THE STATE OF LAKE HURON IN 2010

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THE STATE OF LAKE HURON IN 2010

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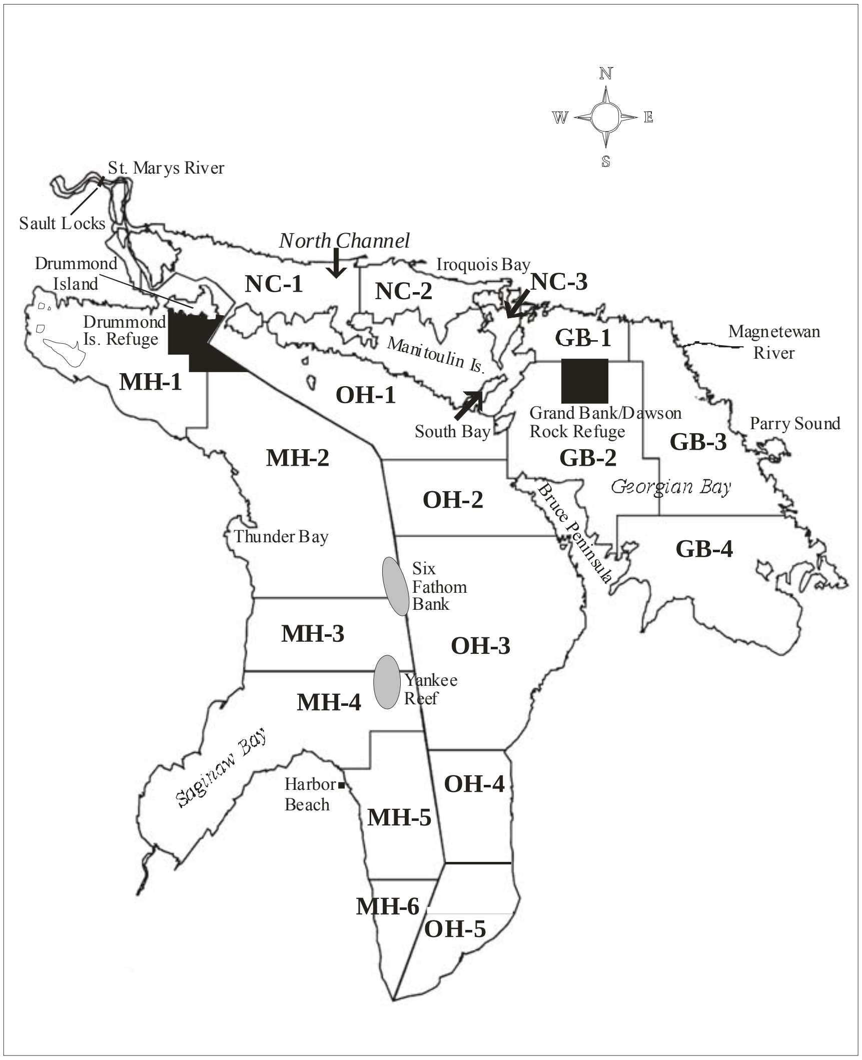
Frontispiece



Map of Lake Huron showing major geographical features and statistical districts.

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ABSTRACT

The fish communities of Lake Huron have undergone profound ecological changes in the last century, including invasions of destructive species, particularly the sea lamprey (*Petromyzon marinus*), alewife (*Alosa pseudoharengus*), and rainbow smelt (*Osmerus mordax*); the collapse of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*) stocks; and the extirpation of four species of deepwater ciscoes (*Coregonus* spp.). More recently, the effects of several new invasive species, especially those caused by the spiny water flea (*Bythotrephes longimanus*), zebra and quagga mussels (*Dreissena* spp.), and round goby (*Neogobius melanostomus*), have become apparent. This report focuses on the period 2005-2010 and summarizes the most recent changes in the ecology of Lake Huron. Since 2005, offshore phosphorus levels have remained low, and chlorophyll levels have continued to decline, suggesting that the lake is trending toward a more oligotrophic state. The 2006 zooplankton data, the latest available, suggest that the marked changes in the zooplankton community observed in the early 2000s have persisted. The abundance of the native amphipod *Diporeia* spp. has remained very low, and quagga mussel density in the offshore waters has continued to increase. The total estimated lakewide biomass of offshore demersal fish continued to decline through 2009 (to 16.5 Kt) but increased modestly in 2010 (to 29.1 Kt). Alewife abundance remains at very low levels following the population crash of 2004, and rainbow smelt abundance has continued to decline but showed a slight increase in 2010. The abundance of bloater (*C. hoyi*), a native fish, has increased since the previous reporting period (2000-2004), while the remainder of the native offshore demersal species remains at low abundance. The cisco (formerly lake herring, *C. artedi*) persists in most parts of Lake Huron, except in western Michigan waters, including Saginaw Bay, where it was historically very abundant. The offshore demersal fish community appears to be in a state of flux, and further changes to the structure

of this community are likely. Commercial harvest and estimated abundance of lake whitefish have continued to decline since the previous state-of-the-lake report. The estimated biomass of large lake trout in Lake Huron has remained high and relatively stable since 2004, and angler catch rate in 2010 was similar to that in 2004. Wild age-0 lake trout were captured regularly in trawl surveys in Lake Huron beginning in 2004, and unclipped (presumably wild) adult lake trout also have become common in assessment surveys since 2004, suggesting that widespread natural reproduction of lake trout has been occurring in Lake Huron. These reports represent the first lakewide evidence since the 1940s of natural reproduction by lake trout outside of Lake Superior, and, as such, is an important step forward in lake trout restoration in the Great Lakes. Chinook salmon (*Oncorhynchus tshawytscha*) weight-at-age has increased since the last reporting period, although angler catch rate has remained low, but Chinook salmon abundance is much less than the average for the previous reporting period. Most of the Chinook salmon in Lake Huron are now naturally produced—the early survival of stocked fish appears to have decreased dramatically. Increased biomass and production of walleye (*Sander vitreus*) has been observed in most parts of the lake. Yellow perch (*Perca flavescens*) reproductive success has also increased leading to increased abundance in some locations, but yellow perch populations remain depressed in Saginaw Bay due to poor survival. Progress toward sea lamprey suppression targets has continued during 2005-2010 with reductions of 12% in adult (spawning-phase) abundance and 29% in marking, but the mean estimated population of 149,000 during this period was more than double the abundance target, and the marking rate (8.4 per 100 lake trout) was 68% above the maximum allowable rate. Populations of lake sturgeon (*Acipenser fulvescens*), northern pike (*Esox lucius*), and muskellunge (*Esox masquinongy*) appear to be stable in most parts of the lake, but northern pike currently may have low reproductive success in some areas due to low water levels. Smallmouth bass (*Micropterus dolomieu*) populations appear to be increasing in several areas of the lake, and channel catfish (*Ictalurus punctatus*) populations appear stable. Although many encouraging signs of progress in the Lake Huron ecosystem are evident, the majority of the management objectives for the fish community remained unmet as of 2010. A regime shift may be occurring in the Lake Huron ecosystem, and whether the lake has achieved a new stable state or is still in a state of flux remains uncertain. As was stated in previous state-of-the-lake reports for Lake Huron, the management objectives for Lake Huron need to be revised as they appear to have little relevance to current and potential near-future conditions in the lake.

INTRODUCTION

Stephen C. Riley[1]

International fishery management on the Great Lakes is facilitated through the Great Lakes Fishery Commission, which established a lake committee for each lake to coordinate fisheries management. Fish-community objectives (FCOs) for Lake Huron (DesJardine et al. 1995) were established by the Lake Huron Committee (LHC) in response to the 1994 modification of *A Joint Strategic Plan for Management of Great Lakes Fisheries* (Joint Plan) (Great Lakes Fishery Commission 2007). The LHC is composed of one fishery manager each from the Michigan Department of Natural Resources, the Ontario Ministry of Natural Resources, and the Chippewa Ottawa Resource Authority. The FCOs are intended to define desirable structures for fish communities and to provide means for measuring progress toward their achievement. The LHC has charged the Lake Huron Technical Committee to produce a state-of-the-lake report documenting this progress, typically every five years. This report describes the status of Lake Huron's fish communities for six years, from 2004 to 2010, evaluates progress towards achieving the FCOs for the lake, and identifies new and emerging issues that likely will affect the future management of the lake. This fourth state-of-the-lake report builds upon descriptions of the lake and its history presented in previous reports (Ebener 1995; Ebener 2005; Bence and Mohr 2008).

Lake Huron is the second largest of the Laurentian Great Lakes and is oligotrophic, except for Saginaw Bay and several nearshore areas. Basin morphometry, hydrology, geology, and limnology were summarized in DesJardine et al. (1995) and Ebener (1995). The lake encompasses three discrete basins (Georgian Bay, the North Channel, and the main basin,

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which includes Saginaw Bay), and is divided into statistical districts used for reporting and management (see Frontispiece). The St. Marys River connects Lakes Superior and Huron and is managed as part of Lake Huron. Although the human population of the basin is low compared to three of the other four Great Lakes, the lake's proximity to population centers makes it a prime destination for fishing, boating, and other recreational activities.

Prior to 1900, the lake trout (see Table 1 for an alphabetical list of common fish names and their corresponding scientific names) was the dominant predator in the lake, and walleye and burbot were subdominant. The prey community was dominated by cisco (formerly lake herring), sculpins, and deepwater ciscoes. Round whitefish, lake whitefish, and ninespine stickleback were also abundant. The structure and function of that fish community began to change in the late 1800s and became radically changed by 1960 through invasions of the sea lamprey, alewife, and rainbow smelt; over-exploitation of important species; and habitat degradation in nearshore areas and tributaries (Berst and Spangler 1972). A new wave of invasive species, including the spiny water flea (*Bythotrephes longimanus*), dreissenid mussels, and round goby, have further affected fish communities since approximately the mid-1980s.

Table 1. Common and scientific names of fish species (updated from Nelson et al. 2004) referenced in this report. A single asterisk (*) indicates the species is imperiled or endangered, and double asterisks (**) indicate the species is considered extirpated from Lake Huron.

Common name	Scientific name
Native species (cold water):	
bloater	*Coregonus hoyi*
cisco (formerly lake herring)	*Coregonus artedi*
deepwater cisco**	*Coregonus johannae*
deepwater sculpin	*Myoxocephalus thompsonii*

Table 1, continued

Common name	Scientific name
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
round whitefish	*Prosopium cylindraceum*
shortjaw cisco*	*Coregonus zenithicus*
shortnose cisco**	*Coregonus reighardi*
Native species (cool water):	
banded killifish	*Fundulus diaphanus*
black redhorse	*Moxostoma duquesnei*
burbot	*Lota lota*
channel darter	*Percina copelandi*
emerald shiner	*Notropis atherinoides*
grass pickerel	*Esox americanus*
lake sturgeon	*Acipenser fulvescens*
muskellunge	*Esox masquinongy*
northern brook lamprey	*Ichthyomyzon fossor*
northern pike	*Esox lucius*
ninespine stickleback	*Pungitius pungitius*
redside dace	*Clinostomus elongatus*
slimy sculpin	*Cottus cognatus*
spotted sucker	*Minytrema melanops*
trout-perch	*Percopis omiscomaycus*
walleye	*Sander vitreus*
yellow perch	*Perca flavescens*

Table 1, continued

Common name	Scientific name
Native species (warm water):	
channel catfish	*Ictalurus punctatus*
lake chubsucker*	*Erimyzon sucetta*
largemouth bass	*Micropterus salmoides*
pugnose shiner*	*Notropis anogenus*
rudd	*Scardinius erythropthalmus*
smallmouth bass	*Micropterus dolomieu*
Non-native species (cold water):	
Atlantic salmon	*Salmo salar*
brown trout	*Salmo trutta*
Chinook salmon	*Oncorhynchus tshawytscha*
coho salmon	*Oncorhynchus kisutch*
pink salmon	*Oncorhynchus gorbuscha*
rainbow smelt	*Osmerus mordax*
rainbow trout	*Oncorhynchus mykiss*
sea lamprey	*Petromyzon marinus*
Non-native species (cool water):	
alewife	*Alosa pseudoharengus*
fourspine stickleback	*Apeltes quadracus*
round goby	*Neogobius melanostomus*

The overarching management objective for Lake Huron is to restore an ecologically balanced and largely self-sustaining fish community dominated by top predators and capable of sustaining combined commercial and sport yields of 8.9-million kg annually (DesJardine et al. 1995). During 1912-1940, the average commercial fisheries yield (8.9-million kg) appeared stable, was supported by a number of native species, and was taken to be the best measure of the lake's long-term potential yield (DesJardine et al. 1995). Consistently reported yields included only commercial catches until 1986, at which time Michigan began to report recreational yield regularly. From 1972 to 1999, total reported fishery yields increased substantially from a low of 2.0-million kg to more than 6.3-million kg. During this reporting period (2005-2010), commercial harvest (U.S. and Canada, all species) averaged 3.7-million kg. If recreational yield is assumed to comprise 25% of the total yield, as per Bence et al. (2008), then total yield in this reporting period roughly approximated 4.9-million kg, which is 11% lower than in the previous (2000-2004) reporting period and 45% below the FCO. This estimate of total yield is likely biased high because the recreational salmon fishery was much reduced in this reporting period (see Status of Introduced Salmonines chapter).

Overall, the fish-species composition in Lake Huron has not changed from what was reported by Bence and Mohr (2008) for 2004. However, some substantial changes in relative abundance of individual species with consequences for achieving the FCOs have occurred. These changes are described in subsequent chapters and involve large declines in prey species, such as alewife (an exotic fish), and a substantial decline in the abundance of sea lamprey in response to control efforts on the St. Marys River. Previous reviews concluded that most of the top predators in Lake Huron were of hatchery origin (Ebener 2005; Dobiesz et al. 2005). While stocking still plays a substantial role in fish management, its importance has diminished. Recruitment of wild-born predators, such as Chinook salmon, walleye (in Saginaw Bay), and lake trout, has increased substantially. In spite of increased recruitment of wild lake trout, populations of this species continue to be supported by stocking, except in the Parry Sound area of Georgian Bay (Reid et al. 2001).

The commercial fishery operates primarily with large- and small-mesh gillnets and trapnets in all three basins (for a review of the fisheries, see Ebener et al. (2008, 2008b) and Mohr and Ebener (2005). Coregonines, especially lake whitefish, continue to dominate commercial yield. The main basin produces approximately 84% of the total commercial yield followed by Georgian Bay (10%) and the North Channel (6%). The Ontario commercial fishery accounts for approximately 60% of the total lakewide commercial yield. In response to a negotiated settlement between Chippewa and Ottawa tribes, the state of Michigan, and the U.S. federal government, gillnet effort in Michigan waters of the northern main basin was reduced by 3.4-million m (11-million ft) beginning in 1999, and a number of gillnet operations converted to trapnets. Furthermore, the settlement led to annual limits or yield targets established for lake trout and lake whitefish in U.S. waters; yield limits already existed in Canadian waters.

Although most recreational fisheries remain concentrated within 10-15 km of ports, bigger and safer boats have made the whole basin and shoreline accessible to recreational fishing. Chinook salmon, lake trout, yellow perch, and walleye make up most of the recreational yield. A popular offshore fishery developed in the 1960s following the introduction of salmon by the state of Michigan, and this fishery now also targets lake trout and rainbow trout. Nearshore recreational fisheries have traditionally accounted for more than half of the recreational-fishing effort in Michigan waters (Fielder et al. 2000). Eastern and southern Georgian Bay, Saginaw Bay, the St. Marys River, the North Channel, and waters adjacent to river mouths are important nearshore fishing areas for prominent species, including yellow perch, walleye, smallmouth bass, cisco, and rainbow trout. Major recreational fisheries for walleye redeveloped in Saginaw Bay following initiation of a stocking program in 1972.

A bottom-up approach is taken in this report—subsequent chapters address in order the status of lower trophic levels, the offshore demersal fish community, whitefishes and ciscoes, lake trout, sea lamprey, introduced salmonines, nearshore fish communities, habitat, and species and genetic diversity. This report ends with a chapter on overall conclusions and recommendations.

STATUS OF PHYTOPLANKTON, ZOOPLANKTON, AND BENTHOS

Richard P. Barbiero[2], Thomas F. Nalepa, Barry M. Lesht, and Glenn J. Warren

Lower Food Web in the Open Waters

The main basin of Lake Huron has historically been regarded as one of the least productive of the Laurentian Great Lakes (Beeton 1965) with a trophic state intermediate between Lake Superior, the most oligotrophic of the lakes, and Lake Michigan. Inputs of chemical constituents to the system are determined in large part by inflows in the north from Lake Michigan and Lake Superior, the latter via the St. Marys River, and inputs from Saginaw Bay in the south (Schelske and Roth 1973). As a result, water-quality characteristics in Lake Huron are intermediate between the other two upper lakes (Barbiero and Tuchman 2001). Plankton communities in Lake Huron, by contrast, have tended to be very similar to those in Lake Michigan (Barbiero and Tuchman 2001; Barbiero et al. 2001). In recent years, however, the offshore waters of Lake Huron have shown signs of increasing

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oligotrophy, as evidenced by changes in the magnitude and seasonality of the chlorophyll content of the lake and shifts in zooplankton community size and composition.

The Great Lakes National Program Office (GLNPO) of the U.S. Environmental Protection Agency (EPA) has conducted regular biannual monitoring of the main basin of Lake Huron since 1983. The monitoring effort is focused on detecting whole-lake responses to changes in loadings of anthropogenic substances as well as impacts of invasive species, so sampling is restricted largely to the relatively homogeneous offshore waters of the main basin. To provide greater temporal resolution than is possible from these surveys, which are conducted in spring and summer, the GLNPO also utilizes estimates of chlorophyll concentrations derived from sea-viewing wide field-of-view sensor (SeaWiFS) imagery. Here we present an assessment of chlorophyll concentrations in the main basin from 1998-2008 and of zooplankton community data from 1984-2006 (no data 1991-1997). Because differences exist in the biology of different regions of the lake, the 15 monitoring stations were allocated to either the deeper northern or the shallower southern portion of the main basin (Fig. 1). Details on remote-sensing data-analysis methodology are in Barbiero et al. (2011a), while zooplankton sampling and analytical methods are described in Barbiero et al. (2001).

Sea-WiFS Estimated Chlorophyll

Seasonality of phytoplankton development, as assessed by remote sensing of chlorophyll, has typically consisted of a spring peak, with a maximum occurring in late April or early May, somewhat later in the northern part of the lake, and a summer minimum in August-September (Fig. 2). A secondary maximum is usually seen in October-November after the erosion of the thermocline and entrainment of hypolimnetic nutrients. In general, chlorophyll levels are lower in the north than in the south. A marked decrease in the magnitude of the spring bloom occurred in 2003 in both regions of the lake with further reductions seen through 2008. The decline appeared to be due in large part to decreases in the large diatoms *Tabellaria flocculosa* and *Aulacoseira islandica*, which had contributed a total of 60% of spring phytoplankton biovolume in 2001-2002 but were reduced by over

95% in 2003-2004 (Barbiero et al. 2011a). By 2005, reductions in summer chlorophyll also were seen in both basins.

Fig. 1. Map of Lake Huron showing U.S. EPA sampling stations. Dashed line indicates division of the main basin into northern and southern basins.

