Hexagenia
Indicator # 122

Overall Assessment

Status:	**Mixed**
Trend:	**Improving**
Primary Factors Determining Status and Trend	**Lack of time-series and historical information. To date, only one area (western Lake Erie) has exhibited any substantial recovery of *Hexagenia* despite anecdotal reports of recovery for many areas in the Great Lakes in the mid to early 1990s. After an absence of 50 years, emerging *Hexagenia* were observed in open water of western Lake Erie in 1992 (Figure 1). Studies confirmed the return of nymphs to sediments between 1995 and 2005 (Figure 2). Between 1995 and 2005, the annual average density of nymphs was approximately 300 nymphs/m^2, a density similar to known historical abundances of nymphs in the basin. The return of this taxon may be entering the final stage of its recovery (i.e., stable annual abundances). However, large decreases in density (1997 to 1998 and 2001 to 2002, Figure 2) and poor young-of-year recruitment into the population (3 of 6 years, Figure 3) indicate that 'restoration' of nymphs has not been totally successful. The cause(s) for population decreases and failed recruitment is not known but it is suspected that it is related to residual pollution. Effects of residual pollution will likely decrease as pollution-abatement programs continue. Continued work in western Lake Erie will allow us to define a quantitative goal for successful 'restoration' of *Hexagenia* in mesotrophic waters in western Lake Erie and throughout the Great Lakes (Figure 4).**

Lake-by-Lake Assessment

Lake Superior

Status:	Poor
Trend:	Undetermined
Primary Factors Determining Status and Trend	Lack of time-series and historical information. Baseline (2001) information on the abundance of Hexagenia has been obtained for Duluth Harbor, Minnesota and Wisconsin (Edsall *et al*. 2004).

Lake Michigan

Status:	Poor
Trend:	Undetermined
Primary Factors Determining Status and Trend	Lack of time-series and historical studies. There have been no scientific conformations of anecdotal reports of *Hexagenia* except for sporadic accounts of adults near the Fox River, Green Bay, Wisconsin. The absence of Hexagenia was confirmed in Green Bay, Wisconsin in 2001 (Edsall *et al*. 2005).

Lake Huron

Status:	Poor
Trend:	Undetermined
Primary Factors Determining Status and Trend	Lack of time-series and historical information. There have been no scientific conformations of anecdotal reports of *Hexagenia* adults. The absence of *Hexagenia* was confirmed in Saginaw Bay in 2001 (Edsall *et al*. 2005).

Lake Erie

Status:	Good for western Lake Erie; Mixed for the southwest shore of central Lake Erie
Trend:	Improving for western Lake Erie; Mixed for southwest shore of central Lake Erie
Primary Factors Determining Status and Trend	To date, western Lake Erie is the only place where *Hexagenia* has been documented to be recovering in the Great Lakes (Krieger *et al*. 1996; Madenjian *et al*. 1998, Schloesser *et al*. 2000). Initial signs of recovery of *Hexagenia* (i.e., evidence of adults) along the south shore of central Lake Erie (i.e., appearance and increasing distribution) occurred 1997-2000. However, since that time reports have decreased and intensive lake sampling (2001-2003) have not been able to confirm *Hexagenia* recovery.

Lake Ontario

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Lack of baseline studies and historical information. There have been no scientific conformations of anecdotal reports of mayflies near Presque Isle, Pennsylvania and Bay of Quinte, Ontario.

Purpose

To assess the distribution and abundance of burrowing mayflies (*Hexagenia*) in the Great Lakes. To establish a quantitative goal for the restoration of *Hexagenia* nymphs in mesotrophic waters of the Great Lakes.

Ecosystem Objective

Historical mesotrophic habitats should be restored and maintained as balanced, stable, and productive elements of the Great Lakes ecosystem with *Hexagenia* as the key benthic invertebrate organism in the food chain. (Paraphrased from **Final Report of the Ecosystem Objectives Subcommittee**, 1990, to the IJC Great Lakes Science Advisory Board). In addition, this indicator supports Annex 2 of the GLWQA.

State of the Ecosystem
In the early 20th century, mesotrophic ecosystems in the Great Lakes had unique faunal communities that included commercially valuable fishes and associated benthic invertebrates. The primary invertebrate taxon associated with mesotrophic habitats was *Hexagenia*. *Hexagenia* was chosen by the scientific community to be a mesotrophic indicator because it is important to fishes, is relatively long lived, lives in sediments where pollution often accumulates, and is relatively sensitive to habitat changes brought on by urban and industrial pollution associated with changes as mesotrophic systems deteriorate to eutrophic systems (Schloesser and Hiltunen 1984; Schloesser 1988; Reynoldson *et al*. 1989). For example, *Hexageni*a was very abundant and important to yellow perch and walleye in the 1930s and 1940s. Then in the mid-1950s, *Hexagenia* was eliminated by low oxygen and resulting anoxic conditions created by urban and industrial pollution and growth of yellow perch declined (Beeton 1969; Burns 1985).

Initiation of pollution-abatement programs in the 1970s improved water and sediment quality in *Hexagenia* habitat throughout the Great Lakes, but the recovery of *Hexagenia* populations has been elusive (Krieger *et al*. 1996; Schloesser *et al*. 2000). Then in the early 1990s, soon after the invasion of exotic dreissenid mussels, anecdotal reports of adult *Hexagenia* (winged dun ans spinner) occurred in many bays and interconnecting rivers of the Great Lakes after absences of 30-60 years (Figure 1).

The first sign of the potential recovery of *Hexagenia* in western Lake Erie began with an anecdotal report of adult mayflies in open waters of the basin by scientists on the research vessel *Limnos* (Kreiger *et al*. 1996; Madenjian *et al*. 1998; Schloesser *et al*. 2000). Nymphs were confirmed in sediments at very low densities (ca. 9 nymphs/m^2) in 1993 and intensive studies began in 1995 (Figure 2) (Kreiger *et al*. 1996; Schloesser, unpublished data). Densities of nymphs increased between 1995 and 1997 and then decreased between 1997 and 1998. This pattern of increasing densities followed by a large decrease occurred again between 2001 and 2002. A population study of *Hexagenia* revealed that sharp declines in densities were partly attributable to failed young-of-year (YOY) recruitment (Figure 3) (Bridgeman *et al*. 2002). No YOY nymphs were found in 1997, which corresponded to the largest observed decline in *Hexagenia* density during the last decade. A similar decline occurred between 2001 and 2002 when few YOY nymphs were produced. However, a slight increase occurred between 2002 and 2003 even though relatively few YOY nymphs were recruited into the population indicating that some other factor(s) contributes to density fluctuations observed in western Lake Erie in the 1990s and 2000s.

Anecdotal reports of winged *Hexagenia* mayflies in the 1990s also included the south shore of Lake Michigan, Chicago, Illinois, the Fox River near Green Bay, Lake Michigan, Saginaw Bay near Standish, Michigan, the south shore of central Lake Erie near Sandusky, Ohio, Presque Isle of eastern Lake Erie, Pennsylvania, and the northern shore in the Bay of Quinte, eastern Lake Ontario, Picton, Ontario. To date, only the possible recovery of *Hexagenia* along the south shore of central Lake Erie has been investigated (K. Kreiger, personal communication). An initial recovery of nymphs occurred along the south shore between 1997 and 2000. However, intensive scientific surveys between 2001 and 2003 indicate that a sustained recovery of *Hexagenia* along the shore of south central Lake Erie has not occurred.

Pressures

Hexagenia are extirpated at moderate levels of pollution and may even show a graded response to the degree of pollution (Edsall *et al*. 1991; Schloesser *et al*. 1991). High *Hexagenia* abundance is strongly indicative of adequate levels of dissolved oxygen in overlying waters and uncontaminated surficial sediments. Probable causative agents of impaired *Hexagenia* populations include excess nutrients, oil, heavy metals, and various other pollutants in surficial sediments.

A portion of the general public has developed a negative perception of *en masse* swarms of adult *Hexagenia* because they can disrupt recreational use of shorelines and this perception has been incorporated into management goals for the recovery of *Hexagenia* in western Lake Erie (see Management Implications below). Such perceptions may create pressures for management to implement actions that manage lake systems below the natural carrying capacity of *Hexagenia* in mesotrophic waters of the Great Lakes.

Management Implications

Management entities in both Europe and North America desire some level of abundance of burrowing mayflies, such as *Hexagenia*, in mesotrophic habitats (Fremling and Johnson 1990; Bij de Vaate *et al*. 1992; Ohio Lake Erie Commission 1998). Recoveries of burrowing mayflies, such as *Hexagenia* spp., in rivers in Europe and North America and now in western Lake Erie clearly show how properly implemented pollution controls can bring about the recovery of large mesotrophic ecosystems. With recovery, *Hexagenia* in the Great Lakes will probably reclaim its functional status as a major trophic link between detrital energy pools and economically valuable fishes such as yellow perch and walleye.

The recovery of *Hexagenia* in western Lake Erie reminds us of an outstanding feature associated with using *Hexagenia* as an indicator of ecosystem health — the massive swarms of winged adults that are typical of healthy, productive *Hexageni*a populations. These swarms are highly visible to the public who use them to judge success of pollution-abatement programs by seeing a 'real' species that signifies the return of a 'real' habitat to a desirable condition in the Great Lakes. This public perception has influenced target values set by management for the recovery of *Hexagenia* in western Lake Erie (i.e., imperiled and good above excellent, Figure 4). However, values above excellent are based on societies' perception of excessive *en masse* emergences of winged *Hexagenia* which affect electrical power generation, vehicle traffic, and outdoor activities. These values may not represent the best scientific information for the historic/natural carrying capacity of *Hexagenia* in mesotrophic waters. For example, the target value of excellent is based on historical densities, a desire to return the system to an earlier more 'pristine' condition, and provide prey for valuable fishes. Yet, there is no scientific information that indicates densities of nymphs above 'excellent' would be in conflict with historical data, previous system conditions, and prey availability to fishes.

Comments from the author(s)

In the early 20th century, *Hexagenia* were believed to be abundant in all mesotrophic waters of the Great Lakes including Green Bay (Lake Michigan), Saginaw Bay (Lake Huron), Lake St. Clair, western Lake Erie, Bay of Quinte (Lake Ontario), and portions of interconnecting rivers and harbors. Thirty years of pollution-abatement programs may have allowed *Hexagenia* to return to other areas of the Great Lakes besides western Lake Erie as evidenced by anecdotal sightings of winged mayflies in the 1990s. However, anecdotal reports have slowed and only one scientific study (K. Kreiger, personal communication) has been performed to confirm anecdotal reports and that study in central Lake Erie could not verify any *Hexagenia* recovery.

The only sustained recovery of *Hexagenia* in the Great Lakes (i.e., western Lake Erie) should be monitored for another 4-6 years to determine annual variability and the carrying capacity of this taxon in mesotrophic waters. If scientifically measured, the recovery will provide management agencies with a quantitative endpoint of *Hexagenia* density which can be used to measure recovery to a mesotrophic state in waters throughout the Great Lakes. In addition, a scientifically determined carrying capacity of *Hexagenia* may also be useful as a benthic indicator for remediation of contaminated sediments and as a guide for acceptable levels for food for valuable percid communities. Contaminant levels in sediments that meet USEPA and OMOE guidelines (i.e., "clean dredged sediment") and IJC criterion for oil and hydrocarbons (i.e., "sediment not polluted") will not impair *Hexagenia* populations. There will be a graded response to concentrations of metals and oil in sediment exceeding these guidelines for clean sediment. Reductions in phosphorus levels in formerly eutrophic habitats are likely to be accompanied by colonization of *Hexagenia*, if surficial sediments are otherwise uncontaminated. Since *Hexagenia* can be one of the largest and most abundant prey for percid fishes such as yellow perch and young walleye the reestablishment of *Hexagenia* in nearshore waters of Great Lakes should be encouraged.

Acknowledgments

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Figure 1. Typical life-cycle of a burrowing mayfly such as *Hexagenia* found in the Great Lakes.
Source: Drawn by Martha Thierry, courtesy of the Detroit Free Press.

Figure 2. Densities (number/m^2) of *Hexagenia* obtained in three studies (colored markers) in western Lake Erie 1995-2005. Line of abundance fit by eye.
Source: Unpublished data, DWS)

Figure 3. Recruitment of young-of-year *Hexagenia* in western Lake Erie 1997-2002 Source: Schloesser and Nalepa 2001; Bridgeman *et al*. 2005.

Figure 4. Densities (number/m^2) of *Hexagenia*, three-year running average of densities, and subjective target-reference values of desired abundance (i.e., poor, fair, good, etc.) in western Lake Erie.
Source: After Ohio Lake Erie Commission 2004.

