.

Ecosystem Objective

Air should be safe to breathe. Air quality in the Great Lakes ecosystem should be protected in areas where it is relatively good, and improved in areas where it is degraded.

State of the Ecosystem

Overall, there has been significant progress in reducing air pollution in the Great Lakes Basin. For most substances of interest, both emissions and ambient concentrations have decreased over the last ten years or more. However, progress has not been uniform and differences in weather from one year to the next complicate analysis of ambient trends. Ozone can be particularly elevated during hot summers. Drought conditions result in more fugitive dust emissions from roads and fields, increasing the ambient levels of particulate matter.

In general, there has been significant progress with urban/local pollutants over the past decade or more, though somewhat less in recent years, with a few remaining problem districts. There are still short periods each year during which regional pollutants (primarily ozone and fine particulate and related pollutants - collectively termed smog) reach levels of concern, essentially in southern and eastern portions of the basin.

For the purposes of this discussion, the pollutants can be divided into urban (or local) and regional pollutants. For regional pollutants, transport is a significant issue, from hundreds of kilometres to the scale of the globe; formation from other pollutants, both natural and man-made, can also be important. Unless otherwise stated, references to the U.S. or Canada in this discussion refers to the respective portions of the Great Lakes Basin. Latest published air quality data is for 1997 (Canada - Ontario) and 1999 (U.S.).

Urban/Local Pollutants

Carbon Monoxide (CO): In the U.S., CO ambient levels have decreased approximately 46% over 1989-1998, and there are no CO non-attainment areas. Nationally, U.S. emissions decreased 36% 1990-1999, Over Canada, there has been a 30-40% reduction in composite site concentration over 1988-1997, and there has been no violation of ambient criteria from 1992-1997. Emissions have decreased 17% since 1988, but mostly over 1988-92 with newer vehicle emission standards.

Nitrogen Dioxide (NO2): Over Canada, average ambient NO2 levels remained relatively constant through the 1990's, but with no ambient criteria exceedances in 1997. Emissions (of NOx: the family of nitrogen oxides) decreased 25% from 1988-94 but have since been relatively constant. In the U.S., ambient concentrations have decreased 7% 1989-98, but remain unchanged in the Lake Michigan area. There are currently no NO2 non-attainment areas. For the U.S. as a whole, emissions (of NOx) have increased by 1% over twenty years (to 1999).

Sulphur Dioxide (SO2): over the U.S., ambient concentrations have decreased 43%, with 6 non-attainment regions in the U.S. National emission were reduced 21% (1990-99). Canadian ambient levels show only a slight decrease in the 1990's, with two violations of the one-hour criteria in 1997 (Windsor and Sudbury). Emissions decreased 78% from 1977-97), but have increased slightly from 1995-7 with increasing economic activity, though remain below the target emission limit.

Lead: U.S. concentrations decreased 48% 1989-98, and there are no nonattainment areas in the Great Lakes region. Similar improvements in Canada have followed with the usage of unleaded gasoline, with only isolated exceedances of ambient criteria near industrial sites.

Total Reduced Sulphur (TRS): this family of compounds is of concern in Canada due to odour problems, normally near industrial or pulpmill sources. Ambient concentrations are significantly lower than in 1988-90, paralleling emission reductions, though there is little trend in recent years. There are still periods above the ambient criteria near a few centres.

Particulate Matter: the U.S. Standard addresses PM10 (diameter 10 microns or less): ambient concentrations in the U.S. have decreased 20%, with six nonattainment areas in the Great Lakes region. National emissions decreased 16% (1990-99). Canadian objectives have focused on Total Suspended Particulate matter (TSP), though there is an interim Ontario PM10 objective (50ug/m3). There are still short periods with TSP levels above the objective. Emissions decreased from 1988-92, but have not decreased since. Six of the eleven ambient PM10 monitors (all in urban areas) showed exceedances of the interim objective in 1997, and, based on limited data little evident of a trend in ambient levels (1991-7). Both PM10 and TSP affect locations relatively close to pollutant sources.

Regional Pollutants

Ground-Level Ozone (O3): this is almost entirely a secondary pollutant, which forms from reactions of precursors (VOC - volatile organic compounds, and NOx, oxides of nitrogen) under sunshine; it is a problem pollutant over broad areas of the Great Lakes Basin, largely excluding Lake Superior. National assessments find some uneven improvement in peak levels, but with indications that average levels may be increasing on a global scale (NARSTO report). Local circulations around the Great Lakes can exacerbate the problem: high levels are found in provincial parks near Lakes Huron and Erie, and western Michigan is strongly impacted by transport across Lake Michigan from Chicago. In the U.S., high 1-hour concentrations have decreased 4% from 1989-98, and there are five non-attainment areas in the region. VOC emissions have decreased 20% and NOx emissions have increased 2% from 1989-98. In Canada, there has been little trend in the number of exceedances of the ozone objective in the 1990s, and mean annual levels increase. Man-made VOC emissions have decreased about 15% since 1988; NOx emissions have been constant since 1995.

PM2.5: this fraction of particulate matter (diameter 2.5u or less) is of health concern as it can penetrate deeply into the lung, in contrast to larger particles. It is a secondary pollutant, produced from both natural and man-made

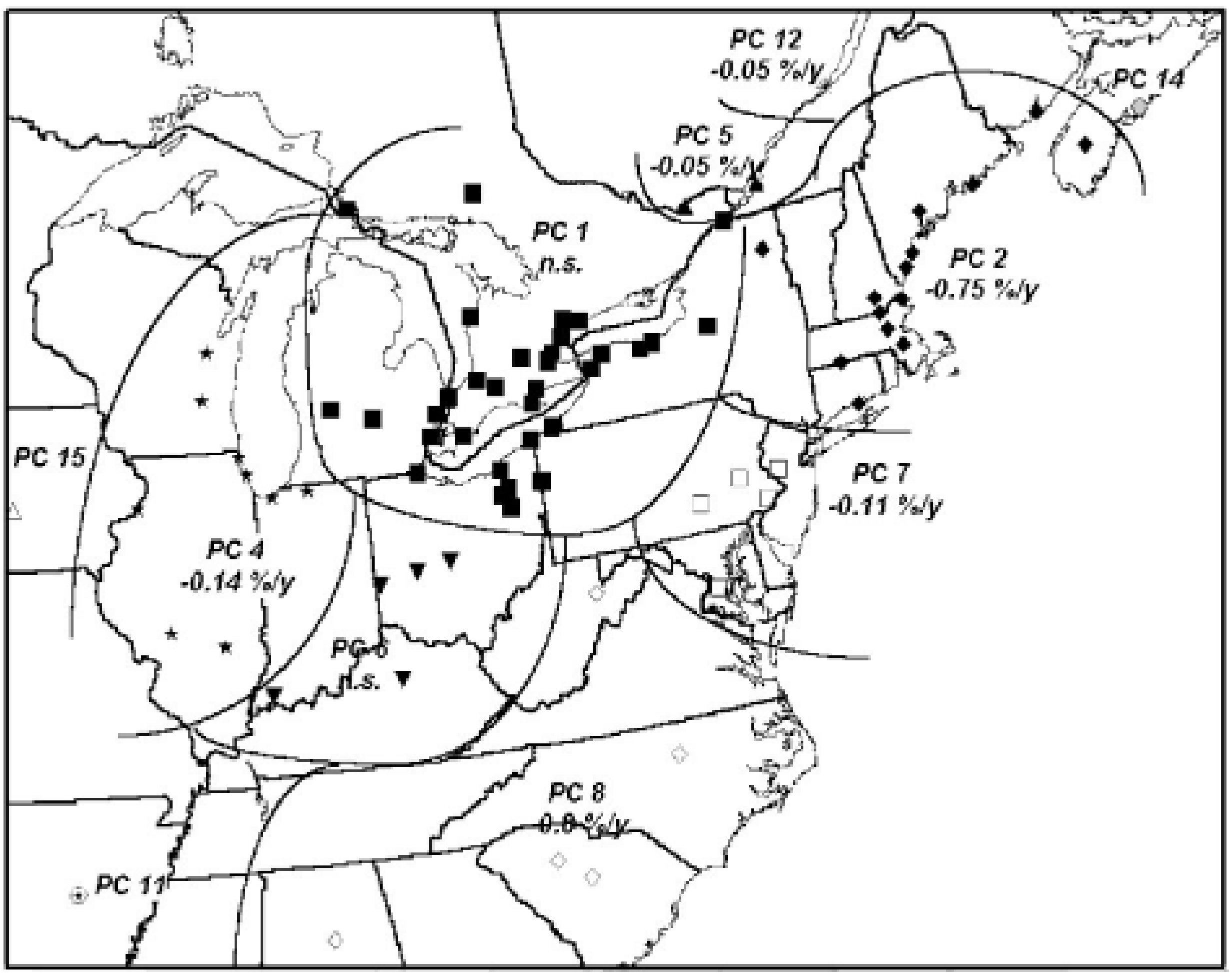


Figure 1. Regional meteorologically adjusted trends (%/yr) in 1-hr averaged O3 in the northern United States and southern Canada using cluster analysis (1980-93 data - NARSTO, 2000)

precursors. In Canada, there systematic monitoring has begun quite recently, but available data indicate that many locations in Southern Ontario will exceed the recently endorsed standard of 30ug/m3 (24-hour average). In the U.S., there are not enough years of data from the recently-established reference-method network to determine trends, but it appears that there may be many areas which do not attain the new U.S. standard.

Air Toxics: this term captures a large number of pollutants that, based on the toxicity and likelihood for exposure, have potential to harm human health (e.g. cancer) or adverse environmental and ecological effect. Some of these are of local importance, near to sources, while others may be transported over long distances. Monitoring is difficult and expensive, and usually limited in scope: usually such toxics are present only at trace levels. In both Canada and the U.S., efforts focus on minimizing emissions. In the U.S. the Clean Air Act targets a 75% reduction in cancer "incidence", and "substantial" reduction in non-cancer risks. The maximum available control technology (MACT) program has set toxic emission standards for about 50 source categories; another nine standards have been proposed. In Canada key toxics such as benzene, mercury, dioxins, and furans are the subject of ratified and proposed new standards, and voluntary reduction efforts. Some ambient trends have been found: in the U.S. concentrations of benzene and toluene have shown significant decreases from 1993-8, notably in the Lake Michigan region due to the use of reformulated gasoline. Styrene has also shown a significant decrease (1996-98).

Emissions are being tracked through the National Pollutant Release Inventory (NPRI - Canada) and the U.S. National Toxics Inventory (NTI). NTI data indicate that national U.S. toxic emissions have dropped 23 per cent between 1990-96, though emission estimates are subject to modification, and the trends is different for different compounds. In Canada, NPRI information includes information on significant voluntary reductions in toxic emissions through the ARET (Accelerated Reduction/ Elimination of Toxics) program.

Future Pressures

Continued population growth and associated urban sprawl are threatening to offset emission reduction efforts and better control technologies, both through increased car-travel and energy consumption.

The changing climate may affect the frequency of weather conditions conducive to high ambient concentrations of many pollutants. There is also increasing evidence of changes to the atmosphere as a whole: average ground-level ozone concentrations may be increasing on a global scale.

Continuing health research is both broadening the number of toxics, and producing evidence that existing standards should be lowered. There is epidemiologic evidence of health effects from ozone or fine particulates down at or below levels previously previously considered to be background or "natural" levels of 30-50 ppb (daily

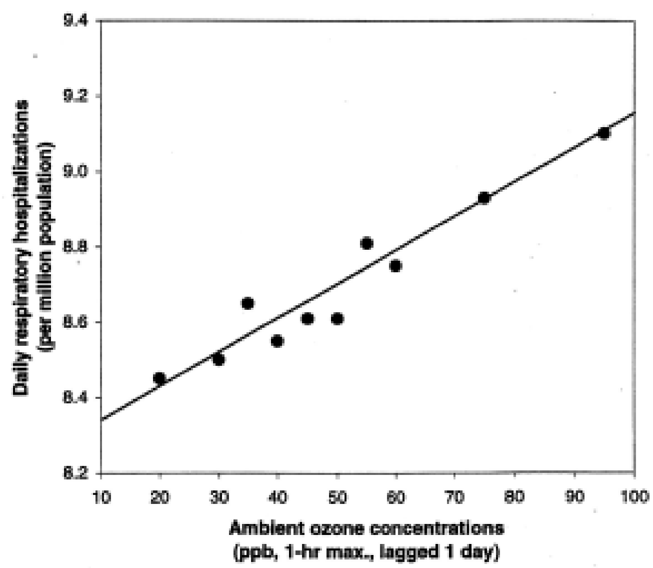


Figure 2. Association of respiratory admissions to Ontario hospitals with ozone pollution. National Air Quality Objectives for Ground-Level Ozone: Science Assessment.

maximum hourly values - see figure).