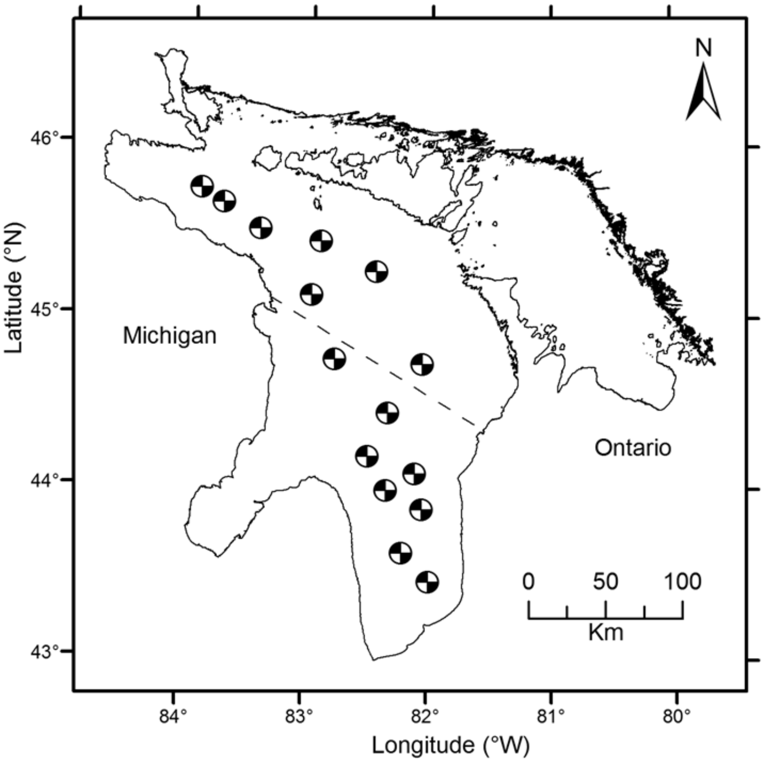
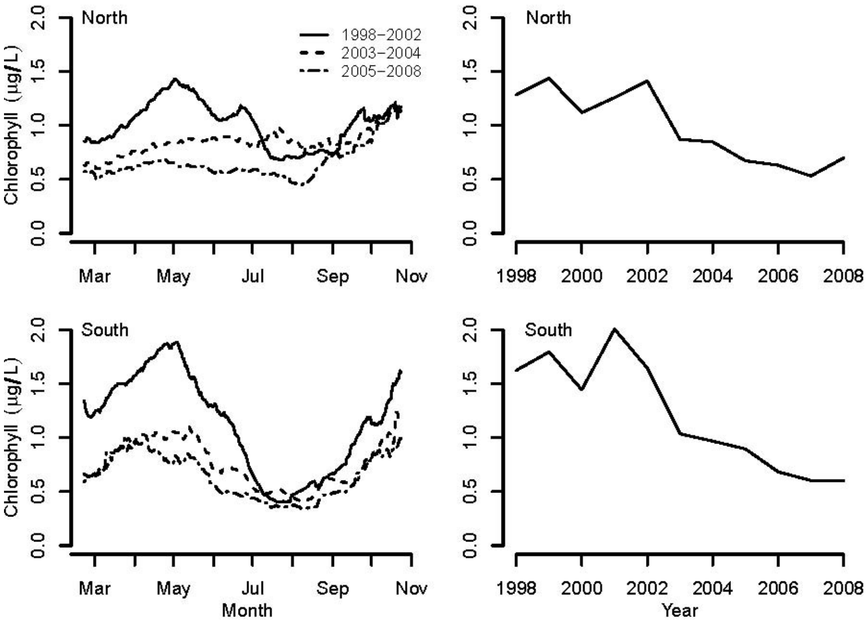


Fig. 2. Chlorophyll concentration, as estimated from SeaWiFS imagery, for the northern and southern regions of Lake Huron. Left panels show seasonal development as estimated from 10-day running means, averaged over three time periods: 1998-2002, 2003-2004, and 2005-2008. Right panels show average May concentrations from 1998 to 2008.

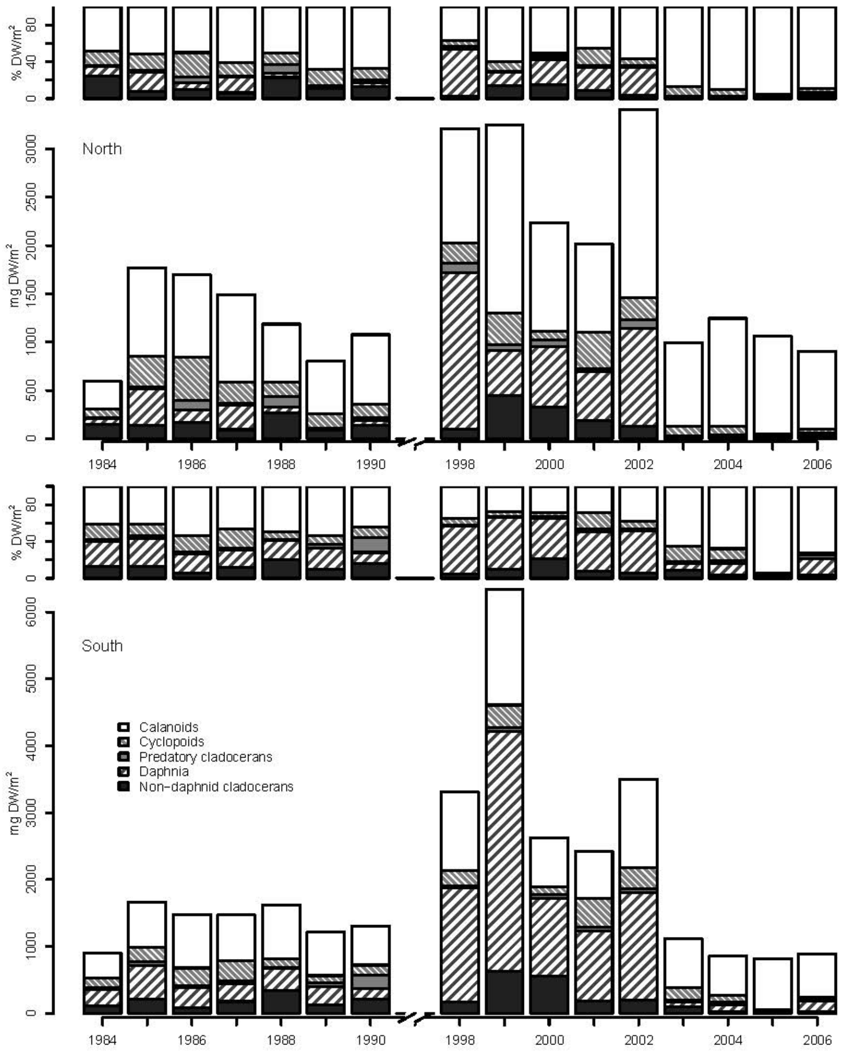


Status of Zooplankton

The crustacean zooplankton community of Lake Huron has for the most part been limited to a small number of species, including the cladocerans *Daphnia mendotae*, *Bosmina longirostris*, and *Bythotrephes longimanus*; the diaptomid calanoid copepods *Leptodiaptomus ashlandi*, *L. minutus*, and *L. sicilis*; the deep-living calanoid *Limnocalanus macrurus*; and smaller numbers of the cyclopoid copepod *Diacyclops thomasi*. The species composition, total biomass, and dominance (on a biomass basis) by cladocerans and diaptomid copepods are very similar now to that of Lake Michigan (Barbiero et al. 2001).

Overall, biomass was higher during 1998-2002 than during 1984-1990 (Fig. 3). The later period was also marked by a somewhat higher contribution of *Daphnia* to the crustacean community. In 2003, a dramatic reduction in biomass and a shift in composition greatly altered the community (Barbiero et al. 2011a). Biomass of cladocerans exhibited an abrupt and dramatic decline in that year, virtually disappearing from the northern region of the lake and declining in the southern region from an average contribution of 58% of areal biomass during 1998-2002 to 14% during 2003-2006 (Fig. 3). During 1984-1990, cladocerans had contributed an average of 23% and 35% to crustacean biomass in the northern and southern basins, respectively. A further change took place in 2005 when cyclopoid copepod biomass decreased substantially. Biomass in 2005-2006 averaged 13% and 7% of levels in 1998-2004 in the northern and southern regions of the lake, respectively.

Fig. 3. Areal biomass dry weight (DW) of crustacean zooplankton by major group, 1984-2006, for the northern and southern basins of Lake Huron. Insets indicate percent biomass by major group.



These changes, and in particular the loss of large-bodied cladocerans, have resulted in a decline in the total August standing stock of zooplankton. Average areal biomass between 2003 and 2006 was 1052 and 920 mg

DW/m^2 in the northern and southern basins, respectively, representing declines of 63% and 75% from 1998-2002 levels in the two basins, respectively. With the loss of most of the cladoceran population, a greater proportion of the large (>0.9 mm) zooplankton community is now accounted for by *L. macrurus*, which, in 2003-2006, contributed to 30-40% of the biomass in this size range. This shift could have important consequences for the prey-fish community. The shift in large crustacean biomass from *Daphnia mendotae* to *L. macrurus* brings with it a change in the depth distribution of that biomass, because *L. macrurus* is primarily a hypolimnetic species (Wells 1960; Barbiero et al. 2005). Although *L. macrurus* is a nutritious food for fish (Birge and Juday 1922), calanoid copepods are more difficult for fish to capture than cladocerans with larger individuals more evasive than smaller ones (Drenner and McComas 1980; Zaret 1980; Link 1996). Capture probabilities of *L. macrurus* by cisco have been shown to be only 30%, compared to 80% for *D. mendotae* (Link 1996). In spite of difficulty of capture, *L. macrurus* is a seasonally important fish food item due to its presence in the water column when other zooplankton are not available. In Lake Michigan, *L. macrurus* constitutes a substantial portion of the diet of alewife (see Table 1 in the Introduction for scientific names of fishes) in spring and winter (Morsell and Norden 1968; Wells 1980; Pothoven and Vanderploeg 2004), and it can also be an important food source to bloaters, particularly in the spring. In addition to a decrease in zooplankton stocks overall, the changes seen in recent years could alter competitive outcomes between individual prey-fish species if differences in their ability to capture calanoids exist.

Benthos

Saginaw Bay

The benthic macroinvertebrate community of Saginaw Bay consists of assemblages that reflect distinct physical and chemical features within the inner and outer portions of the bay. The inner bay is warm and shallow with a mean depth of 5 m, and benthic communities here are heavily influenced by inputs of nutrients and organic material from the Saginaw River. The outer bay is influenced by the colder, less-productive waters of Lake Huron and, with a mean depth of 14 m, the outer bay is deeper than the inner bay.

Trends in densities of the major taxonomic groups were examined between 1987 and 1996 (Nalepa et al. 2003). While some changes were related to nutrient control efforts, most major changes were related to the introduction and rapid expansion of zebra mussels (*Dreissena polymorpha*). Zebra mussels were first found in the bay in late 1990, peaked in 1992, and then declined to stable levels during 1993-1996 (Nalepa et al. 2003). In 1992, a maximum mean density of 33,800 m^{-2} occurred at sites with hard substrates (sand, gravel) in the inner bay. Mean density at the same sites had declined to 4,200 m^{-2} by 1993-1996. For non-dreissenid taxa, the most significant changes during this period were increased densities of the amphipod *Gammarus* in the inner bay and complete loss of the amphipod *Diporeia* in the outer bay. After the peak in zebra mussel abundance in 1992, the mean density of *Gammarus* increased from 65 m^{-2} in 1987-1990 to 400 m^{-2} in 1993-1996. *Gammarus* benefits from the habitat complexity created by zebra mussel clusters and/or from the increase in food availability resulting from mussel biodeposits (Ricciardi et al. 1997). The exact mechanism for the negative response of *Diporeia* to dreissenids remains unclear.

At sites with a silt substrate, oligochaetes and chironomids declined after the peak in zebra mussel numbers in 1992, but, by 1996, densities had returned nearly to levels found in the pre-mussel period (1987-1990). Since these sites were located in the deeper, depositional zone of the bay, it is likely that, at least initially, filtering activities of abundant zebra mussel populations in the shallower regions led to diminished organic inputs to this deep region. Mussels were rarely found in this deep region over the entire sampling period.

Only a few individuals of the mayfly *Hexagenia* were collected in 1987-1996. This important fish-food organism was abundant in the bay until the mid-1950s. At that time, populations essentially disappeared because of pollution and resulting habitat degradation. A similar decline occurred in western Lake Erie in the mid-1950s, but populations recovered in the mid-1990s (Schloesser et al. 2000). There was no indication of a similar recovery of *Hexagenia* in Saginaw Bay as of 1996.

After 1996, there were no benthic surveys over the entire bay until annual surveys were conducted again between 2008 and 2010 (TFN, unpublished data). Although most data are yet unavailable to assess the entire macroinvertebrate community, some changes in the dreissenid population were evident. In the 1990s, the entire dreissenid population in the bay consisted of zebra mussels, but when hard substrates in the inner bay were sampled in 2008-2010, the population consisted of 80% quagga mussels (*Dreissena rostriformis bugensis*) and 20% zebra mussels. Also, mean density was 79% lower in 2008-2010 compared to the 1990s, while biomass was 80% lower. Why the population declined to such an extent is uncertain, but one hypothesis is that predation by round gobies may be the cause. This fish became established in Saginaw Bay in 1999, and goby predation has reduced dreissenid populations in other systems (Lederer et al. 2008).

Main Basin

Until recently, the benthic macroinvertebrate community of the main basin of Lake Huron has been the least studied of all the Great Lakes, with no surveys having been conducted since the early 1970s. In the past decade, however, several ongoing sampling programs were initiated. Based on the results and timing of these programs, trends in the major groups can best be characterized over two periods, that is, between the early 1970s and 2000, and between 2000 and the present. Over the first period, perhaps the most significant change has been the lakewide decline of the amphipod *Diporeia*. Between 1972 and 2000, mean abundances declined 99.8, 90.0, and 52.1% at 18-30, 31-50, and 51-90 m, respectively (Nalepa et al. 2007). Although not as severe, declines were also evident in oligochaetes and sphaeriids over all depth intervals, but consistent changes in chironomids were not apparent. For *Diporeia*, declines continued through the 2000s, recent surveys have found that this amphipod was virtually gone at 18-30 m, and mean densities were <400 m^{-2} at 30-90 m (Nalepa et al. 2007; French et al. 2009; Barbiero et al. 2011b). For comparison, mean densities at these two depth intervals were >4,500 m^{-2} in 1972. Although declines were also evident at depths >90 m, as of 2009 this was the only depth interval where *Diporeia* was present to any extent (Barbiero et al. 2011b). In the 2000s, trends in oligochaetes varied by depth interval. Mean densities increased at shallow depths (<50 m), but decreased at deep depths (>50 m) (French et al. 2009; TFN, unpublished data). Over the same time period, densities in sphaeriids and chironomids were inconsistent, and a clear temporal trend within any depth interval was not apparent.

The zebra mussel established in Lake Huron in the early 1990s, and the quagga mussel established in the late 1990s (Nalepa et al. 1995, 2001). Over the period 2000-2007, quagga mussels replaced zebra mussels as the dominant dreissenid at shallow depths (<50 m) and expanded to deeper depths (>50 m) where zebra mussels rarely had been found (TFN, unpublished data). In 2007, mean densities of quagga mussels were 850, 2122, 305, and 135 m^{-2} at 18-30, 31-50, 51-90, and >90 m, respectively. For all depth intervals, these densities were greater than found in 2003, with the greatest percentage increase occurring at >90 m. Thus, based on the latest lakewide survey, the quagga mussel population is continuing to expand throughout the main basin of the lake, particularly at deeper depths.

Georgian Bay and the North Channel

Historically, there have been few broad-scale surveys of the macroinvertebrate community in Georgian Bay and the North Channel. Surveys were conducted in these two regions of Lake Huron in 1973 and 2002, and a spatially limited survey was conducted in southern Georgian Bay (off Cape Rich) on an annual basis in 2000-2004 (Nalepa et al. 2007). Densities of the major groups (*Diporeia*, oligochaetes, sphaeriids, and chironomids) changed little between 1972 and 2002 at all depth intervals (18-30, 31-50, and 51-90 m) in both regions; differences between years were non-significant for all taxa. In 2002, densities of zebra and quagga mussels were low. In Georgian Bay, mean density of zebra and quagga mussels across all depth intervals was 12 and 11 m^{-2}, respectively, and, in the North Channel, mean density of zebra mussels was <1 m^{-2}, while quagga mussels were not found. In contrast, the more temporally intense sampling off Cape Rich indicated that major changes in densities of *Diporeia*, sphaeriids, and quagga mussels occurred between 2000 and 2004. The former two taxa declined, while quagga mussels increased. For *Diporeia*, density exceeded 1100 m^{-2} at depths between 40 and 92 m in 2000, but no *Diporeia* were collected at any of these depths up to 2004.

In 2007, samples were again collected in Georgian Bay and the North Channel at the same sites sampled in 1972 and 2002. Preliminary analysis of data indicated that *Diporeia* had declined throughout both regions between 2002 and 2007. In Georgian Bay, the range in mean densities across depth intervals in 2002 was 1400-1700 m^{-2}, but the range in 2007 was only 40-100

m^{-2}. Declines in *Diporeia* were less severe in the North Channel where the range in mean densities in 2002 was 900-3300 m^{-2}, but in 2007 the range was only 250-890 m^{-2}. In 2007 the mean density of quagga mussels across all depth intervals in Georgian Bay increased to 420 m^{-2}, but the density of zebra mussels remained low. No zebra or quagga mussels were found at sites sampled in the North Channel in 2007.

STATUS OF THE OFFSHORE DEMERSAL FISH COMMUNITY

Stephen C. Riley[3] and Edward F. Roseman

Maintain a diversity of prey species at population levels matched to primary production and to predator demands.

The above objective established by DesJardine et al. (1995) remains unmet—the total main-basin offshore demersal-prey biomass (from bottom trawling) has continued to decline since 2004, which was already a near-record-low year. During this reporting period, 2005-2010, the estimated mean main-basin demersal prey-fish biomass (32.6 Kt) was 41% of the estimate (79.8 Kt) for the previous reporting period (2000-2004). Moreover, the trend since 2004 is not encouraging as demersal biomass in 2010 (29.1 Kt) was the second-lowest ever recorded, a 32% reduction from 2004 (42.2 Kt), and approximately 12% of the 1987 record high (242.5 Kt) (Fig. 4; Roseman et al. 2011). For this report, the entire U.S. Geological Survey (USGS) main-basin bottom-trawl time series (1976-2010) was included due to the development of fishing power corrections that allowed adjustments for a change in 1991 in trawl design (Adams et al. 2009). The USGS, in cooperation with the U.S. Fish and Wildlife Service and the Ontario Ministry of Natural Resources, also has produced pelagic-fish abundance estimates derived from acoustic surveys in most years since 2004 (Schaeffer et al. 2012), but, due to the short time series and missing data, these estimates are less useful in assessing long-term trends in abundance but are included here for comparisons with the trawl estimates.

