

THE STATE OF LAKE HURON IN 2004



SPECIAL PUBLICATION 08-01

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries between Canada and the United States, which was ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: first, develop coordinated programs of research in the Great Lakes, and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; second, formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes.

The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties. In fulfillment of this requirement the Commission publishes the Technical Report Series, intended for peer-reviewed scientific literature; Special Publications, designed primarily for dissemination of reports produced by working committees of the Commission; and other (non-serial) publications. Technical Reports are most suitable for either interdisciplinary review and synthesis papers of general interest to Great Lakes fisheries researchers, managers, and administrators, or more narrowly focused material with special relevance to a single but important aspect of the Commission's program. Special Publications, being working documents, may evolve with the findings of and charges to a particular committee. Both publications follow the style of the *Canadian Journal of Fisheries and Aquatic Sciences*. Sponsorship of Technical Reports or Special Publications does not necessarily imply that the findings or conclusions contained therein are endorsed by the Commission.

COMMISSIONERS

Canada	United States
Peter Wallace, Vice-Chair	Michael J. Hansen, Chair
Robert E. Hecky	William James
Robert G. Lambe	Lyle Laverty
Wendy Watson-Wright	David A. Ullrich
	William W. Taylor (Alternate)

August 2008

THE STATE OF LAKE HURON IN 2004

Edited by

James R. Bence

Department of Fisheries and Wildlife
Michigan State University
East Lansing, MI, 48824, U.S.A.

and

Lloyd C. Mohr

Upper Great Lakes Management Unit
Ontario Ministry of Natural Resources
1450 Seventh Ave. East
Owen Sound, ON, N4K 2Z1, Canada

Citation (entire volume): Bence, J.R., and Mohr L.C. [EDS.]. 2008. The state of Lake Huron in 2004. Great Lakes Fish. Comm. Spec. Pub. 08-01.

Citation (individual chapter): Ebener, M.P., Mohr L.C., Riley, S., Roseman, E.F., and Fielder, D.G. Whitefishes and ciscoes. *In* The state of Lake Huron in 2004. *Edited* by J.R. Bence and L.C. Mohr. Great Lakes Fish. Comm. Spec. Pub. 08-01. pp. 37-46.

Special Publication 08-01

Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 100
Ann Arbor, Michigan 48105-1563

August 2008

ISSN 1090-1051

Printed on recycled paper.

SP08-01/08-2008/900

TABLE OF CONTENTS

Abstract	1
Introduction	3
Offshore Predators and Their Fish Community , James R. Bence, James E. Johnson, Ji He, Jeffrey S. Schaeffer, Stephen Riley, Robert J. Young, Mark Ebener, David Reid, Lloyd C. Mohr, David Gonder, Adam Cottrill, Aaron Woldt, Terry J. Morse, Gavin C. Christie, and Mark Ridgway.....	11
Whitefishes and Ciscoes , Mark P. Ebener, Lloyd C. Mohr, Stephen Riley, Edward F. Roseman, and David G. Fielder	37
Nearshore Fish Community , David G. Fielder, Arunas Liskauskas, Lloyd C. Mohr, and James Boase	47
Issues Relevant across Fish Communities , Arunas Liskauskas, Jerry R. McClain, Stephen Gile, Edward F. Roseman, Wendylee Stott, Mark P. Ebener, James E. Johnson, Kim T. Scribner, and Chris Wilson	59
State of Lake Huron: Current and Future , James R. Bence and Lloyd C. Mohr	71
Recommendations	77
References	79