Future Activities

Major pollution reduction efforts continue in both U.S and Canada. In Canada, new ambient standards for particulate matter and ozone have been endorsed, to be attained by 2010. This will involve updates at the Federal level and at the provincial level (Ontario Anti-Smog Action Plan). Toxics are also addressed at both level. The Canadian Environmental Protection Act (CEPA) was recently amended. In the U.S., new, more protective ambient air standards have been promulgated for ozone and particulate matter. MACT (Maximum Available Control Technology) standards continue to be promulgated for sources of toxic air pollution.

At the international level, annexes to the U.S.-Canada Air Quality Agreement are in discussion, to cover pollutants such as ozone. Efforts to reduce toxic pollutants will continue under NAFTA and through UN-ECE protocols.

Future Work Necessary
PM2.5 networks will continue to develop in both countries, to determine ambient levels, trends, and consequent reduction measures. Review of standards or objectives will continue to consider new information. The U.S. is considering deployment of a national toxic monitoring network.

Limitations
It must be emphasized that this indicator report does not consider indoor air quality, or allergens. The monitoring networks are urban-focused, and are considered deficient for toxic pollutants.

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Acknowledgements
Authors: Fred Conway, Environment Canada, Meteorological Services of Canada, Downsview, ON and Joseph Chung, US Environmental Protection Agency, Air Division, Chicago, IL.

Economic Prosperity

SOLEC Indicator #7043

Purpose

To assess the unemployment rates within the Great Lakes basin, and, when used in association with other Societal indicators, to infer the capacity for society in the Great Lakes region to make decisions that will benefit the Great Lakes ecosystem. Unemployment, as a single economic measure, can generally describe an economy's condition. A healthy economy, one characterized by low or falling unemployment rates, translates into increased business and government (tax) revenues as well as overall personal income. During periods of low unemployment, (i.e. economic well-being) public support for environmental initiatives by government agencies and elected officials may also be increased.

Ecosystem Objective

Human economic prosperity is a goal of all governments and humans are part of the ecosystem. Full employment, or achieving the lowest economically sustainable unemployment level possible, is a goal for all economies. A level of unemployment under 5% is considered full employment.

State of the Ecosystem

By most measures, the binational Great Lakes regional economy is healthy. However, current low unemployment has strained labor markets which, if sustained, could affect the region's economic future. This situation has been building for a decade. The unemployment rate for the Great Lakes states dipped below the U.S. average in 1991 and remained there during the 1990's. In fact, for the Great Lakes states collectively, unemployment is at a 30 year low. Canadian and Ontario economic recoveries unfolded later in the U.S. but have now nearly caught up.

During the 1980's, demographers and labor analysts predicted tighter labor markets for the 1990's. The reasons cited were a reduction in baby-boom entrants to the work force and leveling off of female work force participation. These factors coupled with a dramatic restructuring of the region's important manufacturing sector and greater cross-border trade has virtually eliminated out-migration of people seeking work and has moved the underemployed into better paying, full-time positions.

Both sides of the border reflect a manufacturing intensity greater than their national economies. The Great Lakes states represent about 27% of national output in manufacturing whereas Ontario is twice as large. The earlier tough times for manufacturing when global competition roared onto the scene forced regional firms and industry clusters to rationalize unproductive plant and trim workforces. Lean production was adopted with more emphasis on technology and just-in-time inventory systems became standard. The manufacturing sector has many cross-border linkages particularly for the auto industry. About half of the billion dollar-a-day U.S.-Canada trade is tied to the Great Lakes states with Ontario as the most prominent province in this relationship.

Future Pressures

Low unemployment rates can result in difficulty in worker recruitment, possible job training consequences, increased use of overtime, and wage inflation. A "worker market" may also increase mobility from job-to-job and place-to-place. Other factors may add to job mobility such as job matching information technology and more uniform skill standards. On the other hand, as workers age as they are in the Great Lakes region, job mobility rates usually trend downward.

National and regional economies entail complex interactions among goods and service sectors. These sectors and industry clusters are also subject to overall business cycles. When an industry or related cluster of businesses are relatively concentrated in a region or place, cyclical economic trends may have industry and geographic consequences. For example, in northwest Indiana, with its several integrated steel mills, tens of thousands of steel workers lost their jobs in the 1980's. This industry's restructuring period was partly brought on by overseas competition and a recession. The economic and social fabric of area communities was torn apart and recovery is still underway.

The 1990's have shown that good economic times translate into high levels of consumer spending and home buying. These activities are presumed to increase pressures on the ecosystem through household and business waste generation, increased air pollution particularly from transportation sources and accelerated land use changes. Residential development is the largest category of land use change and its environmental impacts are widely recognized.

Future Activities
Business cycles happen but enlightened monetary policy can delay onset of recessionary periods and dampen them as well. Measures that promote economic diversification should be encouraged and particularly for places where the local economy is not diversified. With respect to workers, unemployment insurance, job training and placement are traditional methods to mitigate effects of unemployment. Land use change can be better managed through coordinated planning within and across municipal jurisdictions. Efforts to revitalize urban areas in conjunction with open space and farmland protection can redirect some growth.

Further Work Necessary
The unemployment rate as a measure of economic prosperity should be reevaluated for use in the SOLEC process. Its connection to general economic prosperity is acknowledged but it is not precise enough to account for ecosystem impacts, however indirect they may be. Employment differs from place to place irrespective of hydrologic boundaries and even political jurisdictions. It may hold promise as one of several economic prosperity measures, but may be more useful if linked directly to tax revenue generation and household attitudes regarding environmental protection through government action.

Case Study - Ontario
In recent years labour market conditions have improved, resulting in a falling unemployment rate. Around the peak of the last recession (November 1992), 592,600 people were unemployed in Ontario (10.7% of the labour force). However, by 1999 the unemployment rate had dropped to 6.3%, its lowest level since 1990.

These figures represent the official unemployment rates published each month by Statistics Canada. They are based on the number of persons who were without work and both available for work and actively looking for work. The hidden unemployed include discouraged workers who gave up looking for work and who would therefore be counted as not in the labour force.

In addition to the official unemployment rate, Statistics Canada publishes from time to time a set of supplementary measures of unemployment to illustrate additional dimensions of labour market behaviour. For instance, Statistics Canada has published a supplementary unemployment rate for the Province of Ontario since 1997. The supplementary unemployment rate includes the official unemployment rate plus discouraged searchers, plus waiting group (recall, replies, long-term future starts), plus involuntary part-timers (in full-time equivalents). Over the period 1997 to 1999, the average official unemployment rate was 7.3%, for comparison purposes the average supplementary unemployment rate was 10.4%.

A similar comparison can be made based on gender. The average official unemployment rate, for males in the Province of Ontario, over the period 1997 to 1999 was 7.2%, and the average supplementary unemployment rate was 9.4%. In the case of females, the average official unemployment rate and average supplementary unemployment rate, over the same period as above, were 7.4% and 11.4%, respectively. In the case of females, there appears to be a higher number of females in involuntary part-time positions.

The official unemployment rate does not capture the total number of individuals who experienced unemployment at some point of the year. In contrast, a one-year point reference period would capture this number. According to an Autumn 2000 Perspectives article, annual rates in general, tend to be almost double the monthly rates, whether individual- or family-based. For instance, the individual unemployment rate for Canada based on a one-year reference period was 17.3% in 1997. The rate based on a one week reference period (the official unemployment rate), was 9.1%. In 1999, the official unemployment rate for both sexes, in Ontario, was 6.3%, an estimate of the one-year reference number, for the same year, based on a doubling of the official rate would be approximately 12.6%. Therefore, almost 1 in 8 people in the labour force were unemployed at one point in the year.

In Table 1, official unemployment rates, for the period 1987 to 1999, are provided for the Province of Ontario, as well as Census Metropolitan Areas (CMAs) within the Province. A comparison of the CMA versus Provincial unemployment rates reveals that over the 1987 to 1999 period, the CMAs of Sudbury, Oshawa, St. Catharines-Niagara, Windsor and Thunder Bay have more often had unemployment rates greater than the provincial average. For the most part, the increases in unemployment rates over this period have been a consequence of declines in employment in the manufacturing sector, as well as the resource sector in the case of Sudbury CMA.

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Ontario	**6.1**	**5.1**	**5.1**	**6.2**	**9.5**	**10.7**	**10.9**	**9.6**	**8.7**	**9.0**	**8.4**	**7.2**	**6.3**
Ottawa-Hull	7.4	5.2	6.1	5.9	7.3	8.6	8.5	8.2	9.6	8.4	8.9	7.1	6.5
Sudbury	11.4	9.8	7.9	8.0	10.1	11.7	10.5	10.4	8.9	9.8	9.1	11.0	9.8
Oshawa	6.3	5.5	4.0	6.5	9.5	11.7	11.5	9.7	8.7	9.7	8.0	7.3	5.9
Toronto	4.5	3.8	4.0	5.2	9.5	11.2	11.4	10.4	8.6	9.1	8.0	7.0	6.1
Hamilton	6.4	5.8	5.0	6.2	9.9	10.5	11.6	8.2	6.4	7.4	6.4	5.2	4.9
St. Catharines-Niagara	9.5	6.3	7.2	7.0	11.2	12.5	14.2	10.7	9.0	9.1	9.9	7.6	6.9
London	7.1	4.7	4.3	5.9	7.8	8.7	8.9	7.7	8.0	8.8	7.7	6.1	6.7
Windsor	9.0	7.7	8.1	8.8	12.4	12.6	11.6	9.0	8.5	8.5	9.1	8.7	6.5
Kitchener	5.8	5.3	4.8	6.4	9.4	9.4	9.0	6.6	7.9	8.3	7.4	6.5	5.7
Thunder Bay	8.4	6.3	5.5	7.7	9.4	10.1	11.5	10.8	8.1	9.1	9.1	9.0	7.8

Source: Statistics Canada. (2000). Labour Force Historical Review 1999. Cat. 71F0004XCB.

A breakdown of employment by sector, in the Province of Ontario, over the period 1987 to 1999, reveals a shift in employment from the goods-producing sector to the services-producing sector. In 1987, 32% of all employed persons in Ontario were employed in the goods-producing sector, versus 68% in the services-producing sector. In that same year, persons employed in the manufacturing sector accounted for 66% of all persons employed in the goods-producing sector.

By 1992, the height of the last recession, those employed in the goods-producing sector accounted for 27.3% of all persons employed in Ontario, a decline of 4.7% or 212,600 jobs from 1987 employment levels. During this same year, the services-producing sector accounted for 72.7% of all employed. A decline in those employed in the manufacturing sector accompanied the decline in the goods-producing sector. In 1992, those employed in the manufacturing sector accounted for 63.1% of total employment in the goods producing sector, a decline of approximately 3% or 40,566 jobs from 1987 employment levels.

In 1999, the breakdown of employment between the goods-producing sector and the services-producing sector was unchanged from 1992 percentages. The recorded levels of employment in the manufacturing sector have increased in each year since 1993. By 1999, those employed in the manufacturing sector accounted for 67.6% of all goods-producing jobs.

In 1999 the increase in foreign demand for Canadian made products has spurred employment in the computer and electronic parts sector, which in part have positively effected employment in the manufacturing sector. In 1999, the manufacturing sector in Ontario reported gains in employment of an additional 59,700 jobs. In addition to high-tech manufacturing, the automotive sector has experienced an increased labour market in part due to a strong U.S. economy.

A comparison of 1999 versus 1987 labour market numbers for the Province of Ontario reveals that the size of the labour market in the goods-producing sector has declined by 0.1%, at the same time the services-producing sector has experienced an increase of 24.3%. In 1993, employment in the manufacturing sector in Ontario was at its lowest level, just 79% of the reported 1987 level.

Over the period 1997 to 1999, in the Province of Ontario, the growth in permanent and temporary employment in the goods-producing sector was 11.5% and 9.8%, respectively. For purposes of comparison, over the same period, the growth in permanent and temporary employment in the services-producing sector was reported at 4.8% and 15.7%, respectively. In addition, in 1999 the average hourly wage rate for the manufacturing sector, the largest sector within the goods-producing sector, was $17.79, while in the trade sector, the largest sector within the services-producing sector, the average hourly wage rate was $12.99. Consequently, the shift from goods-producing employment to services-producing employment has resulted in more temporary positions, as well as a decline in the average hourly wage rate for those individuals forced out of the goods-producing sector and into the services-producing sector.