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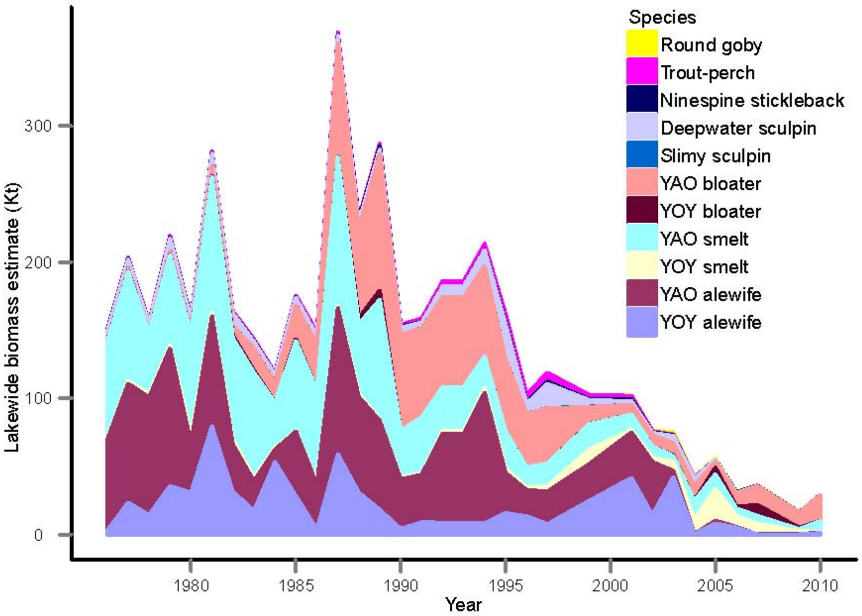
Fig. 4. Estimated offshore demersal-fish-community biomass in the main basin of Lake Huron, 1976-2010. Data are from the USGS autumn bottom-trawl survey. Valid data were not collected in 1992, 1993, 1998, 2000, and 2008; biomass estimates for those years are interpolations.



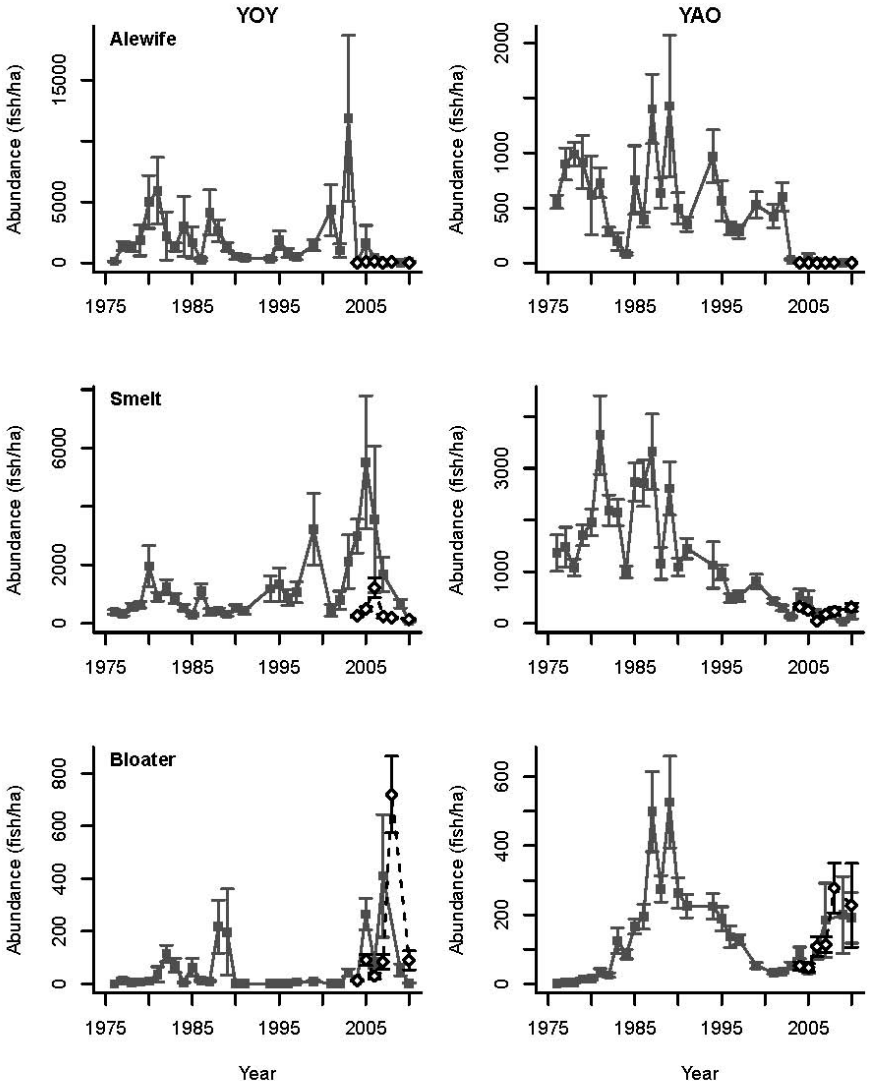
The native deepwater demersal-prey-fish community in Lake Huron was dominated historically by deepwater ciscoes, sculpins, and cisco, with ninespine sticklebacks and trout-perch also present (see Table 1 in the Introduction for scientific names of fishes). By the 1950s, the native community was disrupted by introductions of alewife and rainbow smelt and came to be dominated by these invasive species. By the 1990s, four species of native deepwater ciscoes had been extirpated from the lake, another was exceedingly rare, and the remaining species, the bloater, was common (Dobiesz et al. 2005; Ebener et al. 2008b). In the 1980s, introductions of dreissenid mussels, two predatory zooplankters (*Bythotrephes* sp. and

Cercopagis sp.), and the round goby further affected this community, which, by 2006, was in a state of collapse (Riley et al. 2008).

Perhaps the most striking change that has occurred in Lake Huron in recent years was the collapse of the alewife population in 2004 (Riley et al. 2008). The estimated biomass of yearling-and-older (YAO) alewife remained very low through 2010 compared to earlier data (Fig. 5), and existing populations were dominated by small fish. The alewife may suppress the recruitment of native species, such as cisco, lake trout, burbot, walleye, and yellow perch (Eshenroder and Burnham-Curtis 1999). Alewife was the primary prey of salmonine piscivores, and its continuing near absence from the lake may have affected food-web dynamics (e.g., Bunnell et al. 2011).

Rainbow smelt have been the most common fish in USGS trawl surveys for decades (Fig. 5). The estimated abundance and biomass of yearling-and-older (YAO) rainbow smelt has remained low since 2004; 2010 was the first year since 2004 where estimated YAO rainbow smelt abundance increased from the previous year. Low abundance of rainbow smelt and alewife is consistent with the fish-community objective for Lake Huron (DesJardine et al. 1995), but does not bode well for Chinook salmon populations (Roseman and Riley 2009), which previously relied on these species as a primary prey.

Fig. 5. Abundance (fish/ha) of young-of-the-year (YOY) (left panel) and yearling-and-older (YAO) (right panel) alewife (top row), rainbow smelt (middle row), and bloater (bottom row) in the main basin of Lake Huron as estimated by autumn bottom-trawl surveys, 1976-2010 (solid line and symbols), and acoustic surveys (dashed line and open symbols), 2004-2010. Error bars are 95% confidence limits. The bottom-trawl time series was corrected for a change in trawl design, except for YOY smelt, for which no correction was possible (Adams et. al 2009).

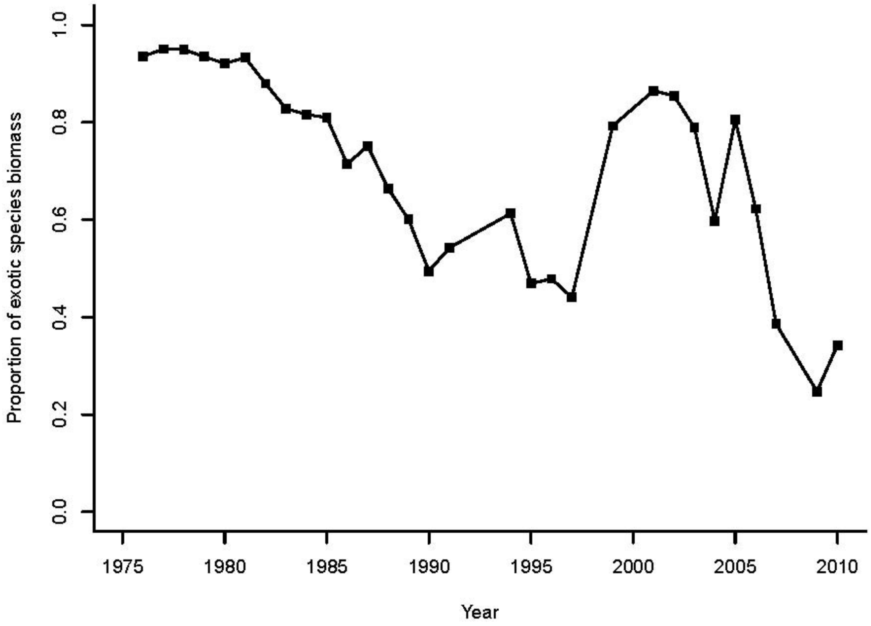

YOY
YAO
Alewife
Smelt
Bloater
Abundance (fish/ha)
0
5000
15000
500
1000
2000
2000
6000
3000
200
400
600
800
1975
1985
1995
2005
Year

YAO bloater was the only offshore demersal fish in Lake Huron to show a positive trend in abundance since 2004 (Fig. 5). YAO bloater abundance and biomass have been increasing since approximately 2001, and the 2010 biomass estimate was the highest observed since 1997 (Roseman et al. 2011). Young-of-the-year (YOY) bloater abundance peaked in 2005 and again in 2007 at high levels never seen before, although abundance has since declined. The abundance of this native species appears to be approaching the levels observed in the late 1980s and early 1990s, but biomass remains lower due to a shortage of larger fish.

Estimates of YAO alewife, rainbow smelt, and bloater abundance and biomass from the USGS acoustic survey generally followed trends similar to those of the trawl survey but were often somewhat lower (Fig. 5; Riley et al. 2010; Roseman et al. 2011; Schaeffer et al. 2012). In 2010, results from the two surveys were very similar for alewife and smelt, but the acoustic estimates for YOY and YAO bloater abundance were slightly higher than the trawl estimates. In general, the two surveys agreed that YAO alewife abundance remains low, that there are signs of increasing abundance for YAO rainbow smelt and bloater, and that YOY abundance for these species has been highly variable. The acoustic survey also estimates fish density and biomass in the North Channel and Georgian Bay, and differences in fish density among these basins has been observed, although these differences have not been consistent. Acoustic surveys on Lake Huron also have estimated very high abundances of the emerald shiner in some recent years and, on several occasions, have captured cisco, which has not been recently sampled in the bottom-trawl survey (Schaeffer et al. 2012).

The estimated abundance of YOY alewife, rainbow smelt, and bloater has spiked erratically since 2003 in the USGS bottom-trawl time series. Estimated YOY alewife abundance reached an all-time high in 2003, the year that the adult population crashed. YOY bloater abundance estimates were very high in 2005 and 2007, whereas, in the acoustic survey, YOY bloater abundance was high in 2008. Estimated YOY rainbow smelt abundance peaked in 2005 and was also high during 2004-2006. These high YOY abundance estimates do not appear to have resulted in recruitment of older, larger fish, however, except possibly for the bloater, whose abundance of YAO fish has increased recently. These observations suggest that recent conditions have been intermittently conducive to the production of large year-classes of these species but not to their long-term survival.

Fig. 6. Proportion of the offshore demersal-fish-community biomass made up of exotic species, 1976-2010. Data from the USGS fall bottom-trawl survey.



Deepwater and slimy sculpins, ninespine sticklebacks, and trout-perch are currently minor components of lake trout diets in the Great Lakes but were probably more important before the establishment of alewife and rainbow smelt (e.g., Van Oosten and Deason 1938). Biomass estimates for sculpins, sticklebacks, and trout-perch during 2005-2010 were near the lowest observed in the time series, indicating that benthic offshore conditions in Lake Huron changed in a way that does not favor their survival (Roseman et al. 2011). Round gobies were first captured in the Lake Huron trawl survey in 1997, reached peak abundance in 2003, and have declined to relatively low abundance since (Roseman et al. 2011). The proportion of the offshore demersal fish community that is made up of exotic species has declined since the last reporting period and amounted to 34% in 2010 (Fig. 6).

Dramatic changes in the numbers of fish schools and their characteristics in Georgian Bay and the North Channel were observed using hydroacoustics between 2000 and 2004, and these included a reduction in the number of schools; an increase in the distance of schools from the bottom; and a decrease in the depth, height, length, area, and volume of schools (Dunlop et al. 2010). These changes were attributed to loss of the alewife. Changes in the mean depth of capture of offshore demersal fishes in the western main basin of Lake Huron were recently observed (Riley and Adams 2010), with most species, starting in 1999-2002, exhibiting a nearly simultaneous trend of being captured in shallower water. These observations may indicate that large-scale factors are affecting the habitat use by offshore demersal fishes in Lake Huron and that the benthic ecology of Lake Huron is undergoing profound changes across a large spatial scale.

The peak estimated biomass of offshore demersal prey fish in Lake Huron occurred in the late 1980s and has declined steadily since then; a similar decline has occurred in Lake Michigan (Bunnell et al. 2009). The abundance of a number of fishes (e.g., YOY benthopelagic planktivores, round goby) has shown high variability since 2004, while the overall abundance and biomass of prey species in the main basin of Lake Huron remain near the lowest levels observed. These findings may indicate that the offshore demersal fish community in Lake Huron is currently unstable. Possibly, the observed population declines are associated with the invasion of the lakes by exotic species, including *Bythotrephes longimanus*, driessenid mussels, and the round goby, all of which have been introduced since the mid-1980s. However, similar declines in some species (particularly coregonines) have occurred in Lake Superior (Gorman et al. 2010) where dressenids and gobies are not invasive. Continuing low levels of prey-fish abundance may have serious implications for the growth, condition, and survival of predatory fish in Lake Huron.

Low abundance of offshore demersal fishes in Lake Huron also may be due to high predation levels. Double-crested cormorants, for example, have consumed large numbers of alewives, rainbow smelt, sticklebacks, trout-perch, and sculpins in Lake Huron (Neuman et al. 1997; Diana et al. 2006) and have been implicated in declines of some species (Fielder 2010), but cormorant numbers have declined in recent years (Ridgway et al. 2006; Dorr et al. 2010; Fielder 2010; Ridgway 2010). Predatory fish also have consumed offshore prey fish (Dobiesz et al. 2005). Walleye abundance appears to have increased recently in Lake Huron, while burbot appear to be at low abundance (Riley et al. 2008). Angler catch rates of Chinook salmon also have remained low in the lake since 2004 (see Status of Introduced Salmonines chapter), and Chinook salmon abundance is apparently low (Brenden et al. 2012), suggesting that predation by fishes currently may be lower than previous estimates.

In summary, the estimated abundance and biomass of offshore prey fish in Lake Huron have remained at unprecedented low levels since 2004, and the offshore demersal-fish community appears to have collapsed. The estimated biomass of alewife has remained very low, but there are indications that bloater and, to a lesser extent, rainbow smelt are beginning to rebound. Changes in habitat use and fish-school characteristics suggest that large-scale changes may be occurring in the benthic environment. We find it difficult to place our estimates of prey-fish biomass in the context of primary production and predator demand, as wanted in the prey-fish objective, because these parameters are currently highly variable (Barbiero et al. 2011a; He et al. 2012), poorly understood, and dependent on ongoing food-web changes. Nonetheless, the very-low offshore prey-fish biomass observed since 2004 indicates little progress towards meeting the objective. However, decreases in the abundance of invasive forage fishes may lead to a recovery of the native cisco as called for by DesJardine et al. (1995).

STATUS OF WHITEFISH AND CISCOES

Mark P. Ebener[4]

> *Maintain the present diversity of coregonines; manage lake whitefish and ciscoes at levels capable of sustaining annual harvests of 3.8 million kg; restore cisco to a significant level, and protect, where possible, rare deepwater ciscoes.*

The average commercial yield of coregonines (lake whitefish, cisco, bloater, and round whitefish) (see Table 1 in the Introduction for scientific names of fishes) from Lake Huron during this reporting period (2005-2010) was 3.3-million kg, 13% less than the above fish-community objective (FCO) (DesJardine et al. 1995). Commercial yields of coregonines have been declining since 1999 and have been less than the FCO every year since 2003 (Fig. 7; Ebener et al. 2008b). Sustainability of the commercial yield is difficult to assess because, except for lake whitefish, commercial fisheries seldom target the other species, and there are scant data and no management commitment to estimate biologically meaningful harvest limits for coregonines other than lake whitefish. Rare deepwater ciscoes include the shortjaw and shortnose, but only the shortjaw has been observed in recent years (Webb and Todd 1995; Ebener et al. 2008b).

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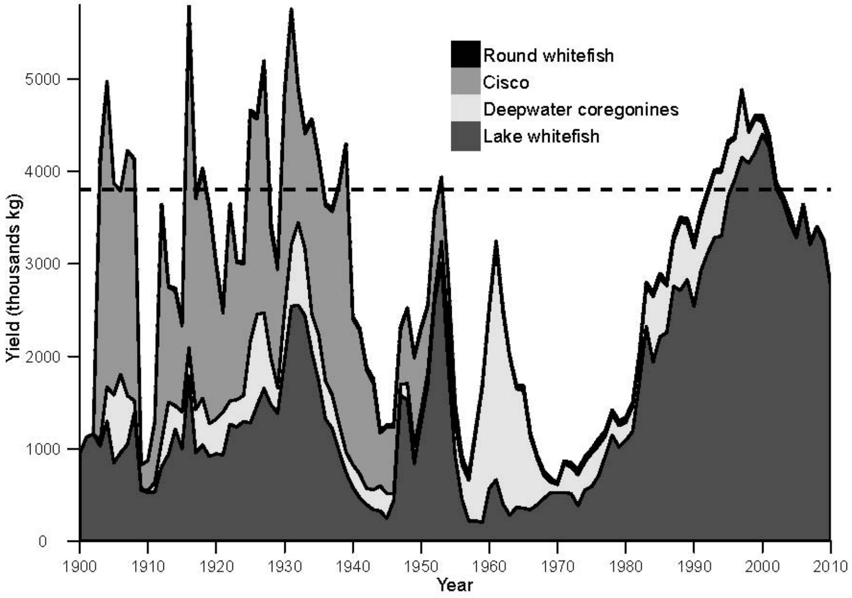
Fig. 7. Commercial-fishery yield of coregonines from Lake Huron, 1900-2010. Deepwater coregonines refers to bloater and other deepwater ciscoes. Horizontal line indicates the fish-community objective of 3.8-million kg.



Lake Whitefish

Lake whitefish populations continue to support the largest commercial fishery on Lake Huron. Yields averaged 3.2-million kg, 97% of the coregonine harvest and 81% of the total commercial-fishery yield of all species from Lake Huron during 2005-2010. The average commercial yield during this reporting period declined 21% from the average yield reported during the previous reporting period. Annual commercial yields of lake whitefish have declined by 35% since the peak yield of 4.2-million kg in 1999.

Multiple factors not related to the abundance of lake whitefish continue to affect lake whitefish yields. While dockside prices paid to commercial fishermen for lake whitefish have increased since the last reporting period, prices have not kept pace with increased fuel or equipment costs and are not substantially different from prices observed in the 1970s and 1980s. Consequently, fishermen have resorted to lifting nets less often, which has reduced fishing effort. Dreissenid mussels and filamentous algae *Cladophora* spp. continue to clog nets, dramatically altering catchability of gear and the number of days that nets can be lifted, particularly during April through mid-July. Generational shifts in the desire to pursue a livelihood in the commercial fishery, low dockside prices, and allocation issues between tribal and non-tribal operators have also reduced the number of active operations (Ebener et al. 2008a).

