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

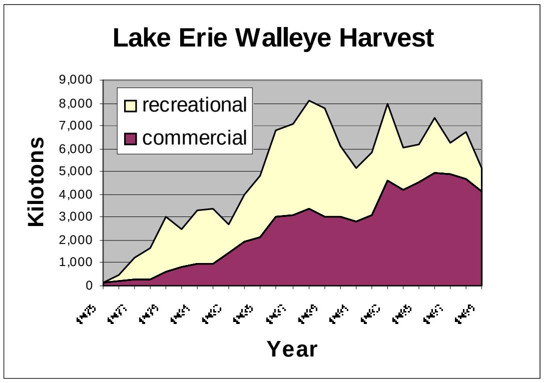
Fishery yields can serve as appropriate indicators of walleye health but need to include all types of fisheries (i.e., recreational, commercial, tribal) in the areas of interest. Yield assessments are lacking for some fisheries or in some years for most of the areas. Moreover, measurement units are not 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.

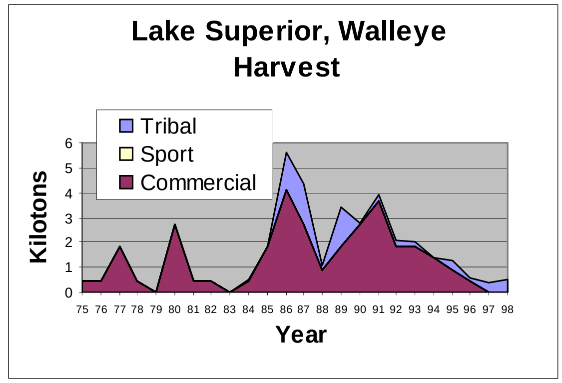
Sources

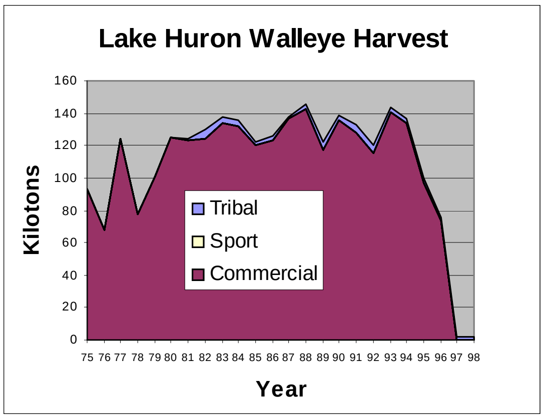
Fishery harvest data were obtained from Tom Stewart (Lake Ontario-OMNR), Tom Eckhart (Lake Ontario - NYDEC), Karen Wright (Upper Lakes tribal data-

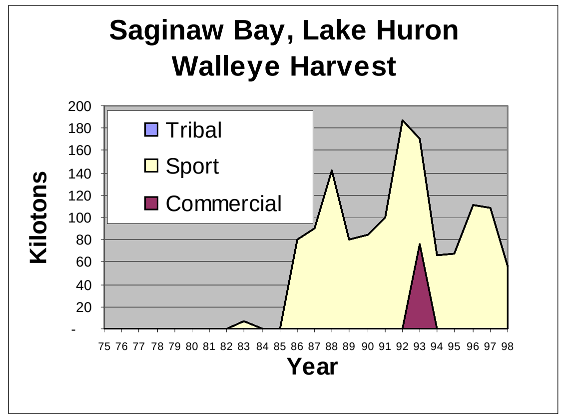
COTFMA), Dave Fielder (Lake Huron-MDNR), Terry Lychwyck (Green Bay-WDNR), various annual OMNR and ODNR Lake Erie fisheries reports, and the GLFC commercial fishery data base. Gene Emond (ODNR) collated data into a standardized form. Fishery data should not be used for purposes outside of this document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

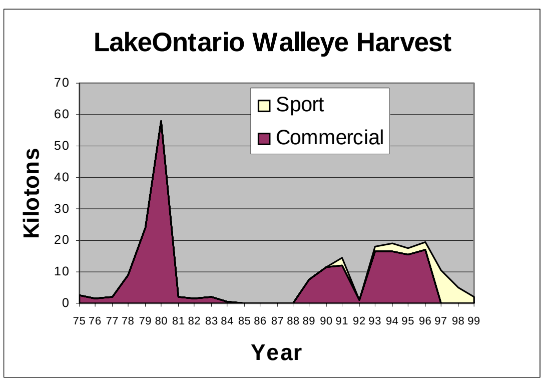
Acknowledgments
Author: Roger Knight, Ohio Department of Natural Resources, OH.

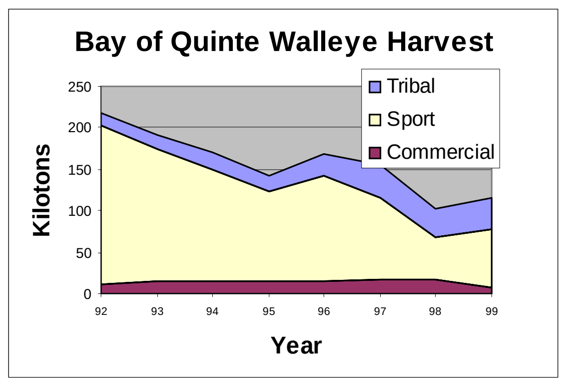


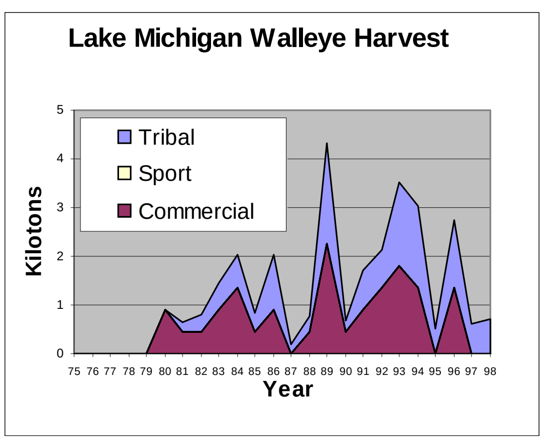


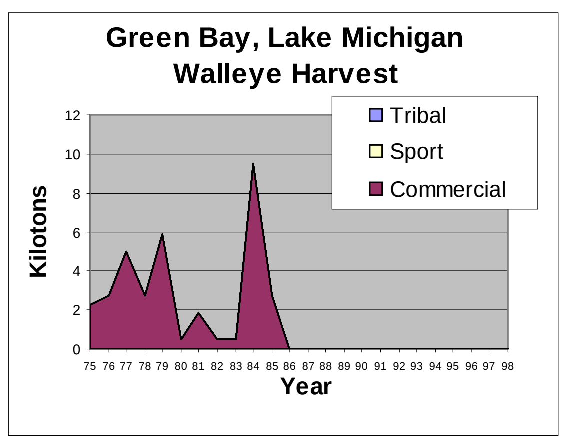












FCGOs
Lake Huron: 0.7 million kg
Lake Michigan: 0.1 to 0.2 million kg
Lake Erie: sustainable harvests in all basins
Achievement of these targets will require healthy walleye stocks in each lake.

[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

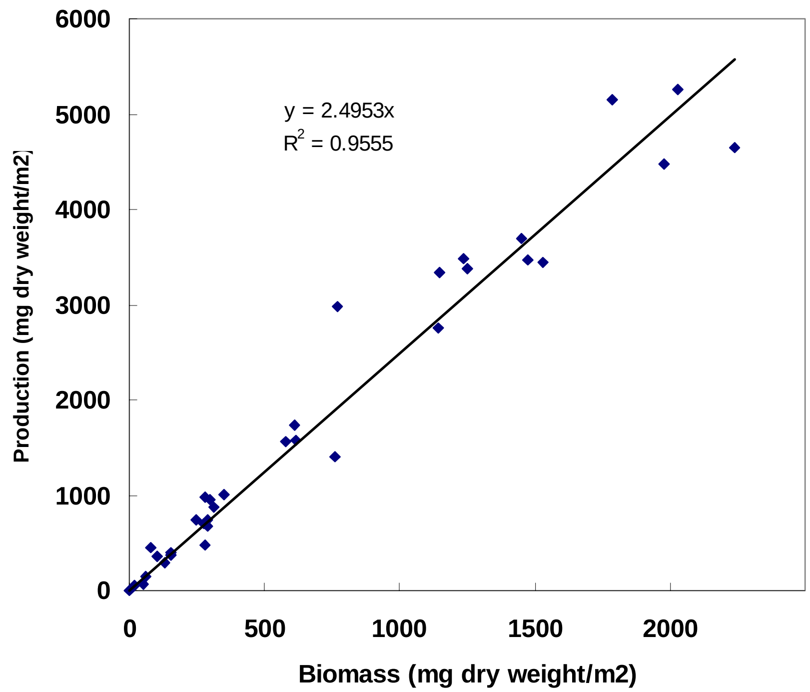


Figure 1. Mean annual biomass and production of *Hexagenia* populations in North America.
Biomass values >500 (production values > about 1000) represent populations from unpolluted portions of Lake St. Clair, the St. Marys River, and eastern Lake Superior. Lower values represent populations from polluted 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.

