Sea Lamprey

Indicator #18

Assessment: Good/Fair, Improving

Purpose

- To estimate the abundance of sea lamprey as an indicator of the status of this invasive species; and
- To infer the damage sea lamprey cause to the fish communities and aquatic ecosystems of the Great Lakes.

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*" (GLFC 1955). Under the Joint Strategic Plan for Great Lakes Fisheries, all fishery management agencies established Fish Community Objectives (FCOs) for each of the lakes. These FCOs call for suppressing sea lamprey populations to levels that cause only insignificant mortality of fish in order to achieve objectives for lake trout and other members of the fish community (Horns *et al.* 2003, Eshenroder *et al*. 1995, DesJardin *et al.* 1995, Ryan *et al.* 2003., Stewart *et al***.** 1999).

The GLFC and fishery management agencies have agreed on target abundance levels for sea lamprey populations that correspond to the FCOs (Table 1). Targets were derived from available estimates of the abundance of spawning-phase sea lampreys and from data on wounding rates on lake trout. Suppressing sea lampreys to abundances within the target range is predicted to result in tolerable mortality on lake trout and other fish species.

Lake	FCO Sea Lamprey Abundance Targets	Target Range (+/- 95% Confidence Interval)
Superior	35,000	18,000
Michigan	58,000	13,000
Huron	74,000	20,000
Erie	3,000	1,000
Ontario	29,000	4,000

Table 1. Fish Community Objectives for sea lamprey abundance targets.
Source: Great Lakes Fishery Commission

State of the Ecosystem

Background

Populations of the native top predator, lake trout, and other fishes are negatively affected by mortality caused by sea lamprey. The first complete round of stream treatments with the lampricide TFM, as early as 1960 in Lake Superior, successfully suppressed sea lamprey to less than 10% of their pre-control abundance in all of the Great Lakes.

Mark and recapture estimates of the abundance of sea lamprey migrating up rivers to spawn are used as surrogates for the abundance of parasites feeding in the lakes during the previous year. Estimates of individual spawning runs in trappable streams are used to estimate lake-wide abundance using a new regression model that relates run size to stream characteristics (Mullett *et al*. 2003). Sea lamprey spend one year in the lake after metamorphosing, so this indicator has a two-year lag in demonstrating the effects of control efforts.

Status of Sea Lamprey

Annual lake-wide estimates of sea lamprey abundance since 1980, with 95% confidence intervals, are presented in Figure 1. The FCO targets and ranges also are included for each lake.

Lake Superior: During the past 20 years, populations have fluctuated but remain at levels less than 10% of peak abundance (Heinrich *et al. 2003*). Abundances were within the FCO target range during the late 1980s and mid-1990s. Abundances have trended upward from a low during 1994 and have been above the target range from 1999-2003. These recent increases in abundance have raised concern in all waters. Rates of sea lamprey markings on fish have shown the same pattern of increase. These increases appear to be most dramatic in the Nipigon Bay and north-western portion of the lake and in the Whitefish Bay area in the south-eastern portion of the lake. Survival objectives for lake trout continue to be met but lake trout populations could be threatened if these increases continue. In response to this increased abundance of sea lampreys, stream treatments with lampricides were increased beginning in 2001 through 2004. The effects of the increased treatments during 2001 may have contributed to the downward trend in the 2003 observation. The effects of additional stream treatments in 2002 and beyond will be observed in the spawning-run estimates during 2004 and following years.

Lake Michigan: The population of sea lamprey has shown a continuing, slow trend upward since 1980 (Lavis *et al*. 2003). The population was at or below the FCO target range until 2000. The marking rates on lake trout have shown the same upward trend past target levels during the recent years. Increases in abundance during the 1990s had been attributed to the St. Marys River. The continuing trend in recent years suggests sources of sea lamprey in Lake Michigan itself. Stream treatments were increased beginning in 2001 through 2004. This increase included treatment of newly discovered populations in lentic areas and treatment of the Manistique River, a large system where the deterioration of a dam near the mouth allowed sea lamprey access to nursery habitat. The 2003 spawning-phase population estimate did not show any decrease as a result of the increased treatments during 2001.

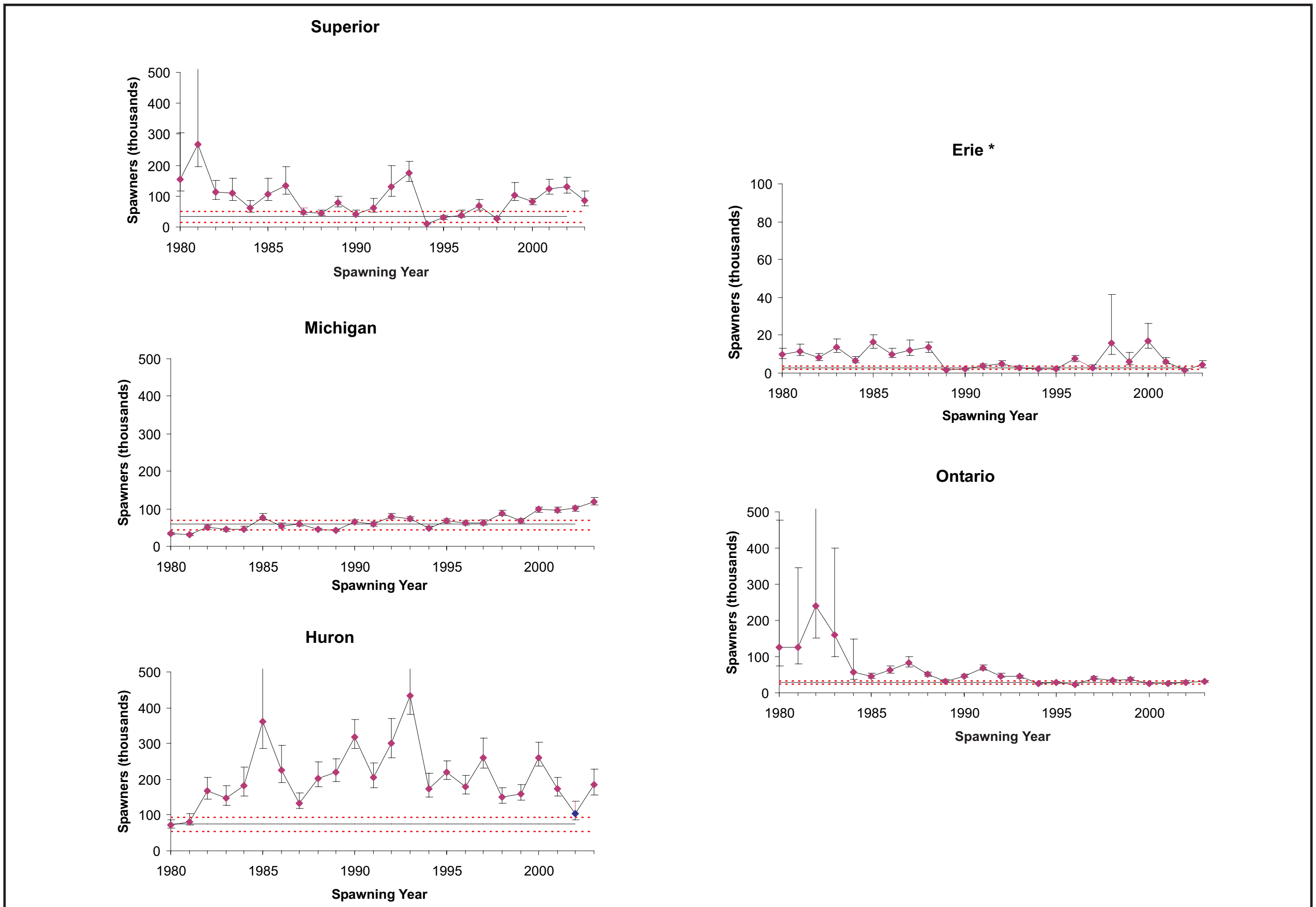

Figure 1. Total abundance of sea lampreys estimated during the spawning migration. Solid line and dashed line represent FCO target abundance and ranges, respectively.
*Note: the scale for Lake Erie is 1/5 that of the other four Lakes.
Source: Great Lakes Fishery Commission

Lake Huron: The first full round of stream treatments during the late 1960s suppressed sea lamprey populations to levels less than 10% of those before control (Morse *et al.* 2003). During the early 1980s, abundance increased in Lake Huron, particularly the northern portion of the lake, peaking in 1993. Through the 1990s there were more sea lampreys in Lake Huron than all the other lakes combined. FCOs were not being achieved. The damage caused by this large population of parasites was so severe that the Lake Huron Committee abandoned its lake trout restoration objective in the northern portion of the lake during 1995. The St. Marys River was identified as the source of the increasing sea lamprey population. 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 formulation of a bottom-release lampricide, enhanced trapping of spawning animals, and sterile-male release, was initiated in 1997 (Schleen *et al.* 2003). As predicted, the spawning-phase abundance has been significantly lower since 2001 as a result of the completion of the first full round of lampricide spot treatments during 1999. However, the population shows considerable variation and it increased during 2003. Wounding rates and mortality estimates for lake trout have also declined during the last three years. The full effect of the St. Marys River control program will not be observed for another 2-4 years (Adams *et al.* 2003). The GLFC has repeated lampricide treatments in limited areas with high densities of larvae during 2003 and 2004. These additional treatments are aimed at continuing the decline in sea lamprey in Lake Huron.

Lake Erie: Following the completion of the first full round of stream treatments in 1987, sea lamprey populations collapsed (Sullivan *et al.* 2003). Marking rates on lake trout declined and lake trout survival increased to levels sufficient to meet the rehabilitation objectives in the eastern basin. However, during the mid-1990s, sea lamprey abundance increased to levels that threatened the lake trout restoration effort. A major assessment effort during 1998 indicated that the source of this increase was several streams in which treatments had been deferred due to low water flows or concerns for non-target organisms. These critical streams were treated during 1999 and 2000. Sea lamprey abundance was observed to decline to target levels in 2001 through 2003. Wounding rates on lake trout have also declined.

Lake Ontario: Abundance of spawning-phase sea lamprey has shown a continuing declining trend since the early 1980s (Larson *et al.* 2003). The abundance of sea lamprey has remained stable in the FCO target range during 2000-2003.

Pressures

Since parasitic-phase sea lamprey are at the top of the aquatic food chain and inflict high mortality on large piscivores, population control is essential for healthy fish communities. Increasing abundance in Lake Erie demonstrates how short lapses in control can result in rapid increases in abundance and that continued effective stream treatments are necessary to overcome the reproductive potential of this invading species. The potential for sea lamprey to colonize new locations is increased with improved water quality and removal of dams. For example, the loss of integrity of the dam on the Manistique River, and subsequent production from this river, has contributed to the increase in sea lamprey abundance in Lake Michigan. Any areas newly infested with sea lamprey will require some form of control to attain target abundance levels in the lakes.

As fish communities recover from the effects of sea lamprey predation or over-fishing, there is evidence that the survival of parasitic sea lamprey may increase due to prey availability. Better survival means that there will be 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. Pheromones that affect migration and mating have been discovered and offer exciting potential as new alternative controls. The use of alternative controls 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.

Management Implications

The GLFC has increased stream treatments and lampricide applications in response to increasing abundances during 2001 through 2004. The GLFC has targeted these additional treatments to maximize progress toward FCO targets. The GLFC continues to focus on research and development of alternative control strategies. Computer models, driven by empirical data, are being used to best allocate treatment resources, and research is being conducted to better understand and manage the variability in sea lamprey populations.

Acknowledgments

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Authors' Commentary

Targeted increases in lampricide treatments are predicted to reduce sea lamprey abundance to acceptable levels. The effects of increased treatments will be observed in this indicator two years after they occur. Discrepancies among estimates of different life-history stages need to be resolved. Efforts to identify all sources of sea lamprey need to continue. In addition, research to better understand lamprey/prey interactions, the population dynamics of sea lamprey that survive control actions, and refinement of alternative control methods are all key to maintaining sea lamprey at tolerable levels.

Last Updated

State of the Great Lakes 2005

Native Freshwater Mussels

Indicator #68

Assessment: Not Assessed

Purpose

- To assess the location and status of freshwater mussel (unionid) populations and their habitats throughout the Great Lakes system, with emphasis on endangered and threatened species; and
- To use this information to direct research aimed at identifying the factors responsible for mussel survival in refuge areas, which in turn will be used to predict the locations of other natural sanctuaries and guide their management for the protection and restoration of Great Lakes mussels.

Ecosystem Objective

The objective is the restoration of the richness, distribution, and abundance of mussels throughout the Great Lakes, which would thereby reflect the general health of the basin ecosystems. The long-term goal is for mussel populations to be stable and self-sustaining wherever possible throughout their historical range in the Great Lakes, including the connecting channels and tributaries.

State of the Ecosystem

Background

Freshwater mussels (*Bivalvia: Unionacea*) are of unique ecological value as natural biological filters, food for fish and wildlife, and indicators of good water quality. In the United States, some species are commercially harvested for their shells and pearls. These slow-growing, long-lived organisms can influence ecosystem function such as phytoplankton ecology, water quality, and nutrient cycling. As our largest freshwater invertebrate, freshwater mussels may also constitute a significant proportion of the freshwater invertebrate biomass where they occur. Because they are sensitive to toxic chemicals, mussels may serve as an early-warning system to alert us of water quality problems. They are also good indicators of environmental change due to their longevity and sedentary nature. Since mussels are parasitic on fish during their larval stage, they depend on healthy fish communities for their survival.

The richness, distribution, and abundance of mussels reflect the general health of the aquatic ecosystems. Because their shells are attractive and easy to find, they were prized by amateur collectors and naturalists in the past. As a result, many museums have extensive shell collections dating back 150 years or more that provide us with an invaluable "window to the past" that is not available for other aquatic invertebrates.

Status of freshwater mussels

The abundance and number of species of freshwater mussels have severely declined across North America, particularly in the Great Lakes. Nearly 72% of the 300 species in North America are vulnerable to extinction or already extinct. The decline of unionids has been attributed to commercial exploitation, water quality degradation (pollution, siltation), habitat destruction (dams, dredging, channelization) riparian and wetland alterations, changes in the distribution and/or abundance of host fishes, and competition with non-native species. In the Great Lakes watershed, zebra mussels (*Dreissena polymorpha*) and, to a lesser extent, quagga mussels (*D. bugensis*) have caused a severe decline in unionid populations. Zebra mussels attach to a mussel's shell, where they interfere with activities such as feeding, respiration and locomotion - effectively robbing it of the energy reserves needed for survival and reproduction. Native mussels are particularly sensitive to biofouling by zebra mussels and to food competition with both zebra mussel and quagga mussels.

Many areas in the Great Lakes, such as Lake St. Clair and Lake Erie, have lost over 99% of their native mussels of all species as a result of the impacts of dreissenids. Although Lake Erie, Lake St. Clair, and their connecting channels historically supported a rich mussel fauna of about 35 species, unionid mussels were slowly declining in some areas even before the zebra mussel invasion. For example, densities in the western basin of Lake Erie decreased from 10 unionids/m^2 in 1961 to 4/m^2 in 1982, probably due to poor water quality. In contrast, the impact of the zebra mussel was swift and severe. Unionids were virtually extirpated from the offshore waters of western Lake Erie by 1990 and from Lake St. Clair by 1994, with similar declines in the connecting channels and many nearshore habitats. The average number of unionid species found in these areas before the zebra mussel invasion was 18 (Figure 1). After the invasion, 60% of surveyed sites had 3 or fewer species remaining, 40% of sites had none left, and abundance had declined by 90-95%.

It was feared that unionid mussels would be extirpated from Great Lakes waters by the zebra mussel. However, significant communities were recently discovered in several nearshore areas where zebra mussel infestation rates are low (Figure 1).