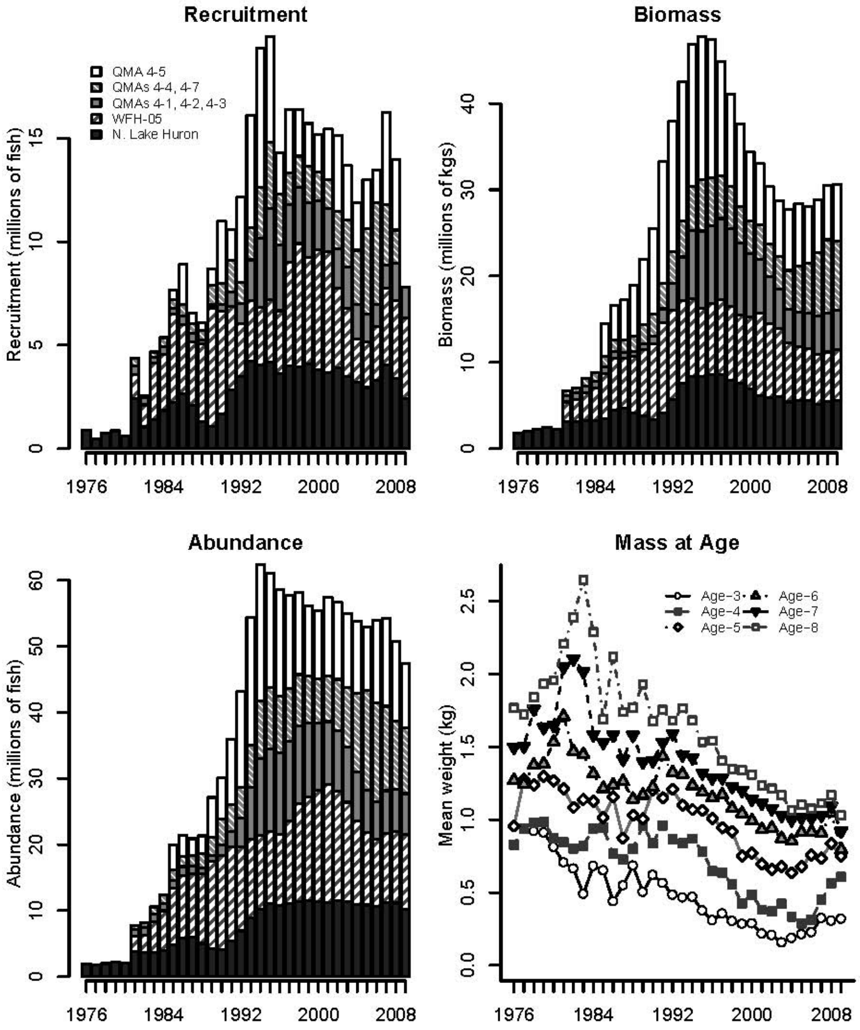
The factors described above have had a substantial effect on fishing effort. Trapnet effort has declined by 429 lifts per year, or roughly one trapnet operation per year, from a peak of 11,000-12,000 lifts in 1996-1997 to only 5,300 lifts in 2010. Lakewide trapnet effort declined 29% from the previous reporting period, and, among basins, trapnet effort declined 21 to 50% from the previous reporting period. Large-mesh gillnet effort has been more consistent on a lakewide basis than trapnet effort, but trends in effort vary considerably among basins and jurisdictions. Large-mesh gillnet effort has increased 17% in the North Channel and 24% in Georgian Bay from the previous reporting period, whereas large-mesh gillnet effort has declined 17% and 25% in the main basin waters of Ontario and Michigan, respectively.

Increases in mass-at-length and recruitment have led to slight increases in both abundance and biomass of lake whitefish in the main basin during this reporting period. Mass-at-length increased for most ages of lake whitefish in the main basin during 2005-2009 (Fig. 8), halting a two-decade-long decline in age-specific mass. To estimate mortality, biomass, abundance, and recruitment of lake whitefish in the main basin, mass-at-length and other biological and catch-per-effort statistics were input into statistical catch-at-age stock-assessment models (see Ebener et al. 2005) that were developed for all six Ontario management units and five of eight management units in Michigan waters. Abundance of age-4 and older lake whitefish estimated with the models declined slightly in 11 main basin management units combined, dropping from 55.6-million fish during the previous reporting period to roughly 52-million fish in this reporting period. Biomass of age-4 and older lake whitefish in these 11 management units averaged 27.7-million kg during 2005-2009 compared to 30.9-million kg during 2000-2004. However, recruitment of age-4 lake whitefish did increase during 2004-2008, although the long-term trend has been one of declining recruitment since 1994-1995.

Current management-unit boundaries in northern Michigan waters, and probably in other areas, appear inappropriate for managing lake whitefish stocks because movement between units can be considerable and fisheries in most areas exploit multiple spawning stocks. Based on tagging studies, Ebener et al. (2010) recommended developing a single northern Lake Huron harvest limit that would apply to four management units in Michigan waters because of the extensive overlap of spawning stocks among units during the non-spawning season. Strong homing tendencies existed within spawning stocks, but it was common for lake whitefish that spawned in one management unit to inhabit 3-4 management units during the non-spawning season.

Linking fish health indices, such as for bacterial kidney disease or fatty acids, to specific stocks of lake whitefish is difficult because of the extensive movement of lake whitefish among management units in Lake Huron. Faisal et al. (2010) found that nearly 50% of lake whitefish sampled from northern Lake Huron during 2003-2006 tested positive for *Renibacterium salmoninarum* (Rs), but the presence of Rs among samples within a management unit ranged from 5 to 100%. Wagner et al. (2010) did not find any spatial patterns between fish health indices and natural mortality of individual lake whitefish stocks from northern Lake Huron, but they did report that some measures of fish health were related to disease dynamics. Brenden et al. (2010) recommended that researchers and agencies examine the role of fish movement in explaining fluctuations in diseases, infections, and transmissions.

Fig. 8. Mass (kg) at length for five areas of the main basin of Lake Huron combined and statistical catch-at-age estimates of abundance, biomass (kg), and recruitment at age 4 for lake whitefish for each area separately, 1976-2009.



Cisco

Cisco is a common member of the fish community in the St. Marys River and in the North Channel, Georgian Bay, and northern Michigan waters of the main basin. Cisco abundance is very low in western areas of Lake Huron, including historically important Saginaw Bay. Cisco populations currently are associated primarily with embayments, such as the Les Cheneaux Islands area in the northern main basin, the south shore of Drummond Island, the north shore of the North Channel, and the northern and eastern shores of Georgian Bay (see Frontispiece for all place names).

Cisco abundance during the current reporting period appears to have declined slightly below levels observed during 2000-2004. Annual lakewide commercial yields of cisco averaged 12,100 kg during 2005-2010 as compared to 24,000 kg during 2000-2004. In Ontario, incidental catches in commercial-fishing gear are reported regularly, mostly in the North Channel and in southeastern Georgian Bay. In both locations, reported catches over the past five years are above the long-term average and above the last 10-year average. Ontario Ministry of Natural Resources (OMNR) gillnet surveys in the North Channel, South Bay, and the southern and central main basin suggest that cisco abundance peaked during 2004 and 2005 and has declined slightly since, especially in the main basin. Along the south shore of Drummond Island, abundance of cisco in graded-mesh-gillnet fall surveys has remained stable during 1998-2010, averaging 3 fish/305 m of net. In South Bay, Manitoulin Island, relative abundance of cisco in survey catches averaged about 6 fish/305 m during 2001-2008 compared to an average of 3 fish/305 m during 1965-1992.

The Michigan Department of Natural Resources embarked on a cisco rehabilitation strategy during this reporting period that relies on stocking hatchery-reared fish. Gametes were collected from adult cisco in the St. Marys River during November 2006-2010, and the fertilized eggs were reared in a state fish hatchery. Hatching success in chilled water was substantially greater (>50%) than in ambient or well water (<15%). Some fingerlings were subsequently stocked into the Thunder Bay area of Lake Huron in 2008-2010. The project remains experimental at this time, and limited funding prevents full-scale production of cisco for stocking.

Round Whitefish and Rare Ciscoes

Round whitefish are normally seen in measureable numbers only in index programs in Ontario's main basin waters. Provincial survey data suggest that round whitefish abundance is declining in the southern and central main basin but is actually increasing in southern Georgian Bay.

There have been no sightings in Lake Huron during this reporting period of the shortjaw cisco or the shortnose cisco. The OMNR continues to conduct deepwater index netting (>60 m) throughout the lake and, in recent years, has added additional sites in southern Georgian Bay, site of the last sighting of the shortnose in Lake Huron (Webb and Todd 1995). To date, no other rare ciscoes have been identified. Commercial catches of deepwater ciscoes continue to be very low throughout Lake Huron.

STATUS OF LAKE TROUT

Ji X. He[5], Mark P. Ebener, Stephen C. Riley, Adam Cottrill, and Scott Koproski

Fish-community objectives (FCOs) for Lake Huron contain no specific targets for lake trout. Lake trout (see Table 1 in the Introduction for scientific names of fishes) are included in the Salmonine Objective that states:

> *…establish a diverse salmonine community that can sustain an annual harvest of 2.4 million kg with lake trout the dominant species and anadromous (stream-spawning) species also having a prominent place.*

The FCOs state specifically that lake trout yields may approximate 1.4-1.8-million kg two decades into this century (i.e., 2020 and beyond; DesJardine et al. 1995), and lake trout stocks should be managed to increase their numbers and to achieve self-sustainability. The reported yield of lake trout in the main basin of Lake Huron decreased from 0.59-million kg in 2004 to only 0.28-million kg in 2010, which is comparable to the late 1990s. The

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decrease in yield after 2004 was due largely to less bycatch resulting from reduced commercial fishing effort targeted at lake whitefish and to less recreational fishing effort.

Re-establishing self-sustaining lake trout populations has been the focus of coordinated multi-agency efforts since the 1970s. Agencies have largely relied on stocking and limiting sea lamprey and fishing mortality (Eshenroder et al. 1995a). As yield-based metrics are unlikely to be meaningful for species under rehabilitation, lake trout rehabilitation plans (Ontario Ministry of Natural Resources 1996; Ebener 1998) have suggested using survival, growth, abundance, age structure, and levels of natural recruitment as more meaningful metrics to assess progress towards rehabilitation end points. Prior to 2004, lake trout dynamics in Lake Huron could be characterized by strong, consistent recruitment of hatchery-reared fish, rapid growth, increasing abundance and biomass, and increasing spawning-stock biomass, with relatively little evidence of natural reproduction.

From 2005 to 2010, lake trout stocking in Lake Huron was relatively stable. In Michigan waters of the main basin, between 1.5- and 1.8-million yearlings were stocked each year. Lake trout stocking in Ontario waters was also stable and averaged 1.7-million yearlings per year in Georgian Bay and 0.9-million yearlings per year in the main basin and the North Channel combined. In northern Michigan waters of the main basin, Seneca-strain lake trout made up about 80% of all lake trout stocked during 2005-2010, whereas the Lewis Lake and Marquette strains made up most (75%) of the plantings in central and southern Michigan waters.

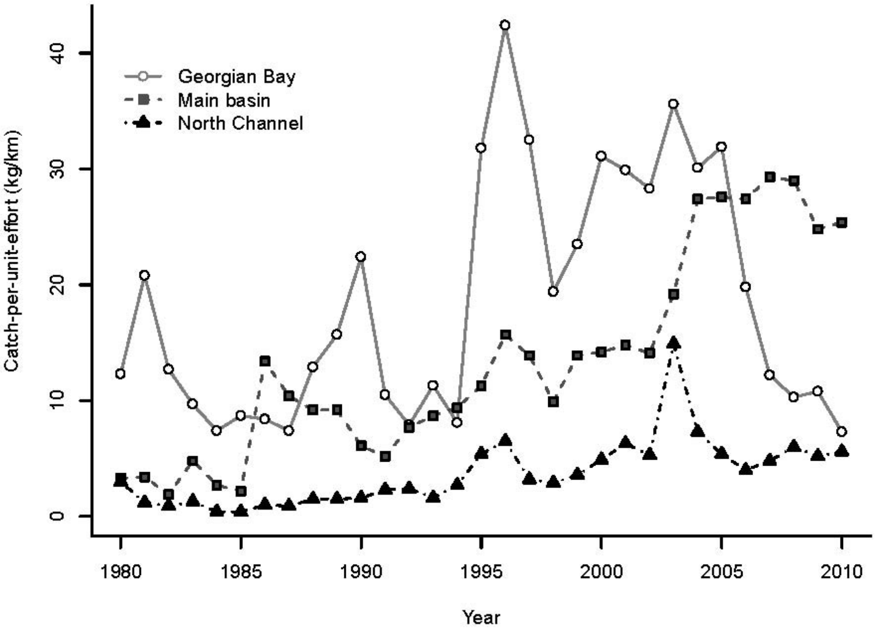
For stocked fish, the age of recruitment to fisheries and survey gear has increased in Michigan waters of the main basin since 2004. Relative survival for each year-class is estimated as the gillnet catch-per-unit-effort (CPUE) per million fish stocked (CPUE/R) in fishery-independent surveys. This metric is calculated for each year-class at age 5, historically the first age group fully recruited to survey and commercial-fishery gillnets. Relative survival of stocked fish decreased from 2.06 for the 1995 year-class to near zero for more recent year-classes. However, at the same time, age-7 CPUE/R remained relatively high and stable. The stability of age-7

CPUE/R, despite the decline in age-5 CPUE/R, is consistent with a delay in recruitment from ages 5 to 7 (He et al. 2012); it owes to reduced growth and may not be attributable to reduced survival. This delay in recruitment is also evident in the age structure observed in lake trout sampled from the recreational and commercial fisheries in Michigan waters.

In Georgian Bay, year-classes stocked in the 1990s typically recruited to survey gillnets at age 4 or 5 with CPUE/R ranging between 3 and 4. Between 1999 and 2007, CPUE/R for 5-year-old lake trout in Ontario Ministry of Natural Resources (OMNR) surveys declined from 1.60 to 0.02. Similarly, in southeastern Georgian Bay, recruitment to the commercial fishery from the most recent pulse-stocking events has been minimal. The low abundance of lake trout stocked recently in southeastern Georgian Bay has been further corroborated by catch rates in OMNR surveys in both 2009 and 2010. The apparent absence of recently stocked lake trout in southeastern Georgian Bay suggests that survival has declined dramatically in that part of the lake. This contrasts with the situation in Michigan waters where the decline in CPUE/R appears to be related to delayed recruitment to survey and commercial-fishing gear rather than to a substantial change in survival.

The survey catch in the main basin has changed substantially from being dominated primarily by juveniles (<532-mm total length) to being dominated by adults (>532 mm). Total lake trout catch rate in Michigan Department of Natural Resources (DNR) gillnet surveys declined steadily from 16 fish/305 m in 1996 to only about 4 in 2010. In contrast, the gillnet CPUE for adults was stable, averaging between 4-8 fish/305 m during 1996-2010—much higher than during 1977-1995, when adult CPUEs varied from 0.5 to 4.5. Catch rates in surveys in Ontario waters of the main basin and Georgian Bay were essentially unchanged between 2005 and 2010 and were similar to those in Michigan waters, although age-composition broadened and mean age increased. Delayed recruitment in Ontario is also evident as age-3 and age-4 lake trout are now rarely observed in survey catches. Catch rates in southern Georgian Bay declined by a factor of 10 between 1999 and 2007, while catch rates in other areas of Georgian Bay steadily increased over time. These differences are exemplified further by the catch rates of lake trout reported in large-mesh gillnet fisheries (Fig. 9). Mean CPUEs in the main basin and North Channel have generally increased since the mid-1980s.

Fig. 9. Mean catch-per-unit effort (CPUE) of lake trout in large-mesh gillnets fished in the main basin of Lake Huron, the North Channel, and Georgian Bay between 1980 and 2010. CPUE is calculated as aggregate harvest divided by aggregate large-mesh effort.

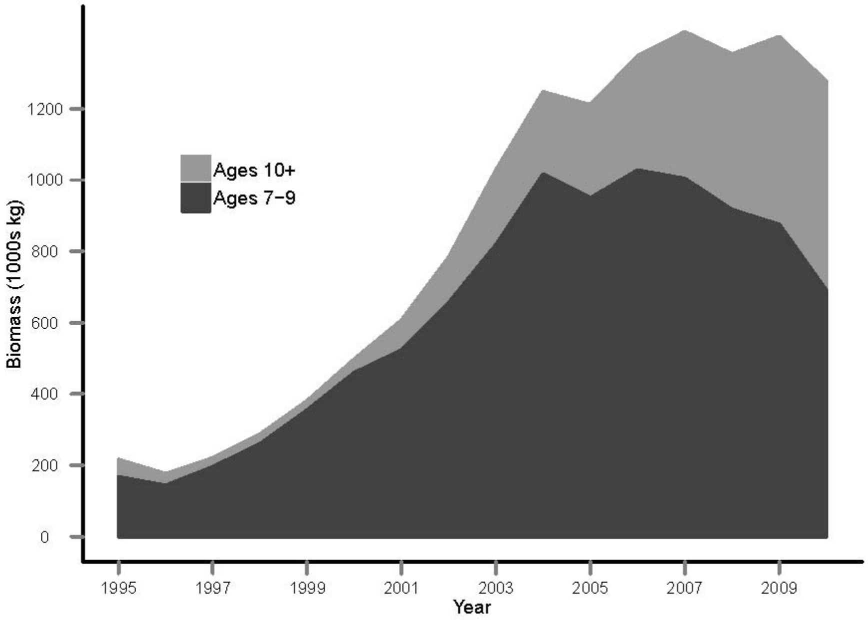


Natural reproduction of lake trout has increased substantially since the last state-of-the-lake report (Bence and Mohr 2008). Prior to 2003, natural reproduction was generally limited to isolated locations, such as Parry Sound and South Bay in Ontario and Thunder Bay in Michigan. A few unclipped and presumably wild lake trout also were observed occasionally in offshore bottom-trawl surveys (Riley et al. 2007), but these year-classes rarely recruited in appreciable numbers to the commercial, recreational, or survey fisheries. By 2006, the percentage of unclipped lake trout in Ontario waters of the central main basin was above 25%, and, by 2010, that number had risen to 53%. The proportion of unclipped fish observed in southern Georgian Bay increased coincident with increases in other parts of the lake but dropped off from a peak of 32% in 2009 to less than 22% in 2010. By 2010, wild lake trout made up 12% of the total lake trout catch in Michigan DNR spring surveys, 12-20% in Chippewa Ottawa Resource Authority and U.S. Fish and Wildlife Service summer surveys, 18% of the commercial-fishery catch in northern Michigan waters, and 36% of recreational-fishery catches in Michigan waters.

Parental biomass of lake trout is substantially greater now than during the previous reporting period. Biomass of age-7 and older lake trout estimated by statistical catch-at-age analysis has been remarkably stable varying between 1.2- and 1.4-million kg during 2005-2010 in the main basin of Lake Huron (Fig. 10). However, biomass of age-10 and older lake trout increased from 0.23-million kg in 2004 to 0.58-million kg in 2010, while biomass of ages 7-9 lake trout decreased from 1.0-million kg in 2004 to 0.69-million kg in 2010. The increase in biomass of age-10 and older lake trout indicates that adult mortality is not excessive and generally below the 40% maximum limit. The stable biomass of age-7 and older lake trout can be attributed to (1) good survival of stocked fish, (2) reductions in sea lamprey marking (see Status of Sea Lamprey chapter), (3) stable fishery harvests, and (4) low total mortality rates.

The contribution of unclipped fish to the age-composition of lake trout sampled from Drummond Island, Six Fathom Bank, and Yankee Reef together and Ontario waters of the central main basin all show similar temporal trends with marked increases in unclipped fish after 2003. This surge in lake trout reproduction occurred after the collapse of the alewife population in 2003-2004, which led to increases in thiamine concentrations in lake trout eggs (alewives carry a thiamine-destroying enzyme) (Riley et al. 2011). This increase in viable eggs and an overall increase in adult biomass (He et al. 2012) has led to levels of natural reproduction in many areas of the lake that appear to be approaching targets identified in the Lake Trout Rehabilitation Guide for Lake Huron (Ebener 1998).