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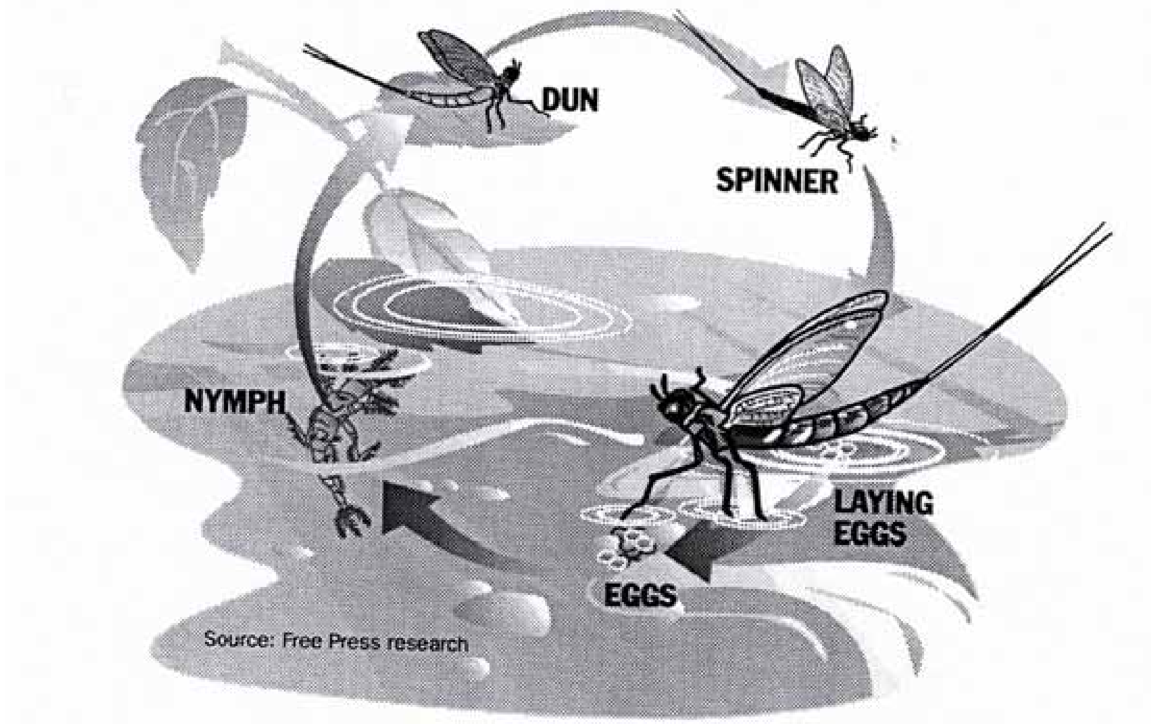

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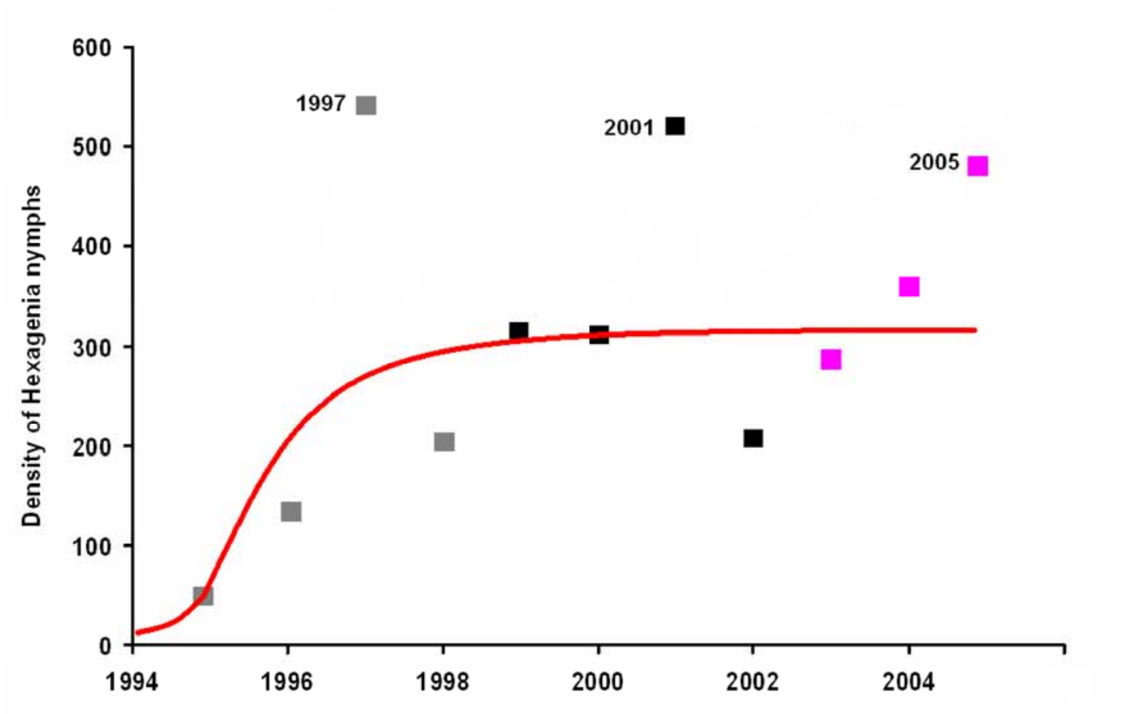

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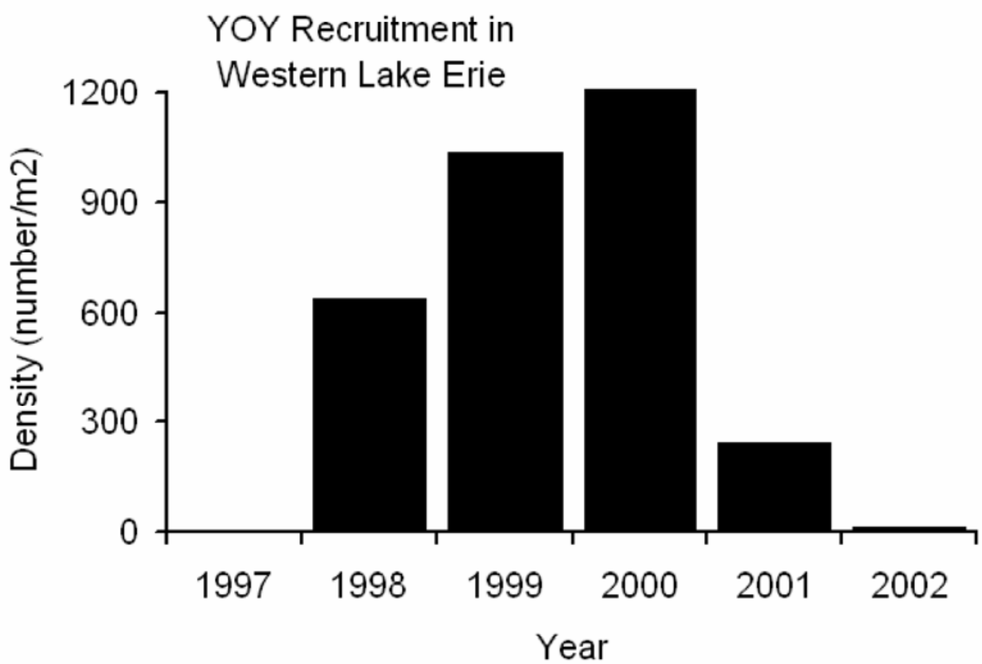

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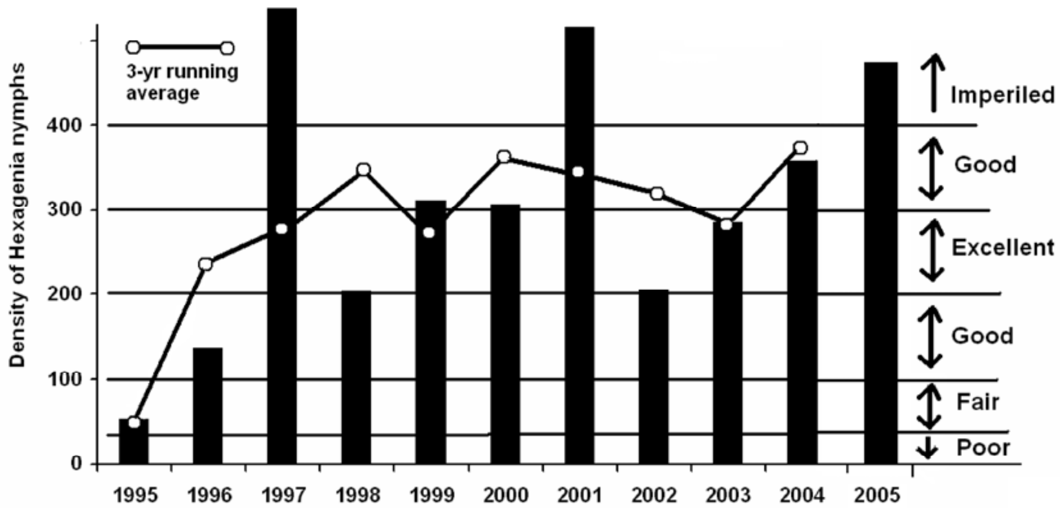

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Source: After Ohio Lake Erie Commission 2004.

Abundances of the Benthic Amphipod Diporeia spp.
Indicator #123

Overall Assessment

Status:	**Mixed**
Trend:	**Deteriorating**
Primary Factors Determining Status and Trend	**Abundances of the benthic amphipod *Diporeia* spp. continue to decline in Lakes Michigan, Huron, and Ontario. While it is presently gone or rare in shallow waters in each of these lakes, it is also declining in deeper, offshore waters. The decline in the latter regions is temporally linked to the expansion and increase of quagga mussels. Studies on trends in Lake Superior are conflicting, but the general opinion of researchers is that declines are not occurring. *Diporeia* are currently gone or very rare in Lake Erie.**

Lake-by-Lake Assessment

Lake Superior

Status:	Mixed
Trend:	Unchanging
Primary Factors Determining Status and Trend	Data sets are conflicting on current trends of *Diporeia* populations in Lake Superior. One long-term monitoring program shows that *Diporeia* abundances are declining in offshore areas (> 90 m), but abundances in nearshore areas (< 65 m) remain unchanged. Other long and short-term sampling programs show no overall trend in either offshore or nearshore areas.

Lake Michigan

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	*Diporeia* abundances continue to decline in Lake Michigan. A recent lakewide survey (in 2005) indicated abundances were lower by 84 % compared to abundances found in 2000 (Figure 1). *Diporeia* are now completely gone from depths < 80 m over most of the lake and abundances are in the state of decline at depths > 80 m.

Lake Huron

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	*Diporeia* abundances continue to decline in Lake Huron. The most recent lakewide survey in the main basin (in 2003) indicated abundances were lower by 57 % compared to abundances found in 2000. *Diporeia* are now completely gone from depths < 60 m except in the northeastern end and continue to decline at depths > 60 m. Annual monitoring at 11 sites indicated that, in 2005, *Diporeia* were gone from 5 sites and abundances were lower compared to 2004 at the other 6 sites. Because of insufficient data, trends in Georgian Bay and North Channel are not known. However, limited temporal and spatial data from the southern end of Georgian Bay showed that *Diporeia* have been declining since 2000 and are now completely gone at depths < 93 m.

Lake Erie

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Because of shallow, warm waters, *Diporeia* are naturally not present in the western and central basins. *Diporeia* declined in the eastern basin beginning in the early 1990s and have not been found since 1998.

Lake Ontario

Status:	Poor
Trend:	Deteriorating
Primary Factors Determining Status and Trend	Based on several limited surveys in 2005, *Diporeia* continue to decline in Lake Ontario. In one survey of 11 sites, Diporeia declined at 2 sites and increased slightly at 2 sites compared to 2004. It was not found at 6 sites in both years. In another survey of 14 sites, *Diporeia* declined at sites < 140 m, but abundances increased slightly at sites > 190 m. It was not found at sites < 90 m over most of the lake.

Purpose

To provide a measure of the biological integrity of the offshore regions of the Great Lakes by assessing the abundance of the benthic macroinvertebrate *Diporeia*.

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.

State of the Ecosystem

Background

This glacial-marine relic was once the most abundant benthic organism in cold, offshore regions (> 30 m) of each of the lakes. It was present, but less abundant in nearshore regions of the open lake basins, but naturally absent from shallow, warm bays, basins, and river mouths. *Diporeia* occurs in the upper few centimetres 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 species of fish, in particular by many forage fish species which 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. Also, lake whitefish, an important commercial species, feeds heavily on *Diporeia*. Thus, *Diporeia* was an important pathway by which energy was 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).

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.

Status of *Diporeia*

Diporeia populations are currently in the state of dramatic decline in Lakes Michigan, Ontario, and Huron, and are completely gone or very rare in Lake Erie. Results are conflicting for Lake Superior. One data set shows a trend of declining abundances in offshore waters, but other data sets show no trend. In all the lakes except Superior, abundances have decreased progressively from shallow to deeper areas. Initial declines were first observed in all lake areas within 2-3 years of when zebra mussels (*Dreissena polymorpha*) or quagga mussel (*Dreissena bugensis*) first became established. These two 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. One hypothesis is that dreissenid mussels are out competing *Diporeia* for available food. That is, large mussel populations were filtering food material before it reached the bottom, thereby decreasing amounts available to *Diporeia*. However, evidence suggests that the reason for the decline is more complex than a simple decline in food because *Diporeia* have completely disappeared from areas where food is still settling to the bottom and where there are no local populations of mussels. Also, individual *Diporeia* show no signs of starvation before or during population declines. Further, *Diporeia* and *Dreissena* apparently coexist in some lakes outside of the Great Lakes (i. e., Finger Lakes in New York).