The unemployment rate may not be an appropriate stand alone indicator of the aggregate state of the economy or the economic prosperity of the population. It is not that the unemployment number is wrong; rather it may be asking too much of a single measure to measure economic prosperity, especially when dramatic demographic changes have occurred in the labour force. The discussion above has demonstrated that the unemployment rate may underestimate the degree of hardship and loss in the population. The possibility of reduced hardship during periods of low unemployment may be unsupported, as the unemployed may be looking for temporary jobs. For these reasons additional indicators such as poverty rate, demand on social services, income inequality, high school dropouts, low-weight births, and so on, may be better indicators in measuring the economic prosperity of the Great Lakes region.

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Acknowledgements

Authors: Steve Thorp, Great Lakes Commission, Ann Arbor, MI, Tom Muir, Environment Canada, Burlington, ON and Mike Zegarac, Environment Canada, Burlington, ON.

Water Use

SOLEC Indicator #7056

Purpose

This indicator directly measures the amount of water used by residents of the Great Lakes basin and indirectly measures the stress to the Great Lakes ecosystem caused by the extraction of this water and the generation of wastewater pollution.

Ecosystem Objective

High rates of water use are associated with a number of environmental problems. For example, groundwater depletion can result from high water use in combination with high rates of population growth. Also, there is a strong correlation between water use and the quality of wastewater released from sanitary sewage treatment plants. This indicator supports Annex 8 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Generally, there are not great differences among the Great Lakes Basin communities' in terms of water use, although the Regional Municipality of Niagara, Ontario appears to be using more per capita than the other municipalities sampled. Figure 1 below illustrates the sample results of water usage rates from four municipalities in the basin. The larger urban communities of Toronto, Ontario and Cuyahoga (including Cleveland), Ohio exhibited similar water use patterns per capita. The largely rural community of Niagara County, New York had the lowest per capita water usage rates of the sample, although a bias was possible since there were a small number of residents that were using ground water, thus deflating the water use numbers.

The Regional Municipality of Niagara had significantly higher water use rates than the other municipalities, almost 50 cubic meters per capita more. Initial research results indicates that there also appear to be differences between Canadian and US communities. Additional research is needed to better appreciate the differences among these communities in their rates of water use. The sample of the four Great Lakes communities did not indicate any apparent linkages between urban density, for example, and water use rates.

Future Pressures on the Ecosystem

While water is essential to life, water use is a stressor to the ecosystem. Minimizing the amount of water that humans use, at rates more consistent with those in other places, such as European cities, for example would reduce stress on the ecosystem. Further, there is a positive relationship between the amount of water used and the quantity and quality of wastewater discharged.

As Great Lakes populations grow, there will be increasing demand for water for all purposes. In addition, there is expected to be a decline in the availability of water and lower water levels for the Great Lakes as a result of longer term global climate change.

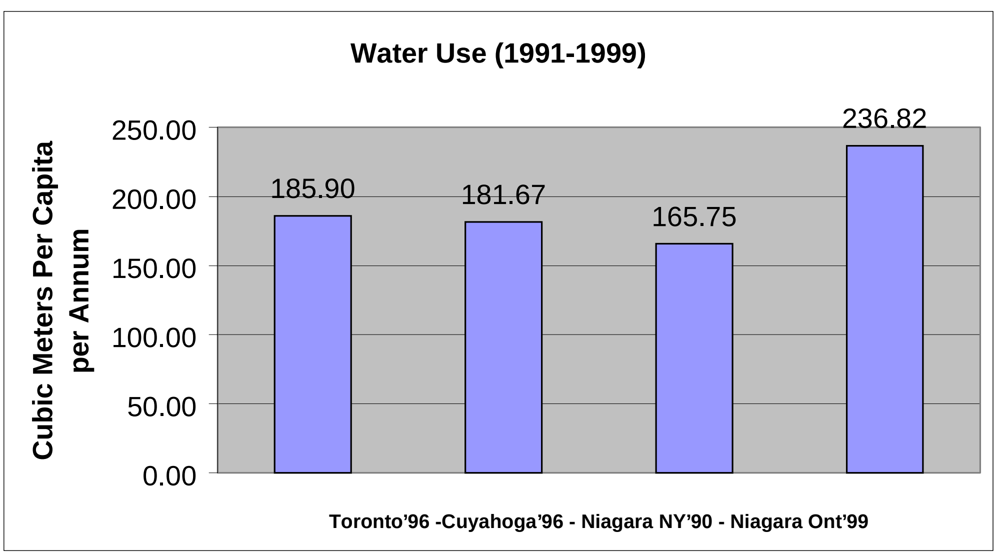

Figure 1. Water Use Rates of Four Sampled Communities in the Great Lakes Basin

Future Action

Water conservation programs implemented throughout the Great Lakes basin would help to alleviate the stresses caused by excessive and unnecessary water use by residents in the basin. There is significant potential for reduction in water use given the technology. Perhaps the most significant shortcoming in water policy throughout the Great Lakes basin is in the area of economic incentives for water conservation. There is significant potential for developing water pricing strategies that ensure equitable access to water while rationalizing use.

Further Work Necessary

Additional research would be beneficial in a number of areas. First of all, there is a need to better understand the relationship between water use and urban form. Although the sample information was not sufficient to draw any conclusions about any relationship that might exist it should be expected that there is a relationship between population density and water use. The existence of any such relationship could be explored through a broad survey other communities in the Great Lakes basin and an exploration of water use in these communities over various time periods.

Second, as with other developing land use indicators, there is also a need to set standards for collecting and reporting on water use data. Third, governments at all levels should join public interest groups and academic institutions in this research to broaden its appeal and understanding. Fourth, there are opportunities inherent in researching water use to better understand the relationship between water use and wastewater generation, between the demand for water and its pricing, and between water use an technological innovation.

Finally, the initial survey results of communities in the Great Lakes basin is apparently inconclusive with respect to size of community or urban density and rate of water use. The role of this indicator in land use decisions needs to be explored. It is possible that it might best serve as a basin-wide, rather than a community indicator of land use and human/societal activity.

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Acid Rain

SOLEC Indicator #9000

Purpose

To assess the pH levels in precipitation and critical loadings of sulphate to the Great Lakes basin, and to infer the efficacy of policies to reduce sulphur and nitrogen acidic compounds released to the atmosphere.

Ecosystem Objective

The 1991 Canada/U.S. Air Quality Agreement pledges the two nations to reduce the emissions of acidifying compounds by approximately 40% relative to 1980 levels. The 1998 Canada-Wide Strategy for Post 2000 intends to further reduce emissions to the point where deposition containing these compounds does not adversely impact aquatic and terrestrial biotic systems.

State of the Ecosystem

Acid rain, more properly called "acidic deposition", is caused when two common air pollutants (sulphur dioxide—SO_2 and nitrogen oxide—NO_x) are released to the atmosphere, react and mix with high altitude water droplets and return to the earth as acidic rain, snow, fog or dust. These pollutants can be carried over long distances by prevailing winds, creating acidic precipitation far from the original source of the problem. Environmental damage typically occurs where local soils and/or bedrock do not effectively neutralize the acid.

Lakes and rivers have been acidified by acid rain causing the disappearance of many species of fish, invertebrates and plants. Not all lakes exposed to acid rain become acidified however. Lakes located in terrain that is rich in calcium carbonate (e.g. on limestone bedrock) are able to neutralize acidic deposition. Much of the acidic precipitation in North America falls in areas around and including the Great Lakes basin. Northern Lakes Huron, Superior and Michigan, their tributaries and associated small inland lakes are located on the geological feature known as the Canadian Shield. The Shield is primarily composed of granitic bedrock and soils that cannot easily neutralize acid, thereby resulting in acidification of many of the small lakes (many of which are in norther Ontario). The five Great Lakes are so large that acid precipitation has little effect on them directly. Impacts are mainly felt on vegetation and on inland lakes.

Sulphur dioxide emissions come from a variety of sources. Most common releases of SO2 in Canada are a byproduct of industrial processes, notably metal smelting. In the United States, electrical utilities constitute the largest emissions source (Figure 1). The primary source of NO_x emissions in both countries is the combustion of fuels in motor vehicles.

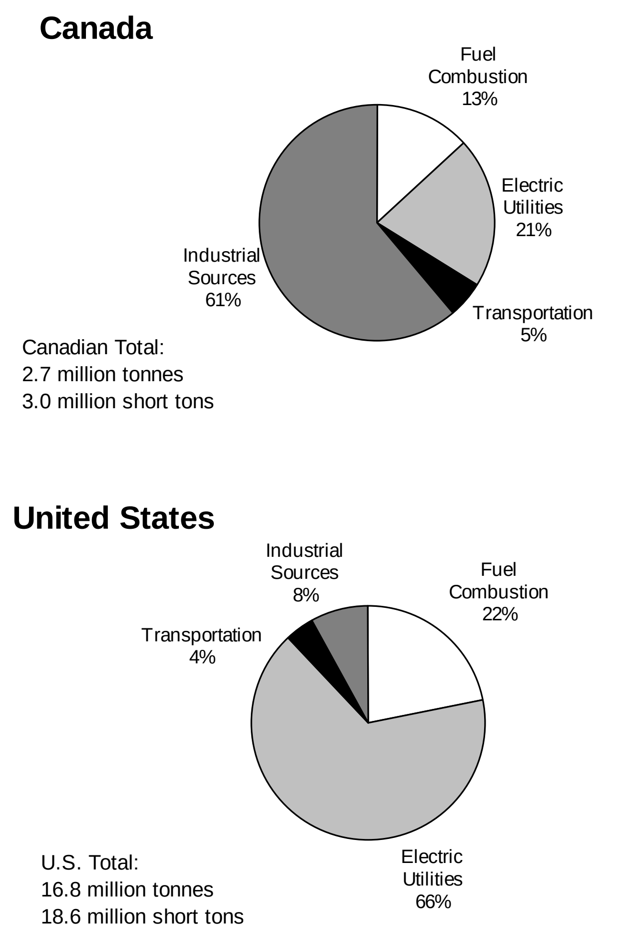

Figure 1. Sources of Sulphur Dioxide Emissions in Canada and the U.S. (1995)

Future Pressures

Figure 2 illustrates the trends in SO_2 emission levels in Canada and the United States measured from 1980 to 1995 and predicted from 1995 to 2010. U.S. levels are expected to decrease by approximately one-third by 2000 and by up to 40% by 2010. Canadian levels dropped 54% from 1980 to 1994 and thereafter are expected to remain at approximately current levels. Despite these

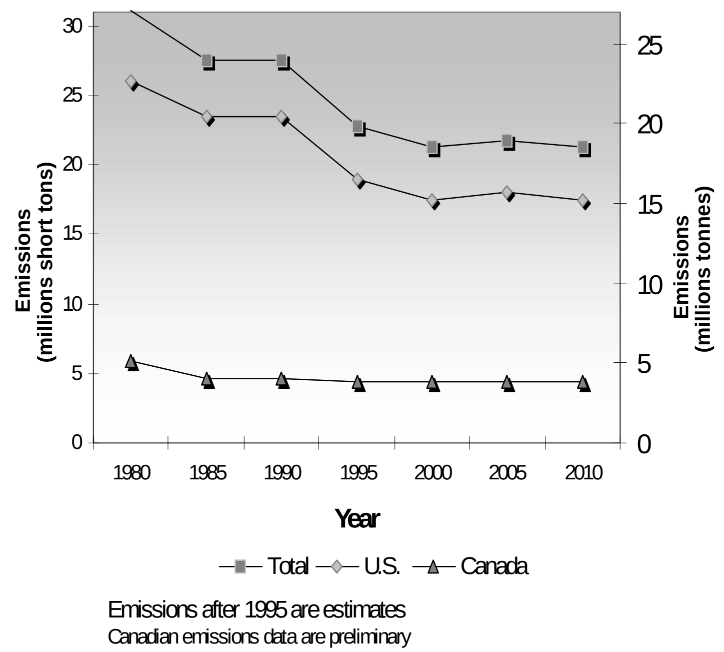

Figure 2. Past and Predicted Sulphur Dioxide Emissions in Canada, the U.S. and Combined.

efforts, rain is still too acidic throughout most of the Great Lakes region.

Figure 3 compares wet sulphate deposition over eastern North America between two five-year periods, 1980-84 and 1991-95 in kilograms sulphate per hectare per year. In response to the decline in SO_2 emissions, deposition decreased between the two periods. If SO_2 emissions remain relatively constant after the year 2000, as predicted (Figure 2), it is unlikely that sulphate deposition will change in the coming decade. The predicted sulphate deposition exceedances of critical loads for 2010 in Canada are seen in Figure 4.