Fig. 10. Biomass estimated for age-7 and older lake trout in the main basin of Lake Huron, 1995-2010.



In summary, widespread natural reproduction of lake trout is occurring in Lake Huron, and wild fish are recruiting to fisheries and spawning stocks. The first milestone for lake trout rehabilitation in Lake Huron has been achieved, i.e., build spawning stocks and measure meaningful quantities of offspring. Further, one-quarter to one-third of the second milestone has been achieved, i.e., wild lake trout make up a sustainable proportion of the spawning population (Ebener 1998). The current spawning-stock biomass in Lake Huron is low compared to those Lake Superior populations that transitioned from being hatchery sustained to being dominated by wild fish. Successful rehabilitation of lake trout in Lake Huron will require protection of wild spawning stocks, effective sea lamprey control, adequate fishery regulations, and eventual reductions in stocking.

STATUS OF SEA LAMPREY

Paul Sullivan[6], Lisa Walter, and Ted Treska

DesJardine et al. (1995) recognized that elevated predation by sea lamprey (see Table 1 in the Introduction for scientific names of fishes) posed a serious impediment to the achievement of the Lake Huron fish-community objectives and prescribed aggressive suppression to levels of abundance that would support the rehabilitation of fish stocks. Moreover, control of the burgeoning sea lamprey population in the St. Marys River, which was identified as the largest single source of juvenile (parasitic-phase) sea lamprey in Lake Huron, was considered key to this reduction. The Lake Huron Committee subsequently defined precise lakewide suppression targets, namely a lakewide abundance of less than 73,000 adult (spawning-phase) sea lampreys and an incidence of no more than 5 marks (Type A, Stages I-III, see Ebener et al. 2006) per 100 lean lake trout >533-mm total length (Bence and Mohr 2008).

Abundance of adult sea lamprey (lakewide) was 12% lower during 2005-2010 as compared to the previous (2000-2004) reporting period, and the marking rate in the main basin was also lower by 41% (Figs. 11, 12). These reductions were in addition to an 11% decline in abundance and a 40% decline in marking rate between the two previous reporting periods (Bence et al. 2004). However, the estimated lakewide population of 149,000 sea

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lampreys during this reporting period was more than double the target, and marking in the main basin remained just above the maximum prescribed rate, averaging 6.0 marks per 100 lake trout in 2010 (Fig. 12).

Fig. 11. Estimated sea lamprey abundance in Lake Huron, 1980-2010. See Mullett et al. (2003) for estimation procedures. The solid line is the target maximum abundance and the dashed lines represent the 95% confidence interval for the target abundance.

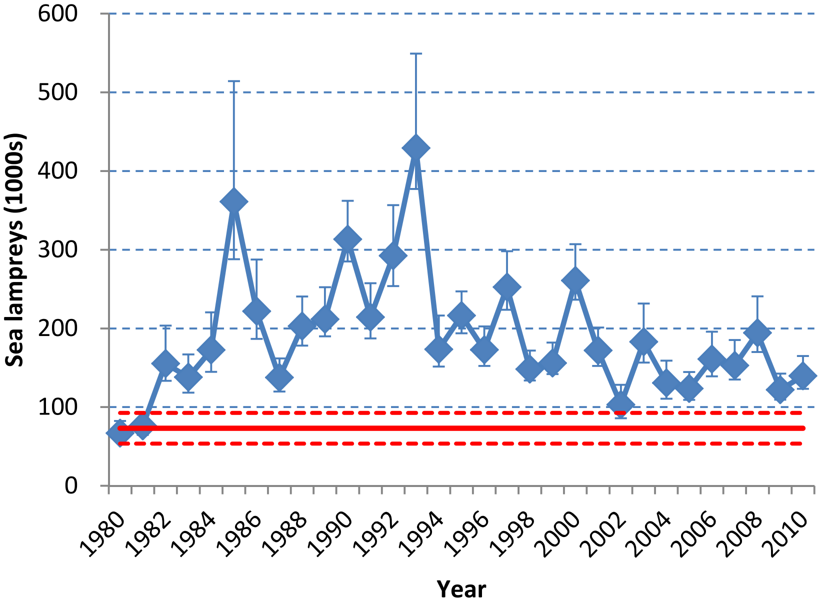
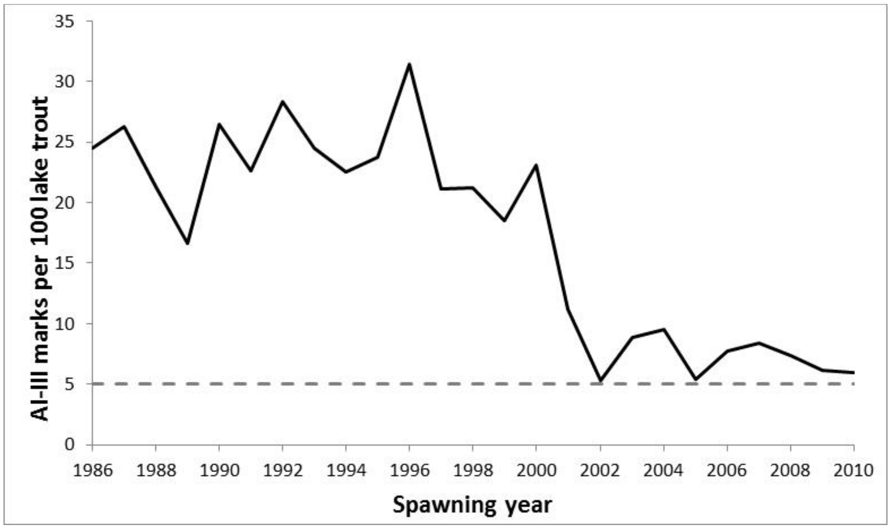


Fig. 12. Average number of Type A, Stages I-III sea lamprey marks per 100 lake trout ≥532-mm total length in the main basin of Lake Huron, April and May, 1986-2010. Dashed line is Lake Huron Committee target of no more than 5.0.

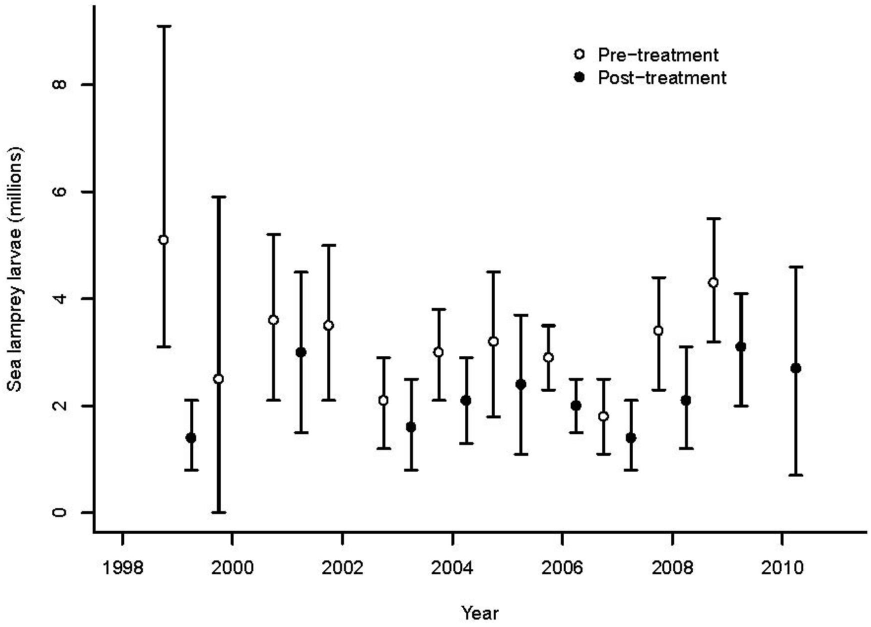


Lakewide abundance of adult sea lamprey is a compilation of stream-specific estimates of adult abundance generated from trap data and model predictions (Mullett et al. 2003). The Lake Huron trapping network consists of 23 trapping sites in 16 tributaries, including new traps that were constructed during 2005-2010 in the Mississagi, Cheboygan, and St. Marys Rivers. A permanent trap was built during 2007 at the Red Rock Generating Station in the Mississagi River to improve spatial coverage of the Lake Huron trapping network and to provide mark-recapture estimates of adults from one more North Channel tributary. A replacement trap in the Cheboygan River became operational during 2009 and has captured more sea lamprey consistently than any other Lake Huron trap, while reducing staff requirements for servicing. Trapping operations in the St. Marys River were also modified. A trap was constructed in 2008-2009 at the F.H. Clergue Generating Station after hydroacoustic data suggested that adjacent waters were frequented by adults, and spatial coverage within the river was enhanced when new traps at the Edison Soo Power Plant became operational during 2006. All traps are located just below the locks in the very upper river (see Frontispiece). The combined catch of the Cheboygan and St. Marys traps averaged nearly 20,000 adults annually.

Recently, Lake Huron fisheries managers identified the need to examine the effects of sea lamprey predation on other fishes, including salmonines other than lake trout, coregonines, and burbot. In response, a biologist was engaged to assemble more sea lamprey and fisheries data and to explore additional metrics relating to sea lamprey marking across the Great Lakes. The project compiles existing data and attempts to streamline future submissions into a series of lake-specific databases featuring standardized data from contributing agencies and consistent approaches for collection. Initial explorations indicate that a lakewide metric may not describe sufficiently the observed spatial variation in sea lamprey marking and in lake trout and sea lamprey abundance, so multiple metrics will be required to improve assessments.

Lampricide treatments that target larvae in the tributaries and lentic areas of Lake Huron remain the primary means of sea lamprey control. Beginning in 2006, measures were adopted to reduce the number of larvae that survive exposure to lampricides, including increasing treatment concentration and duration; treating secondary areas (rivulets, seepage areas, and backwaters) that normally would remain unaffected by the primary treatment and potentially provide refuge to larvae leaving their burrows during treatment or inhabiting these areas prior to treatment; and adjusting the timing of treatments to take advantage of optimal flow conditions (Sullivan and Adair 2010) and seasonal susceptibility (Scholefield et al. 2008). Larvae that survive treatment (referred to as residual larvae) are hypothesized to be a primary source of recruitment for parasitic populations in the Great Lakes, including Lake Huron (Morse et al. 2003). In addition, a change in larval assessment methods from quantitative surveys to less-labor-intensive catch-per-effort surveys enabled assessment efforts to be redirected to lampricide applications, resulting in a higher number of treatments (Adair and Young 2009).

Fig. 13. Estimated pre- and post-treatment abundance of larval sea lamprey in the St. Marys River, 1998-2010.



Control of the St. Marys River larval population, estimated at 5.1 million in 1999, presents a unique challenge, as conventional treatment with conventional lampricides would be extremely costly and technically difficult due to the large volume of water (Eshenroder et al. 1987) and complex flow pattern (Schleen et al. 2003). An alternative control strategy has been implemented that integrates trapping of adults, release of sterile-male adults, and spot treatment of areas of high larval density with a bottom-release formulation of Bayluscide (Schleen et al. 2003). Between 2005 and 2010, an average of 7,700 adult lampreys had been trapped and 24,800 sterile males had been released, resulting in an estimated 84% reduction in spawning potential before lampricides were applied. The first application of

Bayluscide made in 1999 involved 766 ha of larval habitat that in conjunction with trapping and sterile-male release resulted in a post-treatment population of 1.4-million larvae. Between 2005 and 2009, an average of 132 ha was treated annually, while trapping effort and sterile-male releases remained fairly consistent. Contrary to expectations, after 2007, the larval population increased in successive years, peaking at 3.1 million in 2009 (Fig.13).

In 2010, an aggressive, large-scale treatment strategy that focused lampricide treatment effort on the St. Marys River and nearby tributaries in the North Channel began. This regional approach ranked all tributaries based on larval sea lamprey production, and treatment effort was allocated, beginning with the most productive, until 1,500 staff days were utilized. As a result, 875 ha in the St. Marys River, in addition to 36 tributaries and two lentic areas (all between the Spanish River to the northeast and the Carp River to the southwest) were treated in 2010. All are scheduled for re-treatment in 2011 (except where 2010 constituted the second consecutive treatment) to kill larvae residual to the 2010 treatments and the year-classes established between the 2010 and 2011 treatments. Seven streams that ranked for treatment in other parts of Lake Huron were also treated in 2010.

Unfortunately, an undetected technical deficiency with deepwater electrofishing gear in one of two boats rendered half of the 2010 post-treatment assessment data unusable. The resulting reduction in sample size imparted high variability to the larval abundance estimate, muting the ability to gauge the impact of the large-scale treatments on the St. Marys River population. Equipment problems have been rectified, and an estimate with lower variability is anticipated following the second consecutive treatment in 2011. Beginning in 2012, the lakewide effects of the large-scale treatments will be evaluated.

The Great Lakes Fishery Commission continues to advocate alternatives to lampricides, including the construction or modification of barriers to block adult migrations. In Lake Huron, 17 barriers have been constructed or modified for this purpose while others built for alternative purposes, such as hydropower generation or flood control, also serve an important sea lamprey control function. Although no new sea lamprey barriers were constructed during 2005-2010, a barrier on the Still River was reconstructed in 2010 to mitigate the threat of imminent structural failure. As well, during 2006, the Ontario Ministry of Natural Resources commissioned an engineering review of Denny's Dam, a structure built to deny adult sea lampreys access to over 100 km of the Saugeen River watershed and to eliminate the requirement for periodic lampricide treatment. Reconstruction has been recommended to address structural deficiencies.

The identification and synthesis of sea lamprey pheromones offer promise to enhance adult trapping rates, thereby reducing the reproductive potential of sea lamprey spawning migrations and improving adult population estimates (Twohey et al. 2003). Management-scale field trials testing the application of the mating pheromone 3kPZS began in the U.S. during 2009 and in Canada during 2010. This pheromone was applied to 20 streams in the Great Lakes basin, including four Lake Huron tributaries: the St. Marys, East AuGres, Echo, and Thessalon Rivers. Field trials will continue through 2011, and preliminary data from 2010 suggest that applying 3kPZS to an already productive trap can increase captures 10-25%.

Recently, a draft sea lamprey control plan for Lake Huron was endorsed by committees responsible for sea lamprey control in the Great Lakes. The final version of the plan, which will be reviewed and updated annually, is available at http://www.glfc.org/pubs/SpecialPubs/LL_5YearPlan.pdf. The plan describes strategies designed to achieve sea lamprey suppression targets in Lake Huron and will provide the basis for future control actions.

STATUS OF INTRODUCED SALMONINES

James E. Johnson[7] and David Gonder

The fish-community objectives (FCOs) for Lake Huron envision a "diverse salmonine community…with anadromous species also having a prominent place" (DesJardine et al. 1995). The term "anadromous species" refers to six introduced salmonines: Chinook salmon, coho salmon, pink salmon, rainbow trout (steelhead), Atlantic salmon, and brown trout (see Table 1 in the Introduction for scientific names of fishes). The FCOs, although lacking specific objectives for introduced salmonines, do acknowledge the establishment of these fishes, the diversity of angling opportunities they present, and their high economic value, implying recognition of a new state departing from historical conditions when the lake trout was the only prominent salmonine. At the end of the previous reporting period, 2000-2004, the lake's food web appeared to be in the throes of profound changes largely brought about by invasive species: dressenid mussels, *Bythotrephes longimanus,* and the round goby (Bence and Mohr 2008). These changes have persisted through this reporting period, 2005-2010, resulting potentially in a new equilibrium for introduced salmonines. Within this reporting period, the harvests of only two of the six introduced salmonines, coho salmon and Atlantic salmon, are commensurate with what they were in the previous reporting period, whereas the harvests of the other four species have declined by various degrees (discussed later). Overall, in the state of Michigan waters during the previous reporting period, the harvest of introduced salmonines amounted on average to 89,000 fish per year,

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whereas the comparable figure for this reporting period was only 11,000, a decline of 88% (Table 2). Angler effort declined 67% from the previous reporting period, which was less than the decline in harvest of introduced salmonines, possibly owing to a continuing fishery for lake trout (see Status of Lake Trout chapter).

Table 2. Harvest (numbers of fish) from 10 main basin index ports in the Michigan waters of Lake Huron, 1986-2010. N/A = survey not conducted in 1989-90.

Year	**Chinook salmon**	**Coho salmon**	**Brown trout**	**Steelhead**	**Pink salmon**	**Atlantic salmon**	**Lake trout**
1986	85,669	6,801	15,286	5,781	104	0	53,530
1987	79,976	3,524	7,416	7,169	9,559	0	42,430
1988	90,134	4,126	2,730	3,033	201	17	36,991
1989	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1990	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1991	43,100	762	1,685	5,531	4,728	0	18,116
1992	40,751	768	3,312	6,340	372	39	13,300
1993	49,115	1,061	7,765	7,967	1,702	158	6,570
1994	55,149	1,360	12,714	12,060	920	0	13,708
1995	96,393	1,897	14,086	20,703	877	301	34,360
1996	84,015	1,970	9,375	18,419	1,286	92	35,929
1997	125,494	2,719	3,735	13,863	239	139	48,142
1998	90,018	1,338	3,196	7,719	667	24	54,539
1999	74,102	5,014	1,826	10,424	1,062	94	36,810
2000	65,821	3,467	2,697	10,404	1,072	146	27,442
2001	57,024	2,003	1,669	9,083	4,813	322	18,846
2002	104,456	12,006	4,029	9,738	2,595	139	28,209
2003	81,421	1,362	5,743	5,551	52	123	43,981

Table 2, continued.

Year	Chinook salmon	Coho salmon	Brown trout	Steelhead	Pink salmon	Atlantic salmon	Lake trout
2004	46,153	1,767	2,229	6,569	3,135	111	69,274
2005	11,703	722	999	2,514	163	25	39,061
2006	9,820	1,382	361	1,654	616	85	18,411
2007	5,381	1,062	138	1,542	380	39	17,877
2008	4,147	1,956	99	1,971	262	183	10,063
2009	4,407	1,983	133	1,613	115	348	17,046
2010	3,198	887	793	3,330	1,055	135	10,748

By way of background, the rainbow trout (steelhead) was first stocked in the Great Lakes in a Lake Huron stream in 1873, and brown trout fry were introduced in the upper Great Lakes in 1883 after being transported from the state of New York to the state of Michigan (Emery 1985). Successful introductions of Chinook and coho salmon occurred during the 1960s in Michigan waters of Lake Huron (Whelan and Johnson 2004), after which, in the mid-1980s, stocking of Chinook salmon was begun in Ontario waters through a volunteer-run hatchery program. The pink salmon was introduced accidentally into the Lake Superior watershed in the 1950s (Nunan 1967), and the species subsequently spread to the other Great Lakes, including Lake Huron. Atlantic salmon have been stocked annually in Lake Huron since 1987, almost exclusively by Lake Superior State University. Stocking rates for anadromous salmonines increased steadily in Lake Huron until reaching a peak of 7.9-million fish in 1988. Chinook salmon were stocked most heavily, typically around 63% of the total, followed by steelhead (20%) and brown trout (10%) (Whelan and Johnson 2004; U.S. Fish and Wildlife Service and Great Lakes Fishery Commission 2010). Stocking levels since 2006 have been reduced by about 87% from the average number stocked between 1985-2000 in response to concerns about prey availability and evidence of rising rates of natural reproduction (Johnson et al. 2010).