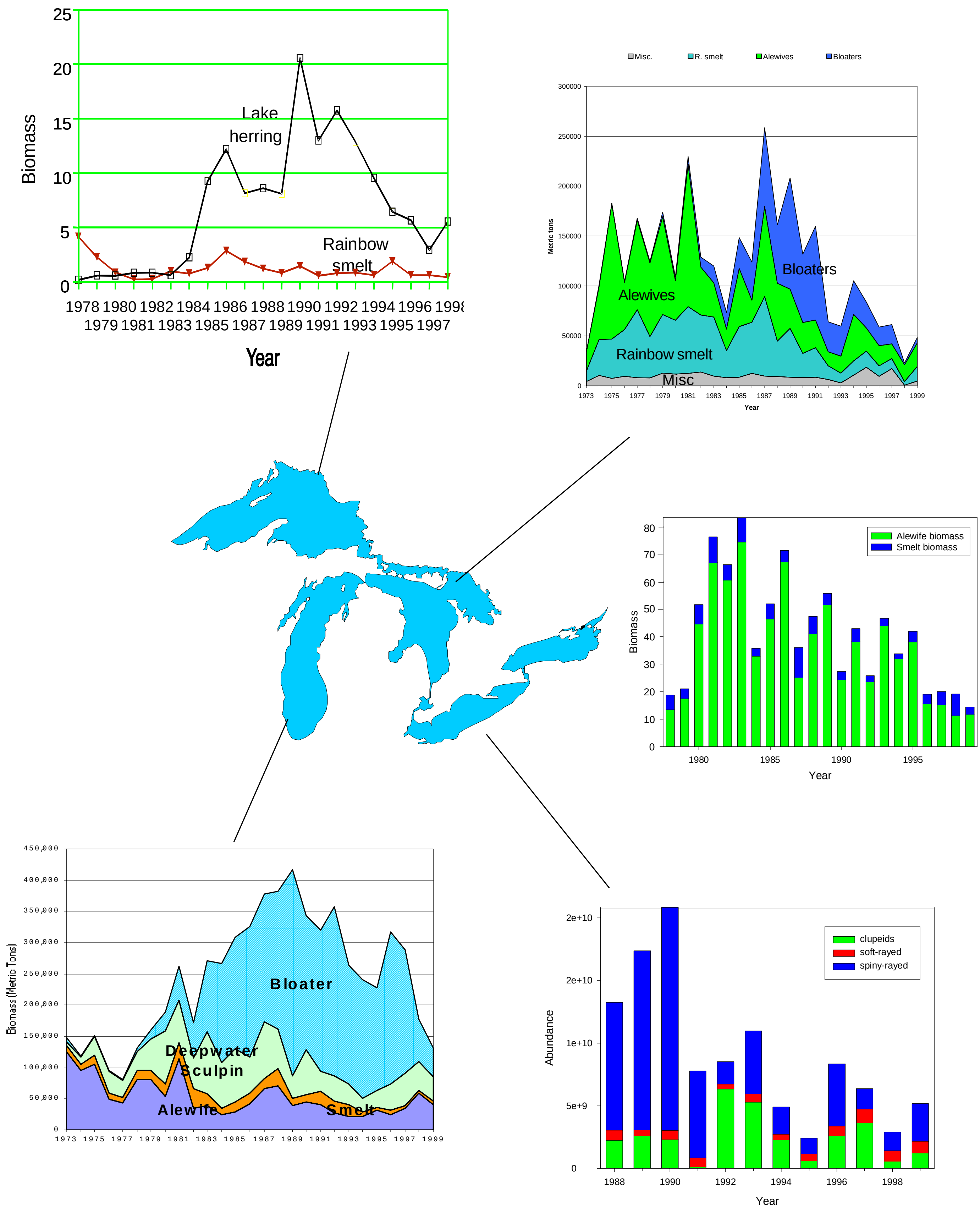
In Lake Erie, the prey fish community is unique among the Great Lakes in that it is characterized by relatively high species diversity. The prey fish community comprises primarily gizzard shad (*Dorosoma cepedianum*) and alewife (clupeids), emerald (*Notropis atherinoides*) and spottail shiners (*N. 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


Biomass
Year
Lake herring
Rainbow smelt
1978 1980 1982 1984 1986 1988 1990 1992 1994 1996
1979 1981 1983 1985 1987 1989 1991 1993 1995 1997
Misc.
R. smelt
Alewives
Bloaters
Metric tons
Alewives
Bloaters
Rainbow smelt
Misc
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year
Alewife biomass
Smelt biomass
Biomass
1980 1985 1990 1995
Year
Biomass (Metric Tons)
Bloater
Deepwater Sculpin
Alewife
Smelt
1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
clupeids
soft-rayed
spiny-rayed
Abundance
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

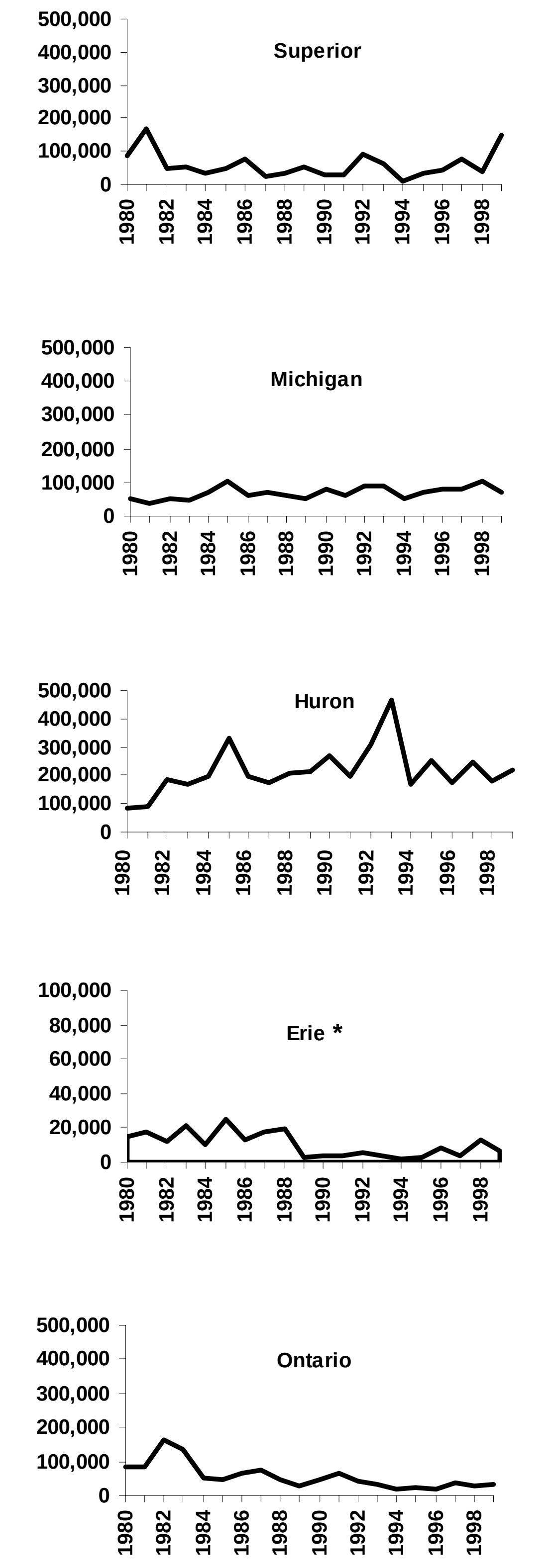


Figure 1. Total annual abundance of sea lamprey estimated during the spawning migration. Note the scale for Lake Erie is 1/5 larger than the other lakes.