ABSTRACT

During this five-year reporting period (2000-2004), progress was made in Lake Huron towards achieving the objective of a fish community dominated by top predators, with self-sustaining populations of lake trout (*Salvelinus namaycush*) playing a prominent role. Some examples include increased representation of wild-born lake trout in surveys of adult lake trout, capture of wild young-of-the-year lake trout, and very large reductions in the abundance of the exotic alewife (*Alosa pseudoharengus*), a species that likely impedes the rehabilitation of lake trout and other native species. Sea lamprey (*Petromyzon marinus*) abundance also decreased, which is a benefit for lake trout rehabilitation and for overall usable fish production. On the other hand, concerns have arisen that overall fishery productivity may have declined since 1999, the end of the previous reporting period. While the objective of a diverse salmon and trout fishery has been partially met, the contribution of the once-dominant Chinook salmon (*Oncorhynchus tshawytscha*) has declined dramatically. Overall yield objectives for both salmonid and non-salmonid species appear to be unrealistic. Predators are showing indications of substantial food limitation with overall prey-fish abundance substantially lower in 2004 than in 1999. Substantial uncertainty exists regarding the nature of the productivity changes and the role of dreissenid mussels and other exotic species in these changes. The yield of lake whitefish (*Coregonus clupeaformis*), the dominant commercial species, declined from 1999 to 2004 to levels just below the yield target in the fish-community objective for all coregonines combined. Given the changes in lower trophic levels and the downward trend in lake whitefish yield, the target for coregonine yield, of which lake whitefish is the major component, is likely unsustainable. Lakewide walleye (*Sander vitreus*) yield remained near 35% of the yield target within the fish-community objective. Large year-classes of juvenile walleye were produced in Saginaw Bay in 2003 and 2004. How strongly these year-classes will contribute to fishery yield and whether juvenile abundance has surged elsewhere remains to be determined. Yellow perch (*Perca flavescens*) yield has declined to levels not seen since the 1920s for reasons that are not well understood. However, strong year-classes were observed in 2003 in the main basin. The lake sturgeon remains listed as a Threatened Species in Michigan, and as a Species of Concern in Ontario waters. Although its population increased, much progress is needed before the listings can be removed. Various esocids, centrarchids, and other nearshore species continue to contribute to diverse fishing opportunities. Species diversity remains essentially unchanged since 1999 with the notable reappearance of the shortjaw cisco (*C. zenithicus*), which was thought to be extirpated at the time of the 1999 report. An increasing number of studies of

genetic stock structure have been conducted or are under way, but these projects are not sufficient to fully evaluate progress towards genetic-diversity objectives. In addition to exotic species that may be influencing the food web, invasive plant species are increasingly dominating wetlands and other nearshore areas and are potentially influencing the value of these areas as fish nursery habitat or as areas for recreation. More information is needed to assess progress towards habitat objectives. The foremost recommendation stemming from this report is to reevaluate the use of yield as the major metric for defining fish-community objectives. Increased research is also needed to better understand how lower trophic-level processes impact fish-community structure and production. Other recommendations include maintaining effective sea lamprey control, identifying high-priority habitat in need of protection, and directing more management towards native species restoration.

INTRODUCTION

This report describes changes in the status of the Lake Huron fish community from 2000 to 2004, evaluates progress towards achieving fish-community objectives (FCOs) (DesJardine et al. 1995), and identifies new and emerging issues that will affect future management of the lake. The intent of this third state-of-the-lake report is to build upon the descriptions of the lake and its history presented in previous reports (Ebener 1995; Ebener 2005).

International fishery management on the Great Lakes is coordinated through the Great Lakes Fishery Commission (GLFC). FCOs for the lake (DesJardine et al. 1995) were established in response to the 1994 modification of A Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Plan) adopted in 1997 (Great Lakes Fishery Commission 2007). The GLFC's lake committees are the groups that implement the Joint Plan on each Great Lake. The Lake Huron Committee (LHC) is composed of one fishery manager each from the Michigan Department of Natural Resources (MDNR), the Ontario Ministry of Natural Resources (OMNR), and the Chippewa/Ottawa Resource Authority. FCOs are intended to define objectives for the structure of the fish community and to provide means for measuring progress toward their achievement. The LHC charges the Lake Huron Technical Committee (LHTC) to produce a state-of-the-lake report documenting this progress every five years.

In surface area, Lake Huron is the second largest of the Laurentian Great Lakes and generally is considered oligotrophic, except for Saginaw Bay and several other nearshore areas. Basin morphometry, hydrology, geology, and limnology were summarized in DesJardine et al. (1995) and in Ebener (1995). The lake encompasses three discrete basins (Georgian Bay, the North Channel, and the main basin (which includes Saginaw Bay)). The lake is divided into statistical districts used for reporting and management (Fig. 1). 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 human population centers makes it a prime destination for fishing, boating, and other recreational activities; many resorts and cottages occupy its shores.