Natural Reproduction

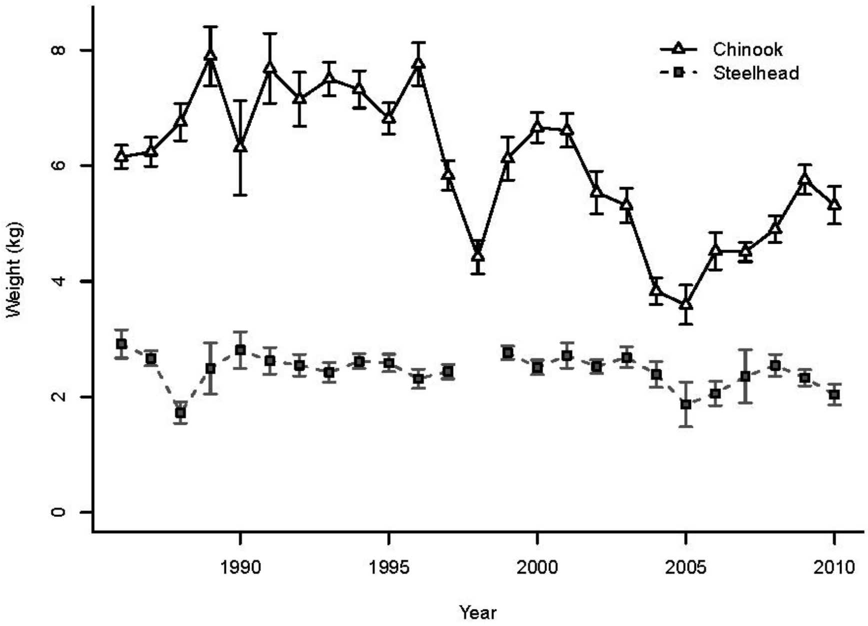
All anadromous salmonines (except for pink salmon) were originally supported by regular stocking, but, during 2000-2003 a marking study determined that natural reproduction accounted for 80% or more of the Chinook salmon taken in Lake Huron's offshore troll fishery and in Ontario's stream fisheries (Johnson et al. 2010). The rise in Chinook salmon reproduction in Lake Huron tributaries occurred sometime between the early 1980s and 2000. Natural reproduction has also sustained the bulk of the steelhead fishery in Ontario waters for many years, despite years of stocking through Ontario volunteer-run hatchery programs (Gonder 2005). Sampling conducted in Ontario tributaries suggests strongly that the majority of wild Chinook salmon (Marklevitz et al. 2011; Johnson et al. 2010) and steelhead (Gonder 2005) are produced in Ontario streams where extensive high-quality-tributary spawning habitat is accessible to fish. Accessibility relates to the fact that fewer streams are blocked by dams in Ontario than in Michigan. Although Bence et al. (2008) reported that steelhead abundance in Ontario waters during 2000-2004 was lower than observed in the early 1980s (see also Gonder 2005), given the lack of a coordinated international program for marking hatchery-reared steelhead, a current assessment of steelhead reproduction is not available. We believe that wild fish continue to make up the majority of steelhead recruits in Ontario waters, whereas hatcheries may be more important recruitment source in Michigan waters.

Coho salmon were last stocked in 1989 but continue to persist in Lake Huron's offshore fishery. Several Lake Huron tributaries are known to host coho spawning populations, both in Michigan and Ontario waters. Spawning populations of Chinook salmon, pink salmon, and steelhead appear to be well established and likely would persist even if all stocking were discontinued. There is little evidence, however, that appreciable natural reproduction of migratory brown trout or Atlantic salmon occurs in Lake Huron tributaries (Johnson and Rakoczy 2004; JEJ and DG, unpublished data).

Fish-Community Interactions

The numbers of age-1 and older Chinook salmon in the main basin during 2005-2009 were approximately 98% lower than at the population's peak, which occurred in the mid-1980s, and 80% lower than abundance levels during the 2000-2004 reporting period (Bence et al. 2008), due primarily to increasing age-0 natural mortality rates (Brenden et al. 2012). After the 2004 collapse of the alewife population (Riley et al. 2008), Chinook salmon weight-at-age and condition factor declined sharply, but, by 2010, weight of three-year-old salmon recovered nearly to what is was in 2003 (Fig. 14). The decline and recovery of weight-at-age suggests that abundance of introduced salmonines, Chinook salmon in particular, was unsustainably high after the alewife population collapse but reached a level during the current reporting period that is more in balance with a reduced availability of pelagic prey. A high incidence of *Bythotrephes longimanus* was noted in the diets of adult Chinook salmon in 2009-2010 (E.F. Roseman, U.S. Geological Survey, personal communication, 2011) and, considering the small size of the salmon, could be an indication of persisting food scarcity for this species.

Fig. 14. Trends in weight (kg ± 2 SE) at age 3 of angler-harvested Chinook salmon and steelhead trout, Michigan waters of Lake Huron, 1986-2010.



Steelhead trout showed no clear trends in weight-at-age during 1886-2010 (Fig. 14). Diets, as measured from stomach contents of the recreational catch in 2008-2010, indicated that various terrestrial invertebrates and fish, including round goby, are a staple for steelhead trout (E.F. Roseman, U.S. Geological Survey, personal communication, 2011). Comparison of diets suggested that Chinook salmon were less likely than steelhead or Atlantic salmon to prey on benthic fish, such as round goby, or on terrestrial invertebrates. The more opportunistic feeding behavior of steelhead and Atlantic salmon may explain their better persistence in the fishery despite food-web disruptions.

In Michigan waters, mortality immediately after stocking of brown trout and Chinook salmon increased sharply after 2004 and now appears to be the principal factor limiting recruitment of stocked fish. Preliminary estimates of the percentage of brown trout stocked as fall yearlings caught by angling (return-to-creel) in Michigan waters during 2010 averaged 0.62% (JEJ, unpublished report). For Chinook salmon, return-to-creel of hatchery-origin fish in Michigan waters averaged 0.07% in 2010 (JEJ, unpublished data). In Michigan, return to the creel has declined to such low levels that stocking of Chinook salmon has been reduced twice, falling from an average of 3,249,000 fish during 1985-2005 to 1,693,000 fish during 2006-2010. Continuation of brown trout stocking is being examined critically. Recreational catch rates of Chinook salmon (both wild and stocked combined) have been measured at some of Ontario's ports; these data suggest declines have occurred in the Ontario sport fishery, although not to the same levels as observed in Michigan waters. For instance, estimated catch rates for Chinook salmon in the southern Manitoulin Island fishery declined from an average of 17 fish per 100 rod hours in 1999-2003 to 6 fish per 100 rod hours in 2005 to 2009.

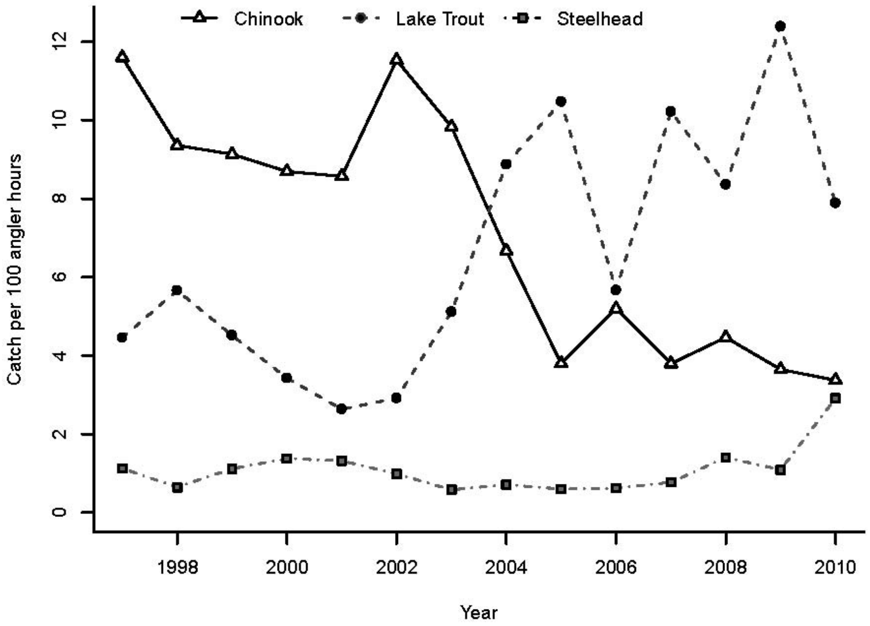
The leading cause of declining post-stocking survival for Chinook salmon and brown trout appears to be predation on juvenile life stages. Juvenile Chinook salmon and brown trout, owing to their tendency to occupy nearshore habitats, appear to be especially vulnerable to predation from Saginaw Bay's recovering walleye population (Johnson and Rakoczy 2004). Recently stocked salmonines have also been observed in stomachs of lake trout (Johnson et al. 2004; JEJ, unpublished data; E.F. Roseman, USGS, personal communication, 2011). In Ontario waters, walleye populations are smaller and are located typically in areas where Chinook salmon and brown trout are not abundant. Despite this difference, declines in Chinook salmon and brown trout catch rates in the Ontario sport fishery, as shown by the declines in catch rates in the southern Manitoulin Island fishery, indicate that recent changes in the fish community, such as the alewife population collapse, have created conditions unfavorable for Chinook salmon and brown trout in both Michigan and Ontario waters of Lake Huron. The virtual absence of alewife affected these species by reducing the availability of prey and by removing an important buffer species that had previously absorbed much of the predation.

Recreational Fishery Harvest

The effects of the 2004 alewife population collapse on fisheries for introduced salmonines were immediate and dramatic especially for Chinook salmon in all basins, although robust creel data are available only for Michigan waters (Table 2). Chinook salmon harvest at 10 index ports in Michigan waters averaged 71,000 during the 2000-2004 reporting period, but only 6,400 during this reporting period (2005-2010), a 91% decline. In 2010, an estimated 3,200 Chinook salmon were harvested at the index ports, the lowest harvest since the time series started in 1986. After accounting for natural reproduction, only 1,100 of these Chinook salmon were likely to be of hatchery origin. The combined harvest of brown trout at the index ports averaged 420 fish from 2005 to 2010, a 93% decline from the 1986-2004 average and an 87% decline from the 2000-2004 reporting period (Table 2).

During 2005-2010, angler use of the main basin index ports in Michigan declined 67% from levels recorded in 2000-2004. Much of the angler effort after 2004 was redirected to lake trout and walleye, which probably caused a reduction in capture efficiency for the reduced numbers of introduced salmonines. For example, the catch of steelhead per angler hour by those targeting trout and salmon was stable after 2004 (Fig. 15), but harvest of steelhead at index ports actually declined 75% (Table 2). The lake trout catch rate rose sharply as offshore fishing effort was redirected from introduced salmonines to lake trout, but the number of lake trout harvested declined, given the reduced levels of total effort caused by declining angler success for introduced salmonines in the Michigan offshore fishery (Fig. 15; Table 2). Unlike in Michigan waters, in Ontario waters of the main basin, Georgian Bay, and the North Channel, the offshore fishery for Chinook salmon continues, but creel data on harvest and catch rates for this reporting period are lacking.

Fig. 15. Trends in catch rates of Chinook salmon, steelhead trout, and lake trout for anglers targeting trout and salmon, Michigan's 10 main basin index ports, Lake Huron, 1997-2010.



Since 2000, an average of 32,000 Atlantic salmon has been stocked annually in Lake Huron. Nearly all of this stocking has been in the St. Marys River at Lake Superior State University, and harvest of this species is also concentrated in this area. Creel surveys are not conducted regularly on all access sites to the St. Marys River, particularly at the rapids in Sault Ste. Marie, which is a focal point for the Atlantic salmon fishery. Even so, estimated Atlantic salmon harvest has been in the range of 1,000 to 2,200 for those years when some St. Marys River sites were surveyed (T. Kolb, personal communication, 2011), and actual harvest is likely substantially higher. Return-to-creel for Atlantic salmon, based upon these partial harvest estimates, is nearly 5%, which is much higher than for other introduced salmonines.

In summary, food-web changes resulting from invasive species and the consequent collapse of the alewife population have proved devastating to Lake Huron's Chinook salmon population and to its economically important recreational fishery. Those introduced salmonines, for example, steelhead and Atlantic salmon, that have a more versatile diet have fared better. Lacking a vibrant Chinook salmon fishery, recreational fishing effort at main basin ports, especially in Michigan, has declined to only a third of former levels, with attendant economic consequences to Lake Huron's coastal communities.

STATUS OF NEARSHORE FISH COMMUNITIES

David G. Fielder[8], Arunas Liskauskas, Lloyd Mohr, and James Boase

Progress in achieving the fish-community objectives (FCOs) during this reporting period (2005-2010) will be addressed for the major nearshore species and groups of species specified in DesJardine et al. (1995). Surveys and data series dealing with nearshore fish communities in Lake Huron are generally focused on specific embayments, in particular Saginaw Bay, and relatively little is known about most of the nearshore area in the lake's main basin. The nearshore region in Lake Huron is critical for understanding the overall state of the lake's fish communities, particularly the effects of recent food-web changes (Bence and Mohr 2008). The proliferation of dreissenid mussels has been predicted to shift production to nearshore zones (Hecky et al. 2004), which has the potential to increase abundance of nearshore species. The near-extirpation of the alewife (see Table 1 in the Introduction for scientific names of fishes), which is a formidable predator and competitor on newly hatched percids (Kohler and Ney 1980; Wells 1980; Brandt et al. 1987; Brooking et al. 1998), also may be affecting nearshore fish communities.

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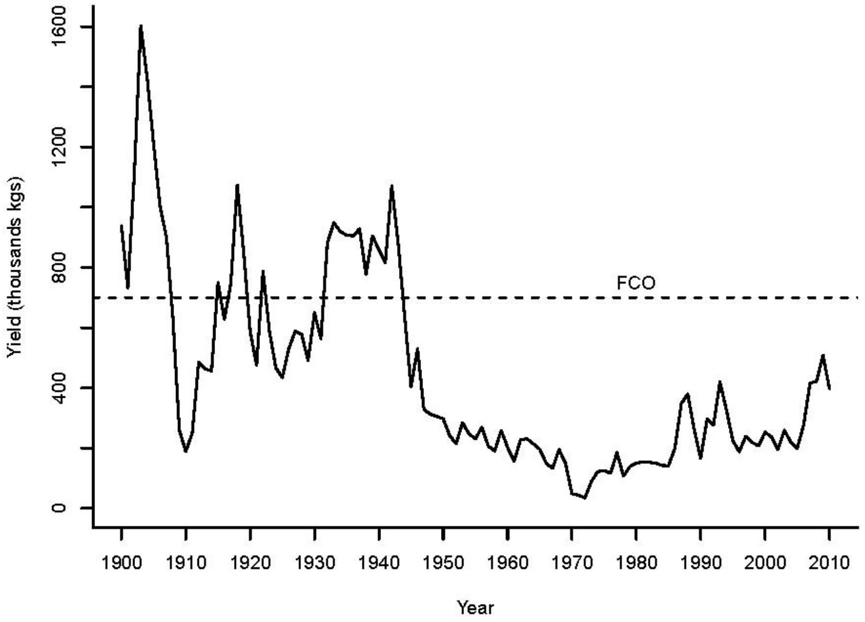
Walleye

Reestablish and/or maintain walleye as the dominant cool-water predator over its traditional range with populations capable of sustaining a harvest of 0.7 million kg.

Walleye yield during 2005-2010 increased substantially lakewide to 0.37-million kg (Fig. 16), a 59% increase from 2000-2004. The increase is credited to a series of strong year-classes in Saginaw Bay and elsewhere around the lake (Fielder and Thomas 2006; Fielder et al. 2010; Ivan et al. 2011; Upper Great Lakes Management Unit 2011a). The increased reproductive success has been attributed to the decline of the alewife in Lake Huron (Fielder et al. 2007). Recovery metrics for Saginaw Bay walleye (Fielder and Baker 2004) were met in 2009, and stocking was suspended in 2006. The recreational-fishery harvest in Saginaw Bay peaked in 2008 at 330,000 individuals compared to a pre-recovery average (1986–2002) of 93,000 (DGF, unpublished data). Yield from the recreational fishery in Saginaw Bay, however, has not reached historical levels (0.35-million kg in 2009 vs. 0.45-million kg, historically). This shortfall may be due to exploitation differences between the modern recreational fishery and the historical commercial fishery. Fishery and population indicators suggest a decline in abundance of Saginaw Bay walleye in 2010, but substantial numbers of Saginaw Bay walleye may inhabit the main basin for parts of the year, removed from the reach of the fishery. The recovery of the Saginaw Bay stock of walleye is an important milestone in the management of the Great Lakes but has not resulted in the achievement of the lakewide FCO for walleye thus far.

Fig. 16. Reported walleye yield in Lake Huron from 1885 to 2010. Horizontal line indicates the fish-community objective (FCO) for sustained yield (0.7-million kg). Omitted is the yield stemming from recreational fisheries in Ontario waters of Lake Huron.



Commercial harvest of walleye from Ontario waters of Lake Huron during 2005-2010 averaged 0.92-million kg, a 7% increase compared to 2000-2004. The southern main basin fishery accounted for most of this increase, as the North Channel and Georgian Bay fisheries are much smaller. Since 2005, walleye harvest in southern Lake Huron has increased gradually to 99-thousand kg in 2010 and is at the highest level seen since the early 1990s (Upper Great Lakes Management Unit 2011a). Catch-per-unit-effort (CPUE) peaked in the trapnet fishery (dominated by 2-year-old fish) in 2005 and in the gillnet fishery (dominated by 5-year-old fish) in 2008, suggesting a very strong 2003 year-class. The North Channel walleye harvest averaged 6,800 kg during 2005-2010, an increase of 28% compared to 2000-2004. Strong year-classes produced in 2002, 2003, and 2005 have been contributing to increased walleye abundance (Upper Great Lakes Management Unit 2011a).

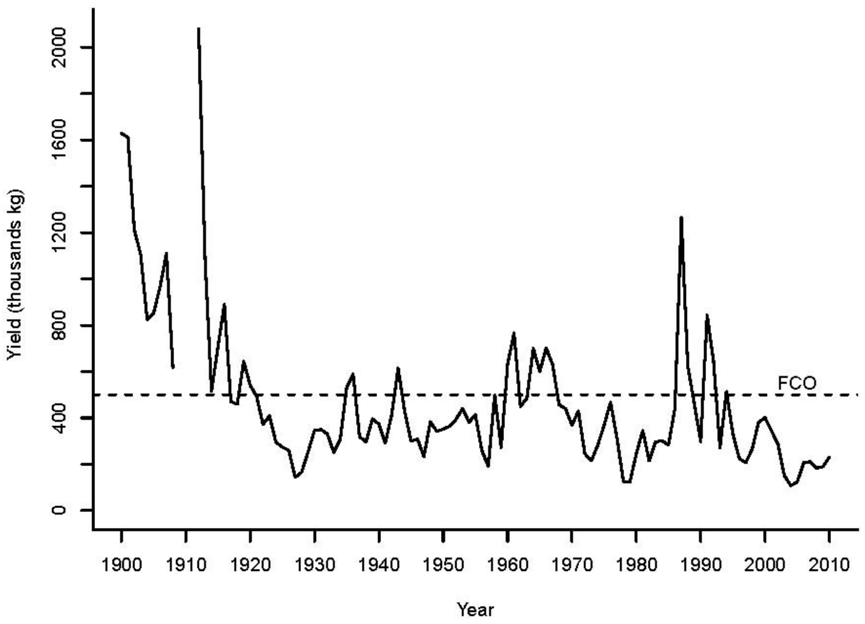
The status of walleye populations in eastern Georgian Bay during 2005-2010 has remained variable, with the exception of higher levels of natural recruitment not seen during 2000-2004. Spawning-stock assessment in Severn Sound (southern Georgian Bay; see Frontispiece for place names) in 2010 showed that the catch rate and estimated population size of spawning walleye was 2-3 times greater than during surveys conducted in 2003 and 2004 (Liskauskas 2010a). Much of the increase in 2010 was accounted for by an exceptionally large 2005 year-class that represented 70% of the fish observed. Assessment of post-spawning walleye in the same location revealed the second-highest level of walleye catch rates since these surveys began in 1999 (Liskauskas 2010b). Further evidence of increased production of walleye was also observed in the Shawanaga delta area of eastern Georgian Bay (Liskauskas 2009). In contrast, the Moon River walleye population continues to decline in abundance based on spring assessments in 2005 and 2008 (Upper Great Lakes Management Unit, unpublished data). Spawning habitat limitation due to fluctuating water levels is seen as a key reason for poor recruitment at this location.