These remnant unionid populations, found in isolated habitats such as river mouths and lake-connected wetlands, are at severe risk. Reproduction is occurring at some of these sites, but not all. Further problems are associated with unionid species that were in low numbers before the influx of the non-native dreissenids. A number of species that are listed as endangered or threatened in the United States or Canada are found in some of these isolated populations in the Great Lakes and in associated tributaries. In the United States, these include the clubshell (*Pleurobema clava*), fat pocketbook (*Potamilus capax*), northern riffleshell

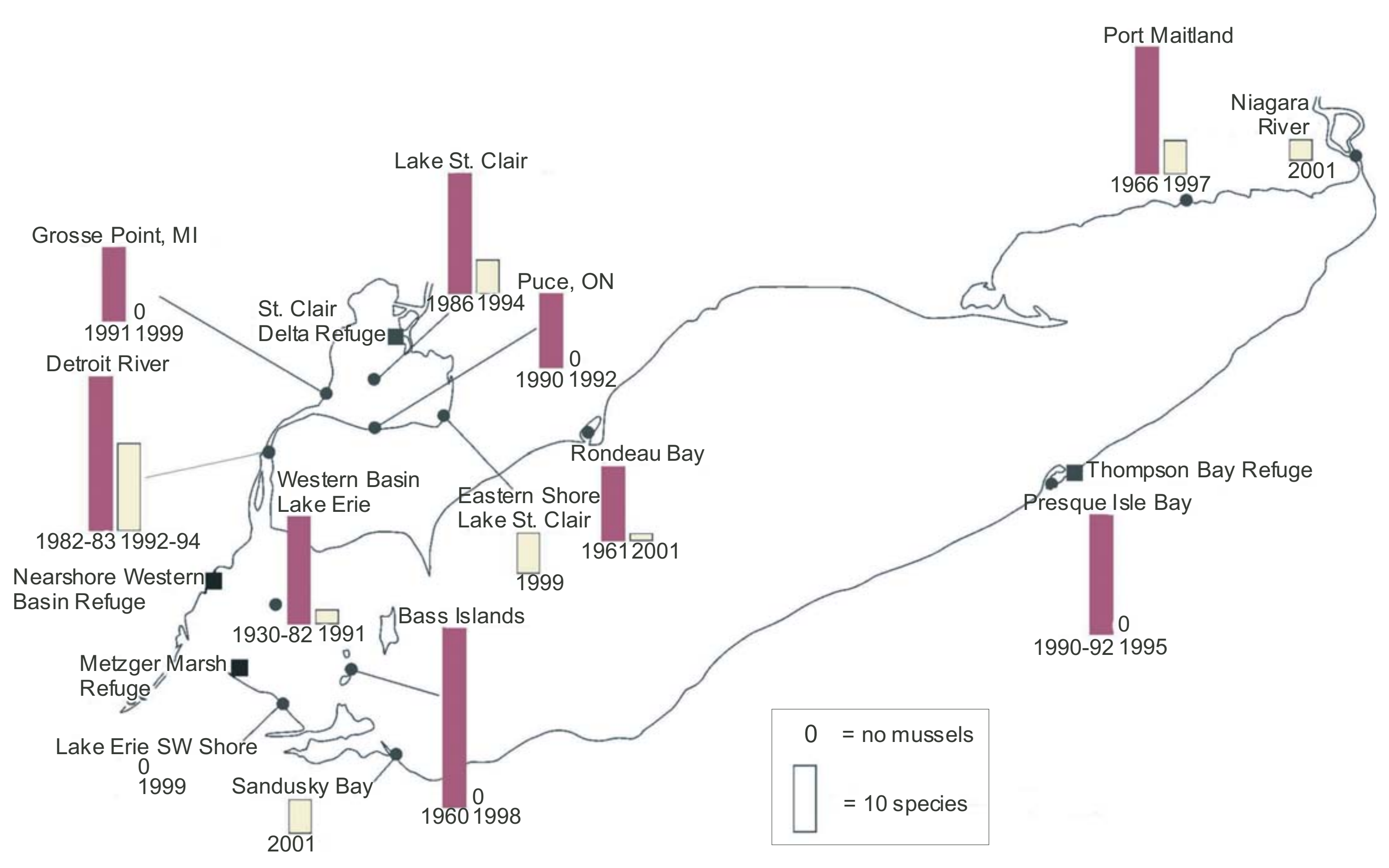

Figure 1. Numbers of freshwater mussel species found before and after the zebra mussel invasion at 13 sites in Lake Erie, Lake St. Clair, and the Niagara and Detroit Rivers (no "before" data available for 4 sites), and the locations of the four known refuge sites (Thompson Bay, Metzger Marsh, Nearshore Western Basin, and St. Clair Delta).
Source: Metcalfe-Smith, J.L., D.T. Zanatta, E.C. Masteller, H.L. Dunn, S.J. Nichols, P.J. Marangelo, and D.W. Schloesser. 2002

(*Epioblasma torulosa rangiana*), and white catspaw (*Epioblasma obliquata perobliqua*). In Canada, the northern riffleshell, rayed bean (*Villosa fabalis*), wavyrayed lampmussel (*Lampsilis fasciola*), salamander mussel (*Simpsonaias ambigua*), snuffbox (*Epioblasma triquetra*), round hickorynut (*Obovaria subrotunda*), kidneyshell (*Ptychobranchus fasciolaris*) and round pigtoe (*Pleurobema sintoxia*) are listed as endangered.

All of the refuge sites discovered to date have two characteristics in common: they are very shallow (<1-2 m deep), and they have a high degree of connectivity to the lake, which ensures access to host fishes. These features appear to combine with other factors to discourage the settlement and survival of zebra mussels. Soft, silty substrates and high summer water temperatures in Metzger Marsh, Thompson Bay and Crane Creek encourage unionids to burrow, which dislodges and suffocates attached zebra mussels. Unionids living in firm, sandy substrates at the nearshore western basin site were nearly infestation-free. The few zebra mussels found were less than 2 years old, suggesting that they may be voluntarily releasing from unionids due to harsh conditions created by wave action, fluctuating water levels and ice scour. The St. Clair Delta site has both wave-washed sand flats and wetland areas with soft, muddy sediments. It is thought that the numbers of zebra mussel veligers (planktonic larval stage) reaching the area may vary from year to year, depending on wind and current direction and water levels.

Since the veligers require an average of 20-30 days to develop into the benthic stage, rivers and streams have limited colonization potential and can provide natural refugia for unionids. However, regulated rivers, i.e., those with reservoirs, may not provide refugia. Reservoirs with retention times greater than 20-30 days will allow veligers to develop and settle, after which the impounded populations will seed downstream reaches on an annual basis. It is therefore vital to prevent the introduction of zebra mussels into reservoirs.

Pressures

Zebra mussel expansion is the main threat facing unionids in the Great Lakes drainage basin. Zebra mussels are now found in all of the Great Lakes and in many associated water bodies, including at least 260 inland lakes and river systems such as the Rideau River in Ontario and in two reservoirs in the Thames River drainage in Ontario.

Other non-native species may also impact unionid survival through the reduction or redistribution of native fishes. Non-native fish species such as the Eurasian ruffe (*Gymnocephalus cernuus*) and round goby (*Neogobius melanostomus*) can completely displace native fish, thus causing the functional extirpation of local unionid populations.

Continuing changes in land use (increasing urban sprawl, growth of factory farms, etc.), elevated use of herbicides to remove aquatic vegetation from lakes for recreational purposes, climate change and the associated lowering of water levels, and many other factors will continue to have an impact on unionid populations in the future.

Management Implications

The long-term goal is for unionid mussel populations to be stable and self-sustaining wherever possible throughout their historical range in the Great Lakes, including the connecting channels and tributaries. The most urgent activity is to prevent the further introduction of non-native species into the Great Lakes. A second critical activity is to prevent the further expansion of non-native species into the river systems and inland lakes of the region where they may seriously harm the remaining healthy populations of unionids that could be used to re-inoculate the Great Lakes themselves in the future.

To ensure the survival of remaining unionids in the Great Lakes basin, and to foster the restoration of their populations to the extent possible, the following actions are recommended:

- All existing information on the status of freshwater mussels throughout the Great Lakes drainage basin should be compiled and reviewed. A complete analysis of trends over space and time is needed to properly assess the current health of the fauna.

- To assist with the above exercise, and to guide future surveys, all data must be combined into a computerized, GIS-linked database (similar to the 8000-record Ontario database managed by the National Water Research Institute), accessible to all relevant jurisdictions.

- Additional surveys are needed to fill data gaps, using standardized sampling designs and methods for optimum comparability of data. The Freshwater Mollusk Conservation Society has prepared a peer-reviewed, state-of-the art protocol that should be consulted for guidance (Strayer and Smith 2003). Populations of endangered and threatened species should be specifically targeted.

- The locations of all existing refugia, both within and outside of the influence of zebra mussels, should be documented, and they must be protected by all possible means from future disturbance.

- Research is needed to determine the mechanisms responsible for survival of unionids in the various refuge sites, and this knowledge should be used to predict the locations of other refugia and to guide their management.

- The environmental requirements of unionids need to be taken into account in wetland restoration projects.

- All avenues for educating the public about the plight of unionids in the Great Lakes should be pursued, as well as legislation for their protection. This includes ensuring that all species that should be listed are listed as quickly as possible.

- The principles of the National Strategy for the Conservation of Native Freshwater Mussels (The National Native Mussel Conservation Committee 1998) should be applied to the conservation and protection of the Great Lakes unionid fauna.

Acknowledgments

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Last Updated
State of the Great Lakes 2005

Lake Trout
Indicator #93

Overall Assessment
Status: **Mixed**
Trend: **Unchanging**

Lake-by-Lake Assessment
Lake Superior
Status: Good
Trend: Improving

Lake Michigan
Status: Poor
Trend: Declining

Lake Huron
Status: Mixed
Trend: Improving

Lake Erie
Status: Mixed
Trend: Unchanging

Lake Ontario
Status: Mixed
Trend: Declining

Purpose
•To track the status and trends in lake trout populations; and
•To infer the basic structure of the cold water predator community and the general health of the ecosystem.

Ecosystem Objective
Self-sustaining, naturally reproducing populations that support target yields to fisheries are the goal of the lake trout restoration program. Target yields approximate historical levels of lake trout harvest or levels adjusted to accommodate stocked non-native predators such as Pacific salmon. These targets are 4 million pounds (1.8 million kg) from Lake Superior, 2.5 million pounds (1.1 million kg) from Lake Michigan, 2.0 million pounds (0.9 million kg) from Lake Huron and 0.1 million pounds (0.05 million kg) from Lake Erie. Lake Ontario has no specific yield objective but has a population objective of 0.5-1.0 million adult fish that produce 100,000 yearling recruits annually through natural reproduction.

State of the Ecosystem
Background
Lake trout were historically the principal salmonine predator in the coldwater communities of the Great Lakes. By the late 1950s, lake trout were extirpated throughout most of the Great Lakes

mostly from the combined effects of sea lamprey predation and over fishing. Restoration efforts began in the early 1960s with chemical control of sea lamprey, controls on exploitation, and stocking of hatchery-reared fish to rebuild populations. Full restoration will not be achieved until natural reproduction is established and maintained to sustain lakewide populations. To date, only Lake Superior has that distinction.

Status of Lake Trout

Trends in the relative or absolute annual abundance of lake trout in each of the Great Lakes are displayed in Figure 1. Lake trout abundance dramatically increased in all the Great Lakes after initiation of sea lamprey control, stocking, and harvest control. Natural reproduction, from large parental stocks of wild fish is occurring throughout Lake Superior, supports both onshore and offshore populations, and it may be approaching historical levels. Stocking there has been discontinued. Sustained natural reproduction, albeit at low levels, has also been occurring in Lake Ontario since the early 1990s, and in some areas of Lake Huron, but has been largely absent elsewhere in the Great Lakes. In Lake Huron substantial and widespread natural reproduction was seen starting in 2004 following near collapse of alewife populations. Abundance of hatchery-reared adults was relatively high in Lake Ontario from 1986 – 1998, but declined by more than 30% in 1999 due to reduced stocking and poor survival of stocked yearlings since the early 1990s. Adult abundance again declined by 54% in 2006 likely due to ongoing poor recruitment and mortality from sea lamprey predation. Parental stock sizes of hatchery-reared fish were relatively high in some areas of Lakes Huron and Michigan, but sea lamprey predation, fishery extractions, and low stocking densities have limited population expansion elsewhere.

Pressures

Sea lamprey continues to limit population recovery, particularly in Lakes Michigan and Superior, and parasitic adults are increasing basin-wide. Fishing pressures also continue to limit recovery. More stringent controls on fisheries are required to increase survival of stocked fish. In northern Lake Michigan parental stock sizes are low and young in age due to low stocking densities, moderate fishing mortality, and substantial sea lamprey mortality; hence egg deposition is low in most historically important spawning areas. Fishing mortality has been reduced in recent years but replaced by sea lamprey mortality. High biomass of alewives and predators on lake trout spawning reefs are thought to inhibit restoration through egg and fry predation, although the magnitude of this pressure is unclear. Recent trends in Lake Huron suggest that alewife may need to reach very low abundances to allow substantial natural reproduction. A diet dominated by alewives may be limiting fry survival (early mortality syndrome) through thiamine deficiencies. The loss of *Diporeia* and dramatic reductions in the abundance of slimy sculpins is reducing prey for young lake trout and may be affecting survival. Current strains of lake trout stocked may not be appropriate for offshore habitats, therefore limiting colonization potential.

Management Implications

Continued and enhanced sea lamprey control is required basin-wide to increase survival of lake trout to adulthood. New sea lamprey control options, which include pheromone systems that increase trapping efficiency and disrupt reproduction, are being researched and hold promise for improved control. Continued and enhanced control on exploitation is being improved through population modeling in the upper Great Lakes but needs to be applied throughout the basin. Stocking densities need to be increased in some areas, especially in Lake Michigan. The use of alternate strains of lake trout from Lake Superior could be candidates for deep, offshore areas not colonized by traditional strains used for restoration. Introduction of such strains has been initiated in Lake Erie and hold promise. Direct stocking of eggs, fry, and yearling on or near traditional spawning sites should be used where possible to enhance colonization.

Comments from the author(s)

Reporting frequency should be every 5 years. Monitoring systems are in place, but in most lakes measures do not directly relate to stated harvest objectives. Population objectives may need to be redefined as endpoints in units measured by the monitoring activities.

Acknowledgments

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Aaron Woldt, U.S. Fish and Wildlife Service, Alpena, MI; and
James Bence, Michigan State University, East Lansing, MI.