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

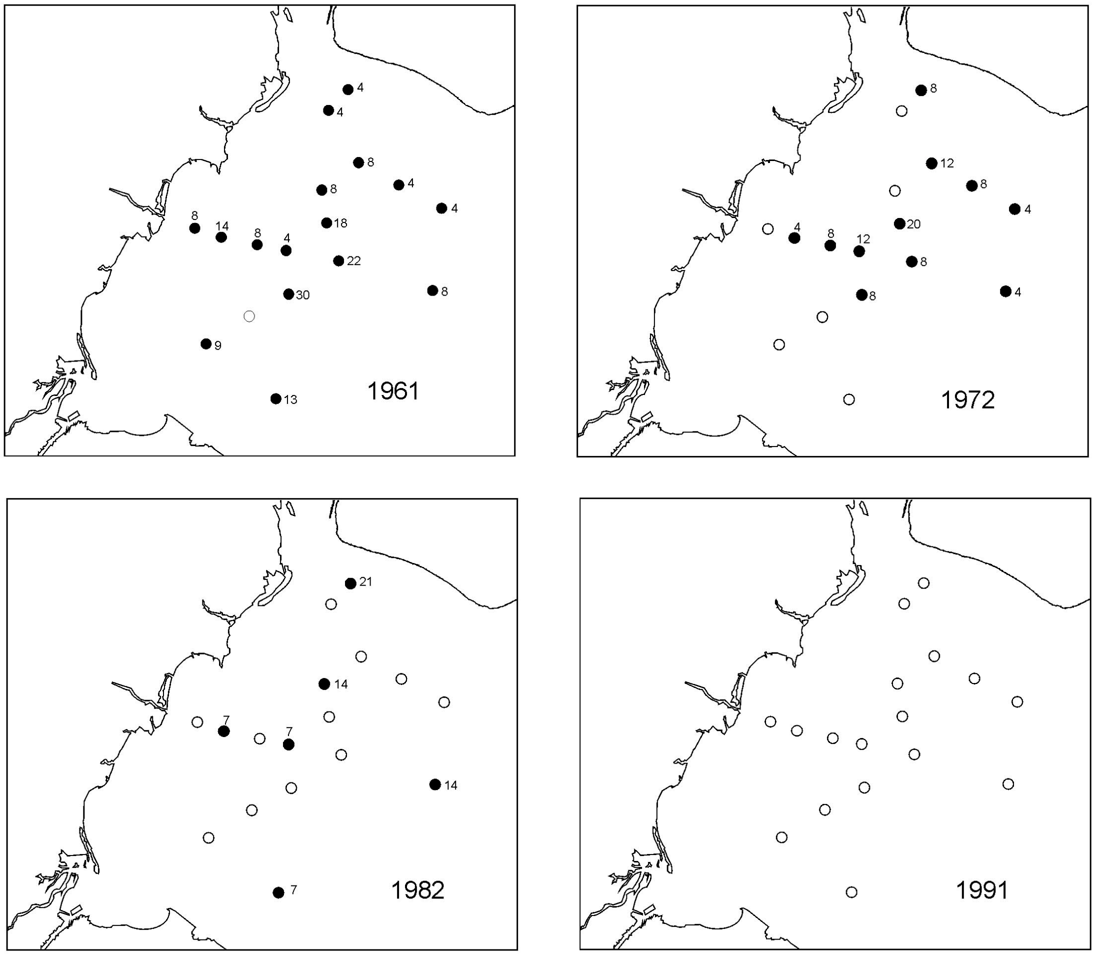


Figure 1. Abundance of freshwater mussels (numbers/m2) collected in 1961, 1972, 1982 and 1991 from 17 sites in the western basin of Lake Erie.
Source: Nalepa et al. (1991) and Schloesser and Nalepa (1994).

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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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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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.

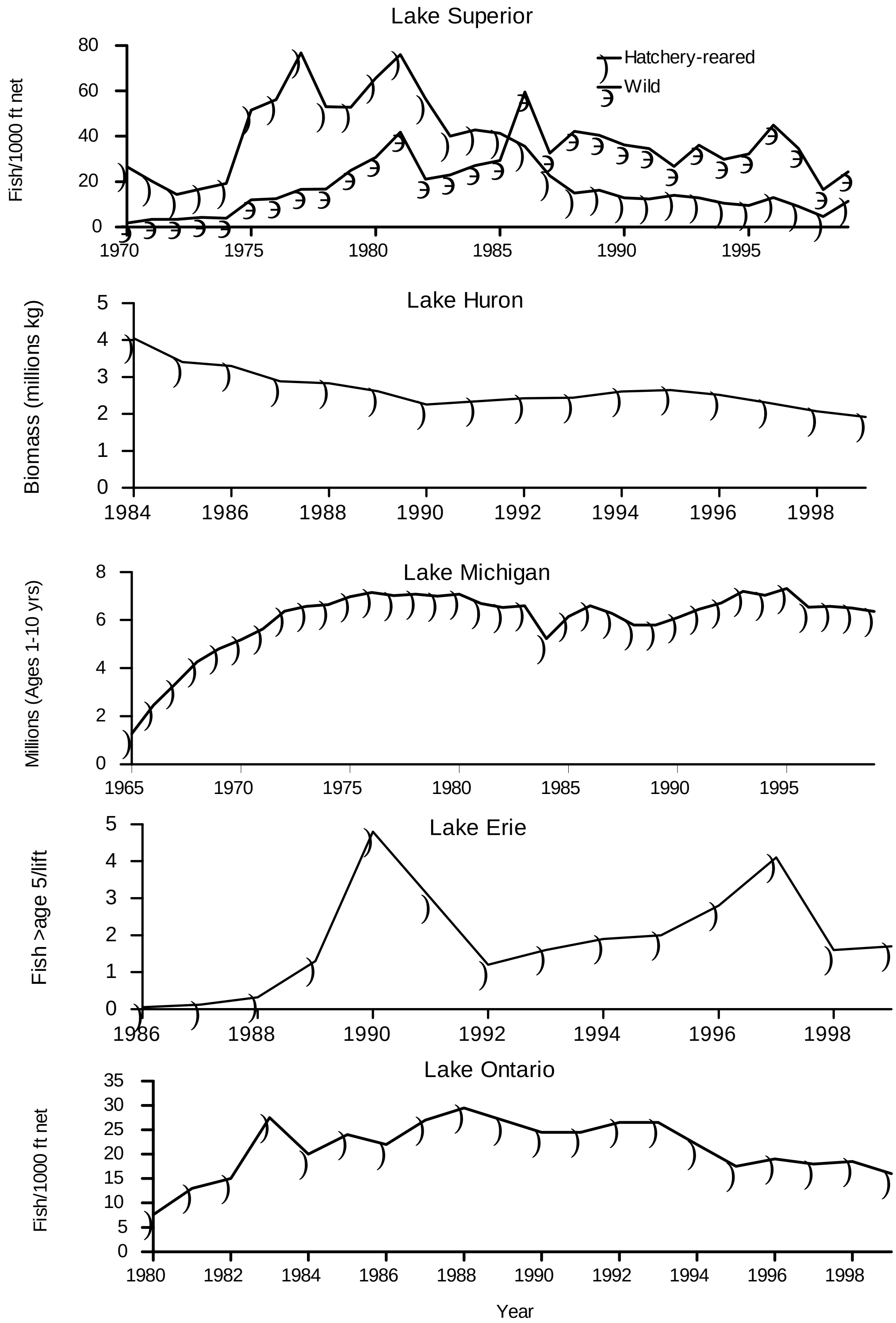

Figure 1.

[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.