Pressures will continue to grow as the population within and outside the basin increases, causing increased demands on electrical utility companies, resources and an increased number of motor vehicles. Considering this, reducing nitrogen deposition is becoming more and more important, as its contribution to acidification may soon outweigh the benefits gained from reductions in sulphur dioxide emissions.

Future Activities

The effects of acid rain can be seen far from the source and so the governments of Canada and the United States are working together to reduce acid emissions. The 1991 Canada/United States Air Quality Agreement addresses transboundary pollution. To date, this agreement has focussed on acidifying pollutants and significant steps have been made in the reduction of SO_2 emissions. However, further progress in the reduction of acidifying substances is required.

The 1998 *Canada-Wide Acid Rain Strategy for Post-2000* provides a framework for further actions, such as establishing new sulphur dioxide emission reduction targets in Ontario, Quebec and other provinces.

Further Work Necessary

While North American SO_2 emissions and sulphate deposition levels in the Great Lakes basin have declined over the past 10 to 15 years, many acidified lakes do not show recovery (increase in water pH or alkalinity). Empirical evidence suggests that there are a number of factors acting to delay or limit the recovery response, e.g. increasing importance of nitrogen-based acidification, soil

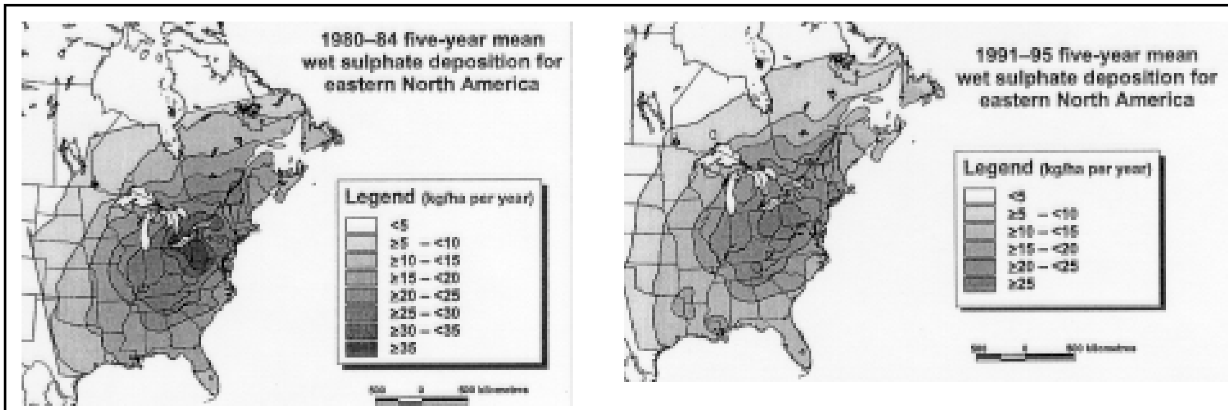

Figure 3. Comparison of Mean Wet Sulphate Deposition in Eastern North America from 1980-84 and 1991-95.

depletion of base cations, mobilization of stored sulphur, climatic influences, etc. Further work is needed to quantify the additional reduction in deposition needed to overcome these limitations and to accurately predict the recovery rate.

Acknowledgments
Authors: Dean S. Jeffries, National Water Research Institute, Environment Canada, Burlington, ON and Robert Vet, Meteorological Service of Canada, Environment Canada, Downsview, ON.

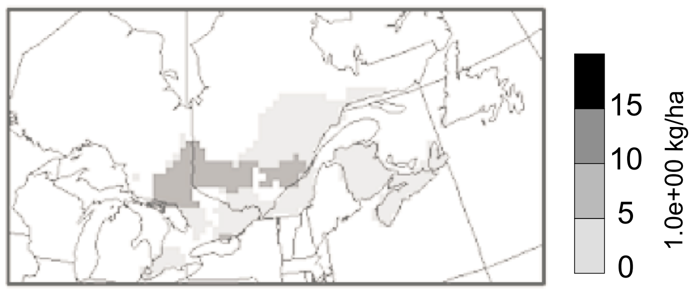

Figure 4. Predicted 2010 Sulphate Deposition Exceedances of Critical Loads

Under Construction

The SOLEC indicator process is an open process, a process that also needs to be flexible enough to revise, remove or add indicators as conditions warrant. Additionally, the process needs to be able to correct oversights.

Since SOLEC 98 one frequent comment has been that the suite of indicators lacks a basinwide indicator to assess the status and potential impact of non-native species. In response to this, SOLEC organizers are proposing the addition of an Exotic Species indicator (ID# 9002). Although we do not know have an indicator descriptor for Exotic Species, an example indicator report for aquatic exotic species is included here. At some point the indicator report will expand to the terrestrial portion of the Great Lakes ecosystem.

Please provide comments to Paul Bertram or Nancy Stadler-Salt on:
1. Whether this indicator should be included in the SOLEC suite of basinwide ecosystem indicators;
2. What features need to be included in the indicator; and/or
3. Provide additional data for the indicator report.

Exotic Species Introduced into the Great Lakes

SOLEC Indicator #9002

Purpose

This indicator reports introductions of aquatic organisms not naturally occurring in the Great Lakes, and is used to assess the status of biotic communities in these freshwater ecosystems. Human activities associated with shipping, canals, deliberate release (authorized and not), and aquaculture are responsible for virtually all new species in the Great Lakes. Reporting new species will highlight the need for more effective safeguards to prevent the introduction and establishment of new non-indigenous species.

Ecosystem Objective

The purpose of the U.S. and Canada Water Quality Agreement is, in part, to restore and maintain the biological integrity of the waters of the Great Lakes ecosystem, that is, at a minimum to prevent extinctions and unauthorized introductions. Nearly 10% of the non-native species introduced in the Great Lakes have had a significant impact on ecosystem health, a percentage consistent with findings in the United Kingdom and the Hudson River of North America. In particular and most recently, live fish and invertebrates in ballast water discharges into the Great Lakes have been demonstrated to constitute a threat to the ecosystem.

State of the Ecosystem

Authorized and accidental introduction of new species by government agencies are managed through consultation and procedural agreements under *A Joint Strategic Plan for Management of Great Lakes, 1981*. Since this agreement, new sport fish related introductions have not become established in the Great Lakes.

The identification of ship ballast water as a major vector transporting unwanted organisms into the Great Lakes has motivated control efforts. In 1989, Canada introduced voluntary ballast exchange, as recommended by the International Joint Commission and Great Lakes Fishery Commission in the wake of Eurasian ruffe and zebra introductions. In 1990, the United States Congress passed the Aquatic Nuisance Control and Prevention Act (followed by the Non-Indigenous Species Act) and by May of 1993, the first and only ballast management regulations in the world was adopted. Since the mandatory ballast exchange policy in the Great Lakes was initiated, new species associated with shipping activities have been identified and non-reproducing 'indicator species' such as the European Flounder are still reported. Consequently, current ballast water management strategies are not sufficiently protective against future Great Lakes invasions.

Future Pressures on the Ecosystem

World trends in global trade will increase the number of potential donor regions importing into the Great Lakes basin, thereby elevating the risk that new species will gain access to the Great Lakes. New diversions of water into the Great Lakes would also increase the risk of new invasive species. Fast-growing aquaculture industries, such as fish farming, live food, and garden ponds, will seek to satisfy their clients' desire for novelty. Changes in water quality, temperature, and, indeed, the previous introduction of key species from outside may make the Great Lakes more hospitable for the establishment of new invaders.

Future Actions

Researchers are seeking to better understand the contributions of various vectors and donor regions, the receptivity of the Great Lakes Ecosystem, and the biology of new invaders, in order to recommend improved safeguards that will reduce the invasion risk of new biological pollutants in the Great Lakes.

Further Work Necessary

To restore and maintain the biological integrity of the Great Lakes, it is essential that vectors be closely monitored and effective safeguards introduced and adjusted as necessary.

Acknowledgments

Authors: Edward L. Mills, Department of Natural Resources, Cornell University, Bridgeport, NY and Margaret Dochoda, Great Lakes Fishery Commission, Ann Arbor, MI.

Table 1. Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic fauna of the Great Lakes

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Fish						
Petromyzontidae	*Petromyzon marinus*	sea lamprey	Atlantic	1830s	Lake Ontario	C, S(F)
Clupeidae	*Alosa pseudoharengus*	alewife	Atlantic	1873	Lake Ontario	C, R(F)
	Alosa aestivalis	blueback herring	Atlantic	1978	Mohawk River	C
Cyprinidae	*Carassius auratus*	goldfish	Asia	<1878	widespread	R(D), R(AQ) R(F), R(A)
	Cyprinus carpio	common carp	Asia	1879	widespread	R(D)
	Notropis buchanani	ghost shiner	Mississippi	1979	Thames River	R(F)
	Phenacobius mirabilis	suckermouth minnow	Mississippi	1950	Ohio	C, R(F)
	Scardinius erythrophthalmus	rudd	Eurasia	1989	Lake Ontario	R(F)
Cobitidae	*Misgurnus anguillicaudatus*	oriental weatherfish	Asia	1939	Shiawassee River	R(A)
Ictaluridae	*Noturus insignis*	margined madtom	Atlantic	1928	Oswego River	C, R(F)
Osmeridae	*Osmerus mordax*	rainbow smelt	Atlantic	1912	Crystal Lake	R(D)
Salmonidae	*Oncorhynchus gorbuscha*	pink salmon	Pacific	1956	Current River	R(A)
	Oncorhynchus kisutch	coho salmon	Pacific	1933	Lake Erie	R(D)
	Oncorhynchus nerka	kokanee	Pacific	1950	Lake Ontario	R(D)
	Oncorhynchus tshawytscha	chinook salmon	Pacific	1873	all lakes but Superior	R(D)
	Oncorhynchus mykiss	rainbow trout	Pacific	1876	Lake Huron	R(D)
	Salmo trutta	brown trout	Eurasia	1883	Lakes Ontario and Michigan	R(A) R(D)
Poeciliidae	*Gambusia affinis*	western mosquitofish	Mississippi	1923	Cook Co., Illinois	R(D)
Gasterosteidae	*Apeltes quadracus*	fourspine stickleback	Atlantic	1986	Thunder Bay	S(BW)
Percichthyidae	*Morone americana*	white perch	Atlantic	1950	Cross Lake	C
Centrarchidae	*Enneacanthus gloriosus*	bluespotted sunfish	Altantic	1971	Jamesville Res.	R(AQ), R(F)
	Lepomis humilis	orangespotted sunfish	Mississippi	1929	Lake St. Mary's	C
	Lepomis microlophus	redear sunfish	Southern U.S.	1928	Inland Indiana	R(D)
Percidae	*Gymnocephalus cernuus*	ruffe	Eurasia	1986	St. Louis River	S(BW)
Gobiidae	*Neogobius melanostomus*	round goby	Eurasia	1990	St. Clair River	S(BW)
	Proterorhinus marmoratus	tubenose goby	Eurasia	1990	St. Clair River	S(BW)

Mechanism codes: Deliberate release R(D); Unintentional release R(I); Aquarium release R(AQ); Cultivation release R(C); Fish release R(F); Accidental release R(A);
Ballast water S(BW); Solid ballast S(SB); Fouling S(F); Canals (C); Railroads and Highways (RH)

Table 1 (Continued). Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic fauna of the Great Lakes