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Figure 1. Relative or absolute abundance of lake trout in the Great Lakes. The measurement reported varies from lake to lake, as shown on the vertical scale, and comparisons between lakes may be misleading. Overall trends over time provide information on relative abundances.
Source: U.S. Fish and Wildlife Service

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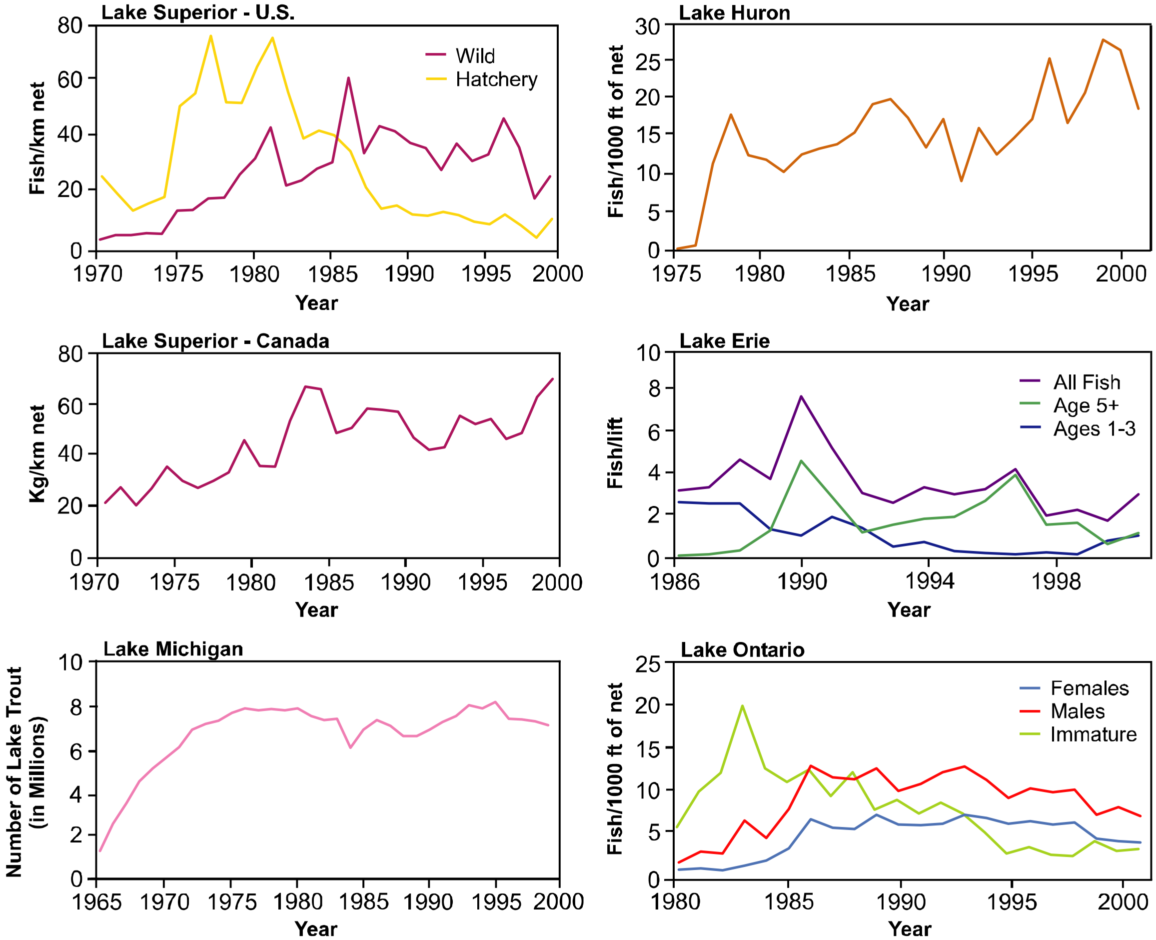

Figure 1. Relative or absolute abundance of lake trout in the Great Lakes. The measurement reported varies from lake to lake, as shown on the vertical scale, and comparisons between lakes may be misleading. Overall trends over time provide information on relative abundances. Source: U.S. Fish and Wildlife Service

Benthos Diversity and Abundance - Aquatic Oligochaete Communities
Indicator #104

Overall Assessment

Status:	Mixed
Trend:	Unchanging/ deteriorating
Primary Factors Determining Status and Trend	**Some lakes or parts of lakes are good and unchanging, while other lakes or parts of lakes are fair to poor and are either unchanging or may be deteriorating.**

Lake by Lake Assessment
Lake Superior

Status:	Good
Trend:	Unchanging
Primary Factors Determining Status and Trend	All sites had index values that ranged from 0 to <0.5, indicating oligotrophic conditions

Lake Michigan

Status:	Mixed
Trend:	Unchanging, Deteriorating
Primary Factors Determining Status and Trend	Most sites had index values that ranged from 0 to <0.5, indicating oligotrophic conditions. The two most southeastern, nearshore sites changed from oligotrophic status in 2000, mesotrophic status in 2001, mesotrophic/eutrophic status in 2002-2004, and back to mesotrophic in 2005. The most east-central, nearshore site changed from oligotrophic (2000-2004) to mesotrophic (2005).

Lake Huron

Status:	Mixed
Trend:	Unchanging
Primary Factors Determining Status and Trend	Saginaw Bay remained mesotrophic throughout the six years. All other sites were oligotrophic.

Lake Erie

Status:	Mixed
Trend:	Unchanging, Deteriorating
Primary Factors Determining Status and Trend	Most sites were mesotrophic to eutrophic. Two western sites were oligotrophic mesotrophic due to reduced numbers of oligochaetes. Eutrophic sites in the eastern part of the lake exhibited increasing index values.

Lake Ontario

Status:	Mixed
Trend:	Unchanging
Primary Factors	Most sites were oligotrophic. The three most southern, nearshore sites

Determining Status and Trend	varied from oligotrophic to eutrophic on a year to year basis.

Purpose

- To assess species diversity and abundance of aquatic oligochaete communities in order to determine the trophic status and relative health of benthic communities in the Great Lakes.

Ecosystem Objective

Benthic communities throughout the Great Lakes should retain species abundance and diversity typical for benthos in similar unimpaired waters and substrates. A measure of biological response to organic enrichment of sediments is based on Milbrink's (1983) Modified Environmental Index (MEI). This index was modified from Howmiller and Scott's (1977) Environmental Index. This measure will have wide application in nearshore, profundal, riverine, and bay habitats of the Great Lakes. This indicator supports Annex 2 of the Great Lakes Water Quality Agreement.

State of the Ecosystem

Shortly after intensive urbanization and industrialization during the first half of the 20th century, pollution abatement programs were initiated in the Great Lakes. Degraded waters and substrates, especially in shallow areas, began to slowly improve in quality. By the early 1980's, abatement programs and natural biological processes changed habitats to the point where aquatic species that were tolerant of heavy pollution began to be replaced by species that were intolerant of heavy pollution.

The use of Milbrink's index values to characterize aquatic oligochaete communities provided one of the earliest measures of habitat quality improvements (e.g., western Lake Erie). This index has been used to measure changing productivity in waters of North America and Europe and, in general, appears to be a reasonable measure of productivity in waters of all the Great Lakes (Figure 1). The index values from sites in the upper lakes continue to be very low (<0.6), indicating an oligotrophic status for these areas. Index values from sites such as the nearshore areas of southeastern and east-central Lake Michigan and Saginaw Bay in Lake Huron, which are known to have higher productivity, exhibited higher index values that indicate mesotrophic (0.6-1.0) to eutrophic (>1.0) conditions. Nearshore sites in southern Lake Ontario continued to be classified as mesotrophic to eutrophic, while offshore sites were oligotrophic. Sites in Lake Erie exhibited the highest index values; nearly all of them fell within the mesotrophic or eutrophic category (one site in western Lake Erie had low values characterized by low numbers of oligochaetes). Over the last six years, a trend of increasing index values was observed for eastern Lake Erie.

Pressures

Future pressures that may change suitability of habitat for aquatic oligochaete communities remain unknown. Pollution abatement programs and natural processes will assuredly continue to improve water and substrate quality. However, measurement of improvements could be overshadowed by pressures such as zebra and quagga mussels, which were an unknown impact only 10 years ago. Other possible pressures include non-point source pollution, regional temperature and water level changes, and discharges of contaminants such as pharmaceuticals, as well as from other unforeseen sources.

Management Implications

Continued pollution abatement programs aimed at point source pollution will continue to reduce undesirable productivity and past residual pollutants. As a result, substrate quality will improve. Whatever future ecosystem changes occur in the Great Lakes, it is likely aquatic oligochaete communities will respond early to such changes.

Comments from the authors

Biological responses of aquatic oligochaete communities are excellent indicators of substrate quality, and when combined with a temporal component, they allow for the determination of subtle changes in environmental quality, possibly decades before single species indicators. However, it is only in the past several years that Milbrink's MEI has been applied to the open waters of all the Great Lakes. Therefore, it is critical that routine monitoring of oligochaete communities in the Great Lakes continue. Additionally, oligochaete taxonomy can be a specialized and time-consuming discipline, and the taxonomic classification of species and their responses to organic pollution is continually being updated. As future work progresses, it is anticipated that the ecological relevance of existing and new species comprising the index will increase. Modifications to this index must be incorporated in future work, which includes the assignment of index values to several taxa that are currently not included in the index, and the re-evaluation of index values for a few of the species that are included in the index. It should be noted that even though the index only addresses responses to organic enrichment in sediments, it may be used with other indicators to assess the effects of other sediment pollutants.

Acknowledgments

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Figure 1. Scatter plots of index values for Milbrink's (1983) Modified Environmental Index, applied to data from GLNPO's 2000-2005 summer surveys. Values ranging from 0-0.6 indicate oligotrophic conditions; values from 0.6-1.0 indicate mesotrophic conditions (shaded area); values above 1.0 indicate eutrophic conditions. Index values for the taxa were taken from the literature (Milbrink 1983, Howmiller and Scott 1977); immature specimens were not included in

any calculations. Data points represent average of triplicate samples taken at each sampling site. Source: U.S. Environmental Protection Agency, 2000-2005.

Figure 2. Map of the Great Lakes showing trophic status based on Milbrink's (1983) Modified Environmental Index using the oligochaete worm community. Data taken from 2005. Gray circles = oligotrophic; yellow squares = mesotrophic; red triangles = eutrophic.

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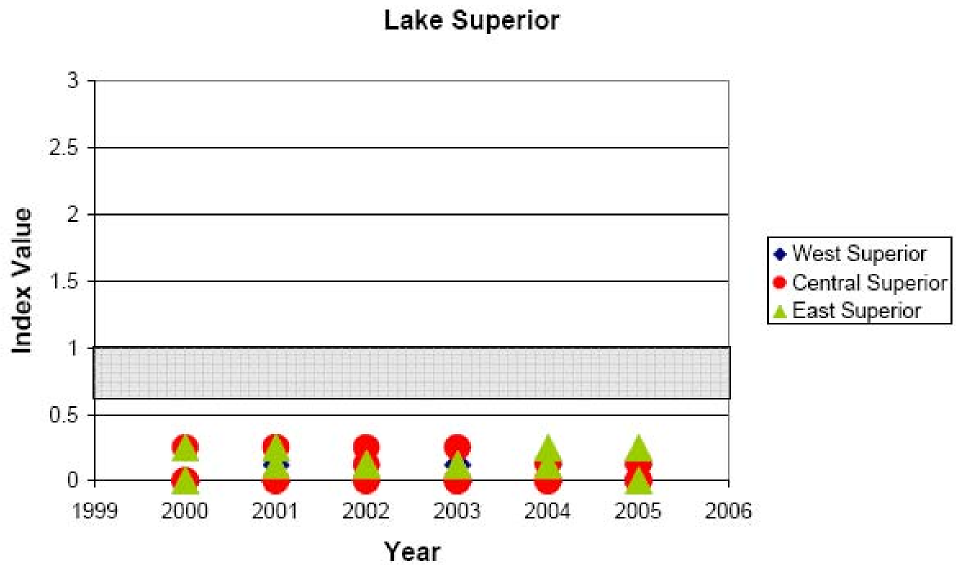
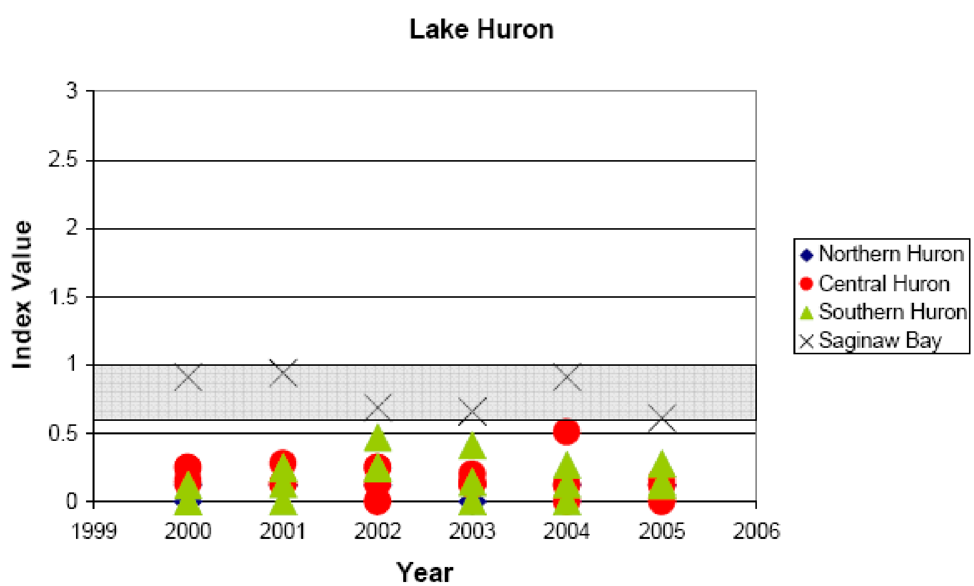
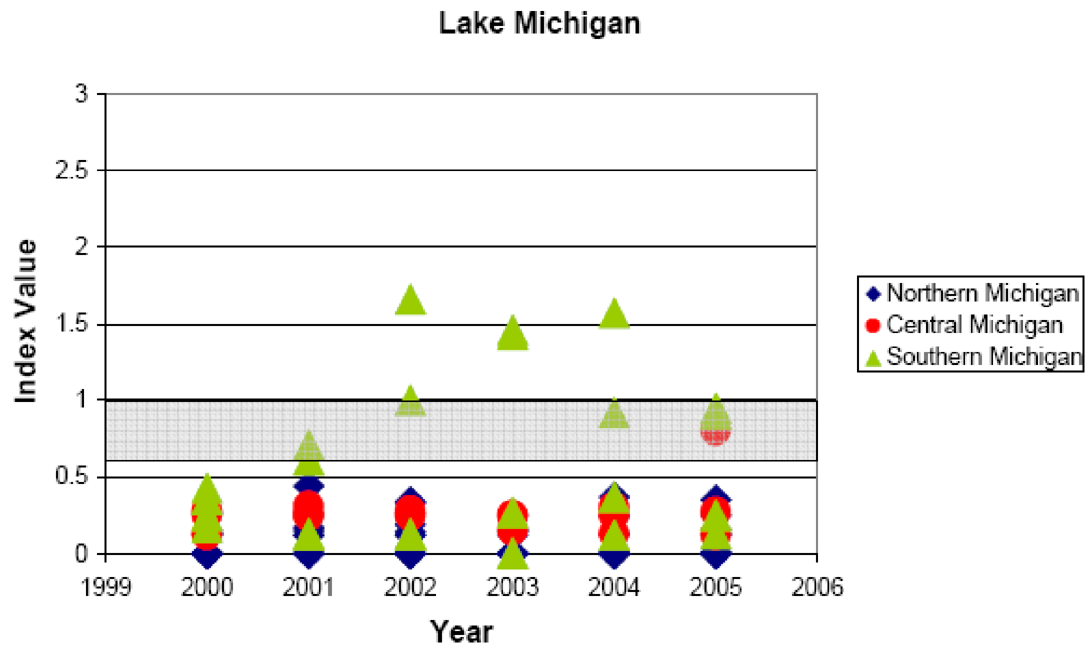
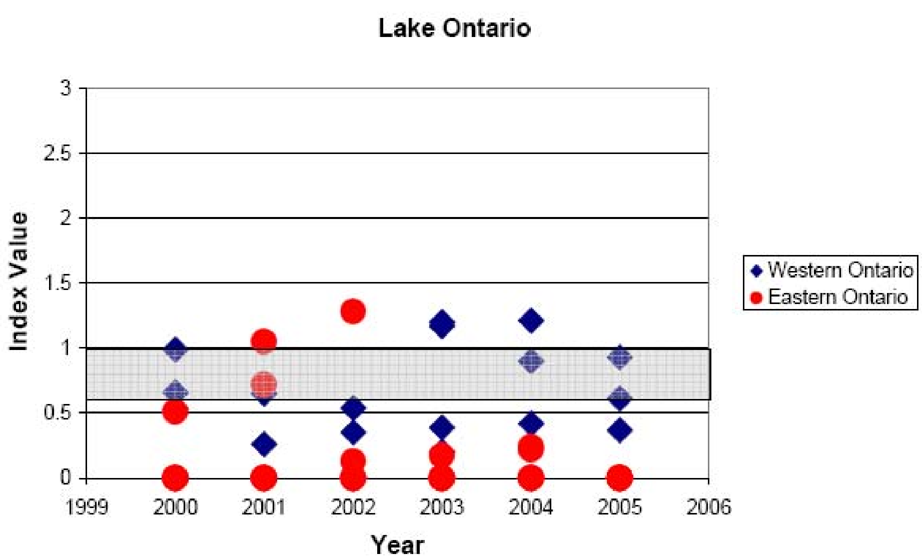
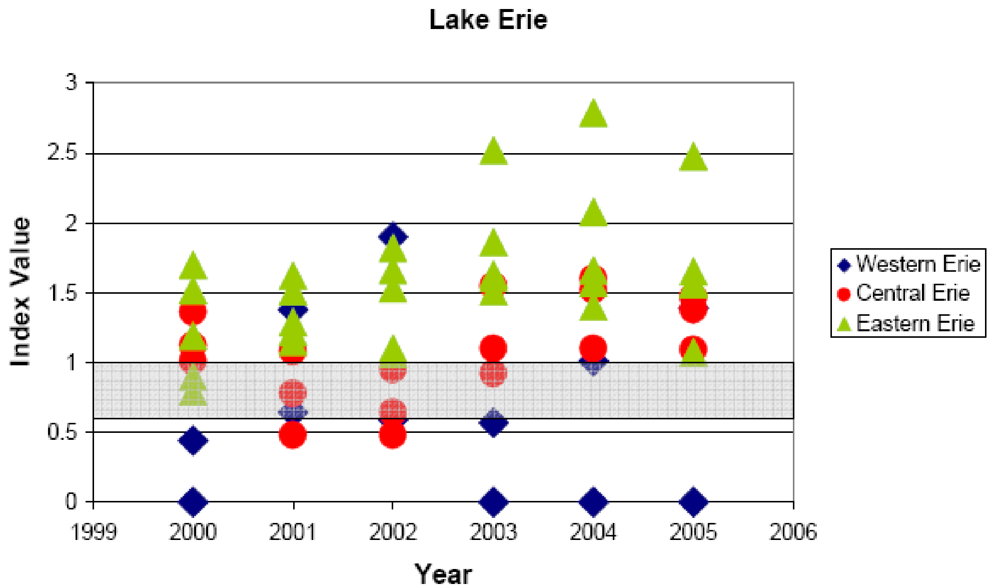