Pressures

As populations of dreissenid mussels continue to expand, it may be expected that declines in *Diporeia* will become more extensive. In the open waters of Lakes Michigan, Huron, and Ontario, zebra mussels are most abundant at depths less than 50 m, and *Diporeia* are now gone or rare from lake areas as deep as 90 m. Recently, quagga mussel populations have increased dramatically in each of these lakes and are occurring at deeper depths than zebra mussels. The decline of *Diporeia* at depths > 90 m can be attributed to the expansion of quagga mussels to these depths.

Management Implications

The continuing decline of *Diporeia* has strong implications to the Great Lakes food web. As noted, many fish species rely on *Diporeia* as a major prey item, and the loss of *Diporeia* will likely have an impact on these species. Responses may include changes in diet, movement to areas with more food, or a reduction in weight or energy content. Implications to populations include changes in distribution, abundance, growth, recruitment, and condition. Recent evidence suggests that fish are already being affected. For instance, growth and condition of an important commercial species, lake whitefish, has declined significantly in areas where *Diporeia* abundances are low in Lakes Michigan, Huron, and Ontario. Also, studies show that other species such as alewife, slimy sculpin, and bloater have been affected. Management agencies must know the extent and implications of these changes when assessing the current state and future trends of the fishery. Any proposed rehabilitation of native fish species, such as the re-introduction of deepwater ciscoes in Lake Ontario, requires knowledge that adequate food, especially *Diporeia*, is present.

Comments from the author(s)

Because of the rapid rate at which *Diporeia* populations are declining and their 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. Also, studies to define the cause of the negative response of *Diporeia* to *Dreissena* should continue and build upon existing information. With an understanding of exactly why *Diporeia* populations are declining, we may better predict what additional areas of the lakes are at risk. Also, by better understanding the cause, we may better assess the potential for population recovery if and when dreissenid populations stabilize or decline.

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Authors: T.F. Nalepa, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, MI.; and
R. Dermott, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, ON.

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Figure 1. Distribution and abundance (number per square meter) of the amphipod *Diporeia* spp. in Lake Michigan in 1994-1995, 2000, and 2005. Small crosses indicate location of sampling stations.
Source: National Oceanic & Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory

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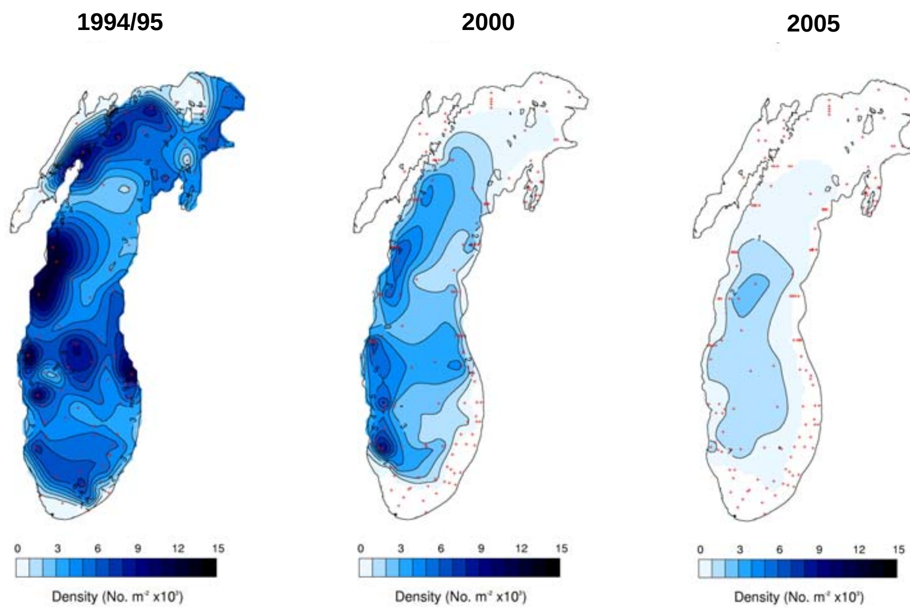

Figure 1. Distribution and abundance (No. m^{-2}) of the amphipod *Diporeia* spp. in Lake Michigan in 1994/1995, 2000, and 2005. Small crosses indicate location of sampling stations.

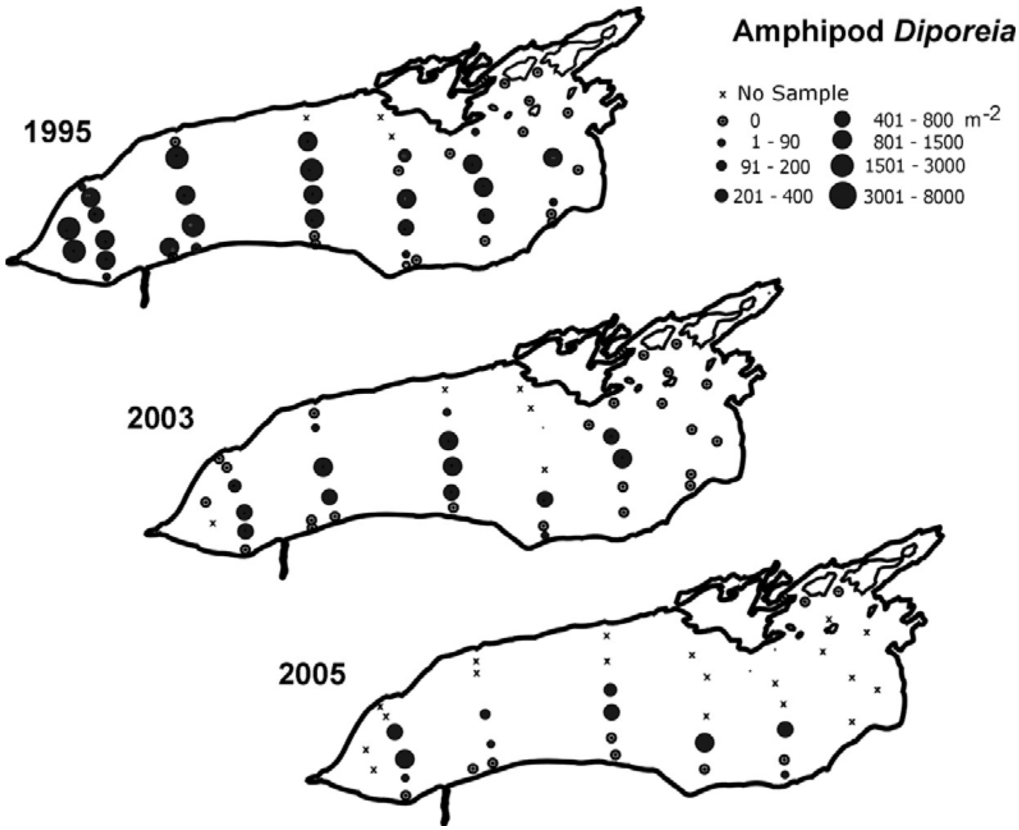

Figure 2. Distribution and abundance (No. m^{-2}) of the amphipod *Diporeia* spp. in Lake Ontario in 1995, 2003, and 2005. Small crosses indicate a site where no sample was taken.

External Anomaly Prevalence Index for Nearshore Fish
Indicator #124

Overall Assessment
Status: **Poor**
Trend: **Unchanging**
Primary Factors Determining Status and Trend

Lake-by-Lake Assessment
Lake Superior
Status: Not Assessed
Trend: Undetermined

Lake Michigan
Status: Not Assessed
Trend: Undetermined

Lake Huron
Status: Not Assessed
Trend: Undetermined

Lake Erie
Status: Poor
Trend: Unchanging

Lake Ontario
Status: Poor
Trend: Unchanging

Purpose
1) To assess select external anomalies in nearshore fish;
2) To identify nearshore areas that have populations of benthic fish exposed to contaminated - sediments; and
3) To help assess the recovery of Areas of Concern (AOCs) following remedial activities
Insert Purpose text

Ecosystem Objective
The objective is to help restoration and protection of beneficial uses in Areas of Concern or in open Great Lakes waters, including beneficial use (iv) *Fish tumors or other deformities* (Great Lakes Water Quality Agreement (GLWQA), Annex 2). This indicator also supports Annex 12 of the GLWQA.

State of the Ecosystem
Background

The presence of contaminated sediments at AOCs has been correlated with an increased incidence of external and internal anomalies in benthic fish species (brown bullhead and white suckers) that may be associated with specific groups of chemicals. Elevated incidence of liver tumors (histopathologically verified pre-neoplastic or neoplastic growths) were frequently identified during the past two decades. These elevated frequencies of liver tumours have been shown to be useful indicators of beneficial use impairment of Great Lakes aquatic habitat. External raised growths (histopathologically verified tumors on the body and lips), such as lip papillomas, have also been useful indicators. Raised growths may not have a single etiology; but, they have been produced experimentally by direct application of polynuclear aromatic hydrocarbons (PAH) carcinogens to brown bullhead skin. Field and laboratory studies have correlated verified liver and external raised growths with chemical contaminants found in sediments at some AOCs in Lake Erie, Lake Michigan, Lake Ontario and Lake Huron. Other external anomalies may also be used to assess beneficial use impairment. The external anomaly prevalence index (EAPI) will provide a tool for following trends in fish population health that can be used by resource managers and community-based monitoring programs.

The EAPI has been developed for mature (> 3 years of age) fish as a marker of both contaminant exposure and of internal pathology. Brown bullhead have been used to develop the index. They are the most frequently used benthic indicator species in the southern Great Lakes and have been recommended by the International Joint Commission (IJC) as a key indicator species (IJC 1989). The most common external anomalies found in brown bullhead over the last twenty years from Lake Erie are: 1) abnormal barbels (BA); 2) focal discoloration (FD); and 3) raised growths (RG) - on the body and lips (Figure1). Initial statistical analysis of sediments and external anomalies at different locations indicates that variations in the chemical mixtures (Total, priority and carcinogenic PAHs; DDT metabolites; organochlorine chemicals (OC); and total metals) show a statistically significant relation with a differing prevalence of individual external anomalies (raised growths and barbell abnormalities). Age and external anomalies indicate a positive correlation (Figure 2). Impairment determinations should be based on age comparisons of the prevalence of external anomalies at contaminated sites with the prevalence at “reference” (least impacted) sites (Figure 3). Preliminary data indicate that if the prevalence of raised growths on the body and lip combined is > 5%, barbell abnormalities >10% and focal discoloration (melanistic alterations) > 5% in brown bullhead, the population should be considered impaired.

Surveys conducted in 1999 and 2000 in the Detroit, Ottawa, Black, Cuyahoga, Ashtabula, Buffalo, and Niagara Rivers and at Old Woman Creek in Lake Erie demonstrated that external raised growths are positively associated with both PAH metabolites in bile and in PAH concentrations in sediment. The association with PAH metabolites in bile (Figure 4) is stronger than that with total PAH concentrations in sediments (Figure 5). Bile metabolite concentrations may be a better estimate of potential exposure of PAHs to individual fish than concentrations in sediments. The EAPI indicates the impacts from the exposure to individual fish from the PAHs as well as other compounds in the mixtures of compounds that may be present in sediments. Barbel deformities (Figure 5) also showed a positive correlation with total PAH levels in sediment. In addition to the locations listed above, the Huron River and Presque Isle Bay sites all showed a statistically significant correlation between external raised growths and concentration of heavy metals in sediment (Figure 6).

Pressures

Many Great Lakes AOCs and their tributaries remain in a degraded condition. Exposure of the fish populations to contaminated sediment continues and the elevated evidence of external anomalies still persist. The human population in the Great Lakes is expected to increase and urbanization along Great Lakes tributaries and shorelines will likely expand in the future. Therefore, some locations impacted by land use changes may continue to deteriorate even as control and remediation actions improve conditions at the older contaminated sites. As recommended for delisting, listed AOCs continue the gain knowledge in order to achieve a low EAPI to help the delisting process of the BUI for fish tumors and other deformities. A single common data base must be implemented for international brown bullhead data sets to evaluate AOC and reference conditions in each of the Great Lakes.

Management Implications

The EAPI provides managers and researchers with a tool to monitor contaminant impacts to the fish populations in Great Lakes AOCs. Additional remediation to clean up contaminated sediments at Great Lakes AOCs will help to reduce rates of external anomalies. The EAPI, particularly for brown bullheads and white suckers and the inclusion of a single common data base will help environmental managers to follow trends in fish population health and to determine the status of AOCs that may be considered for delisting (IJC Delisting Criteria, see IJC 1996).