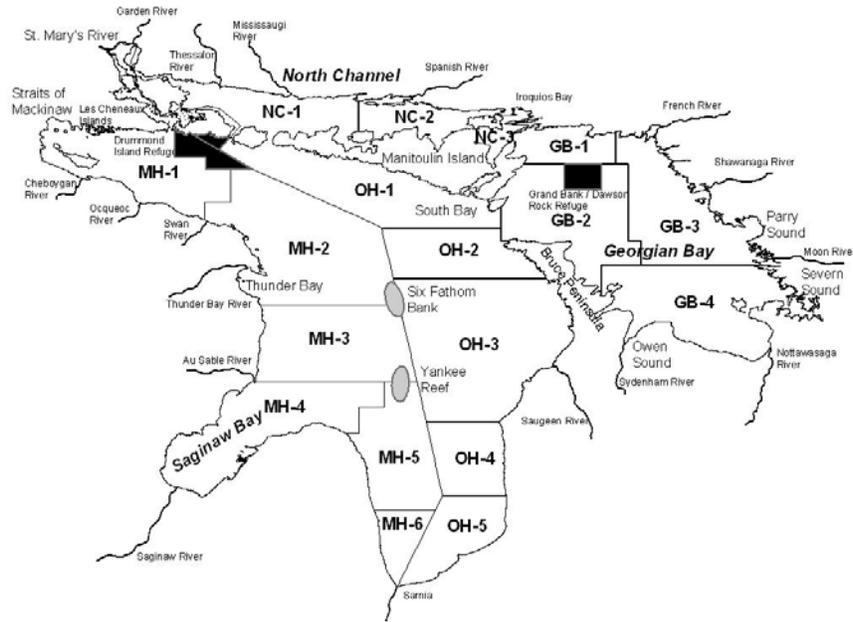


Fig. 1. Map of Lake Huron showing major geographical features and statistical districts.

Prior to 1900, lake trout (an alphabetical list of common fish names and their corresponding scientific names is given in Table 1) was the dominant predator in the lake, and walleye and burbot were subdominants. The prey community was dominated by cisco (formerly lake herring), sculpins, and deepwater ciscoes (members of the lake whitefish (coregonine) subfamily). Round whitefish, lake whitefish, and ninespine sticklebacks 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 by sea lamprey, alewife, and rainbow smelt; over-exploitation of important species; and habitat degradation in nearshore areas and tributaries (Berst and Spangler 1972). Previous reports (Ebener 1995, 2005; Eshenroder et al. 1995; Dobiesz et al. 2005) further documented changes made prior to 1970 as well as during 1970-1999.

Table 1. Common and scientific names of fish species (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	<i>Coregonus hoyi</i>
blackfin cisco**	<i>Coregonus nigripinnis</i>
cisco (formerly lake herring)	<i>Coregonus artedii</i>
deepwater cisco**	<i>Coregonus johanna</i>
deepwater sculpin	<i>Myoxocephalus thompsonii</i>
kiyi**	<i>Coregonus kiyi</i>
lake trout	<i>Salvelinus namaycush</i>
lake whitefish	<i>Coregonus clupeaformis</i>
round whitefish	<i>Prosopium cylindraceum</i>
shortjaw cisco**	<i>Coregonus zenithicus</i>
shortnose cisco**	<i>Coregonus reighardi</i>
Native species—cool water:	
black redhorse	<i>Moxostoma duquesnei</i>
burbot	<i>Lota lota</i>
emerald shiner	<i>Notropis atherinoides</i>
johnny darter	<i>Etheostoma nigrum</i>
lake sturgeon	<i>Acipenser fulvescens</i>
muskellunge	<i>Esox masquinongy</i>
northern brook lamprey	<i>Ichthyomyzon fossor</i>
northern pike	<i>Esox lucius</i>
ninespine stickleback	<i>Pungitius pungitius</i>
slimy sculpin	<i>Cottus cognatus</i>
spottail shiner	<i>Notropis hudsonius</i>
trout-perch	<i>Percopsis omiscomaycus</i>
walleye	<i>Sander vitreus</i>
yellow perch	<i>Perca flavescens</i>
Native species—warm water:	
black crappie	<i>Pomoxis nigromaculatus</i>
channel catfish	<i>Ictalurus punctatus</i>
lake chubsucker*	<i>Erimyzon sucetta</i>
largemouth bass	<i>Micropterus salmoides</i>
pugnose shiner*	<i>Notropis anogenus</i>
pumpkinseed	<i>Lepomis gibbosus</i>
rock bass	<i>Ambloplites rupestris</i>
smallmouth bass	<i>Micropterus dolomieu</i>
spotted gar	<i>Lepisosteus oculatus</i>