Yellow Perch

> *Maintain yellow perch as the dominant nearshore omnivore while sustaining a harvestable annual surplus of 0.5 million kg.*

Although yellow perch have exhibited recent improvements in year-class strength, during this reporting period (2005-2010), lakewide yield averaged only 0.17-million kg, just 34% of the FCO (Fig. 17) and 23% less than the average yield for 2000-2004 (0.22-million kg; Fielder et al. 2008). In Saginaw Bay, improvements in reproduction have been evident by the high abundance of age-0 fish in the fall, but these potentially strong year-classes are not surviving to older ages owing to mortality in some years as high as 99% between their first and second falls (Fielder and Thomas 2006; DGF, unpublished data). Poor survival of age-0 yellow perch in Saginaw Bay is attributed to predation and possibly poor overwinter survival (Fielder and Thomas 2006; Ivan et al. 2011); juvenile yellow perch have become the primary prey of walleye and other predators in Saginaw Bay. An overabundance of age-0 yellow perch has resulted in a decline of first-year mean length due to density-dependent growth (Fielder and Thomas 2006). These fish may be compromised such that they cannot endure winter energy demands. The recreational and commercial yellow perch fisheries in Saginaw Bay have declined to record low levels.

Fig. 17. Reported yellow perch yield in Lake Huron from 1894 to 2010. Horizontal line indicates the fish-community objective (FCO) for sustained yield (0.5-million kg). Yield from recreational fisheries in the Ontario waters of Lake Huron is omitted.



During this reporting period and unlike in Saginaw Bay, two prominent recreational fisheries in Michigan waters improved. The average harvest rate for anglers in southern waters increased greatly and was nearly twice that of Saginaw Bay, suggesting improved recruitment. The yellow perch fishery in the Les Cheneaux Islands region of northern Lake Huron recovered during the 2005-2010 reporting period, with the fishery-independent-survey mean CPUE averaging 50.3 yellow perch per lift compared to 13.1 for the reporting period of 2000-2004. Similarly, angler catch rates returned to pre-collapse levels, averaging 0.66 yellow perch per hour vs. 0.12 for 2000-2004 (Fielder 2010). The recovery was attributed to increased survival resulting from a declining abundance of cormorants, a fish-eating bird (Fielder 2008; Dorr et al. 2010; Fielder 2010).

The commercial harvest of yellow perch in Ontario waters of Lake Huron averaged 0.11-million kg during this reporting period (2005-2010), an increase of 10% over 2000-2004, when 0.096-million kg were harvested (Upper Great Lakes Management Unit 2011a). As was the case for walleye, the majority of the increase in harvest occurred in the southern main basin of Lake Huron. Fishery-independent netting targeting yellow perch in the main basin demonstrated large increases in yellow perch CPUE beginning in 2005, owing to strong year-classes produced in 2003 and 2007 (Upper Great Lakes Management Unit 2011b).

The commercial effort on and harvest of yellow perch in the North Channel and Georgian Bay area remained very low compared to historical levels; the average harvest of 730 kg represented a decrease of 88% from 2005-2010 to 2000-2004 (Upper Great Lakes Management Unit 2011a). Independent assessment netting in the North Channel indicated an increase in CPUE since 2005, with the 2005 year-class being by far the strongest observed in several decades (Upper Great Lakes Management Unit 2010).

Lake Sturgeon

> *Increase the abundance of lake sturgeon to the extent that the species is removed from its threatened status in United States waters, and maintain or rehabilitate populations in Canadian waters.*

Important changes in management of lake sturgeon have occurred in Lake Huron since 2004. In the summer of 2008, the Province of Ontario closed the recreational fishery on the Mississagi River, a key lake sturgeon river in the North Channel. This closure was accompanied by a province-wide change in the recreational harvest limit for lake sturgeon from one to none per day, creating a catch-and-release-only fishery for this species. Commercial lake sturgeon quotas were reduced by 50% in January 2009 and subsequently were set to zero province-wide on July 1, 2009. In September of 2009, Ontario, under the provincial Endangered Species Act, officially listed the lake sturgeon as a threatened species in the Great Lakes/Upper St. Lawrence region. Effective January 1, 2010, no commercial or recreational harvest of lake sturgeon is allowed in this region, although aboriginal subsistence fishing for lake sturgeon continues to be permitted throughout the province. The lake sturgeon is still listed as a threatened species in the state of Michigan, but the species is not listed federally. The only harvest allowed in the vicinity of Lake Huron is currently in the Michigan waters of the St. Clair River and Lake St. Clair where, in the recreational fishery, one fish per year is allowed under a special tag system.

After existing as a rare species in Lake Huron since the very early 1900s, the lake sturgeon appears to be expanding its breeding range. A multi-agency assessment conducted from 2005 to 2010 indicates that the St. Marys River supports a resident population in excess of 500 fish (Bauman et al. 2011; Gerig et al. 2011). Spawning in the Mississagi River was found to occur in two locations approximately 30 km apart. Drift-net trapping identified critical larval habitat in the lower reaches of this tributary. Spawning was also confirmed in the Spanish River, and juvenile habitat was mapped there as well.

The closure of the commercial fishery in Ontario waters has resulted in fewer lake sturgeon being available for sampling, including screening for tags. However, reporting is still mandatory (as is live release). The commercial fishery reported an average annual catch of just over 13,000 kg from 2005 to 2009, of which 30% was harvested; in 2010, the total incidental catch increased to just under 23,000 kg, of which none was harvested.

Genetic assessment of spawning populations shows that most populations are unique; however, lower genetic resolution among these populations suggests that many are recovering and were likely seeded from a small number of parental stocks (Welsh et al. 2008). Also, lake sturgeon migrate extensively between Lakes Michigan, Huron, and Erie, resulting in apparent straying amongst spawning populations originating from different lakes.

Esocids and Centrarchids

Esocids

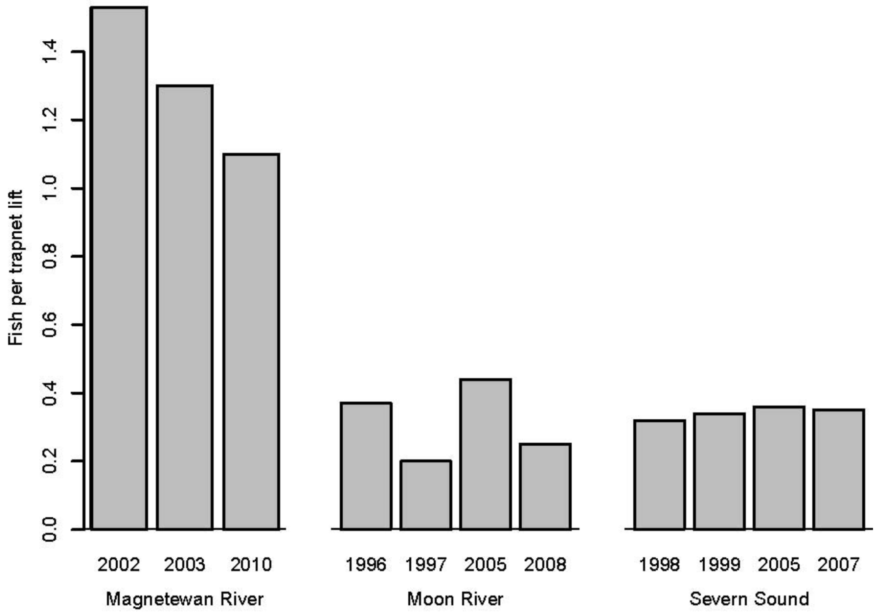
> *Maintain northern pike as a prominent predator throughout its natural range, maintain the muskellunge in numbers and at sizes that will safeguard and enhance its species status and appeal, and sustain a harvestable annual surplus of 0.1 million kg.*

Northern pike is the most common esocid in Lake Huron, and in Michigan waters is found primarily in the St. Marys River, Les Cheneaux Islands region, and Saginaw Bay. The St. Marys River remains the single largest source with an average recreational harvest of 7,200 fish during 2005-2010, with a peak in 2006 of 15,000. The remainder of the recreational harvest in Michigan is approximately equally split between the Les Cheneaux Islands and Saginaw Bay. In the Les Cheneaux Islands, harvest has increased during this reporting period. Total yield of northern pike in Michigan waters of Lake Huron averaged 21,400 kg during the 2005-2010 reporting period.

The relative abundance of northern pike in Ontario waters continued to decline during the 2005-2010 reporting period, maintaining the trend observed during 2000-2004. In the Severn Sound area of southern Georgian Bay, CPUE in surveys conducted during this reporting period declined by over 60% compared to 2000-2004, although average size has been increasing (Liskauskas 2010a). Current levels of abundance are below those observed in the 1980s and 1990s (Gonder 2003). Similar levels of abundance have been observed at additional locations in eastern Georgian Bay, suggesting that low northern pike abundance is a Bay-wide phenomenon. The northern pike is one of the most sought-after species in the recreational fishery (OMNR 2009), but no recent creel surveys have been conducted in Ontario waters to determine how lower abundance is affecting recreational fishing.

Muskellunge populations in eastern Georgian Bay and the North Channel (Severn Sound and the Moon and Magnetewan Rivers) show no consistent trends in CPUE (Fig. 18). On the Magnetewan River, population estimates also indicate no change in abundance of spawning fish has occurred between the current (2005-2010) and previous (2000-2004) reporting periods (Liskauskas 2010b).

Fig. 18. The relative abundance (fish per trapnet lift) of spawning muskellunge during spring surveys of three rivers in eastern Georgian Bay, Lake Huron.



Spawning groups of muskellunge in eastern Georgian Bay and the North Channel are genetically structured. Analysis of microsatellite DNA markers has shown that spawning groups are discrete, localized populations rather than components of a larger, more broadly distributed population (C. Wilson, personal communication, 2010). Results from both individual- and population-based analyses indicate that these populations are generally small with limited ranges and high site fidelity.

Centrarchids

> *Sustain smallmouth and largemouth bass and the remaining assemblage of sunfish at recreationally attractive levels over their natural range.*

Most of the main basin of Lake Huron is too cold and lacks the productivity to support large numbers of centrarchids, although smallmouth bass support sport fishing in some regions, most notably the Les Cheneaux Islands, St. Marys River, portions of the North Channel and eastern Georgian Bay, outer Saginaw Bay, and the Harbor Beach area. In the Les Cheneaux Islands, the one area in Michigan waters where data can be compared between reporting periods, the abundance of smallmouth bass during 2005-2010 was 47% greater than in the previous reporting period (2000-2004). In Ontario waters, similar trends in smallmouth bass have also been noted, with abundance increasing by 23% from 2000-2004 to 2005-2010 in the Severn Sound area of southern Georgian Bay (Liskauskas 2010a). This location is one of the few in Ontario waters where nearshore communities are monitored on a regular basis. Surveys conducted during 2005-2010 showed consistently that smallmouth bass are the most abundant nearshore predator and the second most abundant species both numerically and by weight (Liskauskas 2010a). The age distribution of this species reflects recent strong recruitment, with the 2004, 2005, and 2006 year-classes well represented, continuing a trend of successful recruitment for smallmouth bass in Georgian Bay and the North Channel since the mid-1990s (Fielder et al. 2005). Other areas recently surveyed in eastern Georgian Bay also reflect similar trends in smallmouth bass abundance. Smallmouth bass continue to be the most sought-after species in the recreational fishery in Ontario waters of Lake Huron (Ontario Ministry of Natural Resources 2009), but no recent creel surveys have been conducted.

Other Nearshore Species

Maintain channel catfish as a prominent predator throughout its natural range while sustaining a harvestable annual surplus of 0.2 million kg.

Channel catfish are found principally in Saginaw Bay and, to a lesser extent, in the Ontario waters of the southern main basin and southern Georgian Bay. In the Michigan Department of Natural Resources survey in Saginaw Bay, the catch rate since 2005 has trended downward, declining to a mean of 4.5 channel catfish per net lift, as compared to 9.2 between 2000 and 2004. The reasons for the decline are not known fully, but harvest is not a factor. The average yield between 2005 and 2010 in Saginaw Bay was 72,000 kg, or 36% of the FCO. Commercial harvest of channel catfish in Saginaw Bay is low due principally to fish-consumption advisories and health concerns (DGF, unpublished data). In the southern main basin, commercial harvest has declined over 90% since 2004 and now averages 1,000 kg. Most of this decline was brought about by export restrictions placed on live fish due to concerns associated with the discovery of viral hemorrhagic septicemia in the Great Lakes. In Severn Sound, Ontario Ministry of Natural Resources surveys conducted since 2005 show no discernible trend in abundance. The channel catfish is still of sufficient abundance that it is an important part of the Saginaw Bay, southern main basin, and Georgian Bay fish communities, and it may exert considerable predation.

SPECIES DIVERSITY, GENETIC DIVERSITY, AND HABITAT IN LAKE HURON

Lloyd Mohr[9], Arunas Liskauskas, Wendylee Stott, Chris Wilson, and Jeff Schaeffer

In addition to identifying several species or genera-specific objectives, the fish-community objectives (FCOs) for Lake Huron (Desjardine et al. 1995) emphasize the importance and value of the diversity of indigenous species within the lake's fish communities. The FCOs also recognized the importance of genetic diversity within all fish populations and the need to protect and rehabilitate fish habitat in order to ensure the long-term sustainability of fish populations. This chapter addresses these three issues and provides the relevant objective at the beginning of each subchapter.

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Species Diversity

Recognize and protect the array of other indigenous fish species because they contribute to the richness of the fish community. These fish–cyprinids, rare ciscoes, suckers, burbot, gar, and sculpins–are important because of their ecological significance; intrinsic value; and social, cultural, and economic benefits.

A recent review found that 96 of the 104 species native to Lake Huron were still extant (Roseman et al. 2009), while 21 species have been introduced from elsewhere in the Great Lakes, the Mississippi River drainage, or from outside eastern North America (Coon 1999; Roseman et al. 2009). We know of no new additions or extirpations to the fish fauna of Lake Huron during this reporting period, 2005-2010.

Prospects for maintaining native biodiversity in Lake Huron have improved during this reporting period. First, the alewife (see Table 1 in the Introduction for scientific names of fishes) population has not rebounded after its collapse during 2002-2004. This event triggered sharp reductions in Chinook salmon abundance and also was associated with substantial increases in recruitment of native species, such as walleye and lake trout (Fielder et al. 2007; Riley et al. 2007; He et al. 2012). A continuing depression of the alewife population can be considered a window wherein formerly abundant native species, such as cisco, could be reintroduced successfully in areas where they are now absent or where such species could naturally reoccupy their former ranges.

Monitoring of nearshore fish communities at selected locations in Ontario waters of the main basin, Georgian Bay, and the North Channel recorded over 60 species, indicating a considerable diversity of fishes (Upper Great Lakes Management Unit 2010b). Species thought to be absent from the lake, such as banded killifish (Coon 1999). were captured in substantial numbers at several locations. Monitoring also documented range expansions in the main basin and in Georgian Bay of the round goby, a non-native species, and the resurgence of yellow perch, a native species. Only one of the nine species within the Lake Huron basin listed under the Ontario Endangered

Species Act in 2007, the lake sturgeon, was observed within this reporting period; it continues to be seen throughout the lake. The unobserved listed species (endangered—pugnose shiner and redside dace; threatened—black redhorse, channel darter, and lake chubsucker; and species of concern—grass pickerel, northern brook lamprey, and spotted sucker) inhabit rivers, and little or no assessment information for this habitat was available during the current reporting period.

Several fishes have recently established in proximity to Lake Huron, either in other Great Lakes or in watersheds near the Great Lakes basin. Rudd, a European cyprinid, is established in Lake Ontario and Lake Erie (U.S. Geological Survey 2011a). Fourspine stickleback is native to the Atlantic coast of North America but is now established in Lake Superior. Bighead carp *(Hypophthalmichthys nobilis)* and silver carp (*Hypophthalmichthys molitrix*) are known from the Illinois and Wabash River drainages (U.S. Geological Survey 2011b, 2011c) near Lake Michigan. All of these species may be considered as potential future invaders of Lake Huron.

Threats to native-fish diversity are often exacerbated by concurrent loss of native or introduction of invertebrate species that are widespread (Vanderploeg et al. 2002) and appear especially disruptive to food webs (Hecky et al. 2004; Bunnell et al. 2011). The establishment of the bloody red shrimp (*Hemimysis anomala*) in Lake Huron in 2007 is the most recent invertebrate invasion. At the same time, several mollusks have been listed as endangered or threatened in Ontario waters.

Regardless of their source, all aquatic invasive species are of concern because, while invader effects vary, freshwater invasions often have been followed by declines in biodiversity (Ricciardi and MacIsaac 2011), and invasive species are considered one of the greatest threats to native fishes (Dextrase and Mandrak 2006; Mandrak and Cudmore 2010). Furthermore, invasions are an overlay on long-standing problems of habitat loss, reduced water quality, and over-exploitation of fish stocks and on emerging issues, such as climate change.

Monitoring of all ecozones within Lake Huron and its tributaries continues to be a priority as a means of accurately characterizing the diversity of genes, species, and communities. While many species are found in limited locations or in small numbers, their presence may serve as a key indicator of ecosystem health and resilience (Swain and Wade 1993). The use of new tools for assessing status, evaluating threats, and implementing FCOs (e.g., ecosystem diversity indices, gap analysis, and biodiversity strategies) will help in meeting this FCO.

Genetic Diversity

> *Maintain and promote genetic diversity by conserving locally adapted strains. Ensure that strains of fish being stocked are matched to the environments they are to inhabit.*

The importance of genetic diversity in both native and stocked fish species continues to be a research priority for Lake Huron. For example, understanding population structure and how exploitation is parsed among various spawning stocks of commercial species is seen as an imperative to maintaining sustainable exploitation. During this reporting period, an analysis of microsatellite DNA of lake whitefish identified up to 19 population units in Lake Huron; the largest amount of genetic divergence was associated with sites in Georgian Bay (Stott et al. 2011). The population units, based on spawning collections, were consistent generally with the existing management units used for lake whitefish management, but fish from several population units may occupy the same management unit during the non-spawning period (see Status of Whitefish and Ciscoes chapter).

Analyses of current and historical population genetic structure may also help with reintroduction programs in the Great Lakes. Lake Huron is one of the potential donor lakes for reintroduction of the bloater to Lake Ontario. Two collections of bloater from the main basin and one from Georgian Bay were compared genetically to samples from Lakes Nipigon, Superior, and Michigan and to archival and contemporary cisco from Lake Ontario (Favé and Turgeon 2008). Collections from Lakes Michigan and Huron were similar genetically and were most closely related to Lake Ontario ciscoes, suggesting that bloater from either lake are suitable sources for reintroducing bloater to Lake Ontario.