Comments from the author(s)

This external anomaly index for benthic species has potential for defining habitats that may or may not be impacted from contaminants. Collaborative U.S. and Canadian studies investigating the etiology and prevalence of external anomalies in benthic fishes over a gradient of polluted to pristine Great Lakes habitats are desperately needed. These studies would create a common index that could be used as an indicator of ecosystem health. The establishment of single data base to house all lake wide data for each Great Lake is necessary to enable managers and decision makers to gain an understanding of the health of individual fish (e.g. brown bullhead) and their populations. Unless this takes place, understanding of health conditions at AOCs compared to the least impacted (reference) sites will remain unknown and the delisting process will not advance.

Acknowledgments

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Paul C. Baumann, U.S. Geological Survey, Biological Resources, Columbus, OH; and

*Scott Brown, Environment Canada, National Water Research Institute, Burlington, ON.

*Dedicated to our friend and collogue Scott Brown, whose untimely passing has saddened all who knew him.

Data Sources

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Figure 2. Age of brown bullhead at Lake Erie sites from 1986-87 and 1998-2000 collections in relation to combined external anomalies. Age groups; age 3, ages 4&5, ages 6&7. Source: S.B. Smith, unpublished data.

Figure 3. External anomalies (<u>Melan</u>oma, Raised <u>Grow</u>th on body and lips, and <u>Barb</u>ell abnormalities) in relation to sites classified for sediment contaminants and BB morphology from all collections in the 1980's and 1990's. Source: S. B. Smith, unpublished data.

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Figure 5. Prevalence of external raised growths and barbel deformities in brown bullhead from Lake Erie tributaries compared to PAH concentrations in sediment. Source: Yang and Baumann, unpublished data.

Figure 6. Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to concentrations of heavy metals in sediment. Source: Yang and Baumann, unpublished data.

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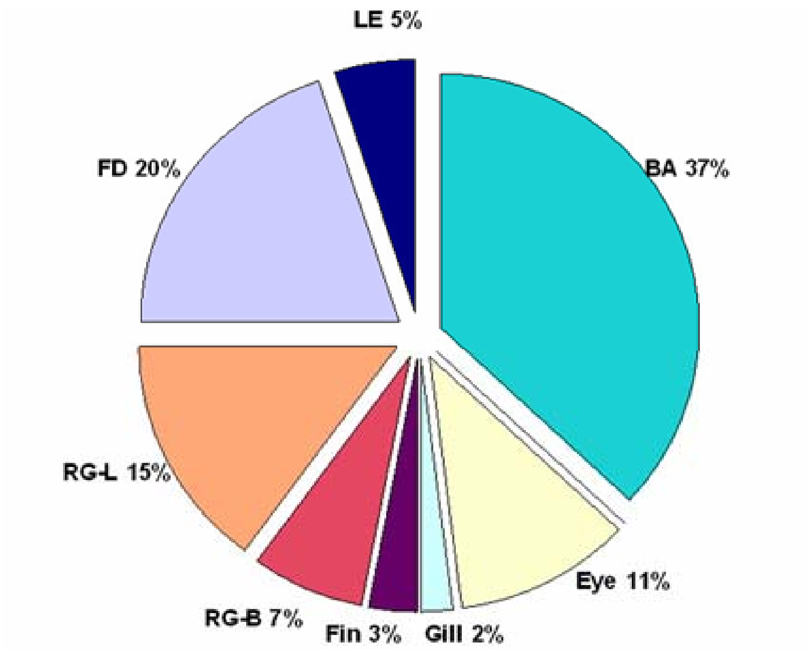

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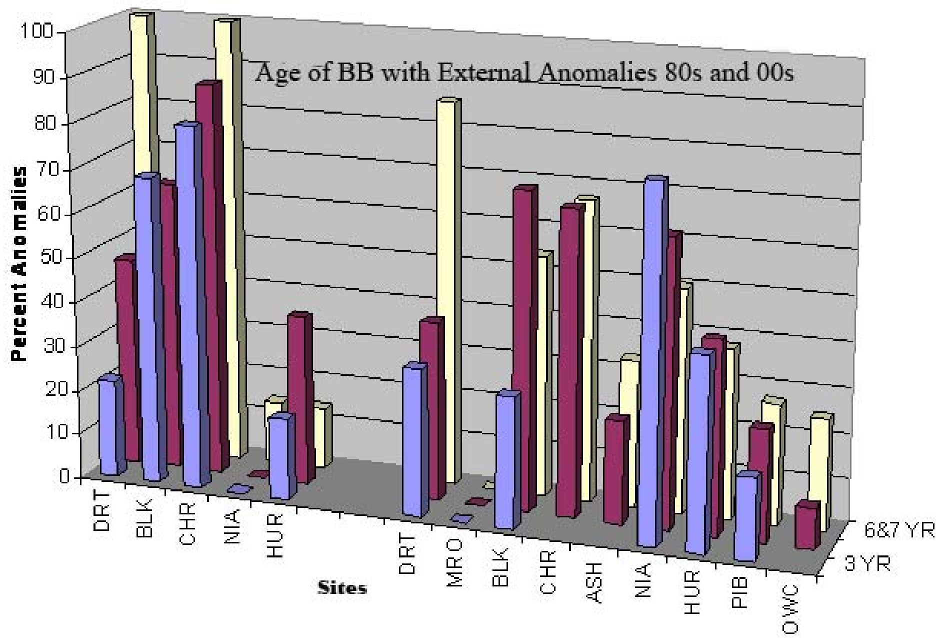

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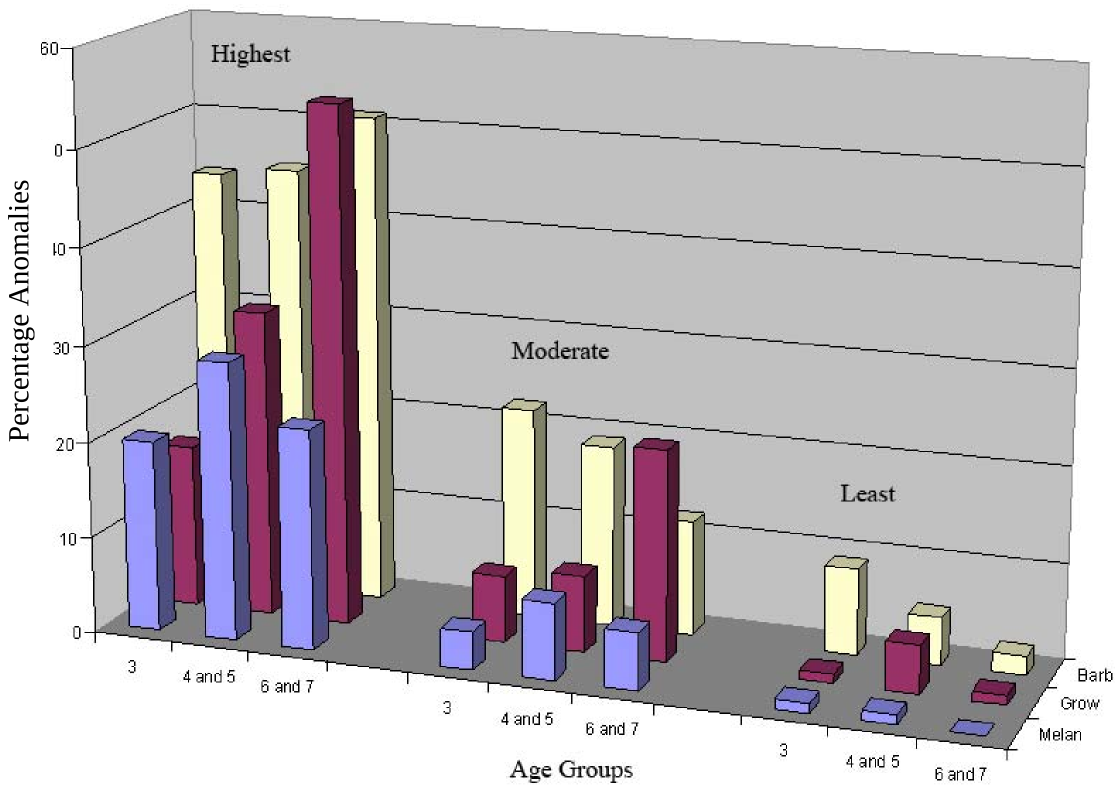

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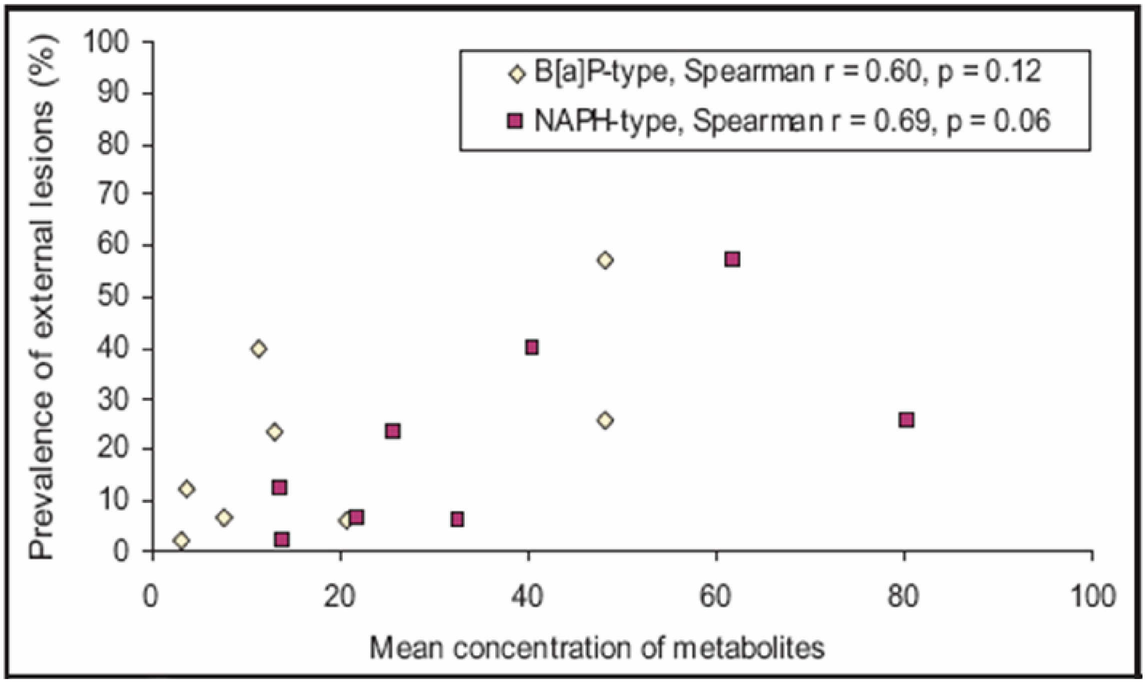

Figure 4. **Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to PAH metabolite concentrations in bile (B[P] and NAPH-type unit are µg/mg protein.**
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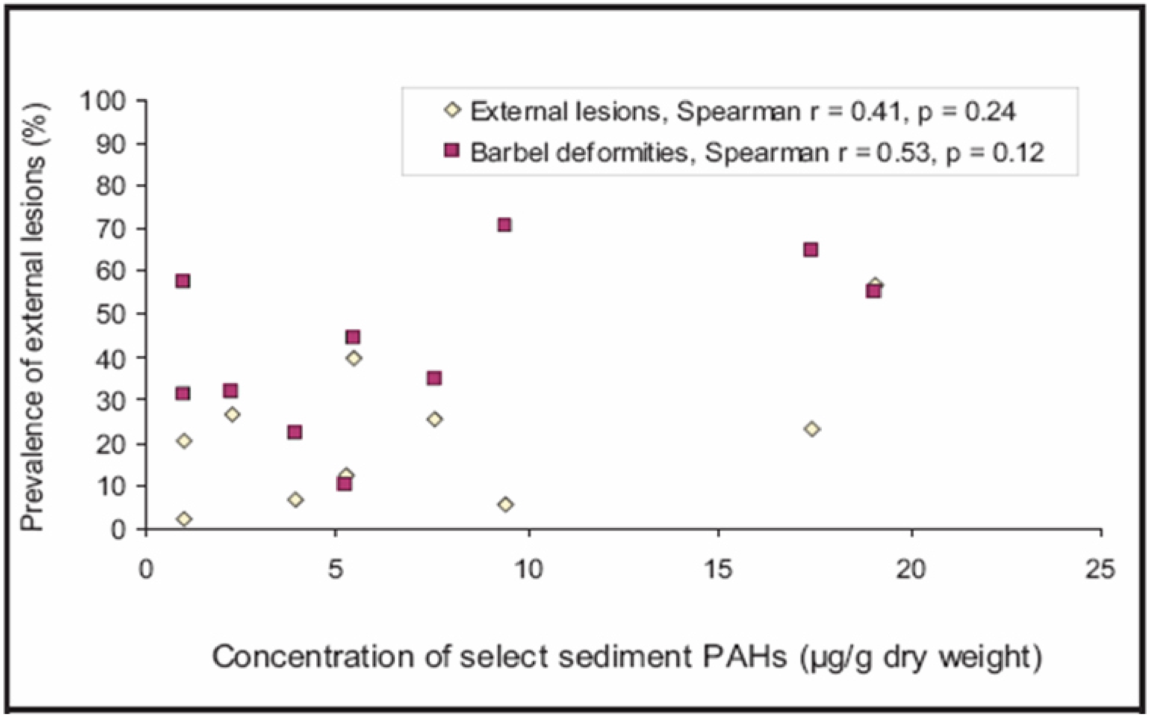