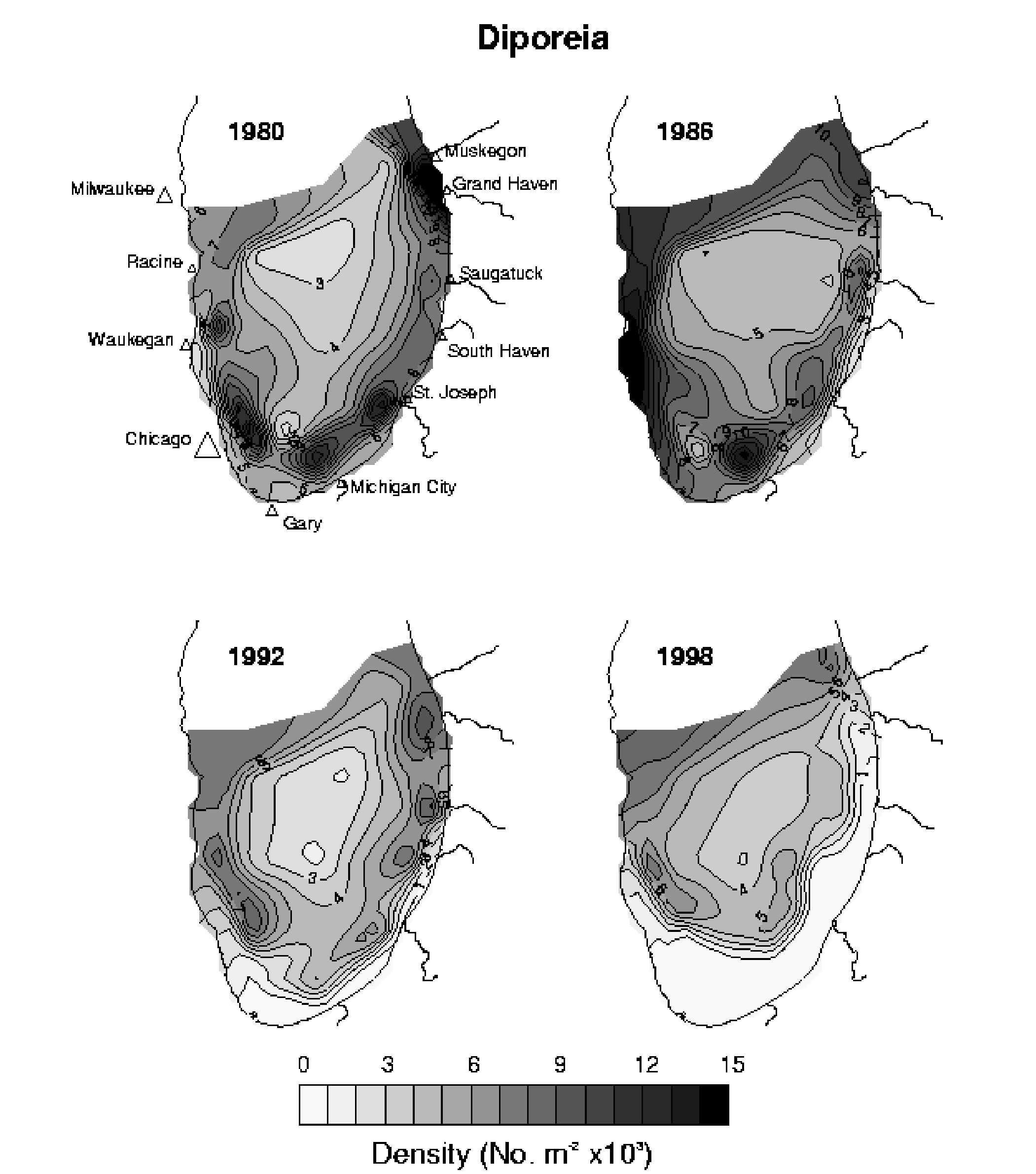

Figure 1. Density (no. m^{-2} x 10^3) of *Diporeia* in the southern basin of Lake Michigan between 1980 and 1998. Note recent declines in the southeastern portion of the basin. (Source: Great Lakes Environmental Research Laboratory, NOAA)

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).

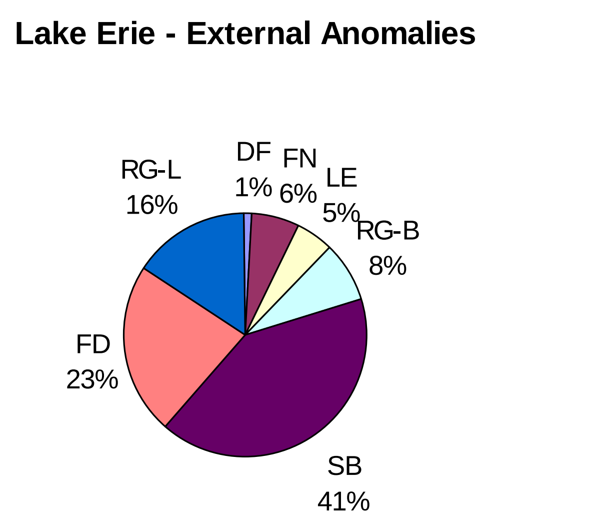

Figure 1. External anomalies on brown bullhead collected from 1980s through 2000. DF- deformities, FN-fin erosion, LE-lesions, RG-B-raised growth-body, SB-stubbed barbell, FD-focal discoloration, and RG-L – raised growth-lip.

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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Acknowledgements
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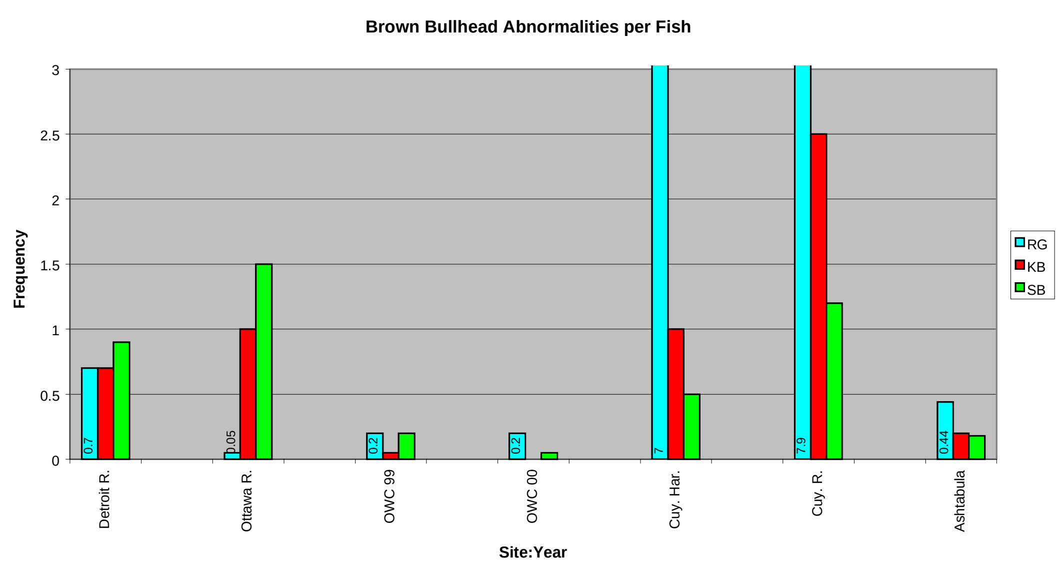


Figure 2. External lesion frequency for brown bullheads in Lake Erie, 1999-2000. OWC-Old Woman Creek-reference, Cuy- Cuyahoga River. RG-raised growth, KB-knobbed barbells, SB-stubbed barbels.

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.