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Mollusks						
Valvatidae	*Valvata piscinalis*	European valve snail	Eurasia	1897	Lake Ontario	S(SB)
Viviparidae	*Cipangopaludina chinensis malleata*	Oriental mystery snail	Asia	1931	Niagara River	R(AQ)
	Cipangopaludina japonica		Asia	1940s	Lake Erie	R(D)
	Viviparus georgianus	banded mystery snail	Mississippi	<1906	Lake Michigan	R(AQ)
Hydrobiidae	*Potamopyrgus antipodarum*	New Zealand mud snail	New Zealand	1991	Lake Ontario	S(BW)
Bithyniidae	*Bithynia tentaculata*	faucet snail	Eurasia	1871	Lake Michigan	S(SB), R(D)
Hydrobiidae	*Gillia altilis*	snail	Atlantic	1918	Oneida Lake	C
Pleuroceridae	*Elimia virginica*	snail	Atlantic	1860	Erie Canal	C
Lymnaeidae	*Radix auricularia*	European ear snail	Eurasia	1901	Chicago	R(AQ), R(A)
Sphaeriidae	*Sphaerium corneum*	European fingernail clam	Eurasia	1952	Rice Lake	Unknown
	Pisidium amnicum	greater European pea clam	Eurasia	1897	Genesee	S(SB)
Corbiculidae	*Corbicula fluminea*	Asiatic clam	Asia	1980	Lake Erie	R(A), R(AQ), R(F)
Dreissenidae	*Dreissena polymorpha*	zebra mussel	Eurasia	1988	Lake St. Clair	S(BW)
	Dreissena bugensis	quagga mussel	Eurasia	1991	Lake Ontario	S(BW)
Unionidae	*Lasmigona subviridis*	mussel	Atlantic	<1959	Erie Canal	C
Crustaceans						
Cladocera	*Bythotrephes cederstroemi*	spiny water flea	Eurasia	1984	Lake Huron	S(BW)
	Eubosmina coregoni	water flea	Eurasia	1966	Lake Michigan	S(BW)
	Cercopagis pengoi	fish hook flea	Ponto-Caspian	1998	Lake Ontario	S(BW)
Copepoda	*Eurytemora affinis*	calanoid copepod	widespread	1958	Lake Ontario	S(BW)
	Skistodiaptomus pallidus	calanoid copepod	Mississippi	1967	Lake Ontario	R(A), R(F)
	Argulus japonicus	parasitic copepod	Asia	<1988	Lake Michigan	R(F), R(AQ)
Amphipoda	*Gammarus fasciatus*	gammarid amphipod	Atlantic	<1940	Unknown	S(BW), S(SB)
	Echinogammarus ischnus	gammarid amphipod	Ponto-Caspian	1995	Detroit River	S(BW)
Oligochaetes						
Naididae	*Ripistes parasita*	oligochaete	Eurasia	1980	North Channel	S(BW)
Tubificidae	*Branchiura sowerbyi*	oligochaete	Asia	1951	Kalamazoo River	R(A)
	Phallodrilus aquaedulcis	oligochaete	Eurasia	1983	Niagara River	S(BW)

Mechanism codes: Deliberate release R(D); Unintentional release R(I); Aquarium release R(AQ); Cultivation release R(C); Fish release R(F); Accidental release R(A); Ballast water S(BW); Solid ballast S(SB); Fouling S(F); Canals (C); Railroads and Highways (RH)

Table 1 (Continued). Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic fauna of the Great Lakes

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Other invertebrates						
Platyhelminthes	*Dugesia polychroa*	flatworm	Eurasia	1968	Lake Ontario	S(BW)
Hydrozoa	*Cordylophora caspia*	hydroid	Unknown	1956	Lake Erie	R(A)
	Craspedacusta sowerbyi	freshwater jellyfish	Asia	1933	Lake Erie	R(A)
Insecta	*Acentropus niveus*	aquatic moth	Eurasia	1950	Lake Ontario, Erie	R(A)
	Tanysphyrus lemnae	aquatic weevil	Eurasia	<1943	Unknown	Unknown
Disease pathogens						
Bacteria	*Aeromonas salmonicida*	furunculosis	Unknown	<1902	Unknown	R(F)
Protozoa	*Glugea hertwigi*	microsporidian parasite	Eurasia	1960	Lake Erie	R(F)
	Myxobolus cerebralis	salmonid whirling disease	Unknown	1968	Ohio	R(F)
Present but not established						
Grapsidae	*Eriocheir sinensis*	Chinese mitten crab	northern China	1965	Detroit River	BW
Pleuronectidae	*Platyichthys flesus*	European flounder	ne Atl. Ocean; Black Sea	1974	Lake Erie	BW
Questionable						
Cambaridae	*Oronectes rusticus*	Rusty crayfish	Ohio River basin	1960	Wisconsin	bait

Mechanism codes: Deliberate release R(D); Unintentional release R(I); Aquarium release R(AQ); Cultivation release R(C); Fish release R(F); Accidental release R(A);
Ballast water S(BW); Solid ballast S(SB); Fouling S(F); Canals (C); Railroads and Highways (RH)

Table 2. Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic plants and algae of the Great Lakes

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Algae						
Chlorophyceae	*Enteromorpha intestinalis*	green alga	Atlantic	1926	Wolf Creek (O)	R(A)
	Enteromorpha prolifera	green alga	Atlantic	1979	Lake St. Clair	Unknown
	Nitellopsis obtusa	green alga	Eurasia	1983	Lake St. Clair	S(BW)
Chrysophyceae	*Hymenomonas roseola*	coccolithophorid	Eurasia	1975	Lake Huron	S(BW)
Bacillariophyceae	*Actinocyclus normanii fo. subsalsa*	diatom	Eurasia	1938	Lake Ontario	S(BW)
	Biddulphia laevis	diatom	widespread	1978	Lake Michigan	S(BW)
	Cyclotella atomus	diatom	widespread	1964	LakeMichigan	S(BW)
	Chaetoceros honii	diatom	unknown	1978	Lake Huron	S(BW)
	Skeletonema potamos	diatom	widespread	1963	Toledo, Ohio (E)	S(BW)
	Skeletonema subsalsum	diatom	Eurasia	1973	Sandusky Bay (E)	S(BW)
	Stephanodiscus binderanus	diatom	Eurasia	1938	Lake Michigan	S(BW)
	Stephanodiscus subtilis	diatom	Eurasia	1946	Lake Michigan	S(BW)
	Thalassiosira guillardii	diatom	widespread	1973	Sandusky Bay (E)	S(BW)
	Thalassiosira lacustris	diatom	widespread	<1978	Lake Erie	S(BW)
	Thalassiosira pseudonana	diatom	widespread	1973	Ohio (E)	S(BW)
	Thalassiosira weissflogii	diatom	widespread	1962	Detroit River	S(BW)
	Thalassiosira baltica	diatom	?	?	?	S (BW)
	Diatoma ehrenbergii	diatom	widespread	1930s	Lake Michigan	S(BW)
	Cyclotella criptica	diatom	widespread	1964	Lake Michigan	S(BW)
	Cyclotella pseudostelligera	diatom	widespread	1946	Lake Michigan	S(BW)
	Cyclotella woltereki	diatom	widespread	1964	Lake Michigan	S(BW)
Phaeophyceae	*Sphacelaria fluviatilis*	brown alga	Asia	1975	Gull Lake (M)	R(AQ), R(A)
	Sphacelaria lacustris	brown alga	unknown	1975	Lake Michigan	S(BW)
Rhodophyceae	*Bangia atropurpurea*	red alga	widespread	1964	Lake Erie	S(BW), S(F)
	Chroodactylon ramosum	red alga	Atlantic	1964	Lake Erie	S(BW)
Submerged Plants						
Marsileaceae	*Marsilea quadrifolia*	European water clover	Eurasia	<1925	Cayuga Lake (O)	R(D)
Cabombaceae	*Cabomba caroliniana*	fanwort	Southern U.S.	1935	Kimble Lake (M)	R(AQ), R(A)
Brassicaceae	*Rorippa nasturtium aquaticum*	water cress	Eurasia	1847	Niagara Falls (O)	R(C)

Mechanism codes: Deliberate release R(D); Unintentional release R(I); Aquarium release R(AQ); Cultivation release R(C); Fish release R(F); Accidental release R(A);
Ballast water S(BW); Solid ballast S(SB); Fouling S(F); Canals (C); Railroads and Highways (RH)

Table 2 (Continued). Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic plants and algae of the Great Lakes

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Haloragaceae	*Myriophyllum spicatum*	Eurasian watermilfoil	Eurasia	1952	Lake Erie	R(AQ), S(F)
Trapaceae	*Trapa natans*	water chestnut	Eurasia	<1959	Lake Ontario (t)	R(A), R(AQ)
Menyanthaceae	*Nymphoides peltata*	yellow floating heart	Eurasia	1930	Conneaut River (E)	R(A)
Hydrocharitaceae	*Hydrocharis morsus-ranae*	European frog-bit	Eurasia	1972	Lake Ontario	R(AQ), R(D), S(F)
Potamogetonaceae	*Potamogeton crispus*	curly pondweed	Eurasia	1879	Keuka Lake (O)	R(D), R(F)
Najadaceae	*Najas marina*	spiny naiad	Eurasia	1864	Onondaga Lake (O)	S(SB)
	Najas minor	minor naiad	Eurasia	1932	Lake Cardinal (E)	R(D)
Marsh Plants						
Chenopodiaceae	*Chenopodium glaucum*	oak leaved goose foot	Eurasia	1867	Onondaga Lake (O)	RH
Caryophyllaceae	*Stellaria aquatica*	giant chickweed	Eurasia	1894	Lake St. Clair	unknown
Polygonaceae	*Polygonum caespitosum var. longisetum*	bristly lady's thumb	Asia	1960	Ohio (E)	unknown
	Polygonum persicaria	lady's thumb	Eurasia	<1843	widespread	unknown
	Rumex longifolius	yard dock	Eurasia	1901	Isle Royale (S)	R(C)
	Rumex obtusifolius	bitter dock	Eurasia	<1840	widespread	unknown
Brassicaceae	*Rorippa sylvestris*	creeping yellow cress	Eurasia	1884	Rochester, NY (O)	S(SB)
Primulaceae	*Lysimachia nummularia*	moneywort	Eurasia	1882	central NY (O)	R(C)
	Lysimachia vulgaris	garden loosestrife	Eurasia	1913	central NY (O)	R(C)
Lythraceae	*Lythrum salicaria*	purple loosestrife	Eurasia	1869	Ithaca, NY (O)	C, S(SB)
Onagraceae	*Epilobium hirsutum*	great hairy willow herb	Eurasia	1874	Ithaca, NY (O)	R(A), S(SB)
	Epilobium parviflorum	small flowered hairy willow herb	Eurasia	1966	Benzie Co., MI (M)	unknown
Apiaceae	*Conium maculatum*	poison hemlock	Eurasia	<1843	widespread	R(C)
Solanaceae	*Solanum dulcamara*	bittersweet nightshade	Eurasia	<1843	widespread	R(C)
Boraginaceae	*Myosotis scorpioides*	true forget-me-not	Eurasia	1886	central NY (O)	R(C)
Lamiaceae	*Lycopus asper*	western water horehound	Mississippi	1892	Lake Erie	R(A)
	Lycopus europaeus	European water horehound	Eurasia	1903	Lake Ontario	S(SB)
	Mentha gentilis	creeping whorled mint	Eurasia	1915	central NY (O)	R(C)
	Mentha piperita	peppermint	Eurasia	<1843	widespread	R(C)
	Mentha spicata	spearmint	Eurasia	<1843	widespread	R(C)
Scrophulariaceae	*Veronica beccabunga*	European brooklime	Eurasia	1915	Monroe Co., NY (O)	S(SB)

Mechanism codes: Deliberate release R(D); Unintentional release R(I); Aquarium release R(AQ); Cultivation release R(C); Fish release R(F); Accidental release R(A); Ballast water S(BW); Solid ballast S(SB); Fouling S(F); Canals (C); Railroads and Highways (RH)

Table 2 (Continued). Origin, date and location of first sighting, and entry mechanism(s) for non-indigenous aquatic plants and algae of the Great Lakes