Table 1, continued

Common name	Scientific name
Non-native species—cold water:	
Atlantic salmon	<i>Salmo salar</i>
brown trout	<i>Salmo trutta</i>
Chinook salmon	<i>Oncorhynchus tshawytscha</i>
coho salmon	<i>Oncorhynchus kisutch</i>
Pacific salmon	<i>Oncorhynchus</i> spp.
pink salmon	<i>Oncorhynchus gorbuscha</i>
rainbow smelt	<i>Osmerus mordax</i>
rainbow trout	<i>Oncorhynchus mykiss</i>
sea lamprey	<i>Petromyzon marinus</i>
Non-native species—cool water:	
alewife	<i>Alosa pseudoharengus</i>
round goby	<i>Neogobius melanostomus</i>
ruffe	<i>Gymnocephalus cernuus</i>

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 kilograms annually (DesJardine et al. 1995). During 1912-1940, the commercial yield appeared stable and was supported by a number of native species. This relatively stable annual yield (8.9 million kg) 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 2000-2004, reported yields have declined modestly, averaging 62% of the overall yield objective and ranging between 5.3 and 5.5 million kg (Fig. 2a). The current (2004) commercial yield amounts to approximately 75% of the actual total yield. This 75% figure is based on the observation that 87% of the reported yield in 2004 was from the commercial fishery, 13% from the Michigan recreational fishery, and the assumption that the Ontario recreational fishery (confined mostly to Georgian Bay (Mohr and Ebener 2005a)) was assumed to be similar in scale to Michigan's and produced a similar yield.

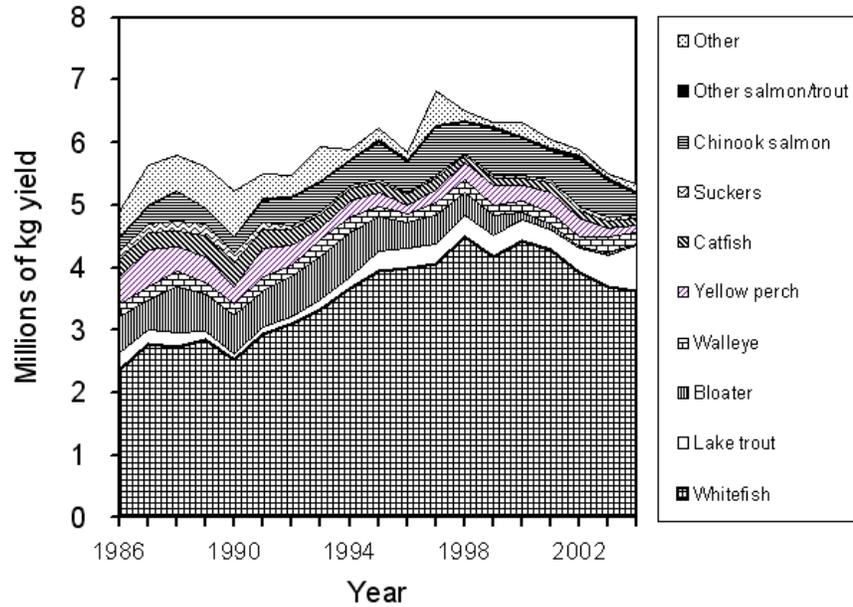


Fig. 2a. Total annual yield from Lake Huron during 1986-2004.

Overall, the fish-species composition in Lake Huron has not changed from what was reported by Ebener (2005) for 1999. However, some substantial changes in relative abundance of individual species, with consequences for achieving FCOs, have occurred. These changes will be described in subsequent sections and involve large declines in prey species, such as alewife (an exotic prey 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 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 (Fig. 2b), its importance appears to have 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 are not yet self-sustaining and continue to be supported by stocking, except in the Parry Sound area of Georgian Bay (Reid et al. 2001).