Figure 5. Prevalence of external raised growths and barbel deformities in brown bullhead from Lake Erie tributaries compared to PAH concentrations in sediment.
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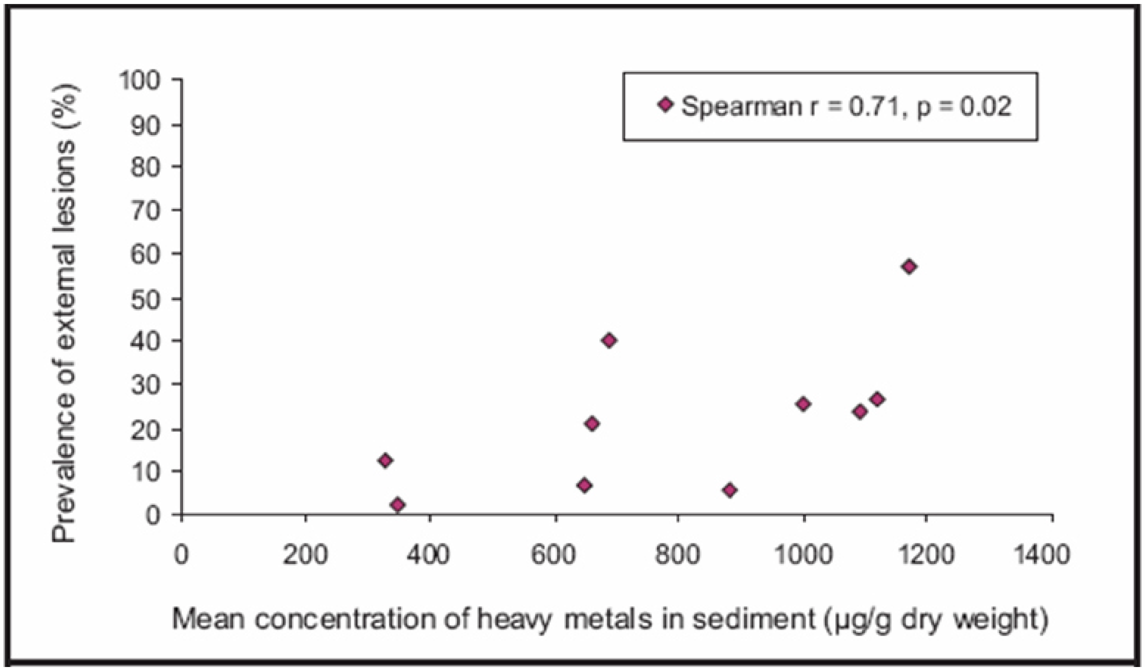

Figure 6. Prevalence of external raised growths in brown bullhead from Lake Erie tributaries compared to concentrations of heavy metals in sediment.
Source: Yang and Baumann, unpublished data.

Status of Lake Sturgeon in the Great Lakes
Indicator #125

Overall Assessment

Status:	**Mixed**
Trend:	**Improving**
Primary Factors Determining Status and Trend	There are remnant populations in each basin of the Great Lakes, but few of these populations are large. Much progress has been made in recent years learning about population status in many tributaries. Confirmed observations and captures of lake sturgeon are increasing in all lakes. Stocking is contributing to increased abundance in some areas. There remains a need for information on some remnant spawning populations. Little is known about the juvenile life stage. In many areas habitat restoration is needed as spawning and rearing habitat has been destroyed, altered or access is blocked.

Lake by Lake Assessment

Lake Superior

Status:	Mixed
Trend:	Improving or Undetermined
Primary Factors Determining Status and Trend	Lake sturgeon abundance shows an increasing trend in a few remnant populations and where stocked in the Ontonagon and St. Louis rivers. Lake sturgeons currently reproduce in at least 10 of 21 known historic spawning tributaries.

Lake Michigan

Status:	Mixed
Trend:	Improving and Undetermined
Primary Factors Determining Status and Trend	Remnant populations persist in at least 8 tributaries having unimpeded connections to Lake Michigan. Successful reproduction has been documented in six rivers and abundance has increased in a few in recent years. Active rehabilitation has been initiated through rearing assistance in 1 remnant population and reintroductions have been initiated in three rivers.

Lake Huron

Status:	Mixed
Trend:	Improving and Undetermined
Primary Factors Determining Status and Trend	Current lake sturgeon spawning activity is limited to five tributaries, four in Georgian Bay and the North Channel and one in Saginaw Bay. Abundant stocks of mixed sizes are consistently captured in the North Channel, Georgian Bay, southern Lake Huron and Saginaw Bay.

Lake Erie

Status:	Poor
Trend:	Undetermined
Primary Factors Determining Status and Trend	Current lake sturgeon spawning activity is unknown except for three spawning areas identified in the Detroit and St. Clair Rivers. The western basin of Lake Erie, the North Channel of the St. Clair River and Anchor Bay in Lake St. Clair appear to be nursery areas for juveniles. In the central and eastern basins lake sturgeon are scarcer.

Lake Ontario

Status:	Mixed
Trend:	Improving
Primary Factors Determining Status and Trend	Lakewide incidental catches since 1995 indicate a possible improvement in their status. Spawning occurs in the Niagara River, Trent River, and possibly the Black River. There are sizeable populations within the St. Lawrence River system. Stocking for restoration began in 1995 in New York.

Purpose

• Lake sturgeon was a key component of the nearshore benthivore fish community and their presence and abundance indicates the health and status of that component of the Great Lakes ecosystem.

Ecosystem Objective

Lake sturgeon is identified as an important species in the Fish Community Objectives for each of the Great Lakes. Lake Superior has a lake sturgeon rehabilitation plan, and many of the Great Lakes States have lake sturgeon recovery/rehabilitation plans which call for increasing numbers of lake sturgeon beyond current levels. [Conserve, enhance or rehabilitate self-sustaining populations of lake sturgeon where the species historically occurred and at a level that will permit all State, Provincial and Federal delistings.]

State of the Ecosystem

Background

Lake sturgeon, *Acipenser fulvescens*, were historically abundant in the Great Lakes with spawning populations using many of the major tributaries, connecting waters, and shoal areas across the basin. Prior to European settlement of the region, they were a dominant component of the nearshore benthivore fish community, with populations estimated in the millions in each of the Great Lakes (Baldwin et al. 1979). In the mid- to late-1800s, they contributed significantly as a commercial species ranking among the five most abundant species in the commercial catch (Baldwin et al. 1979, Figure 1).

The decline of lake sturgeon populations in the Great Lakes was rapid and commensurate with habitat destruction, degraded water quality, and intensive fishing associated with settlement and development of the region. Sturgeon were initially considered a nuisance species of little value by European settlers, but by the mid-1800s, their value as a commercial species began to be recognized and a lucrative fishery developed. In less than 50 years, their abundance had declined sharply, and since 1900, they have remained a highly depleted species of little consequence to the commercial fishery. Sturgeon are now extirpated from many tributaries and waters where they once spawned and flourished (Figure 2 and Figure 3). They are considered rare, endangered, threatened, or of watch or special concern status by the various Great Lakes fisheries management agencies. Their harvest is currently prohibited or highly regulated in most U.S. and Canadian waters of the Great Lakes.

Status of Lake Sturgeon

Efforts are continuing by many agencies and organizations to gather information on remnant spawning populations in the Great Lakes. Most sturgeon populations continue to sustain themselves at a small fraction of their historical abundance. In many systems, access to spawning habitat has been blocked, and other habitats have been altered. However, there are remnant populations in each basin of the Great Lakes, and some of these populations are large in number

(10's of thousands of fish, Figure 3). Genetic analysis has shown that Great Lakes populations are regionally structured and show significant diversity within and among lakes.

Lake Superior: The fish community of Lake Superior remains relatively intact in comparison to the other Great Lakes (Bronte et al. 2003). Historic and current information indicate that at least 21 Lake Superior tributaries supported spawning lake sturgeon populations (Harkness and Dymond 1961; Auer 2003; Holey et al. 2000). Lake sturgeons currently reproduce in at least 10 of these tributaries. Sturgeon populations in Lake Superior continue to sustain themselves at a small fraction of their historical abundance.

Current populations in Lake Superior are reduced from historic levels and none meet all rehabilitation targets. The number of lake sturgeon in annual spawning runs has been estimated over a multi-year period to range from 200-375 adults in the Sturgeon River, (Hay-Chmielewski and Whelan 1997; Holey et al. 2000), 200-350 adults in the Bad River in 1997 and 1998 (U.S. Fish and Wildlife Service, Ashland Fishery Resource Office, USFWS, 2800 Lake Shore Drive, Ashland, Wisconsin, 54806, unpublished data), and 140 adults in the Kaministiquia River, Ontario (Stephenson 1998). Estimates of lakewide abundance are available from the period during or after targeted commercial harvests in the 1880s. Using data from Baldwin et al. (1979), Hay-Chmielewski and Whelan (1997) estimated that historic lake sturgeon abundance in Lake Superior was 870,000 individuals of all ages. If the Rehabilitation Plan target of 1,500 adults were met in all 21 tributaries, the minimum lakewide abundance of adult fish would be 31,500.

Radio telemetry studies suggest that a river resident population inhabits the Kaministiquia River (Mike Friday, OMNR, Upper Great Lakes Management Unit-Lake Superior, 435 James St. South, Thunder Bay, Ontario P7E 6S8, personal communication). The Pic River also has the potential to support a river resident population. Juvenile lake sturgeon index surveys conducted by the Great Lakes Indian Fish and Wildlife Commission and U.S. Fish and Wildlife Service in Wisconsin waters show a gradually increasing trend in catch per unit effort from 1994-2002 (Table 1). Since 2001, sturgeon spawning surveys have been conducted for the first time in 8 tributaries. Genetic analysis has shown that lake sturgeon populations in Lake Superior are significantly different from those in the other Great Lakes. Currently, there is no commercial harvest of lake sturgeon allowed in Lake Superior. Regulation of recreational and subsistence/home use harvest in Lake Superior varies by agency.

Lake Michigan: Sturgeon populations in Lake Michigan continue to sustain themselves at a small fraction of their historical abundance. An optimistic estimate of the lakewide adult abundance is less than 5,000 fish, well below 1% of the most conservative estimates of historic abundance (Hay-Chmielewski and Whelan 1997). Remnant populations currently are known to spawn in waters of at least 8 tributaries having unimpeded connections to Lake Michigan (Schneeberger et al 2005). Two rivers, the Menominee and Peshtigo, appear to support annual spawning runs of 200 or more adults, and four rivers, the Manistee, Muskegon, Fox and Oconto, appear to support annual spawning runs of between 25 and 75 adults. Successful reproduction has been documented in all six of these rivers, although actual recruitment levels remain unknown. However, abundance in some of these rivers appears to be increasing in recent years. Two other rivers, the Manistique and Kalamazoo, appear to have annual spawning runs of less than 25 fish, and reproductive success remains unknown. Lake sturgeon have been observed during spawning times in a few other Lake Michigan tributaries such as the St. Joseph, Grand and Millecoquins, and near some shoal areas where sturgeon are thought to have spawned historically. It is not known if spawning occurs regularly in these systems, however, and their status is uncertain.

Lake Huron: Lake sturgeon populations continue to be well below historical levels. Spawning has been identified in the Garden, Mississaugi and Spanish rivers in the North Channel, in the Nottawasaga River in Georgian Bay and in the Rifle River in Saginaw Bay. Adult spawning populations for each of these river systems are estimated to be in the ten's and are well below rehabilitation targets (Hay-Chmielewski and Whelan 1997; Holey et al. 2000). Barriers on Michigan tributaries to Lake Huron continue to limit successful rehabilitation. Stocks of lake sturgeon in Lake Huron are monitored primarily through the volunteer efforts of commercial fishers cooperating with the various resource management agencies. To date the combined efforts of researchers in U.S. and Canadian waters has resulted in over 6,600 sturgeon tagged in Saginaw Bay, southern Lake Huron, Georgian Bay and the North Channel, with relatively large stocks of mixed sizes being captured at each of these general locations. Tag recoveries and telemetry studies indicate that lake sturgeon are moving within and between jurisdictional boundaries and between lake basins, supporting the need for more cooperative management between the states and between the U.S. and Canada. The Saginaw River watershed and the St. Mary's River systems are being assessed for spawning, both projects are ongoing and will continue through 2007. Similar research is being planned for the Thunder and Rifle Rivers in Michigan.