Lake Michigan
Index Value
3
2.5
2
1.5
1
0.5
0
1999
2000
2001
2002
2003
2004
2005
2006
Year
Northern Michigan
Central Michigan
Southern Michigan


Lake Ontario
Index Value
3
2.5
2
1.5
1
0.5
0
1999
2000
2001
2002
2003
2004
2005
2006
Year
Western Ontario
Eastern Ontario



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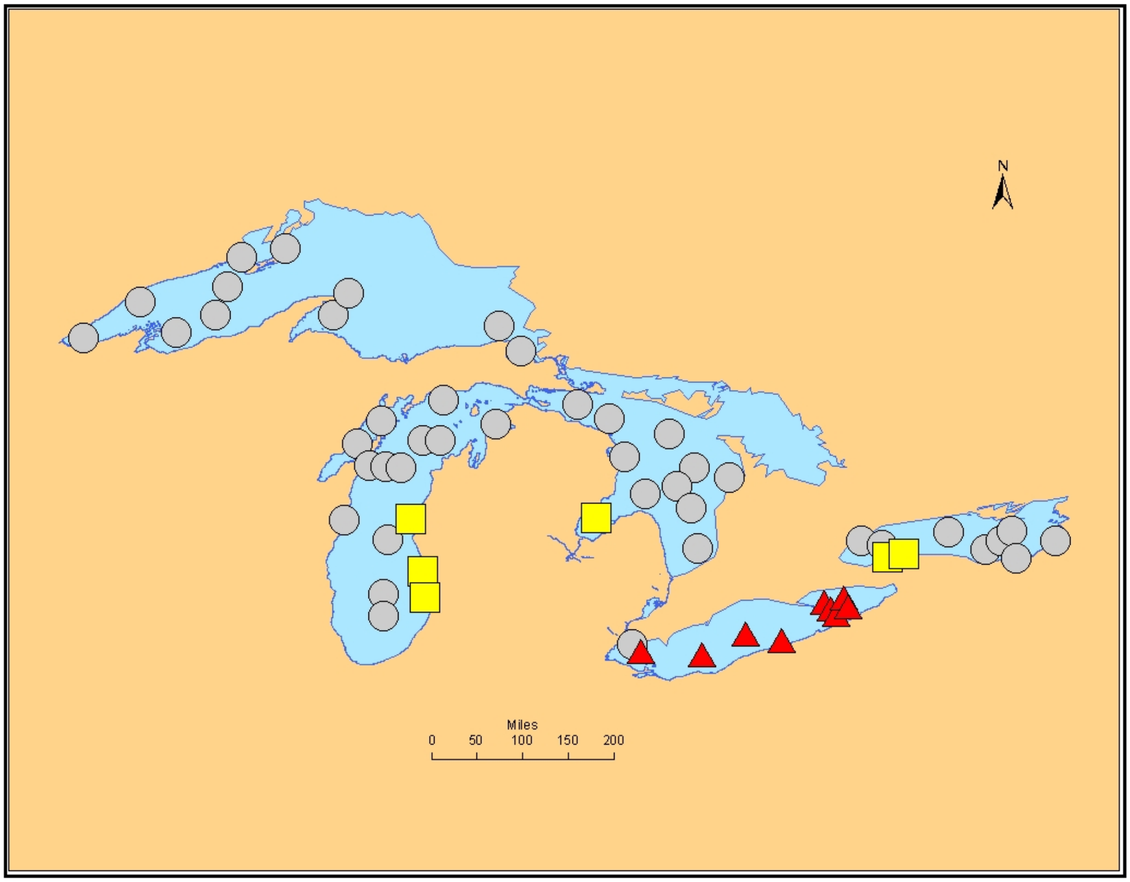

Figure 2. Map of the Great Lakes showing trophic status based on Milbrink's (1983) Modified Environmental Index using the oligochaete worm community. Data taken from 2005. Gray circles = oligotrophic; yellow squares = mesotrophic; red triangles = eutrophic.

Phytoplankton Populations

Indicator #109

Assessment: Mixed, Trend Not Assessed

This assessment is based on historical conditions and expert opinion. Specific objectives or criteria have not been determined.

Purpose

- To directly assess phytoplankton species composition, biomass, and primary productivity in the Great Lakes; and
- To indirectly assess the impact of nutrient and contaminant enrichment and invasive non-native predators on the microbial food-web of the Great Lakes.

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

This indicator assumes that phytoplankton populations respond in quantifiable ways to anthropogenic inputs of both nutrients and contaminants, permitting inferences to be made about system perturbations through the assessment of phytoplankton community size, structure and productivity.

Records for Lake Erie indicate that substantial reductions in summer phytoplankton populations occurred in the early 1990s in the western basin (Figure 1). The timing of this decline suggests the possible impact of zebra mussels. In Lake Michigan, a significant increase in the size of summer diatom populations occurred during the 1990s. This was most likely due to the

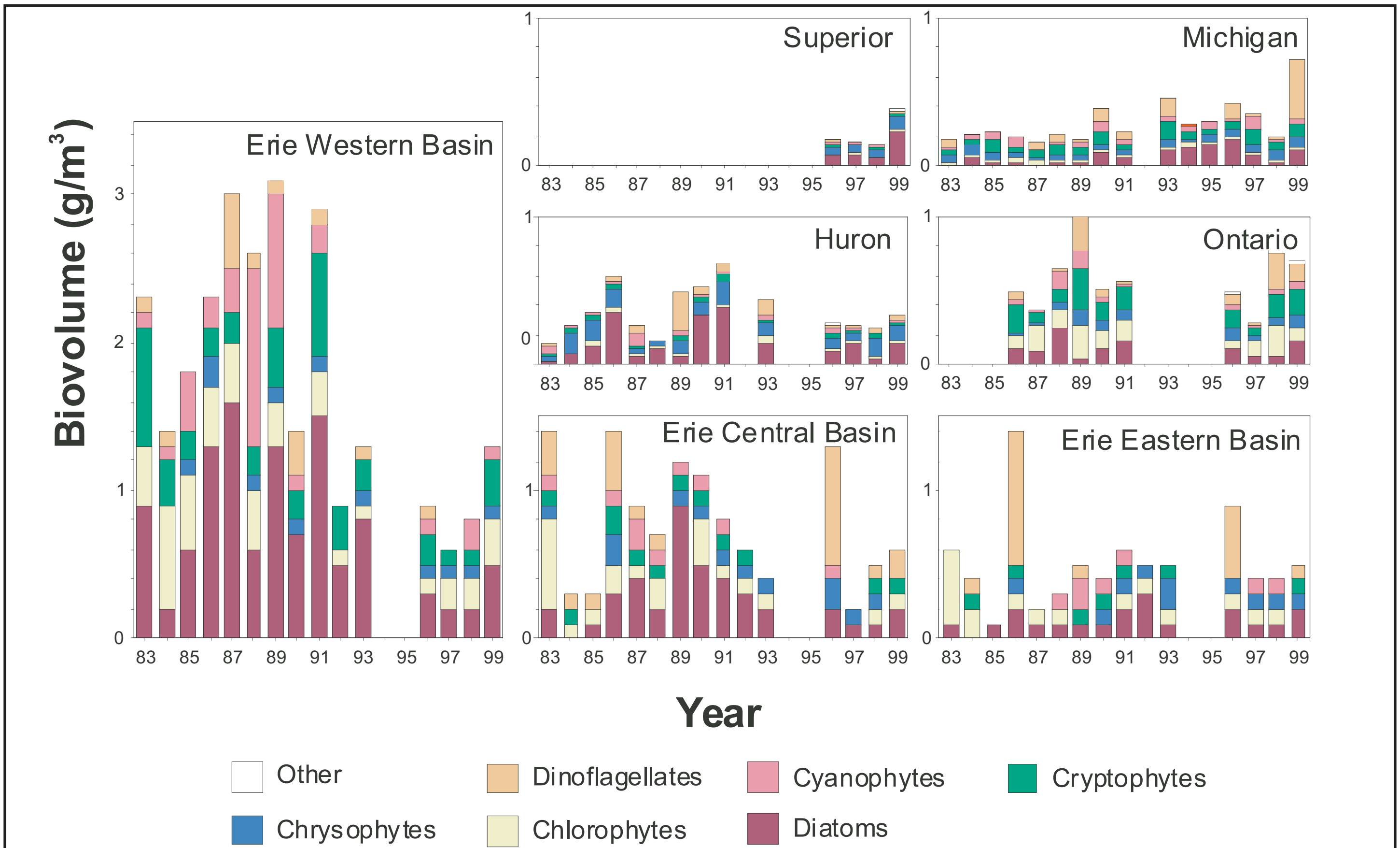

Figure 1. Trends in phytoplankton biovolume (g/m^3) and community composition in the Great Lakes 1983-1999. Samples were collected from offshore, surface waters during August.
Source: U.S. Environmental Protection Agency, Great Lakes National Program Office

effects of phosphorus reductions on the silica mass balance in this lake, and it suggests that diatom populations might be a sensitive indicator of oligotrophication in Lake Michigan. No trends are apparent in summer phytoplankton from Lakes Huron or Ontario, while only three years of data exist for Lake Superior. Data on primary productivity are 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.

It should be noted that these findings are at variance with those reported for SOLEC 2000. This is due to problems with historical data comparability that were unrecognized during the previous reporting period. These problems continue to be worked on, and as such, conclusions reported here should be regarded as somewhat provisional.

Pressures

The two most important potential future pressures on the phytoplankton community are changes in nutrient loadings and continued introductions and expansions of non-native species. Increases in nutrients can be expected to result in increases in primary productivity 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. As seen in Lake Michigan, reductions in phosphorus loading might be expected to have the opposite effect. 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.

Management Implications

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.

Acknowledgments

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Sources

U.S. Environmental Protection Agency, Great Lakes National Program Office. Unpublished data. Chicago, IL.

Authors' Commentary

A highly detailed record of phytoplankton biomass and community structure has accumulated, and continues to be generated, through regular monitoring efforts. However, problems exist with internal comparability of this database. Efforts are currently underway to rectify this situation, and it is essential that the database continue to be refined and improved.

In spite of the existence of this database, its interpretation remains problematic. 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".

Last Updated

State of the Great Lakes 2003

Phosphorus Concentrations and Loadings
Indicator #111

Overall Assessment

Status:	**Open Lake: Mixed Nearshore: Poor**
Trend:	**Open Lake: Undetermined Nearshore: Undetermined**
Primary Factors Determining Status and Trend	**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, harbors and nearshore areas.**

Lake-by-Lake Assessment
Lake Superior

Status:	Open Lake: Good Nearshore: Undetermined
Trend:	Open Lake: Undetermined Nearshore: Undetermined
Primary Factors Determining Status and Trend	Average concentrations in the open waters are at or below expected levels.

Lake Michigan

Status:	Open Lake: Good, Nearshore: Poor
Trend:	Open: Improving Nearshore: Undetermined
Primary Factors Determining Status and Trend	Average concentrations in the open waters are at or below expected levels. Phosphorus concentrations may exceed guidelines in nearshore waters for at least part of the growing season.

Lake Huron

Status:	Open Lake: Good Nearshore: Poor
Trend:	Open Lake: Undetermined Nearshore: Undetermined
Primary Factors Determining Status and Trend	Average concentrations in the open waters are at or below expected levels. Most offshore waters meet the desired guideline but some nearshore areas and embayments experience elevated levels which likely contribute to nuisance algae growths such as the attached green algae, Cladophora and toxic cyanophytes such as Microcystis.

Lake Erie

Status:	Open Lake: Fair-Poor Nearshore: Poor
Trend:	Open Lake: Undetermined Nearshore: Undetermined
Primary Factors Determining Status and Trend	Concentrations in the three basins of Lake Erie fluctuate from year to year and frequently exceed target concentrations. Extensive lawns of Cladophora are common place over the nearshore lakebed in parts of Eastern Lake Erie and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al*. 2006 and Wilson *et al*. 2005). Phosphorus levels in the nearshore (Canadian shores) of eastern Lake Erie are periodically elevated above basin guideline value of 10 µg/L, however, the highly dynamic nature of water quality in the nearshore has made it difficult to achieve either integrated nearshore assessments of

phosphorus levels, or to relate phosphorus levels to growth of Cladophora.

Lake Ontario

Status:	Open Lake: Good Nearshore: Poor
Trend:	Open Lake: Improving Nearshore: Undetermined
Primary Factors Determining Status and Trend	Average concentrations in the open lake are at or below expected levels. Most offshore waters meet the desired guideline but some nearshore areas and embayments experience elevated levels which likely contribute to nuisance algae growths such as the attached green algae, Cladophora and toxic cyanophytes such as Microcystis. For example, in the Bay of Quinte, control strategies at municipal sewage plants have reduced loadings by two orders of magnitude since the early 1970s. In spite of these controls, mean concentrations measured between May and October in the productive upper bay have remained at 30-35 µg/L in recent years. This level of total phosphorus is indicative of a eutrophic environment. Extensive lawns of Cladophora are common place over the nearshore lakebed in parts of Lake Ontario and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al*. 2006 and Wilson *et al*. 2005). Phosphorus levels in the nearshore (Canadian shores) are periodically elevated above basin guideline value of 10 µg/L, however, the highly dynamic nature of water quality in the nearshore has made it difficult to achieve either integrated nearshore assessments of phosphorus levels, or to relate phosphorus levels to growth of Cladophora.