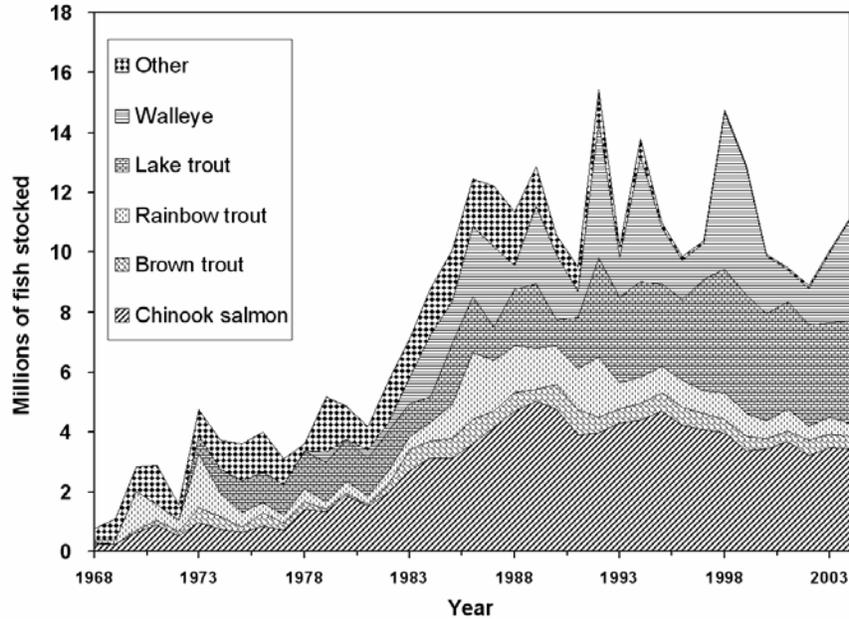


Fig. 2b. Total numbers of hatchery-reared fish stocked into Lake Huron, 1968-2004. Chinook salmon are stocked primarily as spring fingerlings, walleye as fall fingerlings, and other species as yearlings. For rainbow trout and lake trout, fall fingerlings were multiplied by 0.3 and added to yearling totals. Egg and fry stocking is not included.

The commercial fishery operates primarily with large- and small-mesh gillnets and trapnets in all three basins (for a review of the fisheries, see Mohr and Ebener (2005a)). Coregonines, especially lake whitefish, continued to dominate the 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-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 3.35 million m (11 million ft) in 1999, and a number of gillnet operations converted to trapnets. Furthermore, the settlement led to annual limits or target yields being established for lake trout and lake whitefish.

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 a number of 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, and similar programs are in place in eastern Georgian Bay and the North Channel.

Subsequent sections of this report address, in order, offshore predators and their fish community, whitefishes and ciscoes, the nearshore fish community, and issues relevant across fish communities (including species and genetic diversity, habitat, invasive species, and lower trophic levels). This report ends with our overall conclusions and recommendations.

OFFSHORE PREDATORS AND THEIR FISH COMMUNITY

James R. Bence

Department of Fisheries and Wildlife
Michigan State University
East Lansing, MI, 48824, U.S.A.

James E. Johnson and Ji He

Michigan Department of Natural Resources
Alpena Fisheries Research Station
160 E. Fletcher St.
Alpena, MI, 49707, U.S.A.

Jeffrey S. Schaeffer and Stephen Riley

U.S. Geological Survey—Great Lakes Science Center
1451 Green Road
Ann Arbor, MI, 48105, U.S.A.

Robert J. Young

Department of Fisheries and Oceans
Sea Lamprey Control Center
1 Canal Drive
Sault Ste Marie, ON, P6A 1P0, Canada

Mark Ebener

Inter-Tribal Fisheries and Assessment Program
Chippewa/Ottawa Resource Authority
179 W. Three Mile Road
Sault Ste. Marie, MI, 49783, U.S.A.

David Reid, Lloyd C. Mohr, David Gonder, and Adam Cottrill

Upper Great Lakes Management Unit
Ontario Ministry of Natural Resources
1450 Seventh Ave. East
Owen Sound, ON, N4K 2Z1, Canada

Aaron Woldt

U.S. Fish and Wildlife Service
Alpena Fishery Resources Office
145 Water St., Rm. 204
Alpena, MI, 49707, U.S.A.