Lake Erie: Lake sturgeon populations continue to be well below historical levels. Spawning has been identified at two locations in the St. Clair River and at one location in the Detroit River (Manny and Kennedy 2002). Tag recovery data and telemetry research indicates that a robust lake sturgeon stock (> 45,000 fish) reside in the North Channel of the St. Clair River and Lake St. Clair (Thomas and Haas 2002). The North Channel, Anchor Bay and the western basin of Lake Erie have been identified as nursery areas as indicated by consistent catches in commercial and survey fishing gears. In the central and eastern basins of Lake Erie lake sturgeon are scarcer with only occasional catches of sub-adult or adult lake sturgeon in commercial fishing nets and none in research nets. A botulism-related die off in 2001 and 2002, and declines in sightings by anglers and others near Buffalo indicate a possible decline in population abundance of lake sturgeon in Lake Erie. Research is scheduled in 2007 to identify if spawning stocks of sturgeon are using reputed historic spawning sites in the lower Detroit River and the Maumee River. Research efforts will continue to focus on identifying new spawning locations, genetic difference between stocks, habitat requirements, and migration patterns.

Lake Ontario: Lake Ontario has lake sturgeon spawning activity documented in two major tributaries (Niagara River and Trent River) and suspected in at least one more (Black River) on an infrequent basis. There is no targeted assessment of lake sturgeon in Lake Ontario, but incidental catches in research nets have occurred since 1997 (Ontario Ministry of Natural Resources 2004) and 1995 (Eckert 2004), indicating a possible improvement in population status. Age analysis of lake sturgeon captured in the lower Niagara River indicates successful reproduction in the mid-1990s. New York State Department of Environmental Conservation initiated a stocking program in 1995 to recover lake sturgeon populations. Lake sturgeon have been stocked in the St. Lawrence River and some of its tributaries, inland lakes in New York, and the Genesee River. There are sizeable populations within the St. Lawrence River system, most notably the Des Prairies River, Lac St. Pierre and the St. Maurice River. However, access is inhibited for many of the historical spawning grounds in tributaries by small dams and within the St. Lawrence River by the Moses-Saunders Dam.

Pressures
Low numbers or lack of fish (where extirpated) is itself is a significant impediment to recovery in many spawning areas. Barriers that prevent lake sturgeon from moving into tributaries to spawn are a major problem. Predation on eggs and newly hatched lake sturgeon by non-native predators may also be a problem. The genetic structure of remaining populations is being studied by

university researchers and fishery managers, and this information will be used to guide future management decisions. With the collapse of the Caspian Sea sturgeon populations, black market demand for sturgeon caviar could put tremendous pressure on Great Lakes lake sturgeon populations. An additional concern for lake sturgeon in Lake Erie and Lake Ontario is the presence of high densities of round gobies and the spread of Botulism Type E, which produced a die-off of lake sturgeon in Lake Erie in 2001 and 2002. Botulism may also have been the cause of similar mortalities observed in Lake Ontario in 2003 and in Green Bay of Lake Michigan.

Management Implications

Lake sturgeon are an important native species that are listed in the Fish Community Objectives for all of the Great Lakes. Many of the Great Lakes states and provinces either have or are developing lake sturgeon management plans promoting the need to inventory, protect and restore the species to greater levels of abundance.

While overexploitation removed millions of adult fish, habitat degradation and alteration eliminated traditional spawning grounds. Current work is underway by state, federal, tribal, provincial and private groups to document active spawning sites, assess habitat condition and availability of good habitat, and determine the genetics of remnant Great Lakes lake sturgeon populations.

Several meetings and workshops have been held focusing on identifying the research and assessment needs to further rehabilitation of lake sturgeon in the Great Lakes (Holey et al. 2000), and a significant amount of research and assessment directed towards these needs has occurred in the last 10 years. Among these is the research to better define the genetic structuring of Great Lakes lake sturgeon populations, and genetics-based rehabilitation plans are being developed to help guide reintroduction and rehabilitation efforts being implemented across the Great Lakes. Research into new fish passage technologies that will allow safe upstream and downstream passage around barriers to migration also have been underway for several years. Many groups are continuing to work to identify current lake sturgeon spawning locations in the Great Lakes, and studies are being initiated to identify habitat preferences for juvenile lake sturgeon (ages 0-2).

Comments from the author(s)

Research and development is needed to determine ways to pass lake sturgeon at man-made barriers on rivers. In addition, there are significant, legal, logistical, and financial hurdles to overcome in order to restore degraded spawning habitats in connecting waterways and tributaries to the Great Lakes. More monitoring is needed to determine the current status of Great Lakes lake sturgeon populations, particularly the juvenile life stage. Cooperative effort between law enforcement and fishery managers is required as world pressure on sturgeon stocks will result in the need to protect large adult lake sturgeon in the Great Lakes.

Acknowledgments

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Source: Zollweg *et al*. 2003

Figure 3. Current distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

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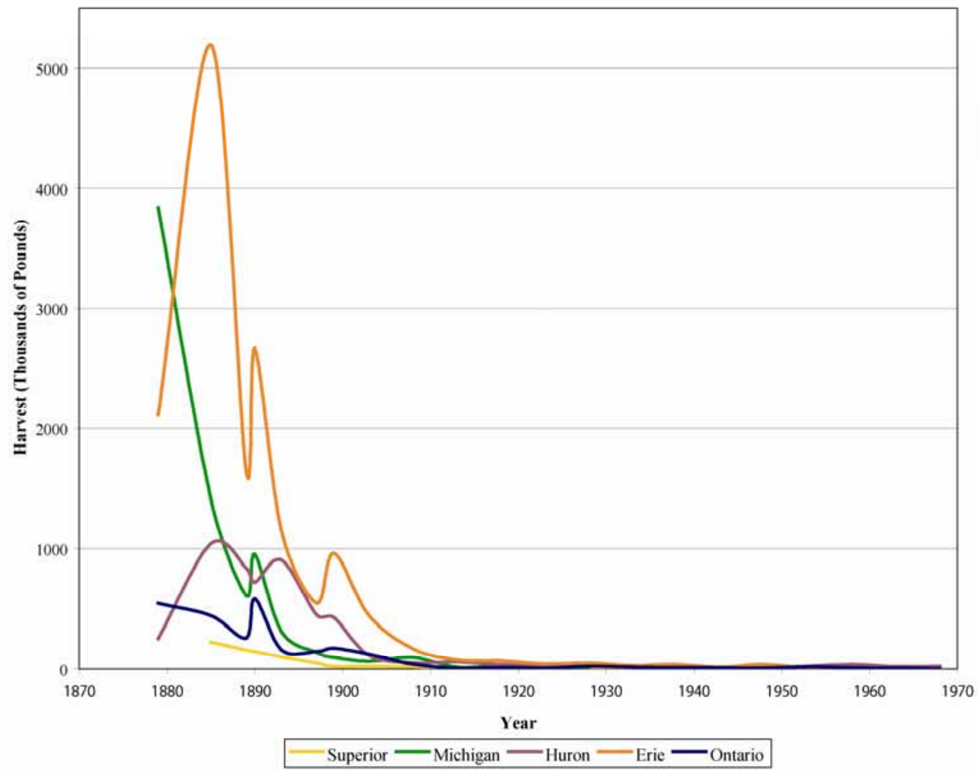

Figure 1. Historic lake sturgeon harvest from each of the Great Lakes.
Source: Baldwin *et al*. 1979

Year	Month	CPE
1994	6	0.333333
1995	6	1
1996	6	0.714286
1997	6	1.142857
1998	6	1.769231
1999	6	2.5
2000	6	2.25
2001	6	4.5
2002	6	5.5

Table 1. Trends in juvenile lake sturgeon CPE during June in Lake Superior near the mouth of the Bad River.

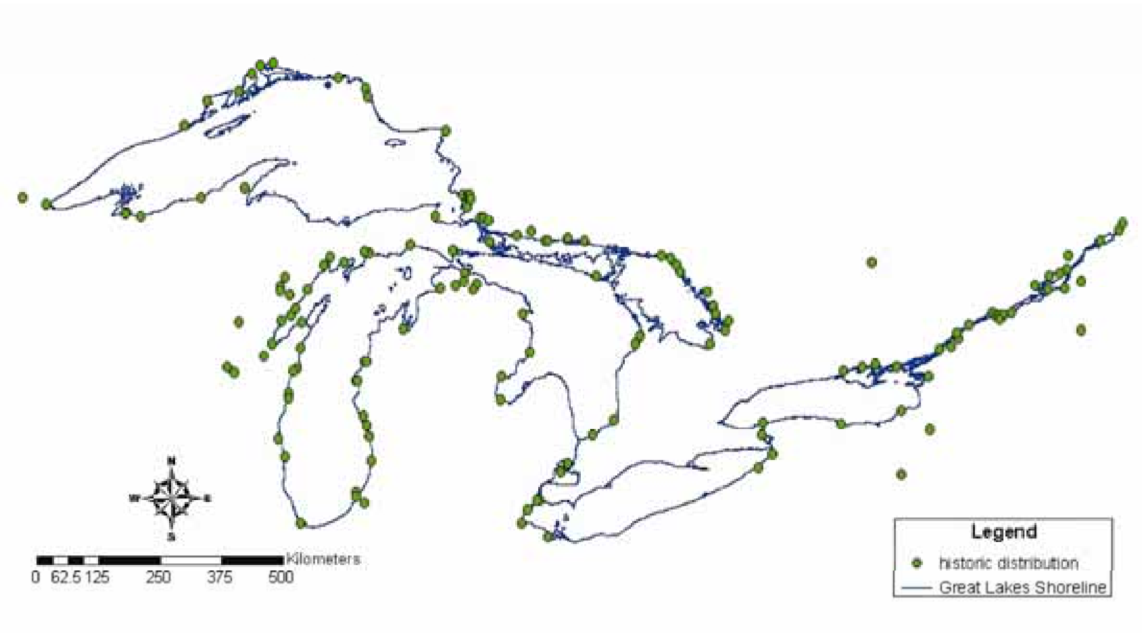

Figure 2. Historic distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

Figure 3. Current distribution of lake sturgeon.
Source: Zollweg *et al*. 2003

Commercial/Industrial Eco-Efficiency Measures

Indicator #3514

Assessment: Not Assessed

Purpose

- To assess the institutionalized response of the commercial/industrial sector to pressures imposed on the ecosystem as a result of production processes and service delivery.

Ecosystem Objective

The goal of eco-efficiency is to deliver competitively priced goods and services that satisfy human needs and increase quality of life, while progressively reducing ecological impacts and resource intensity throughout the lifecycle, to a level at least in line with the earth's estimated carrying capacity (WBCSD 1996). In quantitative terms, the goal is to increase the ratio of the value of output(s) produced by a firm to the sum of the environmental pressures generated by the firm (OECD *et al.* 1998).

State of the Ecosystem

Background

This indicator report for eco-efficiency is based upon the public documents produced by the 24 largest employers in the basin which report eco-efficiency measures and implement eco-efficiency strategies. The 24 largest employers were selected as industry leaders and as a proxy for assessing commercial/industrial eco-efficiency measures. This indicator should not be considered a comprehensive evaluation of all the activities of the commercial/industrial sector, particularly small-scale organizations, though it is presumed that many other industrial/commercial organizations are implementing and reporting on similar strategies.

Efforts to track eco-efficiency in the Great Lakes basin and in North America are still in the infancy stage. This is the first assessment of its kind in the Great Lakes region. It includes 24 of the largest private employers, from a variety of sectors, operating in the basin. Participation in eco-efficiency was tabulated from publicly available environmental reporting data from 10 Canadian companies and 14 American companies based in (or with major operations in) the Great Lakes basin.

Tracking of eco-efficiency indicators is based on the notion that what is measured is what gets done. The evaluation of this indicator is conducted by recording presence/absence of reporting related to performance in seven eco-efficiency reporting categories (net sales, quantity of goods produced, material consumption, energy consumption, water consumption, greenhouse gas emissions, emissions of ozone depleting substances (WBCSD 2002)). In addition, the evaluation includes an enumeration of specific initiatives that are targeted toward one or more of the elements of eco-efficiency success (material intensity, energy intensity, toxic dispersion, recyclability and product durability (WBCSD 2002)).

State of Eco-Efficiency

Of the 24 companies surveyed, 10 reported publicly (available online or through customer service inquiry) on at least some measures of eco-efficiency. Energy consumption and, to some extent, material consumption were the most commonly reported measures. Of the 10 firms that reported on some elements of eco-efficiency, three reported on all seven measures.

Of the 24 companies surveyed, 19 (or 79%) reported on implementation of specific eco-efficiency related initiatives. Two companies reported activities related to all five success areas. Reported initiatives were most commonly targeted toward improved recycling and improved energy efficiency.