Purpose

This indicator assesses total phosphorus levels in the Great Lakes, and 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 anthropogenic sources. Detergents, sewage treatment plant effluent, agricultural and industrial sources have historically introduced 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 growth 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 concentrations of total phosphorus in the open waters of the Great Lakes, if the maximum annual loads are maintained, are listed in the following table: (insert Table 1: Phosphorus guidelines for the Great Lakes)

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, harbors and nearshore areas. 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 the three basins of Lake Erie fluctuate from year to year (Figure 1) and frequently exceed target concentrations. In Lakes Ontario and Huron, most offshore waters meet the desired guideline but some nearshore areas and embayments experience elevated levels which likely contribute to nuisance algae growths such as the attached green algae, Cladophora and toxic cyanophytes such as Microcystis. For example, in the Bay of Quinte, Lake Ontario, control strategies at municipal sewage plants have reduced loadings by two orders of magnitude since the early 1970's. In spite of these controls, mean concentrations measured between May and October in the productive upper bay have remained at 30-35 µg/L in recent years. This level of total phosphorus is indicative of a eutrophic environment. Typical of other zebra mussel-infested and phosphorus enriched bays in the Great Lakes, toxic cyanophytes such as Microcystis have increased in abundance in recent years with blooms occurring in late August and early September.

Similarly, phosphorus concentrations may exceed phosphorus guidelines in nearshore waters for at least part of the growing season. Lake Michigan's eastern shoreline, when sampled in June, 2004, had a median concentration of 9 µg/L. Summer sampling at the same locations yielded a median concentration of 6 µg/L, with a number of sampling locations at or above the 7 µg/L guideline. By comparison, open water concentrations during spring 2004 was 3.7 µg/L. Cladophora growth is a problem on much of this shoreline. In parts of Eastern Lake Erie and Lake Ontario extensive lawns of Cladophora are common place and are suggestive of phosphorus levels supportive of nuisance levels of algal growth (Higgins *et al*. 2006 and Wilson *et al*. 2005). Phosphorus levels in the nearshore (Canadian shores) of eastern Lake Erie and Lake Ontario and are periodically elevated above basin guideline value of 10 µg/L, however, the highly dynamic nature of water quality in the nearshore has made it difficult to achieve either integrated nearshore assessments of phosphorus levels, or to relate phosphorus levels to growth of Cladophora. Phosphorus concentration in nearshore areas tend to be highly variable over time and from point to point, at times on the scale of meters, due to influences of tributary and other shore-based discharges, weather, biological activity and lake circulation.

Pressures
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. Even if current phosphorus concentration discharge limits are maintained, increased populations may result in increased loads. Phosphorus management plans with target loads need to be established for major municipalities. Recent research indicates that even weather and climate changes may be influencing the phosphorus loads to the lakes through changes in snowmelt and storm patterns.

Management Implications
Because of its key role as the limiting nutrient for productivity and food web dynamics of the Great Lakes, vigilance must be exercised by water management agencies with respect to phosphorus loads to prevent a return to conditions observed in the 1960s. Future activities that

are likely to be needed include: 1) Assess the capacity and operation of existing sewage treatment plants in the context of increasing human populations being served. Utilization of state of the art technology to lower effluent concentrations below current targets should be considered for retrofits and upgrades to sewage treatment plants; 2) Conduct studies of the urban and rural nonpoint contributions of phosphorus to better our understanding of their current overall importance, especially with regards to nearshore eutrophication and Cladophora abundance, and 3) Conduct sufficient tributary and point source monitoring to track Phosphorus loadings and to better understand the relative importance of various sources.

The surveillance of phosphorus concentrations in the Great Lakes is ongoing and the data are considered to be reliable. Plans are being formulated for an interagency laboratory comparison of total phosphorus analysis. Enhanced monitoring of nearshore and embayment sites as well as tributary monitoring may be accomplished with better coordination with existing state and provincial environmental programs. Especially if they are tied to a framework, such as a Lakewide Management Plan (LaMP) that recognizes the unique phosphorus related sensitivities of the nearshore and also provides the means to interrelate nearshore and offshore nutrient conditions and concerns. The recent reappearance of Cladophora in some areas of the Great Lakes strengthens the importance of nearshore measurements.

The data needed to support loadings calculations have not been collected since 1991 in all lakes except Lake Erie, which has loadings information up to 2002, and Lake Michigan with information for 1994 and 1995. Efforts to do so should be reinstated for at least Lake Erie, and work is underway to accomplish this. For the other lakes, the loadings component of this SOLEC indicator will remain unreported, and changes in the different sources of phosphorus to these Lakes may go undetected.

Acknowledgments
Authors: Alice Dove, Environment Canada, Burlington, ON & Glenn Warren, US EPA Chicago, Ill
Additional contributions from: Scott Millard, Environment Canada, Burlington, ON & Todd Howell, Ontario Ministry of Environment, Toronto, ON

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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

Table 1. Phosphorus guidelines for the Great Lakes (GLWQA 1978)

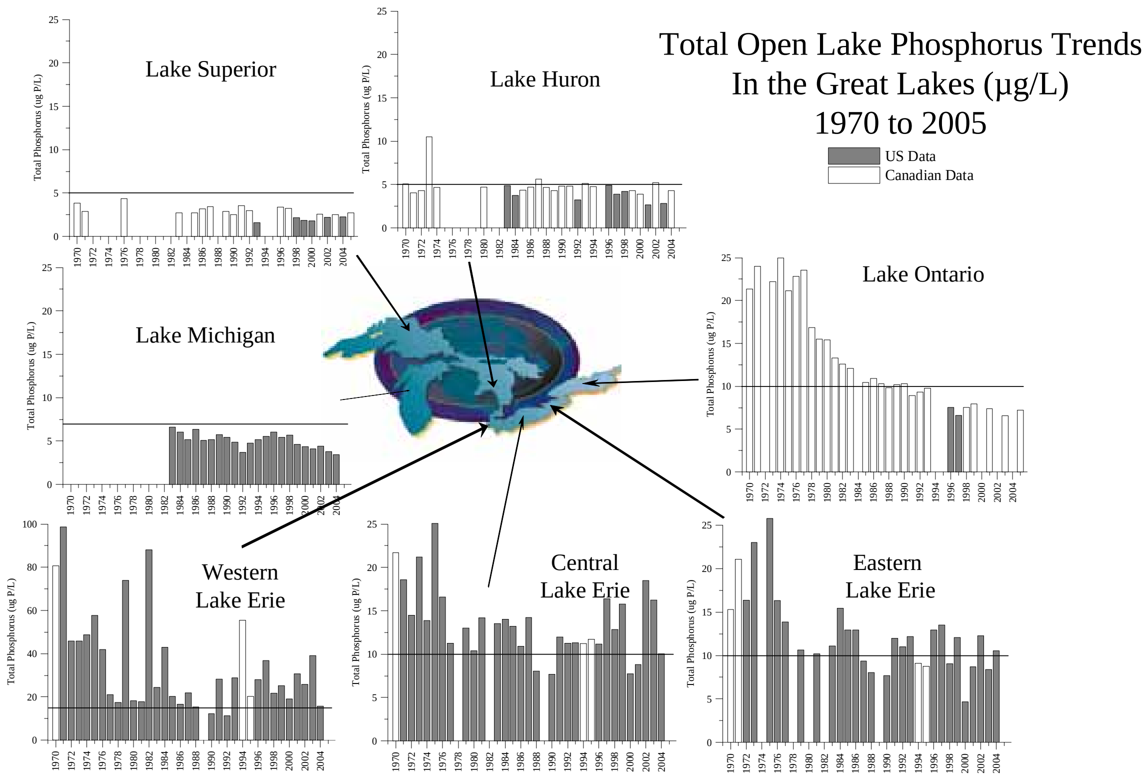

Figure 1. Total Phosphorus Trends in the Great Lakes 1970 to 2005. Blanks indicate no sampling. Horizontal line on each graph represents the phosphorus guideline as listed in the Great Lakes Water Quality Agreement for each Lake. Environment Canada data (white bars - average of spring, surface measurements at open lake sites) are used for Lakes Ontario, Huron and Superior, and are supplemented by US data for years in which no monitoring was conducted on that lake. U.S. Environmental Protection Agency data (black bars - average of spring measurements, all depths at open lake sites) are used for the three basins of Lake Erie and for Lake Michigan, and are supplemented by Canadian data for years in which no US monitoring was conducted on that lake.
Source: Science and Technology Branch, Environment Canada and Great Lakes National Program Office, U.S. Environmental Protection Agency

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

Overall Assessment

Status:	**Mixed**
Trend:	**Improving**
Primary Factors Determining Status and Trend	**Although levels of polychlorinated biphenyls (PCBs) in forage fish have decreased below the guideline at many sites around the Great Lakes, PCB levels remain elevated. As well, dichloro-diphenyl-trichloroethane (DDT) levels in forage fish have declined but remain above the guideline at most Great Lakes' locations.**

Lake-by-Lake Assessment

Lake Superior

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB concentrations in Lake Superior forage fish have declined over the period of record and are currently below the guideline at all sample sites. DDT has declined to levels near the guideline, except for Nipigon Bay, where the most current levels (1990) are elevated.

Lake Michigan

Status:	N/A
Trend:	N/A
Primary Factors Determining Status and Trend	N/A

Lake Huron

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB levels in Lake Huron forage fish have remained static or declined over the period of record and are currently at or below the guideline. DDT levels, however, remain elevated at Collingwood Harbour.

Lake Erie

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB levels in Lake Erie forage fish have declined to levels at or below the guideline. DDT has also declined over the period of record but remains above the guideline.

Lake Ontario

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	PCB levels in Lake Ontario forage fish have declined significantly over the period of record and the most recent levels are at or below the guideline. At some sites, DDT in forage fish has declined considerably, however, levels remain at or above the guideline at all sites. Mirex has also declined and has remained below the detection limit in recent years.

Purpose

•To assess the levels of persistent bioaccumulative toxic (PBT) chemicals in young-of-the-year spottail shiners;
•To infer local areas of elevated contaminant levels and potential harm to fish-eating wildlife; and
•To monitor contaminant trends over time for the nearshore waters of the Great Lakes.

Ecosystem Objective

Concentrations of toxic contaminants in juvenile forage fish should not pose a risk to fish-eating wildlife. The Aquatic Life Guidelines in Annex 1 of the Great Lakes Water Quality Agreement (United States and Canada, 1987), the New York State Department of Environmental Conservation (NYSDEC) Fish Flesh Criteria (Newell *et al*., 1987) for the protection of piscivorous wildlife, and the Canadian Environmental Quality Guidelines (CCME, 2001) are used as acceptable guidelines for this indicator. Canadian Council of Ministers of the Environment Contaminants monitored in forage fish and their respective guidelines are listed in Table 1.

State of the Ecosystem

Contaminant levels in fish are important indicators of contaminant levels in an aquatic ecosystem due to the bioaccumulation of organochlorine chemicals in fish tissue. Contaminants that are often undetectable in water may be detected in juvenile fish. Juvenile spottail shiner (*Notropis hudsonius*) was originally selected by Suns and Rees (1978) as the principal biomonitor for assessing trends in contaminant levels in local or nearshore areas. It was chosen as the preferred species because of its limited range in the first year of life; undifferentiated feeding habits in early stages; importance as a forage fish; and its presence throughout the Great Lakes. The position it holds in the food chain also creates an important link for contaminant transfer to higher trophic levels. However, at some sites along the Great Lakes spottail shiners are not as abundant as they once were, and therefore can be difficult to collect. In this updated indicator report, bluntnose minnow (*Pimephales notatus)* have been included in the Lake Huron/Georgian Bay dataset.

With the incorporation of the CCME guidelines, the total DDT tissue residue criterion is exceeded at most locations. After total DDT, PCB is the contaminant most frequently exceeding the guideline. Mirex was historically detected and exceeded the guideline at Lake Ontario locations. However, mirex concentrations over the past 10 years have been below detection. Other contaminants listed in Table 1 are often not detected, or are present at levels well below the guidelines.

Lake Erie
Trends of contaminants in spottail shiners were examined for four locations in Lake Erie: Big Creek, Thunder Bay Beach, Grand River and Leamington (Figure 1). Overall, the trends show higher concentrations of PCBs in the early years (1970s) with a steady decline over time. At Big Creek, PCB concentrations were elevated (>300 ng/g) until 1986. Since 1986, concentrations have remained near the guideline (100 ng/g). At the Grand River and Thunder Bay beach locations, PCB concentrations exceeded the guideline in the late 1970s, but have declined in recent years and are currently below the IJC guideline (100 ng/g). At Leamington, PCB concentrations were considerably higher than at the other Lake Erie sites. Although they declined from 888 ng/g in 1975 to 204 ng/g in 2001, the concentrations exceeded the guideline in all years except for a period in the early to mid-1990s. In the most recent collection (2004), levels have declined to 136 ng/g, which only marginally exceeds the IJC guideline.

Total DDT concentrations at Lake Erie sites have also been declining. Concentrations of total DDT at Big Creek, Grand River and Thunder Bay Beach have declined considerably to levels close to the guideline (14 ng/g). Maximum concentrations at these sites were found in the 1970s and ranged from 38 ng/g at Thunder Bay Beach to 75 ng/g at Big Creek. At Leamington, however, total DDT levels peaked at 183 ng/g in 1986. Since then, levels have declined, but they remain above the guideline.

Lake Huron
Trend data are available for two Lake Huron sites: Collingwood Harbour and Nottawasaga River (Figure 2). At Collingwood Harbour the highest PCB concentrations were found when sampling began in 1987 (206 ng/g). Since then, PCB concentrations have remained near or just below the guideline. At the Nottawasaga River the highest concentration of PCBs was observed in 1977 (90 ng/g). Concentrations declined to less than the detection limit by 1987 and in 2002 were detected at very low levels.

Total DDT concentrations at Collingwood Harbour have remained near 40 ng/g since 1987. The guideline of 14 ng/g was exceeded in all years. At the Nottawasaga River site, there has been a steady decline in total DDT since 1977 when concentrations peaked at 106 ng/g. In 2002, levels were below the guideline.

Lake Superior
Trend data were examined for four locations in Lake Superior: Mission River, Nipigon Bay, Jackfish Bay and Kam River (Figure 3). Recent data are not available for the first three locations.

Generally PCB concentrations were low in all years and at all locations. The highest PCB concentrations in Lake Superior were found at the Mission River in 1983 (139 ng/g). All other analytical results were below the guideline (100 ng/g). The highest concentrations of PCBs at the other three Lake Superior sites also occurred in 1983 and ranged from 51 ng/g at Nipigon Bay to 89 ng/g at Jackfish Bay.

At Mission River and Nipigon Bay, total DDT levels were high in the late 1970s but decreased below the guideline (14 ng/g) by the mid-1980s. In 1990, the DDT level at Nipigon Bay was 66 ng/g, which is the highest concentration observed in juvenile fish from any Lake Superior site to date. At Jackfish Bay and the Kam River, total DDT levels were below the guideline each year, except for the Kam River in 1991 when levels rose to 37 ng/g.

Lake Ontario
Contaminant concentrations from five sites were examined for trends: Twelve Mile Creek, Burlington Beach, Bronte Creek, Credit River and the Humber River (Figure 4). PCBs, total DDT and mirex were generally higher at these (and other Lake Ontario) locations than elsewhere in the Great Lakes. Overall, PCBs at all locations tended to be higher in the early years, ranging from 3 to 30 times the guideline. The highest concentrations of PCBs were found at the Humber River in 1978 (2938 ng/g). In recent years PCBs at the five sites generally have ranged from 100 ng/g to 200 ng/g.

Total DDT concentrations at all five locations have declined considerably since the late 1970s and early 1980s. However, at all of these locations, levels in juvenile fish still exceed the guideline (14 ng/g). The maximum reported concentration was at the Humber River in 1978 (443 ng/g). Currently, the typical concentration of total DDT at all five locations is approximately 50 ng/g. Mirex has been detected intermittently at all five locations. The maximum concentration was 37 ng/g at the Credit River in 1987. Since 1993, mirex has been below the detection limit at all of these locations.

Lake Michigan
No spottail shiners were sampled from Lake Michigan.