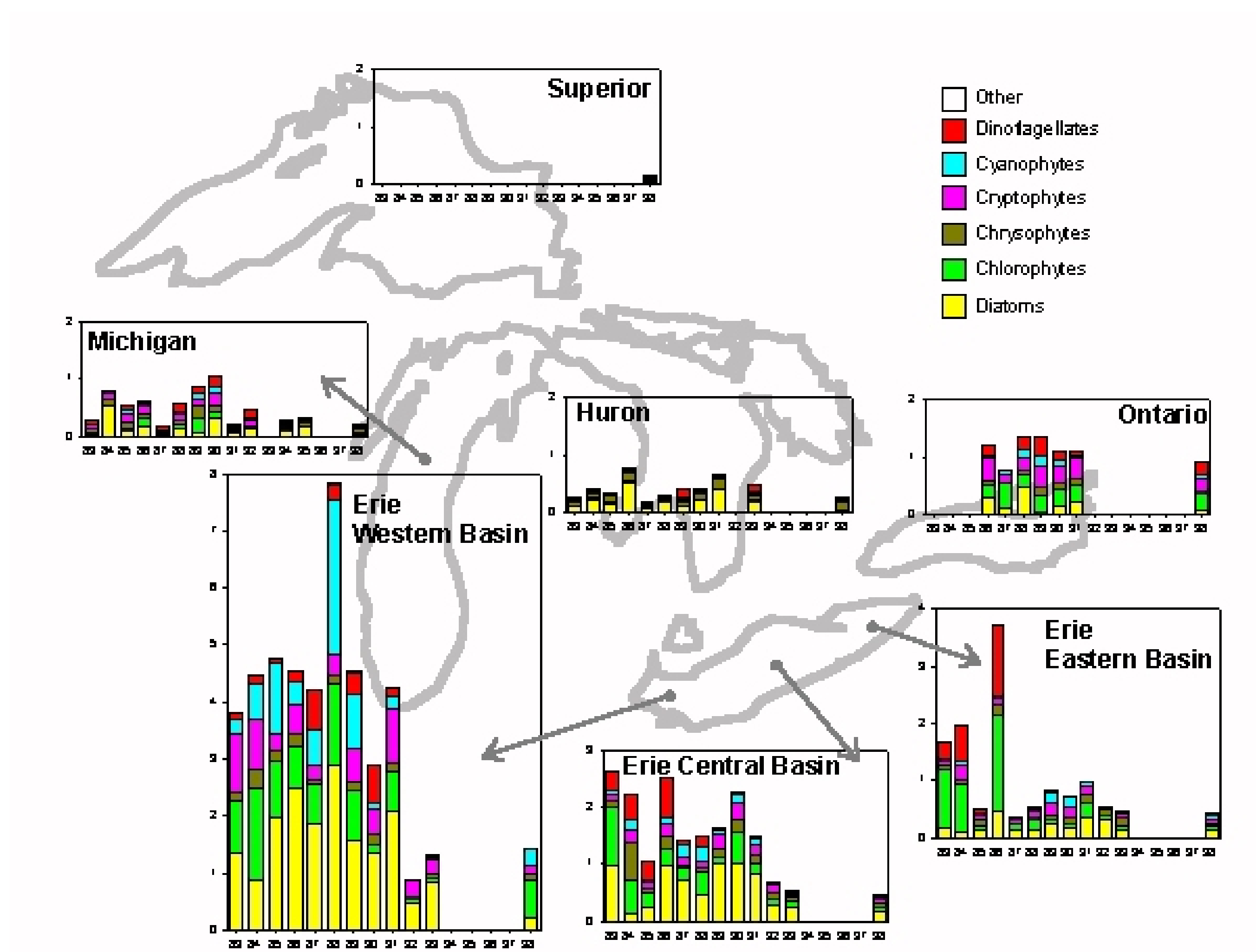


Figure 1. Trends in phytoplankton biovolume (gm/m³) and community composition in the Great Lakes 1983-1998 (Summer, Open Lake, Epilimnion) (Blank indicates no data).
(Source: Great Lakes National Program Office, U.S. Environmental Protection Agency)

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

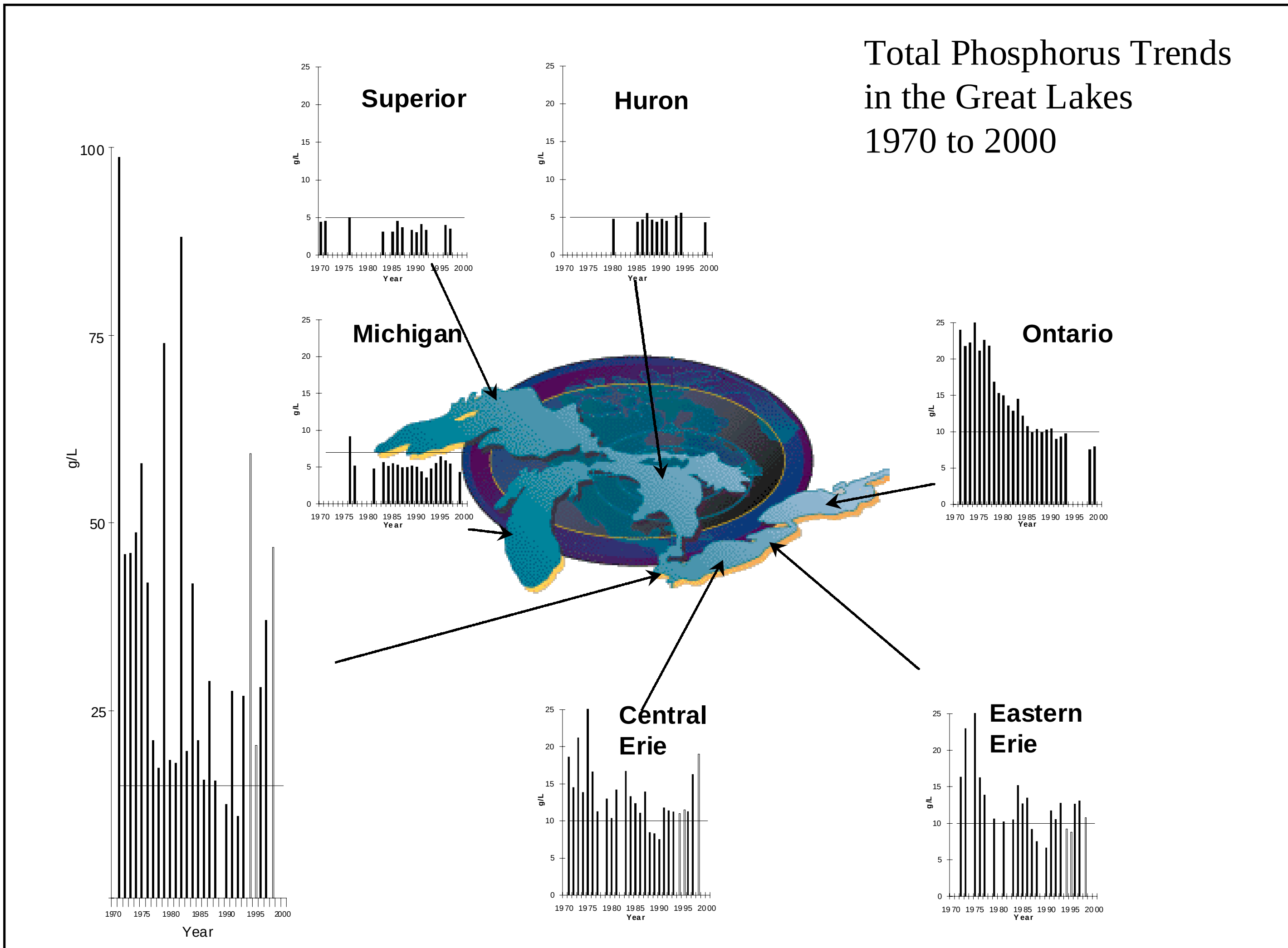
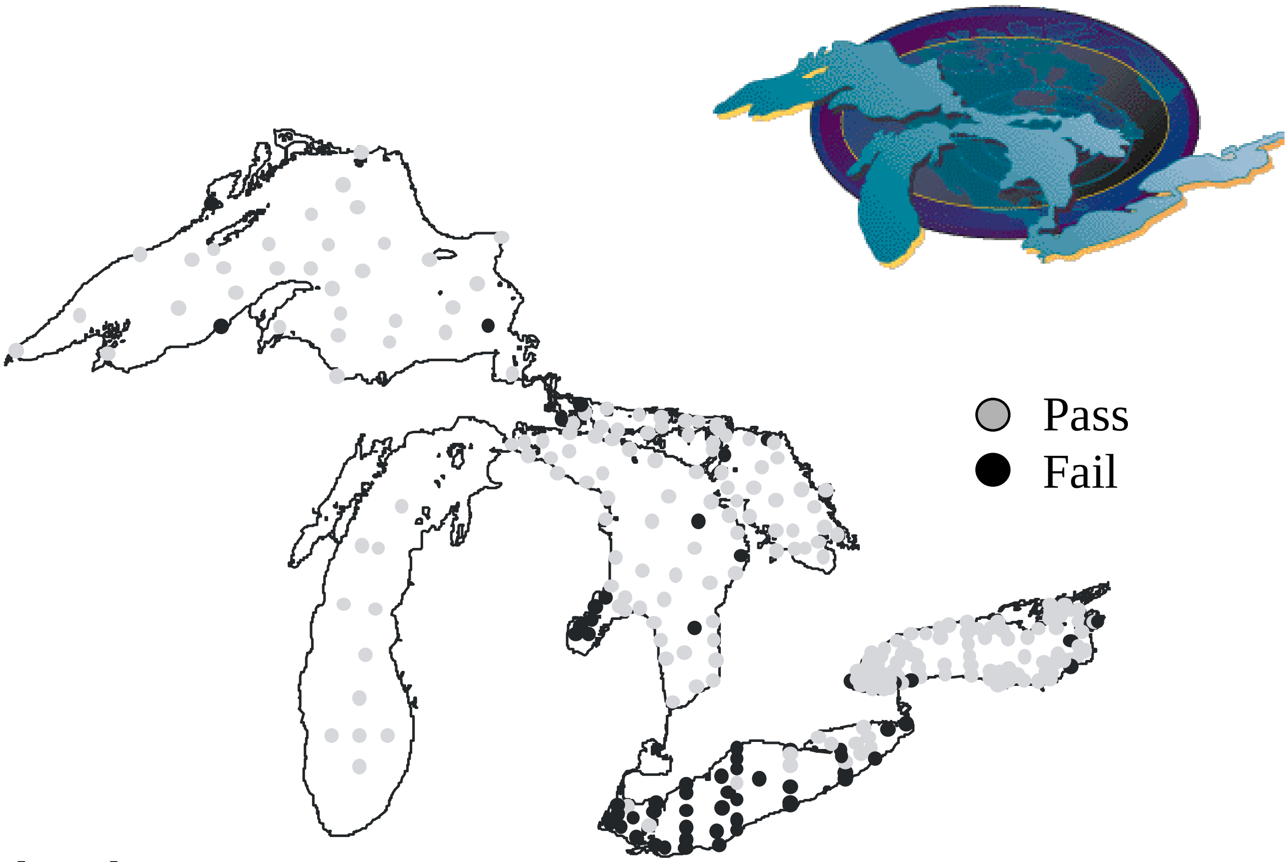