Terry J. Morse

United States Fish and Wildlife Service
Marquette Biological Station
1924 Industrial Parkway
Marquette, MI, 49855, U.S.A.

Gavin C. Christie

Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 100
Ann Arbor, MI, 48105, U.S.A.

Mark Ridgway

Ontario Ministry of Natural Resources
Harkness Laboratory of Fisheries Research
Trent University
2140 East Bank Drive
Peterborough, ON, K9J 7B8, Canada

*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 above statement from DesJardine et al. (1995) is the overarching objective for Lake Huron's offshore predators, a group comprising one native salmonine, six introduced salmonines, and one non-salmonine, the burbot. We will discuss the status of each species, and, in addition, describe the status of their prey, the status of the sea lamprey (which preys on salmonines), and the status of the double-crested cormorant, a competing predator. We further note that the envisioned yield from self-sustaining lake trout stocks would be 1.4-1.8 million kg (DesJardine et al. 1995), implying that the other (non-lake trout) salmonines should be able to sustain harvests of 0.6-1.0 million kg. The annual salmonine yield for this five-year reporting period (2000-2004) averaged roughly 1.6 million kg, of which 0.5 million kg was lake trout. These figures are based on reported yields, except that Michigan's reported recreational yield of Chinook salmon was doubled to account for Ontario's Chinook salmon fishery, which was not surveyed (see the Introduction section). Therefore, the estimated yield (reported and non-reported) of other (non-lake trout) salmonines, amounting to 1.1 million kg,

exceeded, on average, the upper bound of its objective (1.0 million kg). Lake trout yield, which was largely derived from hatchery fish, was well less than half its objective. However, the yield of Chinook salmon decreased during the reporting period, while the yield of lake trout increased.

Lake Trout

The reported yield of lake trout in 2004 reached approximately 0.7 million kg, which was more than double the 1999 yield but still just half of the yield target specified in the FCO. Unfortunately, the objective applies to wild-born trout, and the entire 2004 yield was essentially of hatchery-origin trout. Commercial harvest amounted to 65% of the 2004 reported overall yield. Increases in yield occurred in both the recreational and commercial fisheries in all basins of Lake Huron, although the greatest increase occurred in the main basin.

Although the lake trout objective is framed in terms of sustainable harvest, the lake trout rehabilitation guide for Lake Huron (Ebener 1998) recommends that success be measured based on population parameters, including abundance, mortality, age structure, growth, and natural reproduction. The guide outlines three milestones for the rehabilitation process, which we paraphrase as:

1. Measurable numbers of wild lake trout are being produced
2. Wild spawning stocks are self-sustaining
3. The ecological community associated with lake trout does not inhibit lake trout survival or reproductive success

The guide also indicates that annual mortality should not be higher than 40% during the process of rehabilitation, and it identifies indicators of progress toward each milestone.

Development of a substantial stock of mature hatchery-origin fish, comprising multiple ages, is a precursor for achievement of the first milestone. To achieve this milestone, an average of 3.4 million age-1 lake trout were stocked annually during 2000-2004 (Fig. 2b), and half of these were stocked in the main basin. This level of stocking has been relatively constant since 1992 but has been below the recommended 4.7-5.9 million per year (Ebener 1998). During 2000-2004, stocking increased in northern and north-central waters (49% of total) partly in response to lower expected

lake trout mortality due to improved sea lamprey control and fishery regulation associated with the 2000 Consent Decree (United States vs. Michigan 2000). This change in stocking locations is important because it represents an increase in the proportion of lake trout being stocked into the historically most-important spawning grounds. Several strains of lake trout, including two remnant strains (Parry Sound and Iroquois Bay) continue to be evaluated and utilized in Lake Huron consistent with recommendations in the guide (Ebener 1998).