To assess lake sturgeon movement and ecology during non-spawning periods, a mixed-stock analysis using microsatellite DNA loci was performed on juveniles and adults collected from 2001 to 2005 in southeastern Georgian Bay, the North Channel, Saginaw Bay, and the southern main basin. The genotypes of adults and juveniles were compared to the genetic profiles of lake sturgeon spawning populations described by Welsh et al. (2008). In general, lake sturgeon did not move far from spawning grounds, and the movement patterns of juveniles and adults were similar. Samples from southern Lake Huron were predominately from the St. Clair River, whereas samples from the North Channel were a mixture of fish from the Mississagi and Spanish Rivers. The origins of some fish, such as those collected from southeastern Georgian Bay in 2002 and those from Saginaw Bay, were difficult to determine because it was hard to distinguish among some of the potential source populations, and the suite of baseline samples used in the analysis may be missing data from some areas (e.g., from the Nottawasaga River in Georgian Bay).

To assist in the development of management and rehabilitation plans for muskellunge in Ontario waters of Lake Huron, spawning adults continued to be sampled during the current reporting period (2005-2010). Muskellunge tissue samples have been collected from a total of nine tributaries and embayments in the North Channel and eastern Georgian Bay and have been screened for 21 highly polymorphic microsatellite DNA markers, all to assess spatial structure, diversity, and lineage relationships (CW, unpublished data). The microsatellite data showed substantial genetic diversity among wild muskellunge with good congruence between sampling sites and genetic population structure. Individual and population-based analyses showed strong patterns of spawning-site fidelity and isolation by distance. Based on individual assignment tests and pair-wise divergences among sites, the study indicated limited straying between spawning sites and very low levels of gene flow. These results suggest that muskellunge in Lake Huron and Georgian Bay are partitioned into small, localized populations associated with local habitat patches rather than a broadly distributed or highly mobile population, a finding that has implications for recovery efforts in formerly degraded habitats, such as the Spanish River.

Concerns regarding loss of genetic diversity in walleye stocks in Georgian Bay were raised by Scribner and Liskauskas (2005) based upon work done by Gatt et al. (2002). Work has begun in this reporting period to reevaluate walleye stock structure in eastern Georgian Bay following changes to management protocols in that region. Preliminary results show greater spatial structuring among walleye stocks and regionalization of some stocks with pronounced differences between the North Channel and Georgian Bay (CW, unpublished data). Reduced diversity for some introduced populations, which may have resulted from low founding numbers and/or historical stocking practices (Gatt et al. 2002), emerged as a concern.

Habitat

> *Protect and enhance fish habitat and rehabilitate degraded fish habitats. Achieve no net loss of the productive capacity of habitat supporting Lake Huron fish communities and restore damaged habitat. Support the reduction or elimination of contaminants.*

Habitat conditions in Lake Huron were documented and assessed in two separate efforts during this reporting period. Environmental Objectives (EOs) were developed for Lake Huron (Liskauskas et al. 2007) under the auspices of the Great Lakes Fishery Commission; they identify habitats or processes that are necessary to meet the lake's FCOs. The EOs are organized around four themes: (1) spawning and nursery habitat, (2) shoreline processes, (3) invasive species and food-web issues, and (4) water quality. Each theme was examined in terms of what habitat or environmental requirements are needed to achieve a FCO for individual species or groups of species. Although many EOs focus on habitat requirements of game species, nongame species are mentioned as important components of the ecosystem. The Nature Conservancy (TNC) has also developed a comprehensive biodiversity conservation strategy for Lake Huron (Franks Taylor et al. 2010), which identifies seven conservation features that represent Lake Huron's biodiversity: (1) coastal terrestrial, (2) islands, (3) aerial migrants, (4) coastal wetlands, (5) native migratory fishes, (6) nearshore habitats, and (7) offshore habitats. The conservation action-planning process then examined the viability of those features, identified and evaluated threats, and identified management actions to address or ameliorate them. In most cases, the EOs provide broad, overarching ecosystem goals while the TNC approach develops strategies to mitigate threats to conservation features whose existence is supported by the EOs. Both approaches made specific recommendations toward achieving the FCOs for biodiversity.

A number of ongoing and new initiatives, which support these recent strategic initiatives, build upon the categorization and classification of important aquatic habitats in Lake Huron. Midwood and Chow-Fraser (2012) used satellite imagery to track changes in coastal wetland vegetation during six years of sustained low water levels (2002-2008) and found significant loss of coastal wetland area and structure resulting in declines in species richness. In spite of the negative impacts of low water on wetland function, Georgian Bay wetlands are still noted for their high water quality and diversity (Chow-Fraser et al. 2006; Seilheimer and Chow-Fraser 2007).

Water levels continued to decline in Lake Huron from 1997 to 2007 (Stow et al. 2008), a trend that prompted a comprehensive study examining the potential causes for lake-level declines, including alterations to the St. Clair River (International Joint Commission 2009). This extended period of relatively low lake levels will likely make this issue a high priority for the foreseeable future.

Other characteristics of the current state of habitats in Lake Huron are likely to have negative effects on ecosystem services from the lake. For example, the recent increased occurrence of *Cladophora* in Lake Huron is widely viewed negatively as decomposing mats of sloughed algae are associated with a variety of undesirable problems, including unpleasant odors, fouling of shorelines, clogging of water intakes, fouling of fishing nets, and reduced property values (Bootsma et al. 2005). Nuisance levels of *Cladophora* were observed during the 1960s through the early 1980s in the Great Lakes (Auer et al. 1982; Higgins et al. 2005), but this problem was reduced in subsequent years due to improved phosphorus management (Higgins et al. 2008). Since about the mid-1990s, however, the occurrence of nuisance levels of *Cladophora* has increased in the Great Lakes, and this increase is most likely related to the invasion of the lakes by dreissenid mussels. Dreissenid mussels increase the suitability of benthic Great Lakes habitats for *Cladophora* by increasing the amount of light reaching the lake bottom due to their intensive filtering, by excreting soluble phosphorus utilized by *Cladophora*, and by providing a hard substrate for *Cladophora* colonization (Hecky et al. 2004; Higgins et al. 2005; Bootsma et al. 2008; Malkin et al. 2008).

Invasive species, particularly dreissenid mussels and the round goby, have also been implicated in the recent increased occurrence of type-E botulism-related mortality in Great Lakes fish and birds (Getchell and Bowser 2006; Perez-Fuentetaja et al. 2006), but links between these species and the occurrence of botulism outbreaks have not been definitively demonstrated. Botulism outbreaks are related to water temperature and lake levels and could be expected to increase in frequency if water temperatures increase and lake levels remain low (Lafrancois et al. 2011). Recent increases in the frequency of botulism outbreaks in the Great Lakes may also be associated with the resurgence of *Cladophora*.

Achieving the habitat objective for Lake Huron will require the support and coordination of numerous government agencies, academia, and non-governmental organizations. The Lake Huron Bi-National Partnership, formed in 2002, has identified degradation and loss of historical habitat in tributaries, nearshore zones, and wetlands as major stressors on the Lake Huron ecosystem (Lake Huron Binational Partnership 2008). This partnership will be critical in moving forward and documenting progress towards achieving the Lake Huron habitat objective.

LAKE HURON IN 2010 AND BEYOND

Stephen C. Riley[10], Lloyd Mohr, and Mark P. Ebener

Lake Huron has undergone a number of profound ecological changes in the last century (Eshenroder and Burnham-Curtis 1999; Dobiesz et al. 2005), but particularly just before the late 1950s due to dominance of three invasive fishes (sea lamprey, alewife, and rainbow smelt) (see Table 1 in the Introduction for scientific names of fishes), overfishing, and habitat degradation (Berst and Spangler 1972). More recently, the effects of a new wave of invasive species, including the spiny water flea (*Bythotrephes longimanus*), dreissenid mussels, and round goby, have become apparent (Eshenroder and Lantry 2012). The previous state-of-the-lake report (Bence and Mohr 2008) noted that dramatic changes had occurred in the fish communities of the lake, and these have led to yet further changes in this reporting period (2005-2010). Here we summarize the most recent changes in the ecology of Lake Huron and discuss their future management implications.

Nutrient levels and lower-trophic communities in Lake Huron have continued to show major changes since the end of the last reporting period (see Status of Phytoplankton, Zooplankton, and Benthos chapter). Before 2005, offshore phosphorus levels and chlorophyll concentrations had

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declined, spring Secchi depth had increased, and zooplankton communities had exhibited marked changes, including a drastic reduction in the abundance of cladocerans (see Status of Phytoplankton, Zooplankton, and Benthos chapter). Since then, phosphorus levels have remained low, Secchi depths have reached unprecedented levels (Barbiero et al. 2012), and chlorophyll levels have continued to decline. The most recent zooplankton data, from 2006, suggest that reduced cladoceran abundance has persisted, at least into the first years of this reporting period, and that further reductions in cyclopoid copepod populations have also occurred. Abundance of the important native amphipod *Diporeia* spp. had declined to very low levels in Lake Huron by 2004, particularly at shallower sites, and has remained low through the current reporting period. Quagga mussel density in offshore waters was increasing during the previous reporting period (Nalepa et al. 2007) and, since then, has continued to increase (see Status of Phytoplankton, Zooplankton, and Benthos chapter).

Trends in offshore prey-fish populations observed in the previous reporting period (2000-2004) have continued into this reporting period. Total estimated lakewide biomass of offshore demersal fish reached the lowest level ever observed in 2004 (42.2 Kt), continued to decline through 2009 (16.5 Kt), and increased modestly in 2010 (29.1 Kt). The alewife population collapsed in 2004 and remains at very low levels, while abundance of rainbow smelt in this reporting period continued to decline beyond the already relatively low levels observed in 2004. The abundance of bloater, a native species, however, has increased since the last reporting period, whereas most other native offshore demersal species remain at low abundance (see Status of the Offshore Demersal Fish Community chapter). Recent changes in habitat use of offshore demersal fishes (Riley and Adams 2010) and the number, size, and location of pelagic fish schools (Dunlop et al. 2010) suggest that the utilization of offshore habitats by demersal fishes has been significantly altered. The offshore demersal fish community appears to remain in a state of flux, and further changes to the structure of this community are likely.

Commercial harvest of lake whitefish has continued to decline since the previous state-of-the-lake report, and estimated lakewide abundance of this species has also decreased (see Status of Whitefish and Ciscoes chapter).

The diet, growth, and habitat use of lake whitefish have changed in recent years, due in part to changes in the species composition of benthic invertebrates after the invasion of dreissenid mussels (Pothoven and Nalepa 2006; Pothoven and Madenjian 2008; Nalepa et al. 2009; Rennie et al. 2009; Riley and Adams 2010).

The estimated biomass of large lake trout has remained high and relatively stable since 2004, and angler catch rate in 2010 was similar to that observed in 2004. Relatively large numbers of wild age-0 lake trout were captured in trawl surveys beginning in 2004 (Riley et al. 2007) and have been captured in most years since (Riley et al. 2012), while unclipped, presumed-wild-born adult lake trout have become much more common in assessment surveys since 2004 (He et al. 2012), suggesting that widespread natural reproduction of lake trout has been occurring since well before this reporting period. The increase in natural reproduction may be caused by a number of factors but is due most likely to reduced predation from alewife on lake trout fry (Fitzsimons et al. 2010) and\or a reduction in thiaminase in lake trout diets after the alewife population collapsed (Riley et al. 2011). Whether or not lake trout will continue to reproduce successfully in the lake remains to be seen, but this turnabout represents the first lakewide evidence of natural reproduction and recruitment of lake trout outside of Lake Superior since the 1940s and, as such, is an important step toward achieving the Salmonine Fish-Community Objective (FCO) (DesJardine et al. 1995).

Chinook salmon condition factor and weight-at-age in Lake Huron have increased since the last reporting period, although angler catch rate has remained low, suggesting that Chinook salmon abundance is reduced compared to 2004. Chinook salmon abundance in the main basin, however, has declined drastically since the 1980s (Brenden et al. 2012). Most of the Chinook salmon in Lake Huron are now naturally produced, and the early survival of stocked fish has decreased substantially (see Status of Introduced Salmonines chapter).

Intensified sea lamprey control efforts during this reporting period have resulted in some progress towards achieving lakewide suppression targets (see Status of Sea Lamprey chapter). However, the persistence of high marking rates in some regions and their emergence in others (McLeod et al.

2011) is troubling and may be related to the effect that ongoing fish-community changes are having on sea lamprey populations as has happened in the past (e.g., Eshenroder et al. 1995b; Young et al. 1996). Higher sea lamprey survival and increased parasitism of other hosts, including lake trout, lake whitefish, and burbot, in response to a declining Chinook salmon population may mute or negate further gains in sea lamprey suppression, despite a greater commitment of resources to control efforts.

Increased biomass and production of walleye and yellow perch have been observed in most parts of the lake, which may be related to the absence of predation pressure from alewife on larvae of these species (Fielder et al. 2007). Populations of lake sturgeon, northern pike, and muskellunge appear to be stable in most parts of the lake, but northern pike and muskellunge may currently have low reproductive success in some areas due to low water levels. Smallmouth bass populations appear to be increasing in several areas of the lake, and channel catfish populations appear to be large and relatively stable. Some nearshore fish communities may be benefiting from suppression of cormorants since 2004 (see Status of Nearshore Fish Communities chapter).

Regime Shift in Lake Huron?

Eshenroder and Lantry (2012) have suggested that the combined effects of *Bythotrepes longimanus* and dreissenid mussels have led to the drastic changes in zooplankton communities of Lake Huron and that the overall effects on zooplankton, benthic invertebrates, and fish communities may have resulted in an ecosystem regime shift (*sensu* Carpenter 2003), first evident in 2004. Other studies (Riley and Adams 2010; Dunlop et al. 2010; Ridgway 2010) also suggested that large-scale ecosystem changes or regime shifts have occurred recently in Lake Huron. Regime shifts occur when an ecosystem moves from one state to another, usually as a result of some disturbance (Carpenter 2003). A new ecosystem state, or regime, may be characterized by different ecosystem services, and societal benefits from a shifted ecosystem may vary depending on what state it is in (e.g., Alheit et al. 2005). Methods for early detection of ecosystem regime shifts have been proposed (Lindegren et al. 2012) and could be applied to Lake Huron. If a regime shift has occurred in Lake Huron, management of the lake would benefit from identification of the characteristics and potential stability of the new regime.

In 2010, the Lake Huron ecosystem was characterized by lower nutrient levels, lower abundance of phytoplankton and zooplankton, relatively low offshore forage-fish biomass, reduced Chinook salmon and lake whitefish abundance and yield, increased abundance and harvest of some native fishes (walleye, yellow perch, and bloater), reductions in the abundance of invasive fishes (alewife and rainbow smelt), and widespread natural reproduction of lake trout. Recent declines in nutrients, chlorophyll, and plankton abundance suggest that the offshore waters of Lake Huron have been trending towards a more oligotrophic state (Barbiero et al. 2012), more similar to its historical state, and this oligotrophication may be due at least partially to the sequestering of nutrients in the benthos by dreissenid mussels (Hecky et al. 2004; Barbiero et al. 2011a). The very low offshore-demersal-fish abundances observed during this reporting period suggest that these reductions in nutrients and zooplankton abundance may have exerted bottom-up effects on prey fish. In turn, low prey abundance may have negatively affected survival of age-0 Chinook salmon and other salmonines, reducing their subsequent abundance at older ages. However, alternatively, the near absence of alewife may be related to predation owing to increased recruitment of walleye and yellow perch and the widespread natural reproduction of lake trout (Fielder et al. 2007; Riley et al. 2011; He et al. 2012).

From a fishery perspective, several aspects of Lake Huron’s fish communities in 2010 are encouraging: increased recruitment and abundance of several native species (walleye, yellow perch, and bloater), reductions in invasive species (alewife and rainbow smelt) abundance, and considerable natural reproduction of lake trout. In contrast, recent reductions in abundance and harvest of Chinook salmon and lake whitefish are negative, as fisheries for these species are economically important in the basin (Ebener et al. 2008a). The fish communities were dominated by native species in 2010 and, therefore, were closer to meeting the FCOs for the lake, but the lack of alewife is likely limiting Chinook salmon abundance, which underscores the difficult trade-offs that are inherent in achieving restoration of native species while supporting fisheries for introduced predators (e.g., Eshenroder and Burnham-Curtis 1999; Dettmers et al. 2012). Moreover, the current low prey biomass suggests that the lake likely cannot support the predator abundances specified in the FCOs. Whether the present state of Lake Huron is an improvement over its past is hard to conclude.

If the Lake Huron ecosystem is indeed shifting to a new stable regime, the consequences for ecosystem services from the lake may take many years to become apparent and, to some extent, depend on what stakeholders want. The stability of the new state is likewise uncertain. Ecosystem stability can be defined in different ways, can be affected by a variety of factors, and is difficult to measure in practice (Ives and Carpenter 2007), and fluctuations and variability in ecosystems are common (Scheffer and Carpenter 2003). Dreissenid abundance appears to continue to expand in Lake Huron, and, if dreissenids are a driver of the recent ecosystemic changes, then instability likely will continue. Stability will also depend on the nature of future perturbations, including new invasions. For instance, little information exists about the potential effects of the latest invasive species, *Hemimysis anomola*, on food webs. Research is needed to determine cause/effect relationships between invasive species and the changes that have been observed.

The current state of Lake Huron should be considered in light of the substantial changes to the ecosystem that occurred in the first half of the 20th century when lake trout and lake whitefish stocks collapsed. Progress appears to be occurring with respect to lake trout rehabilitation, and other native species like bloater and walleye are increasing in abundance, but overall prey-fish abundance remains very low, and other negative effects, such as the resurgence of *Cladophora* and type-E botulism, are occurring. Management agencies should recognize that Lake Huron may be shifting to an alternative regime characterized by lower pelagic-prey availability, higher predation rates on juvenile salmonines, and increased natural reproduction of native and introduced predators. The stability and permanence of this new state are, however, uncertain, which impedes development of relevant management strategies that are economically and socially viable.

Although there are some encouraging signs of progress, the majority of the FCOs for the lake remained unmet in 2010. Previous state-of-the-lake reports for Lake Huron have questioned the relevance of the FCOs (Ebener 2005; Bence and Mohr 2008). Given the recent drastic changes in the ecology of the lake, and in light of the fact that a regime shift in the ecosystem appears to have occurred, it is important that the FCOs be revisited to ensure that they are relevant to the new conditions in the lake.

RECOMMENDATIONS

1. More research is needed on the ongoing changes to food webs and the effects these may have on forage fish and predators. Research is needed that explicitly examines how the ongoing regime shift will play out in Lake Huron.
2. The necessity of lake trout stocking should be reevaluated in light of the widespread natural reproduction currently occurring, as well as of the myriad changes in the lake, including reduced alewife populations, high numbers of sea lampreys, and a potential regime shift.
3. More long-term fishery-independent assessment programs should be established for nearshore fish communities around the lake, as potential shifts in productivity may result in increased fish production and recreational fishery opportunities in nearshore waters.
4. As in previous state-of-the-lake reports, we recommend that the fish-community objectives (FCOs) for Lake Huron be revisited. Given the recent drastic changes in the ecology of the lake and the potential for a permanent regime shift, achievement of the current FCOs may no longer be feasible.
5. Support research and assessment aimed at quantifying the impact of invasive species on native species and at development of appropriate management actions to deal with preventing and/or mitigating invasive-species impacts.
6. Quantify the genetic diversity in fish populations and determine how it is distributed across the lakescape. Comprehensive information of this type still is lacking for many species and is necessary to monitor the long-term stability of fish stocks.

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