Taxon	Species	Common Name	Origin	Date	Location	Mechanism
Asteraceae	*Cirsium palustre*	marsh thistle	Eurasia	<1950	Lake Superior	unknown
	Pluchea odorata					
	var. succulenta	salt-marsh fleabane	Atlantic	<1950	central NY (O)	unknown
	var. purpurescens	salt-marsh fleabane	Atlantic	1916	Lake Erie (t)	R(A)
	Solidago sempervirens	seaside goldenrod	Atlantic	1969	Chicago (M)	R(A)
	Sonchus arvensis	field sow thistle	Eurasia	1865	central NY	R(A)
	Sonchus arvensis					
	var. glabrescens	smooth field sow thistle	Eurasia	1902	Ohio (E)	R(A)
Butomaceae	*Butomus umbellatus*	flowering rush	Eurasia	<1930	Detroit River (E)	S(SB)
Balsaminaceae	*Impatiens glandulifera*	Indian balsam	Asia	1912	Port Huron (H)	R(C)
Juncaceae	*Juncus compressus*	flattened rush	Eurasia	<1895	Cayuga Lake (O)	R(A)
	Juncus gerardii	black-grass rush	Atlantic	1862	Chicago	S(SB)
	Juncus inflexus	rush	Eurasia	1922	central, NY	unknown
Cyperaceae	*Carex acutiformis*	swamp sedge	Eurasia	1951	St. Joseph Lake (M)	unknown
	Carex disticha	sedge	Eurasia	1866	Belleville, Ontario (O)	S(SB)
	Carex flacca	sedge	Eurasia	1896	Detroit River	unknown
Poaceae	*Agrostis gigantea*	redtop	Eurasia	1884	Ontario (S)	R(C)
	Alopecurus geniculatus	water foxtail	Eurasia	1882	Lake Erie	R(C)
	Echinochloa crusgalli	barnyard grass	Eurasia	<1843	widespread	R(C), S(SB)
	Glyceria maxima	reed sweet-grass	Eurasia	1940	Lake Ontario	R(C), S(SB)
	Poa trivialis	rough-stalked meadow grass	Eurasia	<1843	widespread	R(C), S(SB)
	Puccinellia distans	weeping alkali grass	Eurasia	1893	Montezuma, NY (O)	S(SB), RH
Sparganiaceae	*Sparganium glomeratum*	bur reed	Eurasia	1936	Lake Superior	unknown
Typhaceae	*Typha angustifolia*	narrow leaved cattail	Eurasia	1880s	central NY (O)	C, R(A)
Iridaceae	*Iris pseudacorus*	yellow flag	Eurasia	1886	Ithaca, NY (O)	R(C)
Shoreline Trees and Shrubs						
Betulaceae	*Alnus glutinosa*	black alder	Eurasia	<1913	widespread	R(C)
Salicaceae	*Salix alba*	white willow	Eurasia	<1886	widespread	R(C)
	Salix fragilis	crack willow	Eurasia	<1886	widespread	R(C)
	Salix purpurea	purple willow	Eurasia	<1886	widespread	R(C)
Rhamnaceae	*Rhamnus frangula*	glossy buckthorn	Eurasia	<1913	Ontario	R(C)

Mechanism codes: Deliberate release R(D); Unintentional release R(I); Aquarium release R(AQ); Cultivation release R(C); Fish release R(F); Accidental release R(A);
Ballast water S(BW); Solid ballast S(SB); Fouling S(F); Canals (C); Railroads and Highways (RH)

Appendix 1 — Brief Description of the Indicators List

Note: The numbers following the indicator name are a means of identifying the indicator in the electronic database.

Open and Nearshore Waters Indicators

State Indicators

Fish Habitat (Indicator #6)

This indicator will assess the quality and amount of aquatic habitat in the Great Lakes ecosystem, and it will be used to infer progress in rehabilitating degraded habitat and associated aquatic communities.

Salmon and Trout (Indicator #8)

This indicator will show trends in populations of introduced trout and salmon populations, and it will be used to evaluate the potential impacts on native trout and salmon populations and the preyfish populations that support them.

Walleye and *Hexagenia* (Indicator #9)

This indicator will show the status and trends in walleye and *Hexagenia* populations, and it will be used to infer the basic structure of warm-coolwater predator and prey communities, the health of percid populations, and the health of the Great Lakes ecosystem.

Preyfish Populations (Indicator #17)

This indicator will assess the abundance and diversity of preyfish populations, and it will be used to infer the stability of predator species necessary to maintain the biological integrity of each lake.

Native Unionid Mussels (Indicator #68)

This indicator will assess the population status of native Unionid populations, and it will be used to infer the impact of the invading Dreissenid mussel on the Unionid mussel.

Lake Trout and Scud (*Diporeia hoyi*) (Indicator #93)

This indicator will show the status and trends in lake trout and *D. hoyi* populations, and it will be used to infer the basic structure of coldwater predator and prey communities and the general health of the ecosystem.

Deformities, Eroded Fins, Lesions and Tumors in Nearshore Fish (Indicator #101)

This indicator will assess the combination of deformities, eroded fins, lesions and tumors (DELT index) in nearshore fish, and it will be used to infer areas of degraded habitat within the Great Lakes.

Benthos Diversity and Abundance (Indicator #104)

This indicator will assess species diversity and abundance in the aquatic oligochaete community, and it will be used to infer the relative health of the benthic community.

Phytoplankton Populations (Indicator #109)

This indicator will assess the species and size composition of phytoplankton populations in the Great Lakes, and it will be used to infer the impact of nutrient enrichment, contamination and invasive exotic predators on the Great Lakes ecosystem.

Zooplankton Populations (Indicator #116)

This indicator will assess characteristics of the zooplankton community, and it will be used over time to infer changes in vertebrate or invertebrate predation, system productivity, energy transfer within the Great Lakes, or other food web dynamics.

Sediment Available for Coastal Nourishment (Indicator #8142) (formerly called Stream Flow and Sediment Discharge) - *also a Nearshore Terrestrial indicator*

This indicator will assess the amount of water and suspended sediment entering the Great Lakes through major tributaries and connecting channels, and it will be used to estimate the amount of sediment available for transport to nourish coastal ecosystems.

Pressure Indicators

Sea Lamprey (Indicator #18)

This indicator will estimate sea lamprey abundance and assess their impact on other fish populations in the Great Lakes.

Phosphorus Concentrations and Loadings (Indicator #111)

This indicator will assess the total phosphorus levels in the Great Lakes, and it will be used to support the evaluation of trophic status and food web dynamics in the Great Lakes.

Contaminants in Young-of-the-Year Spottail Shiners (Indicator #114)

This indicator will assess the levels of PBT chemicals in young-of-the-year spottail shiners, and it will be used to infer local areas of elevated contaminant levels and potential harm to fish-eating wildlife.

Contaminants in Colonial Nesting Waterbirds (Indicator #115)

This indicator will assess chemical concentration levels in a representative colonial waterbird, and it will be used to infer the impact of these contaminants on colonial waterbird physiology and population characteristics.

Atmospheric Deposition of Toxic Chemicals (Indicator #117)

This indicator will estimate the annual average loadings of priority toxic chemicals from the atmosphere to the Great Lakes, and it will be used to infer potential impacts of toxic chemicals from atmospheric deposition 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.

Toxic Chemical Concentrations in Offshore Waters (Indicator #118)

This indicator will assess the concentration of priority toxic chemicals in offshore waters, and it will be used to infer the potential impacts of toxic chemicals 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.

Concentrations of Contaminants in Sediment Cores (Indicator #119)

This indicator will assess the concentrations of IJC priority toxic chemicals in sediments, and it will be used to infer potential harm to aquatic ecosystems by contaminated sediments, as well as to infer the progress of various Great Lakes programs toward virtual elimination of toxics from the Great Lakes.

Contaminant Exchanges between Media: Air to Water and Water to Sediment (Indicator #120)

This indicator will estimate the loadings of IJC priority pollutants to the Great Lakes, and it will be used to infer the potential harm these contaminants pose to human, animal and aquatic life within the Great Lakes, as well as to infer the progress of various Great Lakes programs toward virtual elimination of toxics from the Great Lakes.

Wastewater Pollution (Indicator #7059)

This indicator will assess the loadings of wastewater pollutants discharged into the Great Lakes basin, and it will be used to infer inefficiencies in human economic activity (i.e., wasted resources) and the potential adverse impacts to human and ecosystem health.

Coastal Wetland Indicators

State Indicators

Coastal Wetland Invertebrate Community Health (Indicator #4501)

This indicator will assess the diversity of the invertebrate community, especially aquatic insects, and it will be used to infer habitat suitability and biological integrity of Great Lakes coastal wetlands.

Coastal Wetland Fish Community Health (Indicator #4502)

This indicator will assess the fish community diversity, and it will be used to infer habitat suitability for Great Lakes coastal wetland fish communities.

Deformities, Eroded Fins, Lesions and Tumours (DELT) in Coastal Wetland Fish (Indicator #4503)

This indicator will assess the combination of deformities, eroded fins, lesions and tumors (DELT index) in coastal wetlands, and it will be used to infer ecosystem health of Great Lakes coastal wetlands.

Amphibian Diversity and Abundance (Indicator #4504)

This indicator will assess the species composition and relative abundance of frogs and toads, and it will be used to infer the condition of coastal wetland habitat as it relates to the health of this ecologically important component of wetland communities.

Wetland-Dependent Bird Diversity and Abundance (Indicator #4507)

This indicator will assess the wetland bird species composition and relative abundance, and it will be used to infer the condition of coastal wetland habitat as it relates to the health of this ecologically and culturally important component of wetland communities.

Coastal Wetland Area by Type (Indicator #4510)

This indicator will assess the periodic changes in area (particularly losses) of coastal wetland types, taking into account natural variations.

Presence, Abundance and Expansion of Invasive Plants (Indicator #4513)

This indicator will assess the decline of vegetative diversity associated with an increase in the presence, abundance, and expansion of invasive plants, and it will be used as a surrogate measure of the quality of coastal wetlands which are impacted by coastal manipulation or input of sediments.

Pressure Indicators

Contaminants in Snapping Turtle Eggs (Indicator #4506)

This indicator will assess the accumulation of organochlorine chemicals and mercury in snapping turtle eggs, and it may be used to infer the extent of organochlorine chemicals and mercury in food webs of Great Lakes coastal wetlands.

Sediment Flowing into Coastal Wetlands (Indicator #4516)

This indicator will assess the sediment load to coastal wetlands and its potential impact on wetland health.

Nitrate and Total Phosphorus Into Coastal Wetlands (Indicator #4860)

This indicator will assess the amount of nitrate and total phosphorus flowing into Great Lakes coastal wetlands, and it will be used to infer the human influence on nutrient levels in the wetlands.

Effect of Water Level Fluctuations (Indicator #4861) - *also a Nearshore Terrestrial indicator*

This indicator will assess the lake level trends that may significantly affect components of wetland and nearshore terrestrial ecosystems, and it will be used to infer the effect of water level regulation on emergent wetland extent.

Human Activity (Response) Indicators

Gain in Restored Coastal Wetland Area by Type (Indicator #4511)

This indicator will assess the amount of restored wetland area, and it will be used to infer the success of conservation and rehabilitation efforts.

Nearshore Terrestrial Indicators (within 1 kilometer of shore)

State Indicators

Indicators related to habitats:

Extent and Quality of Nearshore Natural Land Cover (Indicator #8136)

This indicator will assess the amount of natural land cover that falls within 1 km of the shoreline, and it will be used to infer the potential impact of artificial coastal structures, including primary and secondary home development, on the extent and quality of nearshore terrestrial ecosystems in the Great Lakes.

Indicators related to health and stability of ecological communities/species:
Area, Quality, and Protection of Special Lakeshore Communities (Indicator #8129)

This indicator will assess the changes in area and quality of the twelve special lakeshore communities, and it will be used to infer the success of management activities associated with the protection of some of the most ecologically significant habitats in the Great Lakes terrestrial nearshore.

Nearshore Land Use (Indicator #8132)

This indicator will assess the types and extent of major land uses within 1 km from shore, and it will be used to identify real or potential impacts of land use on significant natural features or processes, particularly on the twelve special lakeshore communities.

Nearshore Species Diversity and Stability (Indicator #8137)

This indicator will assess the composition and abundance of plant and wildlife species over time within the nearshore area, and it will be used to infer adverse effects on the nearshore terrestrial ecosystem due to stresses such as climate change and/or increasing land use intensity.

Pressure Indicators

Indicators related to physical stressors:
Effects of Water Level Fluctuations (Indicator #4861) - *also a Coastal Wetland indicator*

This indicator will assess the lake level trends that may significantly affect components of wetland and nearshore terrestrial ecosystems, and it will be used to infer the effect of water level regulation on emergent wetland extent.

Extent of Hardened Shoreline (Indicator #8131)

This indicator will assess the amount of shoreline habitat altered by the construction of shore protection, and it will be used to infer the potential harm to aquatic life in the nearshore as a result of conditions (e.g., shoreline erosion) created by habitat alteration.

Artificial Coastal Structures (Indicator #8146)

This indicator will assess the number of artificial coastal structures on the Great Lakes, and it will be used to infer potential harm to coastal habitat by disruption of sand transport.

Indicators related to biological stressors:
Nearshore Plant and Animal Problem Species (Indicator #8134)

This indicator will assess the type and abundance of plant and wildlife problem species in landscapes bordering the Great Lakes, and it will be used to identify the potential for disruption of nearshore ecological processes and communities.

Indicators related to chemical stressors:
Contaminants Affecting Productivity of Bald Eagles (Indicator #8135)

This indicator will assess 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.

Contaminants Affecting the American Otter (Indicator #8147)

This indicator will assess the contaminant concentrations found in American otter populations within the Great Lakes basin, and it will be used to infer the presence and severity of contaminants in the aquatic food web of the Great Lakes.

Human Activity (Response) Indicators

Community / Species Plans (Indicator #8139)

This indicator will assess the number of plans that are needed, developed, and implemented to protect, maintain or restore high quality, natural nearshore communities and federally listed endangered, threatened, and vulnerable species. This indicator will be used to infer the degree of human stewardship toward these communities and species.