Based on statistical catch-at-age models (e.g., Woldt et al. 2005b), the abundance of age-5 and older lake trout increased more than 38% (from 0.87 to 1.20 million) in the main basin from 1999 to 2004. The trend of increasing abundance started already in 1992 (Fig. 3) and is attributed to decreases in mortality. Total mortality was below the target of 40% in northern and north-central waters of the main basin. In the southern main basin, total mortality declined through 2002 and fell below 40%, but total mortality increased to more than 50% in 2003 and 2004 due to increased commercial and recreational fishing. As of 2004, estimates of basinwide mortality suggested that approximately half was due to fishing with the remainder resulting from sea lamprey predation and natural sources.

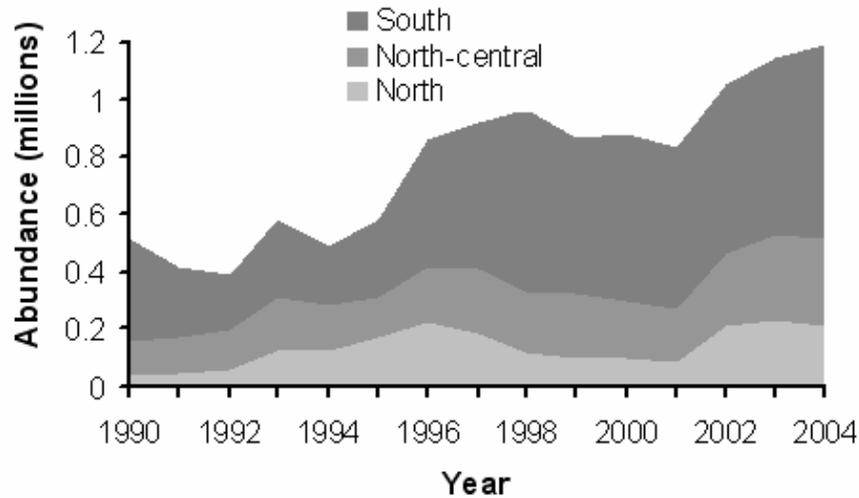


Fig. 3. Estimated abundance of age-5 and older lake trout in three regions of the main basin of Lake Huron based on statistical catch-at-age models. The northern region corresponds to MH-1 and adjacent Ontario waters, the north-central region corresponds to MH-2 and adjacent waters, and the southern region corresponds to MH-3, the adjacent waters, and waters farther south (see Fig. 1 for locations).

In the main basin, estimated female spawning-stock biomass increased nearly 90% (from 0.51 to 0.95 million kg) from 1999 to 2004, which was a much larger increase than the 38% increase in abundance. Substantial decreases in age at maturity caused this increase, and this surprising influence of a life-history response is worth noting. During 2000-2004, the mean age at which 50% of the female lake trout were mature was 6.0, 5.7, and 5.4 years in northern, north-central, and southern waters of the main basin, respectively. This mean age represents about a six-month decrease in mean age at 50% maturity since 1999 and a decrease of 1-2 years (depending on area) since 1990. These changes are important because, all else equal, earlier maturity implies the fish have higher expected lifetime reproductive output and will contribute more to rehabilitation.

Length at age declined in the southern and north-central waters of the main basin, although this decline was only evident for ages 7 and above in the north-central waters. Body condition (mass at length) decreased rapidly lakewide from 2002 to 2004 when it reached its lowest observed level (He et al. 2008). Although lake trout in the northern waters of the main basin also

experienced a decrease in age at maturity and a decline in condition, their mean length at age actually increased. Given the similar maturity and condition changes, we suspect the increase in length at age in the north may partly reflect a release from size-selective mortality caused by the sea lamprey (see the subsections on sea lamprey and related discussion for burbot) rather than a growth response. Although body condition remains highest in the southern main basin and lowest in the north-central main basin, the basinwide declines in condition from 2002 to 2004 started in the south, and these waters experienced the largest decline. These declines in condition were associated with a large decline in abundance of alewife and other prey fishes (see the Prey Fish subsection). Beginning in 2002, the contribution of alewife to lake trout diets decreased in the southern main basin, and, by 2004, the species had nearly disappeared from diets (JEJ and JH, unpublished data). A similar decrease began in 2003 in the central waters of the main basin, but alewives remained common in lake trout diets in the northern part of the main basin through 2004. As alewife became scarcer in lake trout diets, total ration decreased, smelt became the most-common prey type, and diet diversity increased.