Figure 1. Total Phosphorus Trends in the Great Lakes 1971-2000 (Spring, Open Lake, Surface) (Blank indicates No Sampling).
(Source: Environmental Conservation Branch, Environment Canada and Great Lakes National Program Office, U.S. Environmental Protection Agency)



Total Phosphorus Concentrations
compared to Guidelines

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.

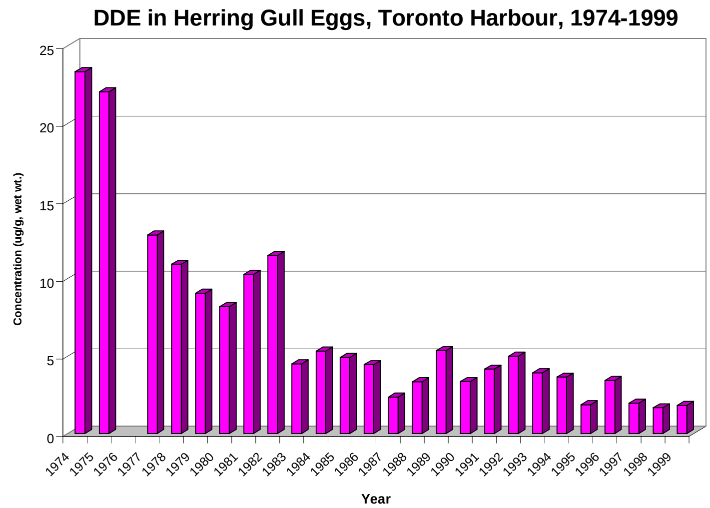


Figure 1. Temporal trends.

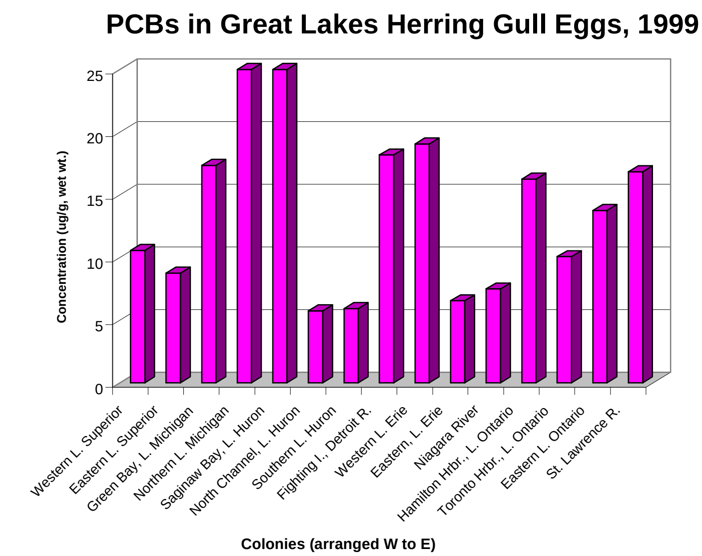


Figure 2. Spatial trends.

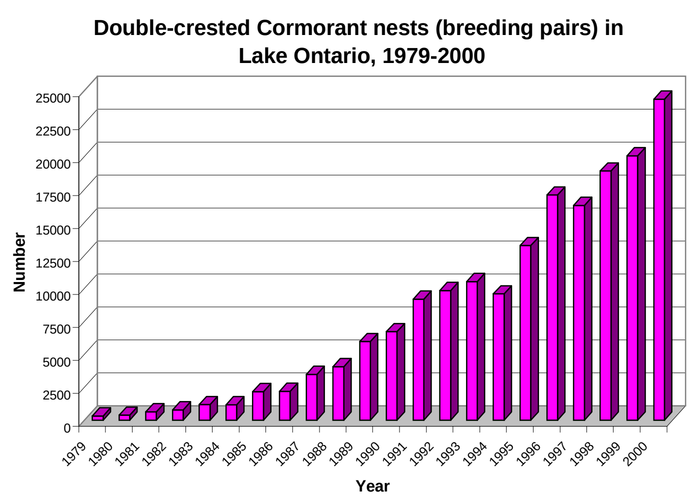


Figure 3. Population trends.

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.

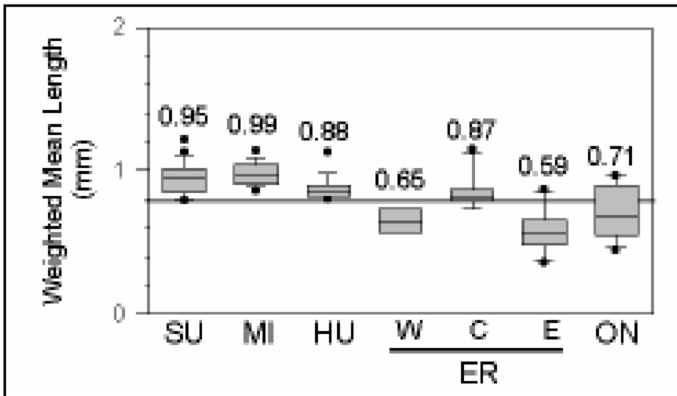


Figure 1. Average individual mean length of zooplankton for the five Great Lakes. Lake Erie is divided into western, central and eastern basins. Length estimates were generated from data collected with 153µm mesh net tows to a depth of 100 m or the bottom of the water column, whichever was shallower.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

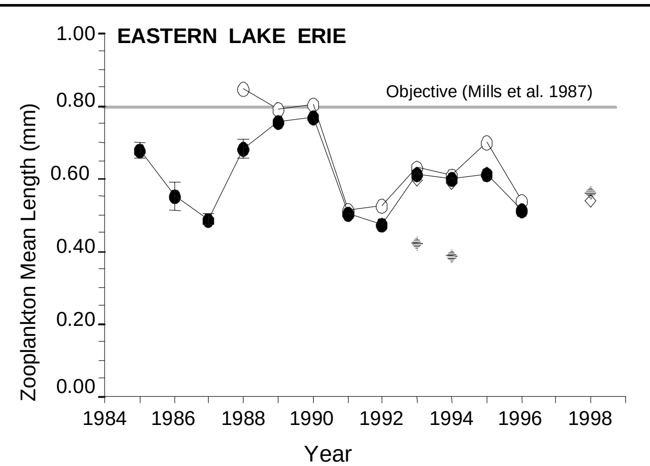


Figure 2. Trend in Jun27-Sep30 mean zooplankton length: NYDEC data (circles) collected with 153-um mesh net, DFO data (diamonds) converted from 64-um to 153-um mesh equivalent. Open symbols = offshore, solid symbols = nearshore (<12 m). 1985-1988 are means+/- 1 S.E.
(Source: Johannsson et al. 1999)

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.

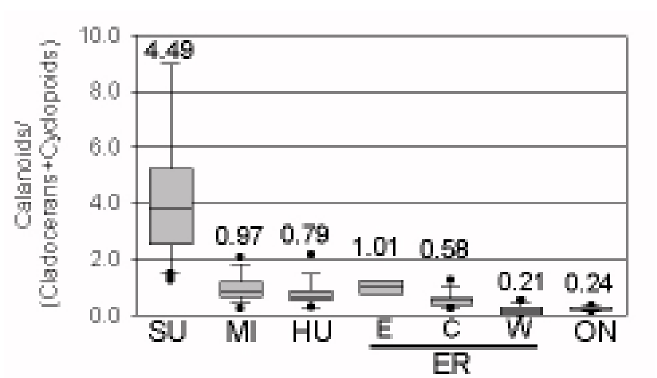


Figure 3. Ratio of biomass of calanoid copepods to that of cladocerans and cyclopoid copepods for the five Great Lakes. Data as in Fig. 1; Boxes as in Fig. 1. Numbers indicates arithmetic averages

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.