Pressures
New and emerging contaminants, such as polybrominated diphenyl ethers, may apply new pressures on Great Lakes' water quality. Analytical methods need to be developed and tissue residue guidelines need to be established for these contaminants. Monitoring programs should also be initiated.

Management Implications
For those contaminants that exceed the wildlife protection guidelines, additional remediation efforts may be required. Continued monitoring is essential to determine the status of contaminants in forage fish from the Great Lakes.

Comments from the author(s)
Organochlorine contaminants have declined in juvenile fish throughout the Great Lakes. However, regular monitoring should continue for all of these areas to determine if levels are below wildlife protection guidelines. Analytical methods should be improved to accommodate revised guidelines and to include additional contaminants such as dioxins and furans, dioxin-like PCBs and PBDEs. For Lake Superior, the historical data do not include toxaphene concentrations. Since this contaminant is responsible for some consumption restrictions on sport fish from this lake (MOE, 2005), it is recommended that analysis of this contaminant be included in any future biomonitoring studies in Lake Superior.

Spottail shiners have been a useful indicator of contaminant levels in the past. However, this species is less abundant than it has been. Due to the difficulties in collecting this species in all areas of the Great Lakes, consideration should be given to adopting other forage fish species as indicators when spottail shiners are not available. This year, bluntnose minnows were used for one site in Georgian Bay. This will improve temporal and spatial trend data and result in a more complete dataset for the Great Lakes.

Acknowledgments
Authors: Emily Awad, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON; and
Alan Hayton, Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment, Etobicoke, ON.
Data: Sport Fish Contaminant Monitoring Program, Ontario Ministry of Environment.

Data Sources
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Figure 3. PCB and total DDT levels in juvenile spottail shiners from four locations in Lake Superior. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.
Source: Ontario Ministry of the Environment

Figure 4. PCB, mirex and total DDT levels in juvenile spottail shiners from five locations in Lake Ontario. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline for PCBs and total DDT. For mirex, the red line indicates the detection limit (5ng/g). When not detected, one half of the detection limit was used to calculate the mean concentration.
Source: Ontario Ministry of the Environment

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Contaminant	Tissue Residue Criteria (ng/g)
PCBs	100*
DDT, DDD, DDE	14[†] (formerly 200)
Chlordane	500
Dioxin/Furans	0.00071[a] (formerly 0.003)
Hexachlorobenzene	330
Hexachlorocyclohexane (BHC)	100
Mirex	below detection*
Octachlorostyrene	20

*IJC Aquatic Life Guideline for PCBs (IJC 1988); [a] Environment Canada, 2000 (CCME 2001); [†] Environment Canada, 1997 (CCME 2001). All other values from NYSDEC Fish Flesh Criteria (Newell *et al*. 1987). Guidelines based on mammals and birds.

Table 1. Tissue Residue Criteria for various organochlorine chemicals or chemical groups for the protection of wildlife consumers of aquatic biota.

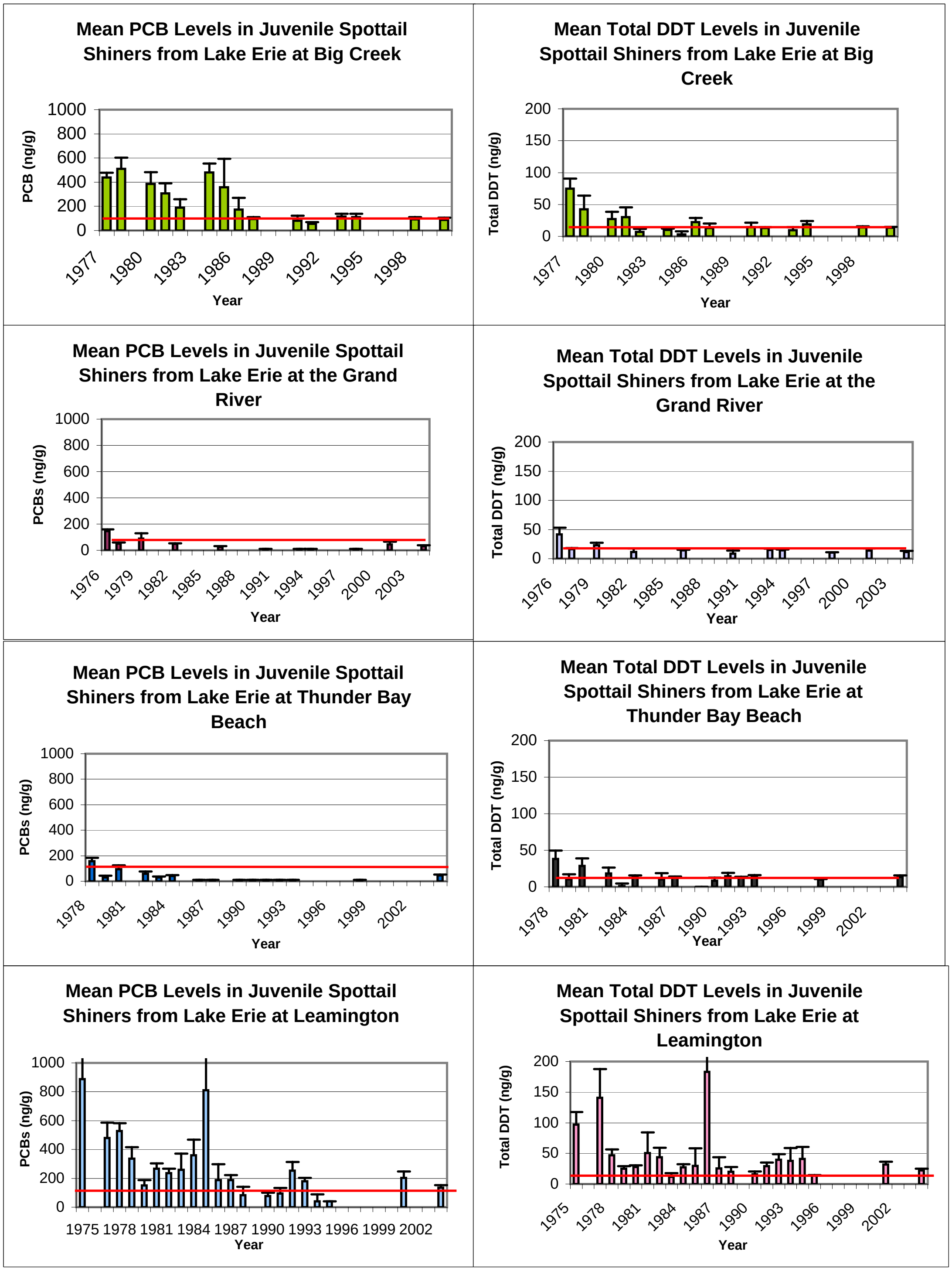


Figure 1. PCB and total DDT levels in juvenille spottail shiners from four locations in Lake Erie. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.

Source: Ontario Ministry of the Environment

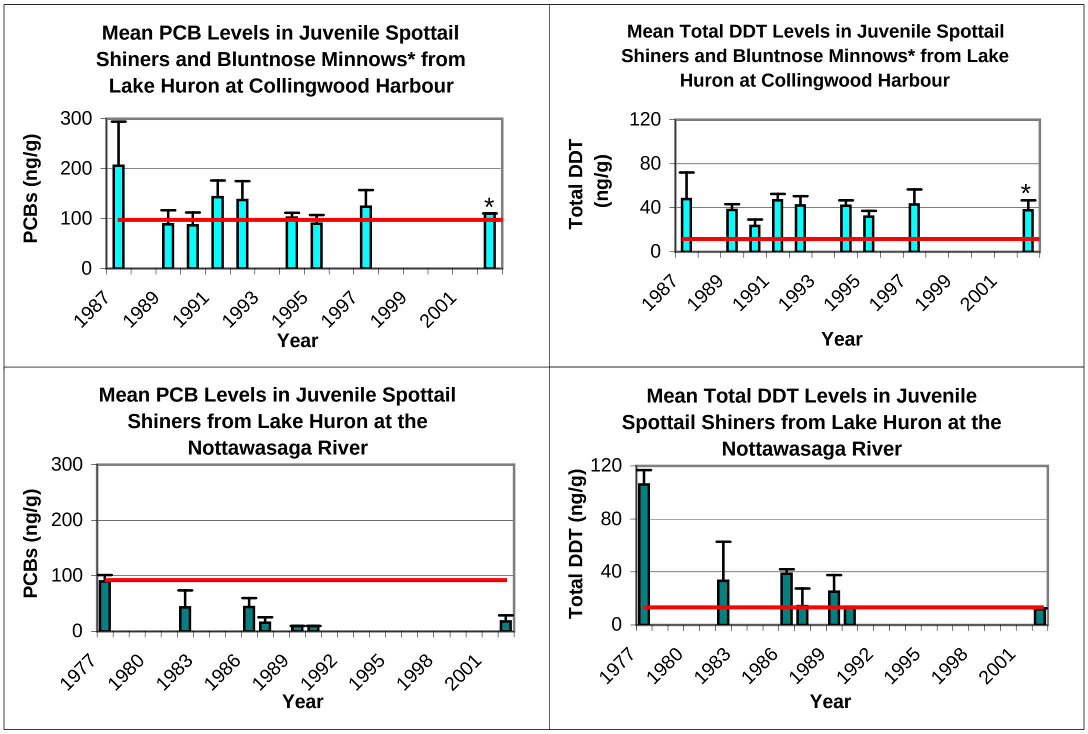


Figure 2. PCB and DDT levels in juvenille spottail shiners from two locations in Lake Huron. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.

Source: Ontario Ministry of the Environment

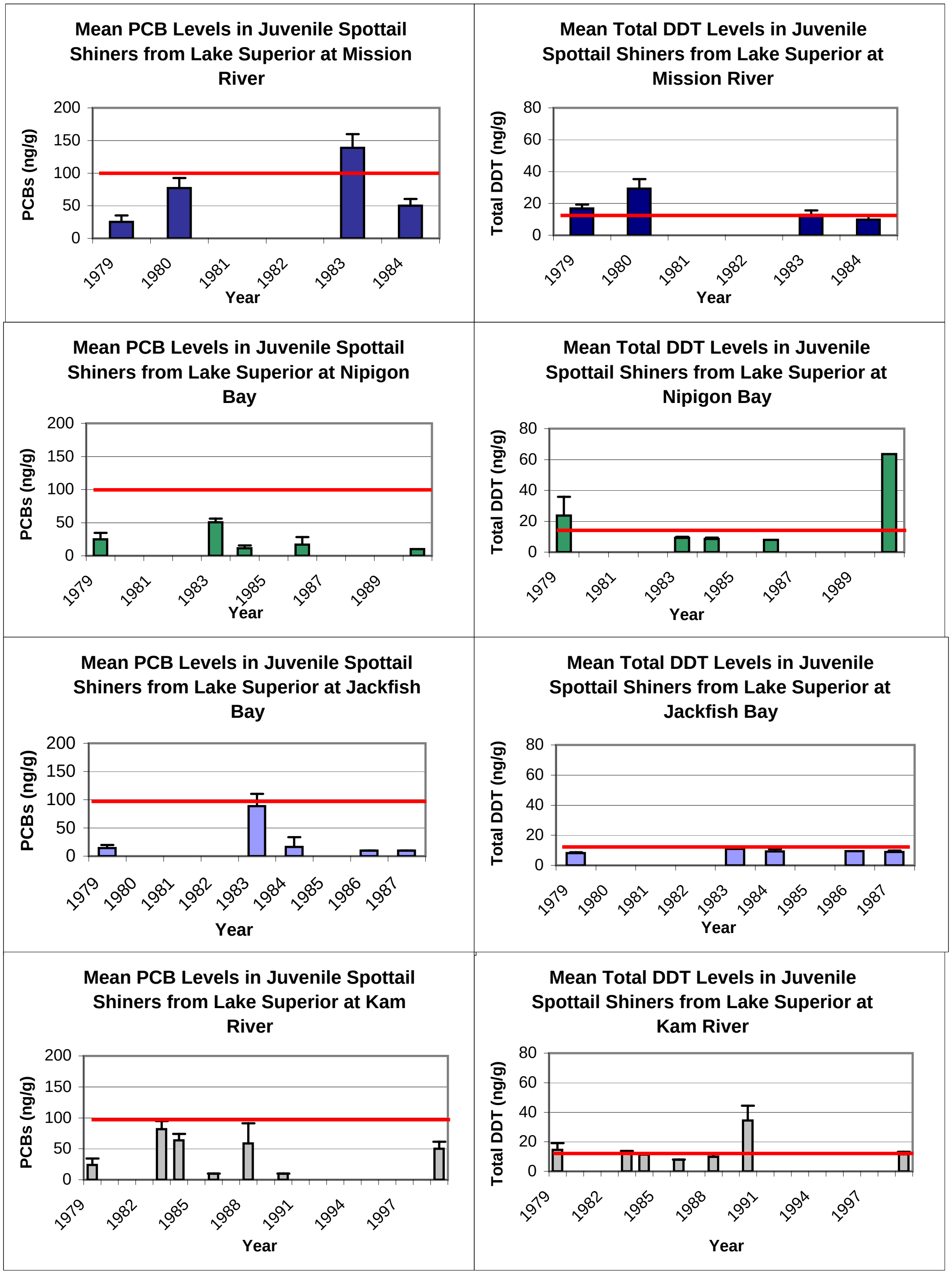
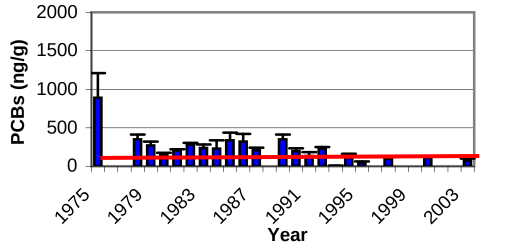


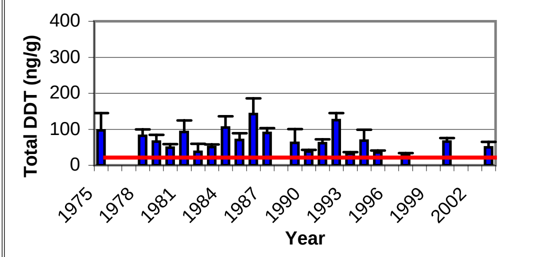
Figure 3. PCB and total DDT levels in juvenille spottail shiners from four locations in Lake Superior. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline. When not detected, one half of the detection limit was used to calculate the mean concentration.