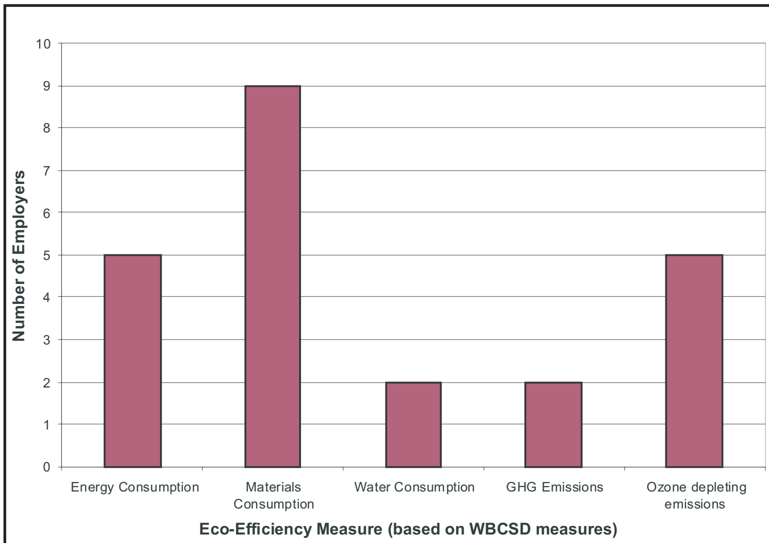

Figure 1. Number of the 24 largest employers in the Great Lakes basin that publicly report eco-efficiency measures. GHG = green house gas.
Source: WBCSD = World Business Council for Sustainable Development

Overall, companies in the manufacturing sector tended to provide more public information on environmental performance than the retail or financial sectors. At the same time, nearly all firms expressed a commitment to reducing the environmental impact of their operations. A select number of companies, such as Steelcase Inc. and General Motors in the U.S. and Nortel Networks in Canada, have shown strong leadership in comprehensive, easily accessed, public reporting on environmental performance. Others, such as Haworth Inc. and Quad/Graphics, have shown distinct creativity and innovation in implementing measures to reduce their environmental impact.

The concept of eco-efficiency was defined in 1990 but was not widely accepted until several years later. Specific data on commercial/industrial measures are only just being implemented, therefore it is not yet possible to determine trends in eco-efficiency reporting. In general, firms appear to be working to improve the efficiency of their goods and service delivery. This is an important trend as it indicates the growing ability of firms to increase the quantity/number of goods and services produced for the same or a lesser quantity of resources per unit of output.

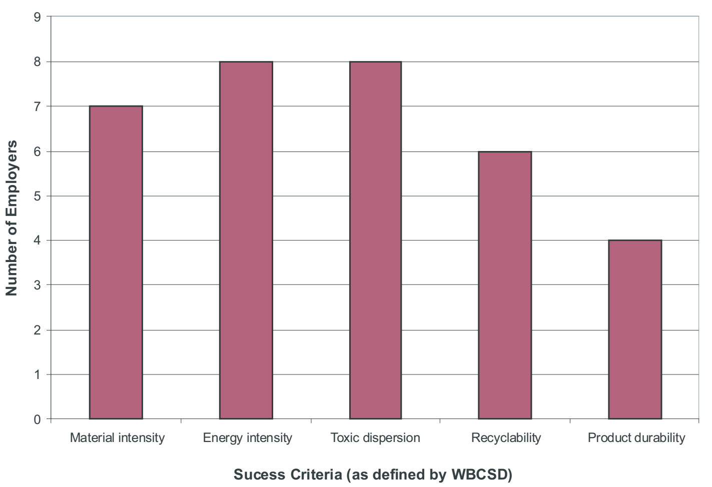

Figure 2. Number of the 24 largest employers in the Great Lakes basin that publicly report initiatives related to eco-efficiency success criteria.
Source: WBCSD = World Business Council for Sustainable Development

While one or more eco-efficiency measures are often included in environmental reporting, only a few firms recognize the complete eco-efficiency concept. Many firms recognize the need for more environmentally sensitive delivery of goods and services; however, the implementation of more environmentally efficient processes appears narrow in scope. These observations indicate that more could be done toward more sustainable goods and services delivery.

Pressures

Eco-efficiency per unit of production will undoubtedly increase over time, given the economic, environmental and public relations incentives for doing so. However, as Great Lakes populations and economies grow, quantity of goods and services produced will likely increase. If production increases by a greater margin than eco-efficiency improvements, then the overall commercial / industrial environmental impact will continue to rise. Absolute reductions in the sum of environmental pressures are necessary to deliver goods and services within the earth's carrying capacity.

Management Implications

The potential for improving the environmental and economic efficiency of goods and services delivery is unlimited. To meet the ecosystem objective, more firms in the commercial / industrial sector need to recognize the value of eco-efficiency and need to monitor and reduce the environmental impacts of production.

Acknowledgments

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Tom Van Camp and Nicolas Dion of Industry Canada provided several data resources.
Many of the firms surveyed in this report also contributed environmental reports and other corporate information. Chambers of commerce in many states and provinces around the Great Lakes provided employment data.

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Authors' Commentary
By repeating this evaluation at a regular interval (i.e. every 2 or 4 years), trends in industrial / commercial eco-efficiency can be determined. The sustainability of goods and service delivery in the Great Lakes basin can only be determined if social justice measures are also included in commercial/industrial sector assessments. The difficulty in assessing the impacts of social justice issues precludes them from being included in this report, however, such social welfare impacts should be included in future indicator assessment.

Last Updated
State of the Great Lakes 2003

Drinking Water Quality
Indicator #4175

Overall Assessment

Status:	**Good**
Trend:	**Unchanging**
Primary Factors Determining Status and Trend	Based on the information provided in the annual CC/WQRs and the Ontario annual reports from the DWSs, the overall quality of the finished drinking water in the Great Lakes Basin can be considered good. Because very few violations of federally, provincially, or state regulated MCLs, MACs, or treatment techniques occurred, the WTPs/DWSs are, in fact, employing treatment techniques that are successfully treating water. As such, the potential risk of human exposure to the noted chemical and/or microbiological continents, and any associated health effects, is generally low.

Lake-by-Lake Assessment

Lake Superior

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Michigan

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Huron

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Erie

Status:	Not Assessed
Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Lake Ontario

Status:	Not Assessed

Trend:	Undetermined
Primary Factors Determining Status and Trend	Not available at this time.

Purpose

- To evaluate the chemical and microbial contaminant levels in source water and in treated water; and
- To assess the potential for human exposure to drinking water contaminants and the effectiveness of policies and technologies to ensure safe drinking water.

Ecosystem Objective

The ultimate goal of this indicator is to ensure that all drinking water provided to the residents of the Great Lakes basin is protected at its source, and treated in such a way that it is safe to drink without reservations. As such, the treated water should be free from harmful chemical and microbiological contaminants. This indicator supports Great Lakes Quality Agreement Annexes 1, 2, 12, and 16.

State of the Ecosystem

Background

The information provided by the United States for this report focuses mainly on finished, or treated, drinking water. This format was chosen as the focus for U.S. reporting in order to adapt to the recommendations of the Environmental Health Indicator Project (www.cdc.gov/nceh/indicators/default.htm). Additionally, the U.S. is in the process of establishing an inclusive national drinking water database, which will include raw, or source water data, thus providing an extensive array of information to all WTPs/DWSs, researchers, and the general public. The information provided by Canada focuses on both finished and raw, or source, water.

In the U.S., the Safe-Drinking Water Act Re-authorization of 1996 requires all drinking water utilities to provide yearly water quality information to their consumers. To satisfy this obligation, U.S. Water Treatment Plants (WTPs) produce an annual Consumer Confidence/Water Quality Report (CC/WQR). These reports provide information regarding: source water type (i.e. lake, river or groundwater), the water treatment process, contaminants detected in the finished water, any violations that occurred, and other relevant information. For this indicator report the CC/WQRs were collected from 59 WTPs for the operational year 2004 (2005 when available). Furthermore, the U.S. based Safe Drinking Water Information System (SDWIS) was also used as a means to verify information presented in the reports and to provide any other relevant information, where CC/WQRs were not yet available.

The data used for the Canadian component of the report were provided by the Ontario Ministry of the Environment and include results from two program areas. Data collected as part of the Drinking Water Surveillance Program (DWSP) was provided for the period 2001/2002. DWSP is a voluntary partnership program with municipalities that monitors drinking water quality. Ontario's Drinking Water Systems Regulation (O. Reg. 170/03), made under the Safe Drinking Water Act, 2002, requires that the owner of a Drinking Water Systems (DWS) prepare an annual report on the operation of the system and the quality of its water. DWSs must provide the Ontario Ministry of the Environment (OMOE) with their drinking water quality data. Data from January to June 2004, collected as part of this regulatory framework from 74 DWSs, were also provided for analysis.

There are several sources of drinking water within the Great Lakes basin which include; the Great Lakes themselves, smaller lakes/reservoirs, rivers, streams, ponds, and groundwater i.e. springs and wells. However, these systems are vulnerable to contamination from several sources (chemical, biological, and radioactive). Substances that may be present in the source water include: microbial contaminants, such as viruses and bacteria; inorganic contaminants, such as salts and metals; pesticides and herbicides; organic chemical contaminants, including synthetic and volatile organic chemicals; and radioactive contaminants. After collection, the raw water undergoes a detailed treatment process prior to being sent to the distribution system where it is then dispersed to consumer taps. The treatment process involves several basic steps, which are often varied and repeated depending on the condition of the source water. It is important to note that raw water can also affect the finished water that is consumed. Good quality raw water is an important part of a multi-barrier approach to assuring the safety and quality of drinking water.

Status of Drinking Water in the Great Lakes Basin

Ten drinking water parameters were chosen to provide the best assessment of drinking water quality in the Great Lakes Basin, which include several chemical parameters, microbiological parameters, and other indicators of potential health hazards. These parameters are regulated by an established standard, which when exceeded, has the potential to have serious affects on human health. The U.S. Environmental Protection Agency (USEPA) defines this regulated standard as the Maximum Contaminant Level (MCL), or the highest level of a contaminant that is allowed in drinking water. The Ontario drinking water standards are described by the Maximum Acceptable Concentration (MAC), which is established for parameters that when present above a certain concentration, have known or suspected health effects, and the Interim Maximum Acceptable Concentration (IMAC), which is established for parameters either when there is insufficient toxicological data to establish a MAC with reasonable certainty, or when it is not feasible, for practical reasons, to establish a MAC at the desired level.

Chemical Contaminants

The chemical contaminants of concern include; atrazine, nitrate, and nitrite. Exposure to these contaminants above the regulated standards has the potential to negatively affect human health.

Atrazine-Atrazine, which has been widely used as an organic herbicide, can enter source water though agricultural runoff and/or wastewater from manufacturing facilities. Consumption of drinking water that contains atrazine in excess of the regulated standard, for extended periods of time, can potentially lead to health complications. The USEPA has set the MCL for atrazine at 3 parts per billion (ppb) and the Ontario Drinking water standards specify the IMAC to be 5 ppb, which is the lowest level at which WTPs/DWSs could reasonably be required to remove this contaminant given the present technology and resources.

In the U.S., atrazine was infrequently detected in finished water supplies, and was only found in finished water originating from Lake Erie, rivers, and small lakes/reservoirs. However when detected, it was found at levels that did not exceed the MCL. Violations of monitoring requirements were reported for two WTPs for failure to monitor atrazine and other contaminants between February and June 2004 and during July 2004, respectively. Therefore, as indicated by the annual CC/WQRs there is a low risk of human exposure to atrazine.

In Ontario, data from the 2003/2004 DWSP indicated that 22 percent of the water samples collected had trace amount of atrazine present. However, the highest level detected was only 0.59 ppb (about one order of magnitude less than the IMAC), which was identified from a raw water source located within an agricultural watershed.

Nitrogen-Nitrogen is a naturally occurring nutrient that is also used in many agricultural applications. However, in natural waters most nitrogenous material tends to be converted into nitrates, which when ingested at levels exceeding the MCL or MAC can cause serious health effects, particularly to infants. The USEPA has set the MCL for nitrate at 10 parts per million (ppm) and nitrite at 1 ppm and the province of Ontario has set the MAC for nitrate at 10 ppm and nitrite at 1 ppm.

In the U.S., nitrate was detected in over 70 percent of the finished water supplies which originated from WTPs using all sources of water except Lake Huron. However, it was never found at levels that exceeded the MCL and therefore, while there is some risk of exposure to nitrate, it is not likely to lead to serious health complications.

In Ontario, over 90 percent of the of the water samples contained nitrates; however, the highest level detected was 9.11 ppm, from a raw ground water sample. As such, there is a risk of exposure to nitrates, especially in agricultural areas, but it is not likely to cause health complications as detected levels never exceeded the Ontario contamination standard.

In the U.S., nitrite was rarely detected in finished water supplies. It was only found in finished water for WTPs which use rivers and small lakes/reservoirs as source water. As such, there is only a small potential for human exposure to nitrite from drinking water. No MCL or monitoring regulation violations were reported for nitrites.