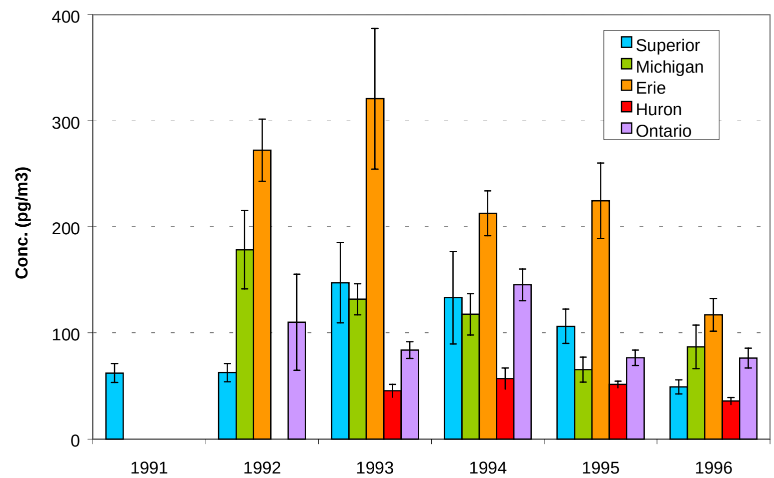
Atmospheric Deposition of Toxic Chemicals

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.

Figure 1. Annual Average Concentrations of Total PCBs in Gas-phase



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.

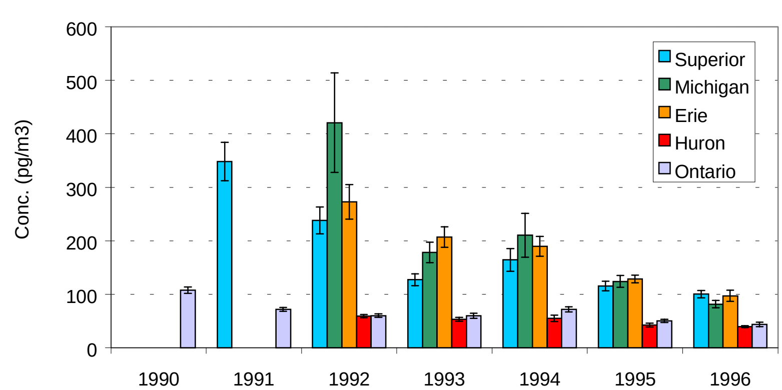
State of the Ecosystem

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.

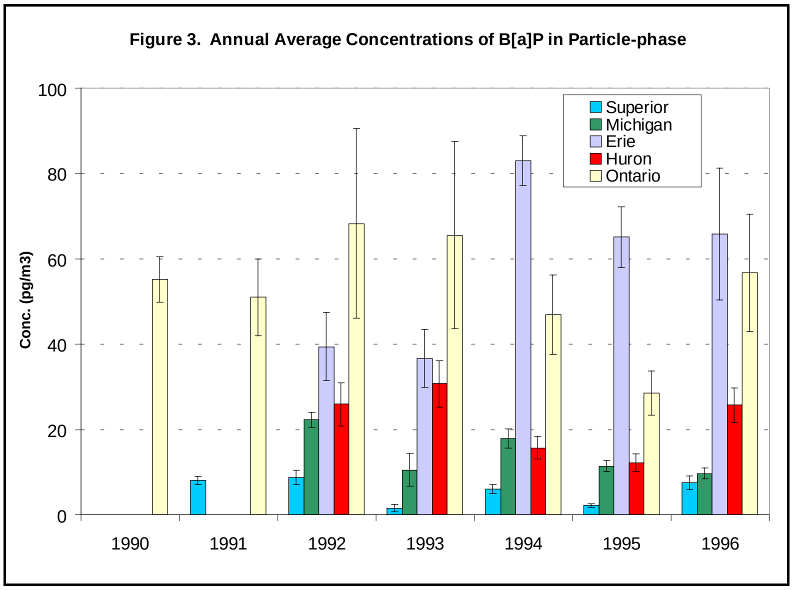
For gas-phase total PCBs (ΣPCB), the Lake Erie site consistently shows relatively elevated concentrations compared to the other Lakes; see Figure 1. For all sites, the trend over time is generally down with half-lives on the order of 3-6 years. The relatively elevated concentrations for Lake Erie are 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.

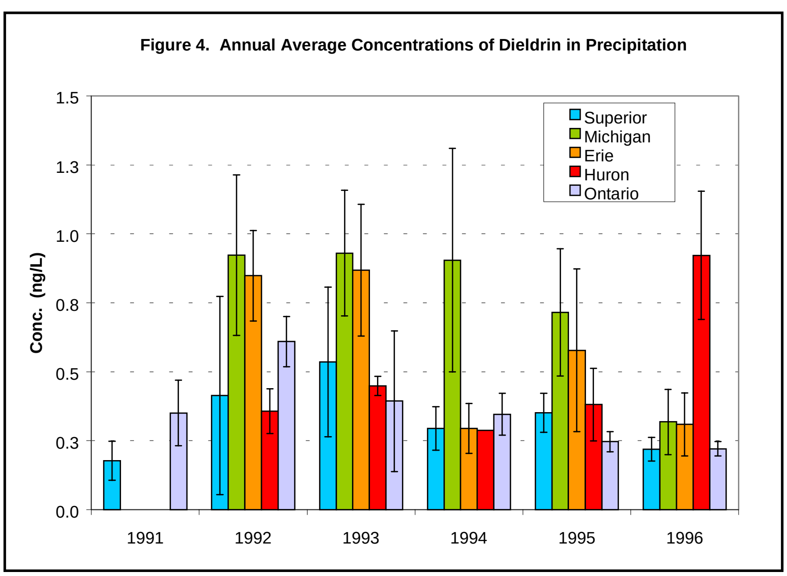
Figure 2. Annual Average Concentrations of Total HCHs in Gas-phase



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.



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.



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

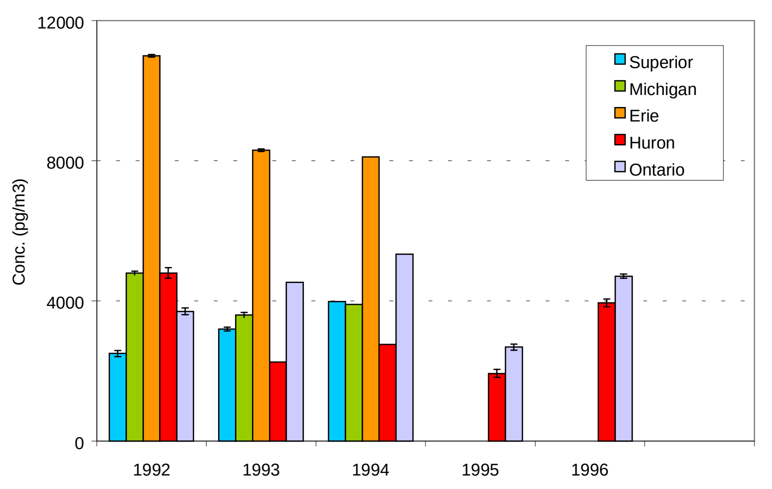
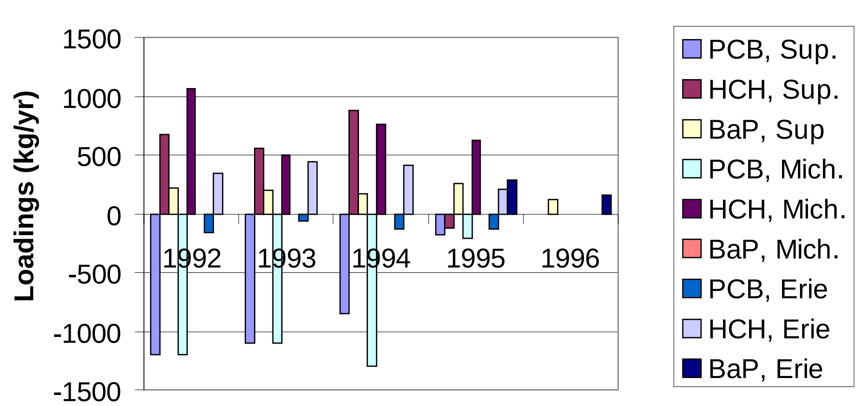


Figure 6. Loadings of Total PCBs, Total HCHs, and BaP to the Great Lakes



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.