Source: Ontario Ministry of the Environment

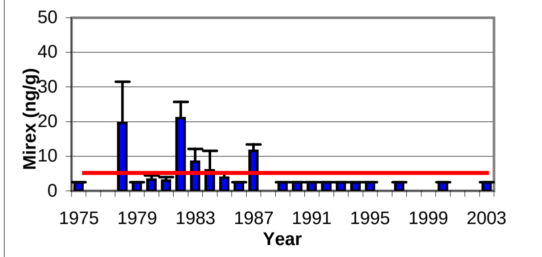
Mean PCB Levels in Juvenile Spottail Shiners from Lake Ontario at Twelve Mile Creek



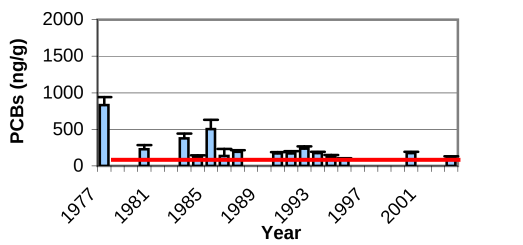
Mean Total DDT Levels in Juvenile Spottail Shiners from Lake Ontario at Twelve Mile Creek



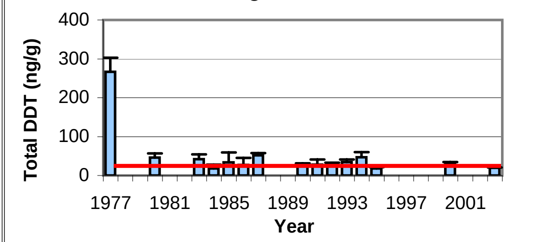
Mean Mirex Levels in Juvenile Spottail Shiners from Lake Ontario at Twelve Mile Creek



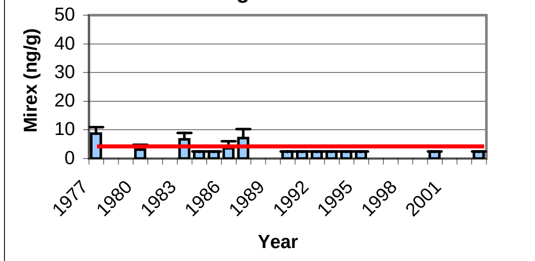
Mean PCB Levels in Juvenile Spottail Shiners from Lake Ontario at Burlington Beach



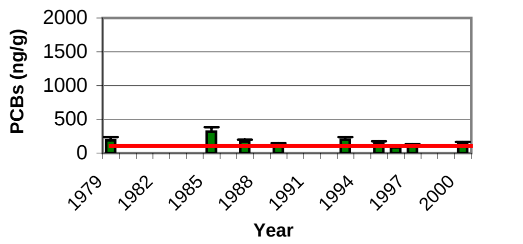
Mean Total DDT Levels in Juvenile Spottail Shiners from Lake Ontario at Burlington Beach



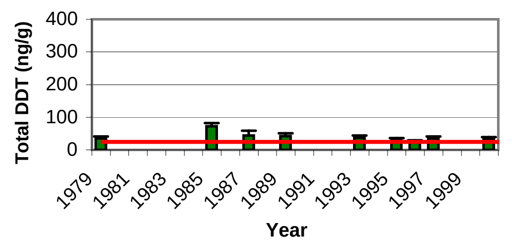
Mean Mirex Levels in Juvenile Spottail Shiners from Lake Ontario at Burlington Beach



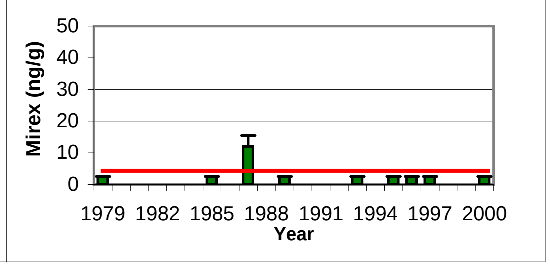
Mean PCB Levels in Juvenile Spottail Shiners from Lake Ontario at Bronte Creek



Mean Total DDT Levels in Juvenile Spottail Shiners from Lake Ontario at Bronte Creek



Mean Mirex Levels in Juvenile Spottail Shiners from Lake Ontario at Bronte Creek



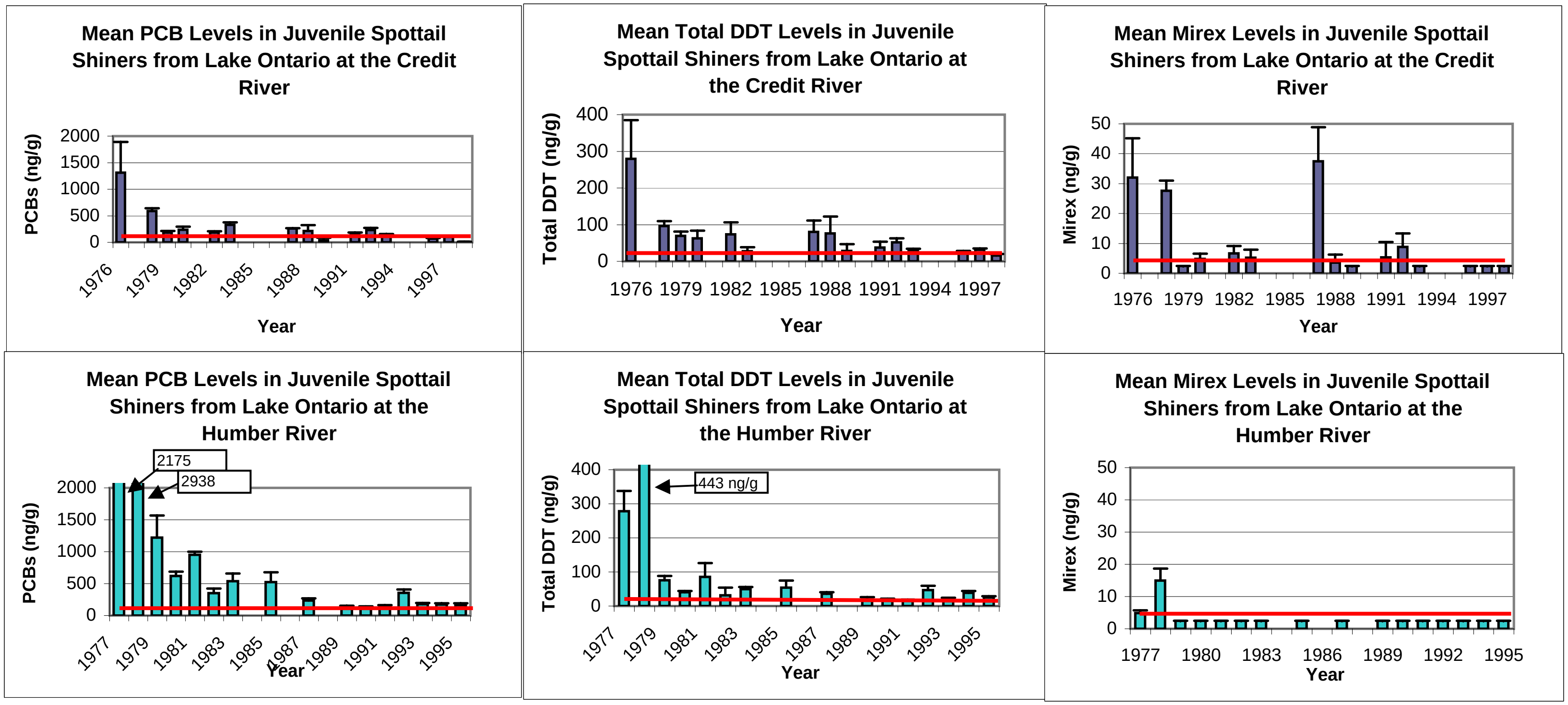


Figure 4. PCB, mirex and total DDT levels in juvenille spottail shiners from five locations in Lake Ontario. The figures show mean concentration plus standard deviation. The red line indicates the wildlife protection guideline for PCBs and total DDT. For mirex, the red line indicates the detection limit of 5 ng/g. When not detected, one half of the detection limit was used to calculate the mean concentration.
Source: Ontario Ministry of the Environment

Contaminants in Colonial Nesting Waterbirds
Indicator #115

Overall Assessment

Status: Mixed
Trend: Improving
Primary Factors Determining Status and Trend: The primary factors being used are: 1. the change in contaminant concentrations in Herring Gull eggs between when they were first measured (usually 1974) and currently, in 2005 (Jermyn-Gee et al. 2005; CWS, unpubl.), 2. the overall ranking of contaminant concentrations at the 15 Great Lakes Herring Gull Egg Monitoring Sites (Weseloh et al. 2006) and 3. the direction and relative slope of the change-point regression line calculated for each compound at each site. (Pekarik and Weseloh 1996; Weseloh et al. 2003, 2005; CWS, unpubl.) Overall, most contaminants have declined substantially (>90%) since first measured. Spatially, some sites in 2-3 of the lakes were much more contaminated than others. Temporally, more than 70% of all contaminant concentrations at all colonies (N=105) were currently declining as fast or faster than they did in the past.

Lake-by-Lake Assessment

Lake Superior

Status: Good
Trend: Improving
Primary Factors Determining Status and Trend: For 6 contaminants that have been measured since the program started in 1974 (PCBs, DDE, HCB, HE, mirex and dieldrin), the two Herring Gull egg monitoring sites in Lake Superior showed declines of 93.9 – 99.8% between then and 2005. Both sites ranked among the lowest for concentrations of 7 major compounds (the above 6 + TCDD) among the 15 monitor sites. The temporal pattern at the two sites showed 71% of colony-contaminant comparisons declining as fast or faster than previously.

Lake Michigan

Status: Mixed
Trend: Improving
Primary Factors Determining Status and Trend: For 6 contaminants that have been measured since the program began, the two Herring Gull egg monitoring sites showed declines of 91.8 – 99.1% between then and 2005. Eggs from one of the Lake Michigan sites ranked as the 3rd most contaminated among the 15 monitor sites; eggs from the other site ranked much lower (9th). The temporal pattern for the two sites showed 86% of the colony-contaminant comparisons declining as fast or faster than previously.

Lake Huron

Status: Mixed
Trend: Improving
Primary Factors Determining: Herring Gull eggs from two of three monitoring sites in Lake Huron were relatively clean. The third site, in Saginaw Bay, had the most contaminated

Status and Trend	gull eggs among all sites tested and reduced the overall status of this indicator in Lake Huron. The three sites showed contaminant declines of 68.9 – 99.7% in gull eggs in 2005. Two of three sites ranked among the lowest for concentrations for 7 major compounds among 15 sites. The temporal pattern at the three sites showed 86% of colony-contaminant comparisons declining as fast or faster than previously.

Lake Erie

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	Of the two monitor sites in Lake Erie, the most easterly, at Port Colborne, had the cleanest gull eggs of all 15 sites tested. Eggs from Middle Island, in the Western Basin, were considerably more contaminated. The two sites showed contaminant declines of 80.2 – 99.3% in gull eggs in 2005. Eggs from Middle Island were in the mid-range and those from Port Colborne were the lowest for contaminants. The temporal pattern at the two sites showed 93% of colony-contaminant comparisons declining as fast or faster than previously.

Lake Ontario

Status:	Poor
Trend:	Improving
Primary Factors Determining Status and Trend	Eggs from the three Lake Ontario Herring Gull Monitoring Sites showed declines of 88.6 – 99.0% in 2005. The three sites ranked among the top 8 for concentrations of contaminants in gull eggs. Temporally, 76% of colony-contaminant comparisons were declining as fast or faster than previously.

Purpose

•To assess current chemical concentrations and trends in representative colonial waterbirds (gulls, terns, cormorants and/or herons) on the Great Lakes;
•To assess ecological and physiological endpoints in representative colonial waterbirds (gulls, terns, cormorants and/or herons) on the Great Lakes; and
•To infer and measure the impact of contaminants on the health, i.e. the physiology and breeding characteristics, of the waterbird populations.

Ecosystem Objective

One of the objectives of monitoring colonial waterbirds on the Great Lakes is to track progress toward an environmental condition in which there is no difference in contaminant levels and related biological endpoints between birds on and off the Great Lakes. Other objectives include determining temporal and spatial trends in contaminant levels in colonial waterbirds and detecting changes in their population levels on the Great Lakes. This includes monitoring contaminant levels in Herring Gull eggs to ensure that the levels continue to decline and utilizing these data to promote continued reductions of contaminants in the Great Lakes basin.

State of the Ecosystem

Background

This indicator is important because colonial waterbirds are one of the top 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 continuously running annual wildlife contaminants monitoring program in the world (1974-present). It determines concentrations of up to 20 organochlorines, 65 polychlorinated biphenyls (PCB) congeners and 53 polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzo furan (PCDF) congeners, as well as 16 brominated diphenyl ethers BDEs) congeners (Braune et al. 2003).

Status of Contaminants in Colonial Waterbirds

The Herring Gull Egg Monitoring Program has provided researchers and managers with a powerful tool (a 30-year database) to evaluate changes in contaminant concentrations in Great Lakes wildlife (e.g., see Figure 1). The extreme longevity of the egg database makes it possible to calculate temporal trends in contaminant concentrations in wildlife and to look for significant changes within those trends. The database shows that most contaminants in gull eggs have declined 90% or more since the program began in 1974 (Figure 2). In 2005, PCBs, hexachlorobenzene (HCB), dichlorodiphenyl-dichloroethene (DDE), heptachlor epoxide (HE), dieldrin, mirex and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) levels measured in eggs from the 15 Annual Monitor Colonies (Figure 3) were analysed for temporal trends (N=105 comparisons). Analysis showed that in 83.8% of cases (88/105), the contaminants were decreasing as fast as or faster in recent years than they had in the past. We interpreted that as a positive sign. In 9.5% of cases (10/105), contaminants were decreasing more slowly than they had in the past (calculated from Bishop et al.1992, Pettit et al.1994, Pekarik et al.1998 and Jermyn-Gee et al. 2005, as per Pekarik and Weseloh 1998). This is viewed as a negative sign. PCBs showed the most frequent reduction in their rates of decline. The decline in contaminant concentrations in gull eggs, however, may not be due wholly to a decrease in contaminants in the environment. Changes in food web dynamics may be playing a role in some of these declines, that is, contaminant exposure at some colonies may have lessened because the birds are now feeding on lower trophic level prey.

The sole exception to these declining herring gull egg contaminant concentrations appears to be brominated diphenyl ethers (BDEs). These compounds, which are used as fire retardants in plastics, furniture cushions, etc., increased dramatically in gull eggs during 1981-2000 (Norstrom et al. 2002). Recent data showed a combined 3.9% decline for the 15 monitor sites from 2000 to 2003 but a 25.3% increase from 2000 to 2005 (CWS, unpubl. data).

A comparison of concentrations of six contaminants (PCBs, HCB, DDE, HE, dieldrin and mirex) at the 15 sites in 2003 and 2005 (N=90 comparisons) was made to show the variability in a short-term (two year) assessment. TCDD was last measured in 2003, therefore for this short-term assessment 2001 and 2003 data were used for an additional 15 comparisons. Of the total 105 comparisons, 89 (84.8%) decreased; only 16 (15.2%) increased. TCDD and PCBs were the most frequently increasing contaminants (Canadian Wildlife Service (CWS) unpublished data). This is illustrated for a single contaminant, PCBs, in Figure 4. Annual fluctuations like these, including both short-term increases and decreases, are part of current contaminant patterns (Figures 1 and 4).

In terms of gross ecological effects of contaminants on colonial waterbirds, e.g. eggshell thinning, failed reproductive success and population declines, most species appear to have recovered. Populations of most species have increased over the past 25-30 years, e.g. see Figure 5 (Blokpoel and Tessier 1993-1998; Austen et al. 1996; Scharf and Shugart 1998, Cuthbert et al. 2001,Weseloh et al. 2002; Morris et al. 2003, Havelka and Weseloh In review, Hebert et al. In review, CWS unpubl. data). Although the gross effects appear to have subsided (but see Custer et al. 1999), there are many other subtle, mostly physiological and genetic endpoints that are being measured now that were not measured in earlier years (Fox et al. 1988, Fox 1993, Grasman et al. 1996, Yauk et al. 2000). A recent and ongoing study, the Fish and Wildlife Health Effects and Exposure Study, is assessing whether there are fish and wildlife health effects in Canadian Areas of Concern (AOCs) similar to those reported for the human population (Environment Canada 2003). To date, the following abnormalities have been found in Herring Gulls in one or more Canadian AOCs on the lower Great Lakes: a male-biased sex ratio in hatchlings, elevated levels of embryonic mortality, indications of feminization in more than 10% of adult males, a reduced or suppressed ability to combat stress, an enlarged thyroid with reduced hormone production and a suppressed immune system. Although there is little question that Herring Gulls and colonial waterbirds on the Great Lakes are healthier now than they were 30 years ago, these findings show that they are in a poorer state of health than are birds from clean reference sites in the Maritimes (Environment Canada 2003).

Pressures
Future pressures for this indicator include all sources of contaminants which reach the Great Lakes. These include those sources that are already well-known, e.g., point sources, re-suspension of sediments, and atmospheric inputs, as well as lesser known ones such as underground leaks from landfill sites. There are also other, non-contaminant factors that regulate the stability of populations, e.g. habitat modification (in the Detroit River), food availability (Lake Superior), interspecific competition at breeding colonies (Lake Ontario) and predation (western Lake Erie). Many of these factors pose much more tangible threats to our ability to collect eggs from these colonies in the future.