Over fifty percent of the water samples contained a measurable amount of nitrite according to the Ontario drinking water system reports. However, the highest value for this contaminant only reached 0.365 ppm, which is lower than the Ontario MAC and the highest value detected last year (0.434 ppm).

Microbiological Parameters

The microbiological parameters evaluated include total coliform, *Escherichia coli (E. coli), Giardia,* and *Cryptosporidium.* These microbial contaminants are included as indicators of water quality, but also as an indication of the presence of hazardous and possibly fatal pathogens in the water.

Total Coliform-Coliforms are a broad class of bacteria that are ubiquitous in the environment and in the feces of humans and animals. The USEPA has set a MCL for total coliform at 5% of the total monthly samples (e.g. for water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month). Canada has set an

MCL of 0 colony forming units (CFU) for DWSs. Both Canada and the U.S. require additional analysis of positive total coliform samples to determine if specific types of coliform, such as fecal coliform or *E coli*, are present.

Escherichia coli (E. coli)-E. coli is a type of thermo tolerant (fecal) coliform bacteria that is generally found in the intestines, and fecal waste, of all animals, including humans. This type of bacteria commonly enters source water through contaminated runoff, which is often the result of precipitation. Detection of *E. coli* in water strongly indicates recent contamination of sewage or animal waste, which may contain many types of disease-causing organisms. It is mandatory for all WTPs to inform consumers if *E. coli* is present in their drinking and/or recreational water (U.S. waters only).

In the U.S., the presence of total coliform was detected in finished water from WTPs using all source water types, except Lake Superior. It was repeatedly detected in finished water from WTPs using Lake Michigan, groundwater, rivers, and small lakes/reservoirs as source water. Between July 2004 and October 2005, there were four violations with regard to total coliform levels exceeding the MCL. As such, repeat samples were collected at the same locations as the positive total coliform bacteria sample and at nearby locations to determine if the original positive sample indicated a localized water problem, or a sampling or testing error. However, samples from two of these WTPs tested positive for either fecal coliform or *E. coli*. Additionally, violations of monitoring requirements of USEPA's Total Coliform Rule (TCR) were reported in one WTP, for not collecting enough repeat samples after coliform bacteria was detected in the monthly routine samples. Although there is a potential for human exposure to total coliform, it is not likely to be a human health hazard in itself. However, the presence of coliform bacteria, especially at levels exceeding the MCL, indicates the possibility that microbial pathogens may be present, and this can be hazardous to human health.

In Ontario, total coliform was detected in many of the raw water samples; however only a few treated water samples contained this contaminant. Furthermore, *E. coli* was identified in raw water samples, which originating mostly from small lakes and rivers, in small amounts. However, the presence of *E. coli* was not identified in finished water supply, indicating that the treatment facilities are working adequately to remove both of these microbiological parameters.

Giardia and *Cryptosporidium- Giardia* and *Cryptosporidium* are parasites that exist in water and when ingested may cause gastrointestinal illness in humans. The U.S. treated water standards, which controls the presence of these microorganisms in the treated water, dictate that 99% of *Cryptosporidium* should be physically removed by filtration. In addition, *Giardia* must be 99.9% removed and/or inactivated by filtration and disinfection. These regulations are confirmed by the levels of post treatment turbidity and disinfectant residual levels. Ontario has also adopted removal/inactivation for *Giardia* and *Cryptosporidium*, however, there is no data to report at this time.

In the U.S., neither *Giardia* nor *Cryptosporidium* were detected in finished water supplies from any of the WTPs. However, several of the CC/WQRs discussed the presence of these microorganisms in the source waters (Lake Erie, Lake Huron, Lake Michigan, Lake Ontario, small lakes/reservoirs). The presence of these organisms in raw water but not in finished water indicates that current treatment techniques are effective at removing these parasites from drinking water. Nevertheless, implementing measures to prevent or reduce microbial contamination from source waters should remain a priority. Even a well-operated WTP cannot ensure that drinking water will be completely free of *Cryptosporidium.* Furthermore, very low levels of *Cryptosporidium* may be of concern for the severely immuno-compromised because exposure can compound their illness.

The annual CC/WQRs indicate that there is a potential for consumers to be exposed to the aforementioned microbiological contaminants. However, total coliform was the most common microbiological contaminant detected. Furthermore, there were very few if any confirmed detections of the more serious contaminants including, *E. coli, Giardia,* and *Cryptosporidium,* in the finished water of the U.S.. As a result, it is not likely that consumption of drinking water containing these contaminants will lead to any serious health complications.

Treatment Technique Parameters
The treatment technique parameters evaluated include turbidity, total organic carbon (TOC) in the U.S. and dissolved organic carbon (DOC) in Canada. These parameters do not pose a direct danger to human health but often indicate other health hazards.

Turbidity-Turbidity is a measure of the cloudiness of water and can be used to indicate water quality and filtration efficiency. Higher turbidity levels, which can inhibit the effectiveness of the disinfection/filtration process and/or provide a medium for microbial growth, are associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. A significant relationship has been demonstrated between increased turbidity and the number of *Giardia* cysts and *Cryptosporidium* oocysts breaking through filters. USEPA's surface water treatment rules require WTPs using surface water or ground water under the direct influence of surface water must disinfect and filter their water. In the U.S., turbidity levels must not exceed 5 Nephelolometric Turbidity Units (NTU) at any time, while WTPs that filter must ensure that the turbidity go no higher than 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month. Ontario has set the aesthetic objective for turbidity at 5.0 NTU, at which point turbidity becomes visible to the naked eye.

In the U.S., turbidity data is difficult to assess due to the different requirements and regulations for WTPs depending on the source water and treatment technique used. However, there were no MCL or monitoring regulations violations reported from January 2004 to October 2005.

In Ontario, the 2003/2004 DWSP report indicated that 78 raw water samples, many of which originated from Lake St. Clair and the Detroit River, exceeded the aesthetic objective. Furthermore, one treated water sample exceed the aesthetic objective with a turbidity level of 11.1 NTU.

Total Organic Carbon-Although the presence of total organic carbon (TOC) in water does not directly imply a health hazard, the organic carbon can react with chemical disinfectants to form harmful byproducts. WTPs remove TOC from the water by using treatment techniques such as enhanced coagulation or enhanced softening. Conventional WTPs with excess TOC in the raw water are required to remove a certain percentage of the TOC depending upon the TOC and the alkalinity level of the raw water. The USEPA does not have a MCL for TOC.

In the U.S., TOC was detected in finished water from WTPs using all source water types, except Lake Superior. However, TOC data was difficult to assess due to the varying formats of CC/WQRs and the way data was presented. As such, it was difficult to quantitatively evaluate and compare the TOC levels reported by each WTP. Violations of monitoring requirements and/or failure to report the results were reported for one WTP from July to September 2005.

Dissolved Organic Carbon-Dissolved organic carbon (DOC) can indicate the potential possibility of water deterioration during storage and distribution. Acting as a growth nutrient, increased levels of carbon can aid in the proliferation of biofilm, or microbial cells that attach to the surface of pipes and multiply to form a layer of film or slime on the pipes, which can harbor and protect coliform bacteria from disinfectants. High DOC levels can also indicate the potential of chlorination by-products problems. The use of coagulant treatment or high pressure membrane treatment can be used to reduce DOC. The aesthetic objective for DOC in Ontario's drinking water is 5 ppm.

In Ontario, there were 110 DOC violations, 11.4 ppm being the highest level, identified from raw water sample; however, no treated water sample contained DOC levels exceeding the aesthetic objective. Most of the high DOC results came from raw water originating from small rivers and lakes.

Taste and Odor

While taste and odor do not necessarily reflect any health hazards, these water characteristics affect the consumer perception of the drinking water quality.

In the U.S., there were no reports of offensive taste or odors associated with the finished drinking water as indicated by the 2005 CC/WQRs.

In Ontario, there has been an increase in the number of reports associated with offensive taste and odor over the past several years; however, specific data is unavailable as it is difficult to quantitatively evaluate and compare results. Many drinking-water systems have now installed granular activated carbon filters to decrease the effect and intensity of these taste and odor events, which are due, in part, to the increased decomposition of blue-green algae in the Great Lakes (Ministry of Environment, 2004).

Summary

Based on the information provided in the annual CC/WQRs and the Ontario annual reports from the DWSs, the overall quality of the finished drinking water can be considered good. However, over the past several years there has been an increase in the quantity of contaminants found in raw source water in the Great Lakes Basin. The overall potential risk of human exposure to the noted chemical and/or microbiological continents, and any associated health effects, is generally low as very few violations of federally, provincially, or state regulated MCLs, MACs, or treatment techniques occurred. This indicates that the WTPs/DWSs are employing treatment techniques that are successfully treating water

Pressures

The greatest pressure to the quality of drinking water within the Great Lakes Basin would be degraded runoff. Several causes for this reduction in quality would including; the increasing rate of industrial development on or near water bodies, low-density urban sprawl, and agriculture - both crop and livestock operations. Point source pollution, from wastewater treatment plants for example, can also contribute to the contamination of raw water supplies and therefore can be considered an important pressure as well. Additionally, there is an emerging set of pressures such as newly introduced chemicals, chemicals of emerging concern (i.e. pharmaceuticals and personal care products (PPCPs), endocrine disruptors, antibiotics and antibacterial agents) and invasive species which might affect water quality; however to what extent is still unknown.

Management Implications
A more standardized, updated approach to monitoring contaminants and reporting data for drinking water needs to be established. Even though the USEPA has established an extensive list of contaminants, and their MCLs, newer parameters of concern might not be listed due to available resources or technology. Additionally, state monitoring requirements may differ; requiring only a portion of this list to be monitored. This would make trend analysis easier, and thus provide a more effective assessment of the potential health hazards associated with drinking water.

Furthermore, a more extensive monitoring program must be implemented in order to successfully correlate drinking water quality with the status of the Great Lakes Basin. Although the CC/WQRs provide useful information regarding the quality of finished drinking water, they merely depict the efficiency of the WTP, rather than the overall quality of the region. Additionally, by solely focusing on treated water, WTPs that rely on several type of source water will not provide accurate data with regard to contaminant origin. Therefore, in order to properly assess the state of the ecosystem, source water data would need to be reviewed.

Another concern for future efforts would be the adherence of a consistent guideline when identifying usable data; a guideline that obtains sufficient data while also providing adequate geographical coverage. In the U.S., data from WTPs serving a population of 50,000 or great was used, while data from all DWSs in Ontario serving a population of 10,000 or greater was analyzed. Furthermore, focusing on this criterion for WTPs only provides a fragmented view of the drinking water patterns in the Great Lakes Basin; however by sporadically including additional WTPs to expand the geographical coverage area, bias results may be introduced.

In addition to raw and treated water, some effort should also be made to analyze distributed water. Even though there are numerous precautions in place to ensure the quality of finished water, contamination is also possible during the distribution stage. Corrosion of copper or lead pipes and/or bacterial growth within these pipes could affect the overall quality of drinking water. Even though WTPs/DWSs are implementing actions to prevent or hinder such contamination, without sufficient data from distributed water supplies it is impossible to determine whether these efforts are effective or need to be altered.

Acknowledgments
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Consumer Confidence Reports

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Alpena Water Treatment Plant – 2005 Annual Drinking Water Quality Report
Aqua Ohio, Inc. PWS – 2005 Water Quality Report
Aqua Ohio – Mentor – 2005 Water Quality Report
Buffalo Water Authority – 2005 Annual Water Quality Report
City of Ann Arbor Water Utilities – 2005 Annual Report on Drinking Water
City of Battle Creek Public Works – 2005 Annual Water Quality Report
City of Cleveland Division of Water – 2006 Water Quality Report
City of Duluth Public Works and Utilities Department – 2005 Guide to Drinking Water Quality
City of Evanston – 2005 Water Quality Report
City of Kalamazoo – 2005 Water Quality Report
City of Kenosha Water Utility – 2005 Annual Drinking Water Quality Report
City of Marquette Water Filtration Plant – 2005 Annual Drinking Water Quality Report
City of Muskegon Water Filtration Plant – 2005 Annual Water Quality Report
City of Oshkosh – Drinking Water Quality Report 2005
City of Rochester – Water Quality Report 2005
City of Syracuse Department of Water – Annual Drinking Water Quality Report for 2005
City of Toledo Water Treatment Plant – 2005 Drinking Water Quality Report
City of Warren – 2005 Water Quality Report
City of Waukegan – 2006 Water Quality Report
City of Wyoming – 2005 Water Quality Report
Department of Utilities Appleton Water Treatment Facility – 2005 Annual Water Quality Report to our Community
Detroit Water & Sewer Department – 2005 Water Quality Report
Elmira Water Board – Annual Drinking Water Quality Report 2005
Elyria Water Department – 2005 Annual Water Quality Report
Erie County Water Authority – 2005 Water Quality Report

Erie Water Works (EWW) – Water Quality Report for Year 2005
Fort Wayne City Utilities – 2006 Annual Drinking Water Quality Report
Grand Rapids Water System – Water Quality Report 2005
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