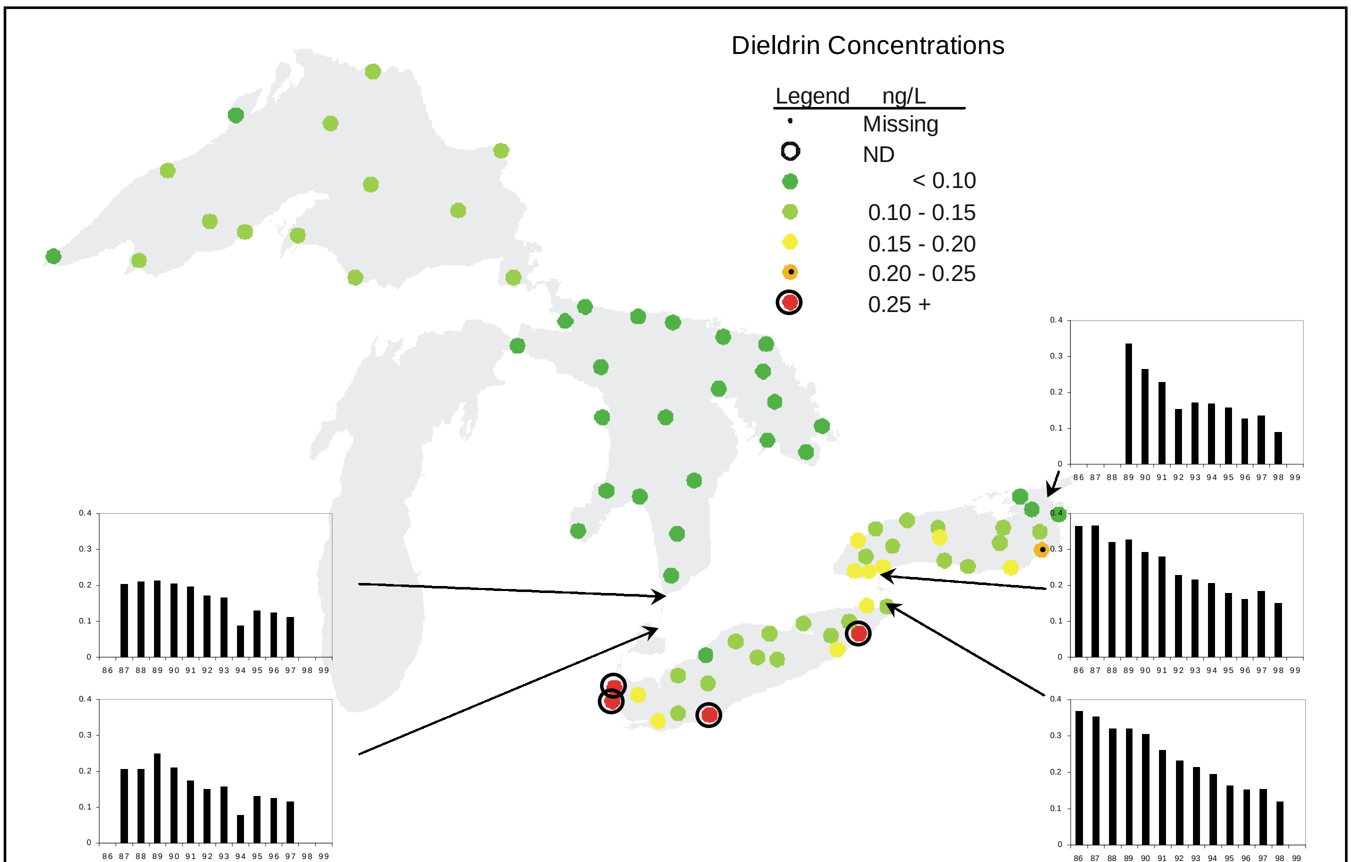


Figure 1. Spatial Dieldrin patterns in the Great Lakes (Spring 1997 or 1998, Surface) and annual most likely estimated averages for the interconnecting channels from 1986 to 1998. Units = ng/L
(Source: Environmental Conservation Branch, Environment Canada)

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.

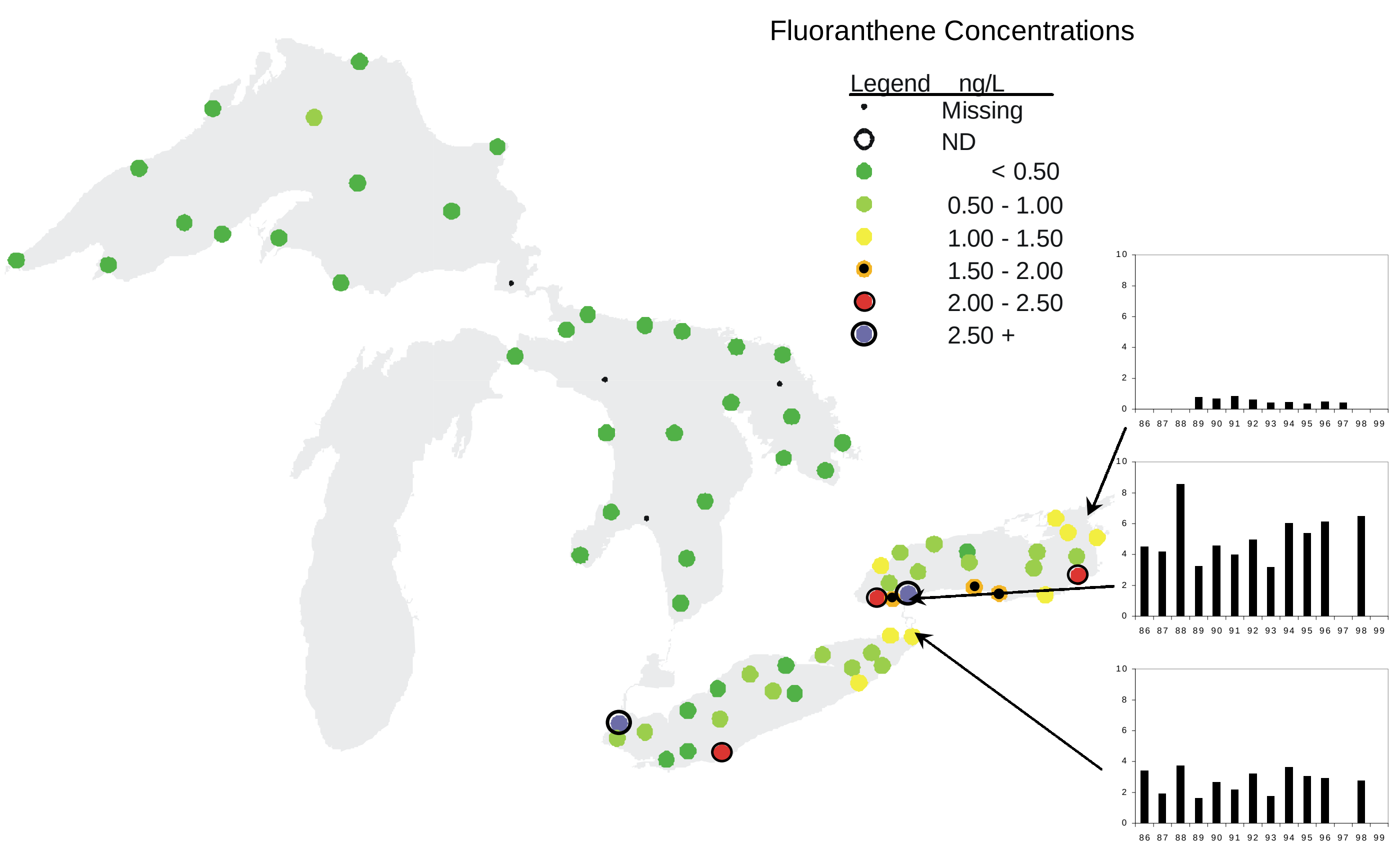


Figure 2. Spatial fluoranthene patterns in the Great Lakes (Spring 1997 or 1998, Surface) and annual most likely estimated averages for the interconnecting channels from 1986 to 1998. Units = ng/L
(Source: Environmental Conservation Branch, Environment Canada)