Management Implications
Data from the Herring Gull Egg Monitoring Program suggest that, for the most part, contaminant levels in wildlife are continuing to decline at a constant rate. However, even at current contaminant levels, more physiological abnormalities in Herring Gulls occur at Great Lakes sites than at cleaner, reference sites away from the Great Lakes basin. Also, with the noted increase in concentrations of polybrominated diphenyl ethers (PBDEs), steps should be taken to identify and reduce sources of this compound to the Great Lakes. In short, although almost all contaminants are decreasing and many biological impacts have lessened, we do not yet know the full health implications of the subtle effects and of newly monitored contaminants.

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 this 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 on improving and expanding the Herring Gull Egg Monitoring Program is done on a more opportunistic, less predictable basis. A lake-by-lake intensive study of possible biological impacts to herring gulls is currently underway in the lower lakes. Recently, ecological tracers (stable isotopes and fatty acids) have been generated from archival eggs as part of the program and provide insights into how food webs in the Great Lakes ecosystem are changing. This information broadens the utility of the program from just examining contaminants to providing insights into ecosystem change. Ecological tracer data are also directly relevant to the interpretation of contaminant monitoring data.

Comments from the author(s)

We have learned much about interpreting the Herring Gull egg contaminants data from associated research studies. However, much of this work is conducted 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, factors regulating chemically induced genetic mutations and ecological tracers.

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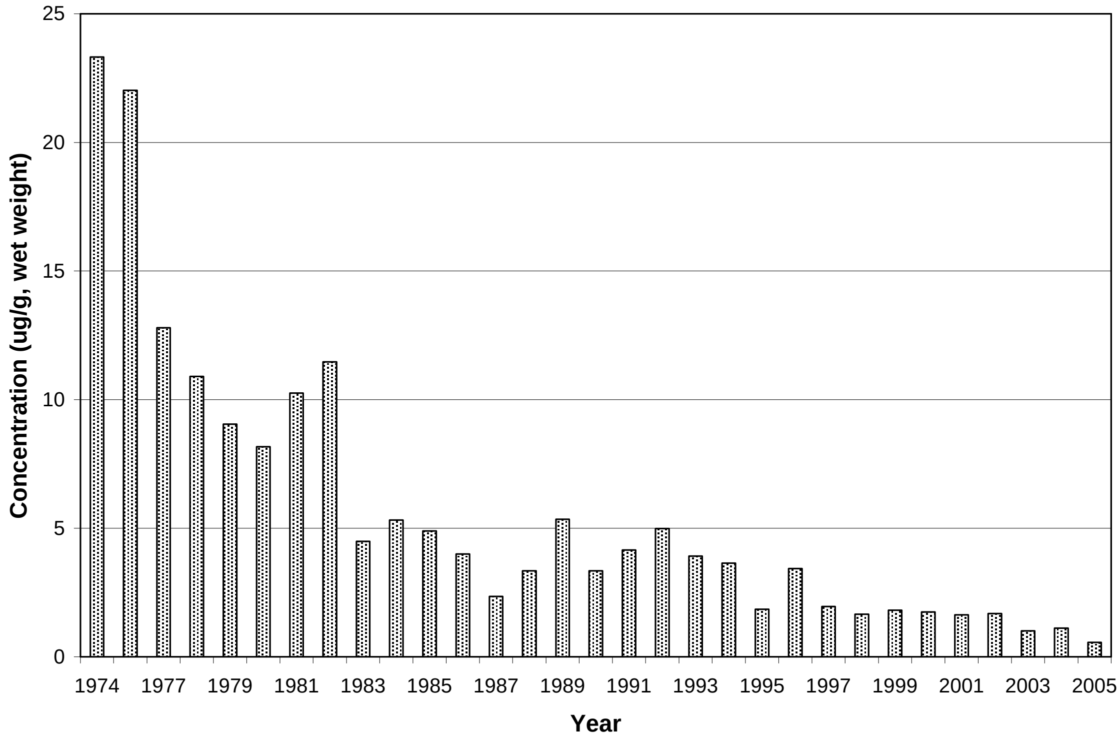

Figure 1. Annual concentration of DDE in Herring Gull eggs, Toronto Harbour, 1974-2005.
Source: Environment Canada, Herring Gull Monitoring Program

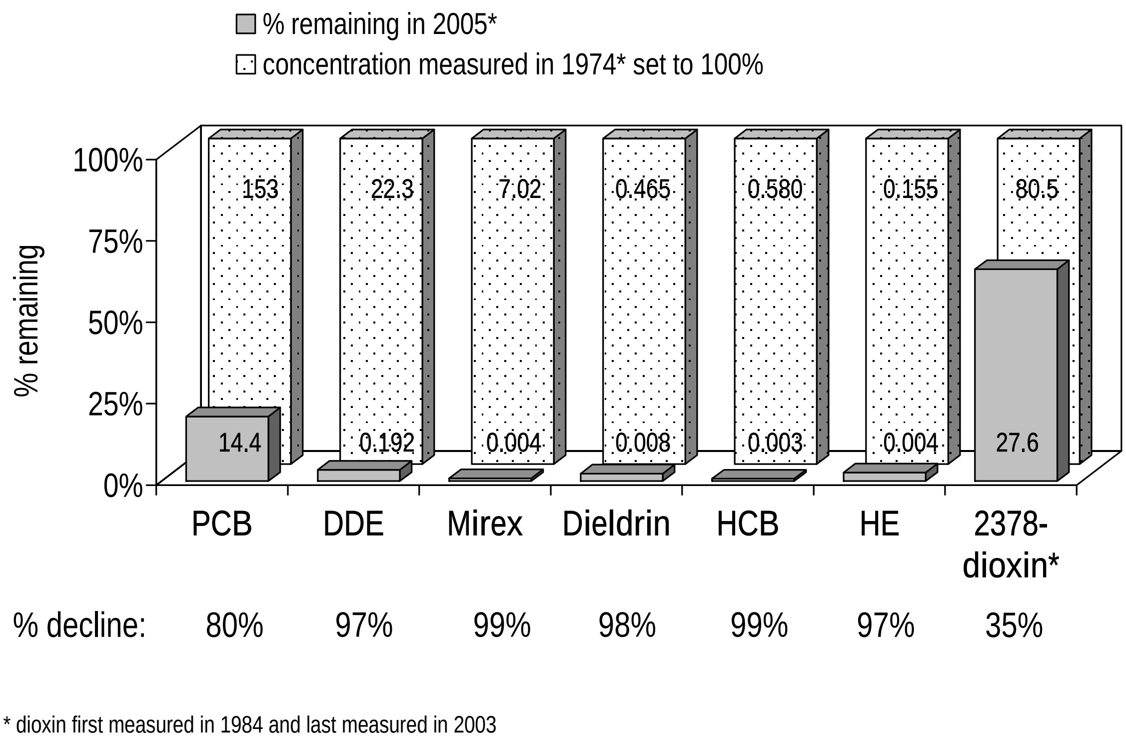

Figure 2. Mean contaminant concentrations and percent decline of 7 contaminants in Herring Gull eggs from year of first analysis to present, Middle Island, Lake Erie. Concentrations in µg/g wet weight except for dioxin in ρg/g wet weight.
Source: Environment Canada, Herring Gull Monitoring Program

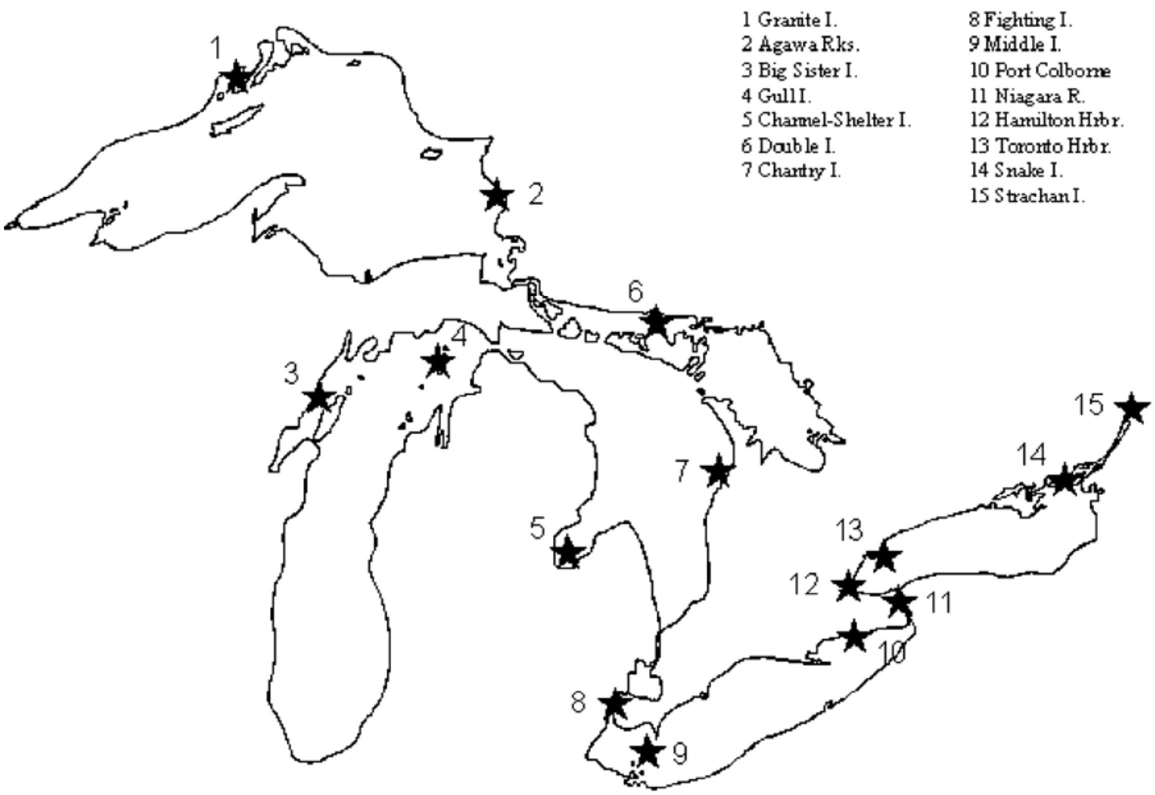

Figure 3. The distribution and locations of the 15 Herring Gull Annual Monitoring Colonies. Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

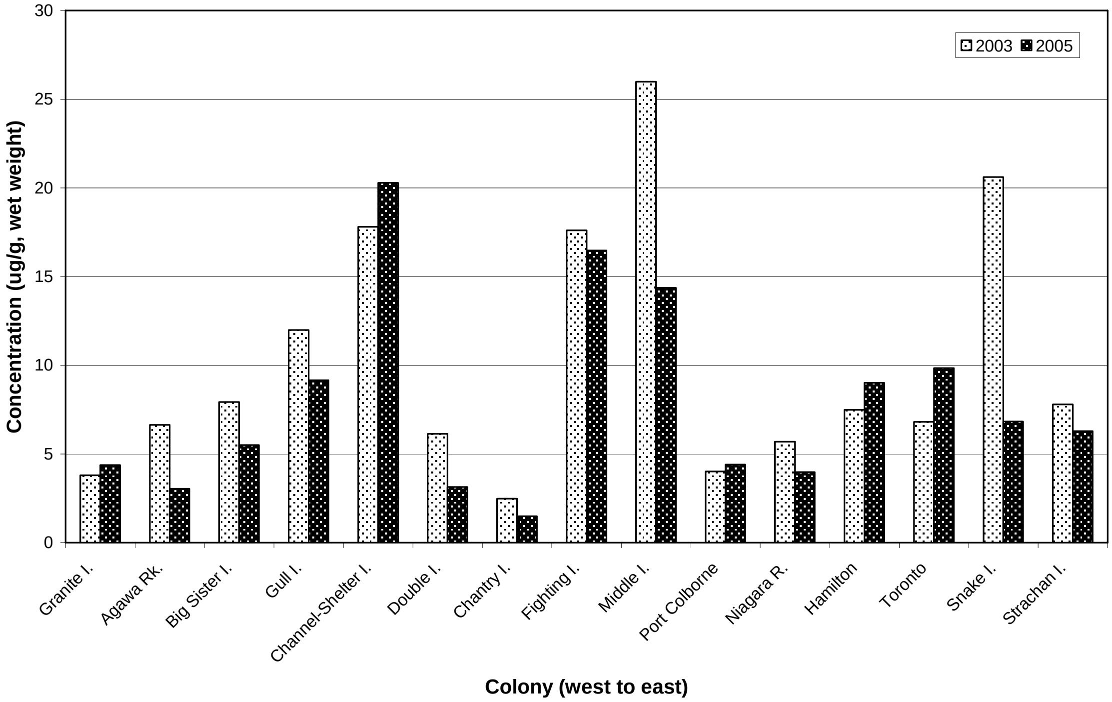

Figure 4. A comparison of PCB concentrations at all sites for 2003 and 2005. Note the between year differences as well as the variation among sites.
Source: Environment Canada, Herring Gull Monitoring Program and Canadian Wildlife Service

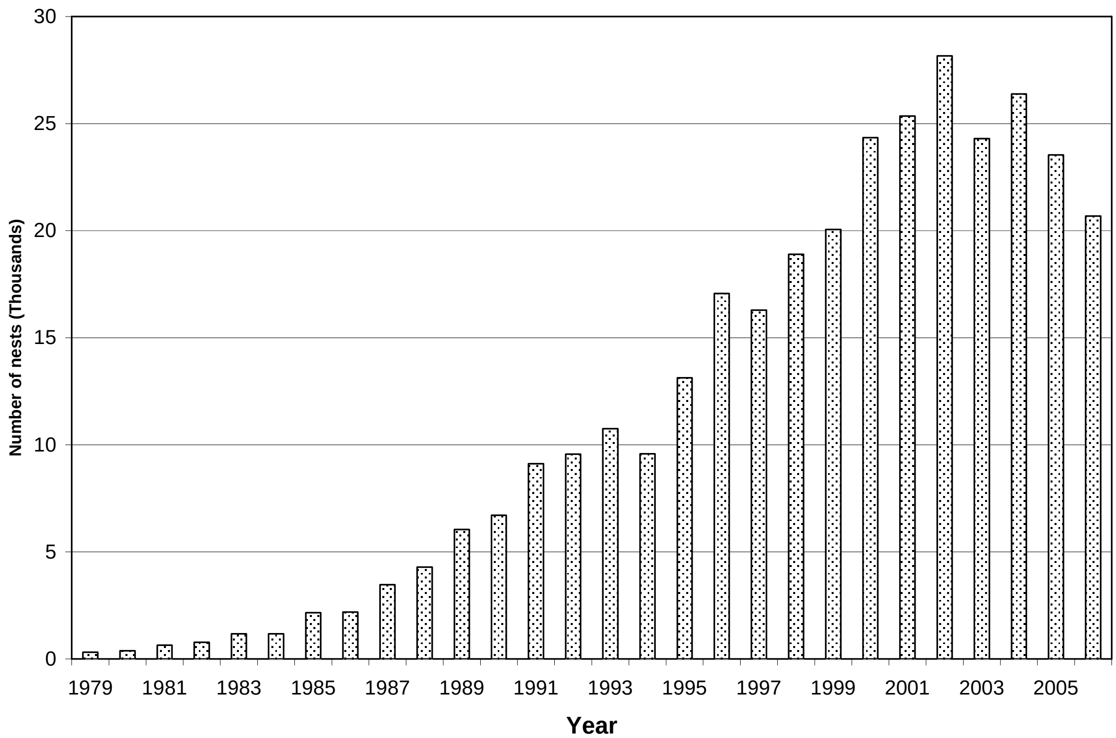

Figure 5. Double-crested Cormorant nests (breeding pairs) on Lake Ontario, 1979-2005. Source: Environment Canada, Canadian Wildlife Service