Shoreline Management Under Integrated Management Plans (Indicator #8141)

This indicator will assess the amount of Great Lakes shoreline managed under an integrated management plan, and it will be used to infer the degree of stewardship of shoreline processes and habitat.

Protected Nearshore Areas (Indicator #8149)

This indicator will assess the kilometers/miles of shoreline in six classes of protective status. This information will be used to infer the preservation and restoration of habitat and biodiversity, the protection of adjacent nearshore waters from physical disturbance and undesirable inputs (nutrients and toxics), and the preservation of essential habitat links in the migration (lifecycle) of birds and butterflies.

Land Use Indicators

State Indicators

Urban Density (Indicator #7000)

This indicator will assess the human population density in the Great Lakes basin, and it will be used to infer the degree of inefficient land use and urban sprawl for communities in the Great Lakes ecosystem.

Habitat Adjacent to Coastal Wetlands (Indicator #7055)

This indicator will provide an index of the quality of adjoining upland habitat which can have a major effect on wetland biota, many of which require upland habitat for part of their life cycle.

Habitat Fragmentation (Indicator #8114)

This indicator will assess the amount and distribution of natural habitat remaining within Great Lakes ecoregions, and it will be used to infer the effect of human land uses such as housing, agriculture, flood control, and recreation on habitat needed to support fish and wildlife species.

Pressure Indicators

Land Conversion (Indicator #7002)

This indicator will assess the changes in land use within the Great Lakes basin, and it will be used to infer the potential impact of land conversion on Great Lakes ecosystem health.

Mass Transportation (Indicator #7012)

This indicator will assess the percentage of commuters using public transportation, and it will be used to infer the stress to the Great Lakes ecosystem caused by the use of the private motor vehicle and its resulting high resource utilization and pollution creation.

Human Activity (Response) Indicators

Brownfield Redevelopment (Indicator #7006)

This indicator will assess the acreage of redeveloped brownfields, and it will be used over time to evaluate the rate at which society rehabilitates and reuses former developed land sites that have been degraded by poor use.

Sustainable Agricultural Practices (Indicator #7028)

This indicator will assess the number of Environmental and Conservation farm plans, and it will be used to infer environmentally friendly practices in place, such as integrated pest management to reduce the unnecessary use of pesticides, zero tillage and other soil preservation practices to reduce energy consumption, and prevention of ground and surface water contamination.

Green Planning Process (Indicator #7053)

This indicator will assess the number of municipalities with environmental and resource conservation management plans in place, and it will be used to infer the extent to which municipalities utilize environmental standards to guide their management decisions with respect to land planning, resource conservation, and natural area preservation.

Human Health Indicators

State Indicators

Geographic Patterns and Trends in Disease Incidence (Indicator #4179)

This indicator will assess geographical and temporal patterns in disease incidences in the Great Lakes basin population, and it will also be used to identify areas where further investigation of the exposure and effects of environmental pollutants on human health is needed.

Pressure Indicators

Indicators of Exposure

Contaminants in Recreational Fish (Indicator #0113)

This indicator will assess the levels of PBT chemicals in fish, and it will be used to infer the potential harm to human health through consumption of contaminated fish.

E. coli and Fecal Coliform Levels in Nearshore Recreational Waters (Indicator #4081)

This indicator will assess fecal coliform contaminant levels in nearshore recreational waters, acting as a surrogate indicator for other pathogen types, and it will be used to infer potential harm to human health through body contact with nearshore recreational waters.

Contaminants in Edible Fish Tissue (Indicator #4083)

This indicator will assess the concentration of persistent, bioaccumulating, toxic (PBT) chemicals in Great Lakes fish, and it will be used to infer the potential exposure of humans to PBT chemicals through consumption of Great Lakes fish caught via sport and subsistence fishing.

Chemical Contaminant Intake From Air, Water, Soil and Food (Indicator #4088)

This indicator will estimate the daily intake of PBT chemicals from all sources, and it will be used to evaluate the potential harm to human health and the efficacy of policies and technology intended to reduce PBT chemicals.

Drinking Water Quality (Indicator #4175)

This indicator will assess the chemical and microbial contaminant levels in drinking water, and it will be used to evaluate the potential for human exposure to drinking water contaminants and the efficacy of policies and technologies to ensure safe drinking water.

Air Quality (Indicator #4176)

This indicator will monitor the air quality in the Great Lakes ecosystem, and it will be used to infer the potential impact of air quality on human health in the Great Lakes basin.

Chemical Contaminants in Human Tissue (Indicator #4177)

This indicator will assess the concentration of PBT chemicals in human tissues, and it will be used to infer the efficacy of policies and technology to reduce PBT chemicals in the Great Lakes ecosystem.

Radionuclides (Indicator #4178)

This indicator will assess the concentrations of artificial radionuclides in cow's milk, surface water, drinking water, and air, and it will be used to estimate the potential for human exposure to artificial radionuclides.

Societal Indicators

State Indicators

Aesthetics (Indicator #7042)

This indicator will assess the amount of waste and decay around human activities in the Great Lakes basin, and it will be used to infer the degree to which human activities are conducted in an efficient and ordered fashion consistent with ecosystem harmony and integrity.

Economic Prosperity (Indicator #7043)

This indicator will assess the unemployment rates within the Great Lakes basin, and it will be used in association with other Societal indicators to infer the capacity for society in the Great Lakes region to make decisions that will benefit the Great Lakes ecosystem.

Pressure Indicators

Water Withdrawal (Indicator #7056)

This indicator will assess the amount of water used in the Great Lakes basin per capita, and it will be used to infer the amount of wastewater generated and the demand for resources to pump and treat water.

Energy Consumption (Indicator #7057)

This indicator will assess the amount of energy consumed in the Great Lakes basin per capita, and it will be used to infer the demand for resource use, the creation of waste and pollution, and stress on the ecosystem.

Solid Waste Generation (Indicator #7060)

This indicator will assess the amount of solid waste generated per capita in the Great Lakes basin, and it will be used to infer inefficiencies in human economic activity (i.e., wasted resources) and the potential adverse impacts to human and ecosystem health.

Human Activity (Response) Indicators

Capacities of Sustainable Landscape Partnerships (Indicator #3509) - *unreviewed*

This indicator assesses the organizational capacities required of local coalitions to act as full partners in ecosystem management initiatives. It includes the enumeration of public-private partnerships relating to the pursuit of sustainable ecosystems through environmental management, staff, and annual budgets.

Organizational Richness of Sustainable Landscape Partnerships (Indicator #3510) - *unreviewed*

This indicator assesses the diversity of membership and expertise included in partnerships. Horizontal integration is a description of the diversity of partnerships required to address local issues, and vertical integration is the description of federal and state/provincial involvement in place-based initiatives as full partners.

Integration of Ecosystem Management Principles Across Landscapes (Indicator #3511) - *unreviewed*

This indicator describes the extent to which federal, state/provincial, and regional governments and agencies have endorsed and adopted ecosystem management guiding principles in place-based resource management programs.

Integration of Sustainability Principles Across Landscapes (Indicator #3512) - *unreviewed*

This indicator describes the extent to which federal, state/provincial, and regional governments and agencies have endorsed and adopted sustainability guiding principles in place-based resource management programs.

Citizen/Community Place-Based Stewardship Activities (Indicator #3513) - *unreviewed*

Community activities that focus on local landscapes/ecosystems provide a fertile context for the growth of the stewardship ethic and the establishment of a "a sense of place." This indicator, or suite of indicators, will reflect the number, vitality and effectiveness of citizen and community stewardship activities.

Financial Resources Allocated to Great Lakes Programs (Indicator #8140)

This indicator will assess the amount of dollars spent annually on Great Lakes programs, and it will be used to infer the responsiveness of Great Lakes programs through annual funding focused on research, monitoring, restoration, and protection of Great Lakes ecosystems by federal and state/provincial agencies and non-governmental organizations.

Unbounded Indicators

State Indicators

Breeding Bird Diversity and Abundance (Indicator #8150)

This indicator will assess the status of breeding bird populations and communities, and it will be used to infer the health of breeding bird habitat in the Great Lakes basin.

Threatened Species (Indicator #8161)

This indicator will assess the number, extent and viability of threatened species, which are key components of biodiversity in the Great Lakes basin, and it will be used to infer the integrity of ecological processes and systems (e.g., sand accretion, hydrologic regime) within Great Lakes habitats.

Pressure Indicators

Global Warming: Number of Extreme Storms (Indicator #4519)

This indicator will assess the number of "extreme storms" each year, and it will be used to infer the potential impact on ecological components of the Great Lakes of increased numbers of severe storms due to climate change.

Global Warming: First Emergence of Water Lilies in Coastal Wetlands (Indicator #4857)

This indicator will assess the change over time in first emergence dates of water lilies in coastal wetlands as a sentinel of climate change affecting the Great Lakes.

Global Warming: Ice Duration on the Great Lakes (Indicator #4858)

This indicator will assess the temperature and accompanying physical changes to each lake over time, and it will be used to infer potential impact of climate change on wetlands.

Acid Rain (Indicator #9000)

This indicator will assess the pH levels in precipitation and critical loadings of sulphate to the Great Lakes basin, and it will be used to infer the efficacy of policies to reduce sulphur and nitrogen acidic compounds released to the atmosphere.

Appendix 2 — Relevancies (or Alternate Indicator Groupings)

The SOLEC list of indicators was developed according to the categories of open and nearshore waters, coastal wetlands, nearshore terrestrial, human health, land use, societal and unbounded. These groupings are convenient for SOLEC reporting, but they represent only one of many ways to organize information about the Great Lakes. Depending on the user's perspective, other groupings will be more convenient or will provide insight to aspects of the Great Lakes that differ from the SOLEC groupings.

Each of the proposed SOLEC indicators has been evaluated by the Indicators Group for relevance to several other organizational categories, and the results are displayed in the attached table. The categories include;

- Indicator Type. Based on the State-Pressure-Human Activity model, each SOLEC indicator has been assigned to the appropriate category. Measurements of contaminants in an environmental compartment are considered a pressure on the ecosystem rather than a measurement of a state condition. There are currently 28 State, 37 Pressure and 15 Human Activity indicators proposed.

- Environmental Compartments. This category sorts the SOLEC indicators by media, i.e., air (6), water (14), land (14), sediments (4), biota (21), fish (13), and humans (14). Fish have been separated from biota as a special case.

- Issues. Environmental management decisions often reflect an attempt to address an issue rather than a medium or geographic location. Specific issues that SOLEC indicators support include toxic contaminants (29), nutrients (12), exotic species (8), habitat (28), climate change (4), and stewardship (11).

- GLWQA Annexes. Several of the annexes of the GLWQA include monitoring and reporting requirements. The proposed SOLEC indicators currently address 10 of the 17 annexes. Annex 11 (Monitoring) is supported if an indicator supports any of the other annexes, and Annex 2 (LaMPs and RAPs) is supported if the indicators address any of the Beneficial Use Impairments.

- GLWQA Beneficial Use Impairments. Under Annex 2 of the GLWQA, fourteen Beneficial Use Impairments are listed for consideration by Lakewide Management Plans and Remedial Action Plans. The SOLEC indicators address to some extent 11 of the 14 listed use impairments.

- IJC Desired Outcomes. The IJC listed nine Desired Outcomes in its report *Indicators to Evalutate Progress under the Great Lakes Water Quality Agreement* (1996). SOLEC indicators address to some extent all nine Desired Outcomes. The many indicators with relevance to the outcomes of Biological Community Integrity and Diversity, and Physical Environment Integrity (including habitat) reflect SOLEC's emphasis on the biotic components of the Great Lakes ecosystem.

- Great Lakes Fish Community Objectives. A series of fish community objectives have been released or are being developed for each of the Great Lakes with the support of the Great Lakes Fishery Commission. Some SOLEC indicators specifically reflect the state of fish communities, and others address related habitat issues.

To facilitate cross referencing of the SOLEC indicators to the alternate categories, a section has been added to each indicator description (Appendix 1) that lists all the applicable categories. This matrix of alternate groupings of SOLEC indicators is also being incorporated into the SOLEC indicators database. Users will be able to retrieve the list of indicators associated with any of the sorting categories.

While the SOLEC indicators are intended to meet the criteria of necessary, sufficient and feasible for SOLEC reporting, no attempt has been made to evaluate the adequacy of the subset of SOLEC indicators that are relevant to any of the alternate organizing categories from the perspective of other users. For example, LaMPs and RAPs are expected to require a greater level of detail and geographic specificity to assess Beneficial Use Impairments than will be provided by the proposed SOLEC indicators. **Suggestions and comments on the relevance of the SOLEC indicators to these or other alternate categories are encouraged**.

ID#	Indicator Name	Indicator Type			Environmental Compartments							Great Lakes Issues						SOLEC Groupings[1]								GLWQA Annex[2]				
		State	Pressure	Human Activity	Air	Water	Land	Sediments	Biota (excluding fish & humans)	Fish	Humans	Contaminants & Pathogens	Nutrients	Exotics	Habitat	Climate Change	Stewardship	Open Waters	Nearshore Waters	Coastal Wetlands	Nearshore Terrestrial	Land Use	Human Health	Societal	Unbounded	1 Spec Objctvs	2 LaMPs / RAPs / BUIs	3 Phosphorus	4 Oil - Vessels	5 Wastes - Vessels
Nearshore and Open Waters Indicators																														
6	Fish Habitat	X				X				X					X			X	X	X							X			
8	Salmon and Trout	X								X		X	X	X	X			X	X								X			
9	Walleye and Hexagenia	X							X	X		X	X	X	X			X	X								X			
17	Preyfish Populations	X								X		X	X	X	X			X	X								X			
18	Sea Lamprey		X							X				X				X	X								X			
68	Native Unionid Mussels	X							X					X				X	X	X							X			
93	Lake Trout and Scud *(Diporeia hoyi)*	X							X	X		X	X	X	X			X								X	X			
101	Deformities, Eroded Fins, Lesions and Tumors (DELT) in Nearshore Fish	X								X		X							X								X			
104	Benthos Diversity and Abundance	X							X			X	X		X			X	X	X							X			
109	Phytoplankton Populations	X							X			X	X	X				X	X								X	X		
111	Phosphorus Concentrations and Loadings		X			X							X					X	X	X						X	X	X		
114	Contaminants In Young-of-the-Year Spottail Shiners		X							X		X							X							X	o			
115	Contaminants in Colonial Nesting Waterbirds		X						X			X						X	X							X	X			
116	Zooplankton Populations	X							X			X	X	X				X	X								X			
117	Atmospheric Deposition of Toxic Chemicals		X		X	X						X						X									o			
118	Toxic Chemical Concentrations in Offshore Waters		X			X						X						X								X				
119	Concentrations of Contaminants in Sediments Cores		X					X				X						X	X								X			
120	Contaminant Exchanges Between Media: Air to Water, and Water to Sediment		X		X	X		X				X						X	X							X				
7059	Wastewater Pollution		X			X						X	X						X							X	X	X		
8142	Sediment Available for Coastal Nurishment	X				X		X							X				X		X						X			
Coastal Wetland Indicators																														
4501	Coastal Wetland Invertebrate Community Health	X							X						X					X							X			
4502	Coastal Wetland Fish Community Health	X								X				X	X					X							X			
4503	Deformities, Eroded Fins, Lesions and Tumors (DELT) in Coastal Wetland Fish	X								X		X								X							X			
4504	Amphibian Diversity and Abundance	X							X						X					X										
4506	Contaminants in Snapping Turtle Eggs		X						X			X								X						X				
4507	Wetland-Dependent Bird Diversity and Abundance	X							X						X					X							X			
4510	Coastal Wetland Area by Type	X				X	X								X					X							X			
4511	Gain in Restored Coastal Wetland Area by Type			X		X	X								X		X			X							X			
4513	Presence, Abundance & Expansion of Invasive Plants	X							X					X	X					X	X						X			
4516	Sediment Flowing Into Coastal Wetlands		X			X		X							X					X	X					X	X			

GLWQA Annex (con'd)												IJC Desired Outcomes									GLFC Objectives					Beneficial Use Impairments														
6 Shipping / Pollution	7 Dredging	8 Facilities	9 Contingency Plan	10 Hazard. Poll. List	11 Monitoring	12 Pers. Toxic Subs.	13 Non-point Sources	14 Contam. Sed's	15 Airborne Toxic Subs.	16 Groundwater	17 Res. & Devel.	1 Fishability	2 Swimmability	3 Drinkability	4 Healthy Humans	5 Economic Viability	6 Bio. Integ. & Divers.	7 Virt. Elim. PTS	8 Excess Phos.	9 Physical Env. Integ.	Ontario	Erie	Huron	Michigan	Superior	1 F&W Consumption	2 Tainting	3 F&W Pop's	4 Tumors	5 Deformities/Reprod.	6 Benthos	7 Dredging	8 Eutrophication	9 Drinking Water	10 Beach Closings	11 Aesthetics	12 Ag./ Indust. Costs	13 Phyto-/ Zoo-plankton	14 F&W Habitat	Totals
					X												X			X	X	X	X	X	X														X	17
					X												X				X		X	X	X			X												16
					X												X				X	X	X					X			X									17
					X												X				X	X	X	X	X			X												17
					X												X				X	X	X	X	X			X												14
					X												X														X									10
					X												X				X	X	X	X	X			X			X									19
					X	X											X	X											X											10
					X												X														X									12
					X												X		X																			X		13
					X		X										X		X			X											X	X		X		X		18
					X	X											X	X																						10
					X	X											X	X				X						X		X										14
					X												X																					X		11
					X	X			X		X							X																						11
					X	X												X																						8
	X				X	X		X										X													X	X								13
					X	X		X	X		X							X																						14
					X	X												X	X														X			X				14
					X															X																			X	10
					X		X										X			X											X									10
					X		X										X			X								X											X	12
					X	X	X				X						X	X											X											12
					X		X										X			X								X											X	10
					X	X	X											X																						9
					X												X			X								X											X	10
					X		X										X			X																			X	11
					X		X										X			X																			X	12
					X		X										X																						X	11
					X		X													X																			X	12

ID#	Indicator Name	Indicator Type			Environmental Compartments							Great Lakes Issues						SOLEC Groupings[1]								GLWQA Annex[2]				
		State	Pressure	Human Activity	Air	Water	Land	Sediments	Biota (excluding fish & humans)	Fish	Humans	Contaminants & Pathogens	Nutrients	Exotics	Habitat	Climate Change	Stewardship	Open Waters	Nearshore Waters	Coastal Wetlands	Nearshore Terrestrial	Land Use	Human Health	Societal	Unbounded	1 Spec Objctvs	2 LaMPs / RAPs / BUIs	3 Phosphorus	4 Oil - Vessels	5 Wastes - Vessels
4860	Nitrate and Total Phosphorus Into Coastal Wetlands		X			X							X							**X**							X	X		
4861	Effect of Water Level Fluctuations		X			X									X	X				**X**	**X**						X			
Nearshore Terrestrial Indicators[3]																														
8129	Area, Quality, and Protection of Lakeshore Communities	X					X		X						X		X				**X**						X			
8131	Extent of Hardened Shoreline		X				X								X						**X**	X					X			
8132	Nearshore Land Use	X					X								X						**X**	X					X			
8134	Nearshore Plant and Animal Problem Species		X						X					X	X						**X**						X			
8135	Contaminants Affecting Productivity of Bald Eagles		X						X			X						X	X		**X**						X			
8136	Extent and Quality of Nearshore Natural Land Cover	X					X								X						**X**						X			
8137	Nearshore Species Diversity and Stability	X							X					X							**X**						X			
8139	Community / Species Plans			X					X								X				**X**			X						
8141	Shoreline Managed Under Integrated Management Plans			X			X										X				**X**	X		X						
8146	Artificial Coastal Structures		X				X								X				X		**X**						X			
8147	Contaminants Affecting the American Otter		X						X			X								X	**X**					X	X			
8149	Protected Nearshore Areas			X			X								X		X				**X**			X			X			
Land Use Indicators																														
7000	Urban Density	X					X															**X**								
7002	Land Conversion		X				X															**X**								
7006	Brownfield Redevelopment			X			X										X					**X**								
7012	Mass Transportation		X		X		X									X	X					**X**								
7028	Sustainable Agricultural Practices			X			X										X					**X**					X	X		
7053	Green Planning Process			X		X	X										X					**X**		X						
7055	Habitat Adjacent to Coastal Wetlands	X					X								X					X	X	**X**					X			
8114	Habitat Fragmentation	X					X								X							**X**					X			
Human Health Indicators																														
113	Contaminants in Recreational Fish		X							X		X						X	X				**X**			X	X			
4081	*E. coli* and Fecal Coliform Levels in Nearshore Recreational Waters		X			X			X			X							X				**X**			X	X			
4083	Contaminants in Edible Fish Tissue		X							X		X						X	X				**X**			X	X			
4088	Chemical Contaminant Intake from Air, Water, Soil and Food		X								X	X											**X**							
4175	Drinking Water Quality		X			X						X	X					X	X				**X**			X	X			
4176	Air Quality		X		X							X											**X**			X	o			
4177	Chemical Contaminants in Human Tissue		X								X	X											**X**			X				
4178	Radionuclides		X		X	X			X			X											**X**			X				

GLWQA Annex (con'd)												IJC Desired Outcomes									GLFC Objectives					Beneficial Use Impairments														
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					X		X												X														X							10
					X						X						X			X																			X	12
					X												X			X																			X	11
					X															X																			X	9
					X												X			X																			X	10
					X						X						X			X								X											X	12
					X	X					X						X	X										X		X										14
					X												X			X																			X	9
					X												X											X												8
																	X																							6
																																								6
					X															X																			X	9
					X	X					X						X	X										X		X										14
					X												X			X																			X	11
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					X		X													X																				6
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					X				X											X																				9
					X	X	X												X	X													X						X	13
							X													X																				8
					X		X													X																			X	11
																	X			X																			X	8
					X	X						X			X		X	X			X	X	X	X	X	X														20
					X		X						X		X																				X					13
					X	X						X			X		X	X			X	X	X	X	X	X														20
					X	X									X			X																						8
					X	X				X				X	X																			X						15
					X		X		X						X																									10
					X	X					X				X			X																						10
					X						X				X																									10

ID#	Indicator Name	Indicator Type			Environmental Compartments							Great Lakes Issues						SOLEC Groupings[1]								GLWQA Annex[2]				
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4179	Geographic Patterns and Trends in Disease Incidence	X									X												**X**							
Societal Indicators																														
3509	Capacities of Sustainable Landscape Partnerships			X							X						X							**X**						
3510	Organizational Richness of Sustainable Landscape Partnerships			X							X						X							**X**						
3511	Integration of Ecosystem Management Principles Across Landscapes			X							X						X							**X**						
3512	Integration of Sustainability Principles Across Landscapes			X							X						X							**X**						
3513	Citizen/Community Place-Based Stewardship Activities			X							X						X							**X**						
7042	Aesthetics	X									X						X							**X**			X			
7043	Economic Prosperity	X																						**X**						
7056	Water Withdrawal		X			X					X						X					X		**X**						
7057	Energy Consumption		X		X						X					X	X					X		**X**						
7060	Solid Waste Generation		X		X		X				X	X				X	X							**X**						
8140	Financial Resources Allocated to Great Lakes Programs			X							X						X							**X**						
Unbounded Indicators																														
4519	Climate Change: Number of Extreme Storms		X		X											X				X	X				**X**					
4857	Climate Change: First Emergence of Water Lily Blossoms in Coastal Wetlands		X						X							X				X					**X**					
4858	Climate Change: Ice Duration on the Great Lakes		X			X										X		X	X	X					**X**					
8150	Breeding Bird Diversity and Abundance	X							X						X										**X**		X			
8161	Threatened Species	X							X	X				X	X										**X**		X			
9000	Acid Rain		X		X	X	X					X													**X**	X				
9002	Exotic Species		X						X	X				X											**X**					
79	COUNT	30	36	13	9	19	19	4	24	14	13	29	11	14	27	7	19	21	24	21	18	13	9	15	7	18	49	5	0	0

[1] Bold **X** designates the primary SOLEC Grouping for each indicator

[2] o = Some LaMPs /RAPs are incorporating these measures into their plans even though the indicators do not have an associated BUI

[3] #8142 Sediment Available for Coastal Nurishment and #4861 Water Level Fluctuations are also co-grouped with Nearshore Terrestrial Indicators

GLWQA Annex (con'd)												IJC Desired Outcomes									GLFC Objectives					Beneficial Use Impairments														
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											X				X																									5
																																								4
																																								4
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																																								4
					X																															X				7
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					X												X			X								X											X	10
					X						X						X			X								X											X	13
					X				X											X																				10
																																								5
0	1	0	0	0	58	19	17	2	6	1	11	2	1	1	9	1	37	17	5	30	8	9	8	7	7	2	0	15	2	3	6	1	4	2	1	3	0	3	22	