Increases in recruitment of wild lake trout have been observed in several locations in Lake Huron. Lakewide bottom-trawl surveys conducted by the Great Lakes Science Center (GLSC) in the main basin heretofore have rarely captured age-0 wild-born lake trout, but 22 were captured in the fall of 2004. Similarly, 11 wild age-0 lake trout were caught by the MDNR in 2004 during bottom-trawl surveys of Thunder Bay (Fig. 1), a number nearly matching the total catch from 1996 to 2003. In addition, wild lake trout were making up an increased proportion of older fish. The percentage of unclipped (assumed wild) spawning lake trout observed during fall gillnet surveys at two reefs in Thunder Bay reached or exceeded 35% in 2004. In South Bay (Manitoulin Island, Fig. 1), unclipped lake trout (mostly immature) amounted to 88% of the summer index catch from 2001 to 2004; during spawning assessments, an average of 48% of the catch was unclipped during the same period. In southern Georgian Bay near Owen Sound, the percentage of unclipped adult lake trout in fall spawning-stock assessments increased from 19% in 2000-2002 to 30% in 2004, and more-limited data from other sites suggested that unclipped trout may be widespread. While these are encouraging signs, the Parry Sound lake trout population remains the only spawning stock dominated by wild lake trout and considered rehabilitated (Reid et al. 2001).

In summary, the first milestone for lake trout rehabilitation in Lake Huron, measurable numbers of wild lake trout being produced, appears to be at hand at several locations. This progress may be maintained if, at a minimum, the

current levels of yearling stocking, sea lamprey control, and fishery regulation are maintained. With an increasing presence of mature wild adult lake trout in some locations, the second milestone pertaining to self-sustaining wild spawning stocks is within sight.

Other Salmonine Predators

There are neither FCOs nor lakewide management guides for individual salmonine species within the “other salmonines” group, which excludes lake trout. Within this group, quantitative estimates of stock size and consumption of prey have been calculated only for Chinook salmon—the remaining species are considered to have played a lesser role in the overall predator-prey dynamics of the lake (Dobiesz 2003). Although lacking species-specific objectives, the group as a whole is expected to yield 0.6-1.0 million kg annually (see above), and each species contributed to an objective for a diverse salmonine community and fishery.

Chinook Salmon

Chinook salmon have been stocked by the MDNR since 1968 and by nongovernmental agencies in Ontario (Whelan and Johnson 2004; Woldt et al. 2005a). Lakewide stocking rates peaked at 5 million fish in 1989 (Fig. 2b). Stocking was capped at 1990 levels in 1991 due to concerns that predator consumption may have exceeded prey production. From 1991-1998, Chinook salmon stocking averaged nearly 4.2 million fish annually. It was reduced in 1999 to 3.5 million fish annually, in response to concerns of reduced prey abundance (Dobiesz 2003). Large reductions in stocking were considered again in 2004 due to declining prey-fish abundance (see the Prey Fish subsection) and declines in Chinook size-at-age and condition.

Prior to the 1980s, no reproduction of Chinook salmon was detected in Michigan tributaries (Carl 1982) or elsewhere in Lake Huron. However, from 1985-1987, presumed-wild Chinook salmon smolts were found in Ontario tributaries to southern Georgian Bay and to the main basin (OMNR, unpublished data). Shoal spawning by Chinook salmon was also reported in 1987 on lake trout spawning reefs in the North Channel (Powell and Miller 1990).

A study of the 1991-1995 Chinook salmon year-classes suggested that 15% of the age-0 recruits in Michigan waters were wild fish. In a more-recent study of the 2000 to 2004 year-classes as they recruited to the summer recreational fishery in both Michigan and Ontario waters, wild fish made up approximately 80% of the total lakewide catch. In retrospect, the estimate of

15% wild for the 1991-1995 year-classes was likely low, because it was based on sampling only age-0 fish near stocking locations at a time when stocked fish would not have been fully dispersed. On the other hand, because of a coded-wire-tag study reported by Johnson et al. (2007), we are confident that the percentage of wild Chinook salmon recruiting to the fishery was substantially less than 80% during the mid-1990s. Therefore, an overwhelming abundance of wild Chinook salmon did not occur until the late 1990s, at the earliest.

Wild Chinook salmon made up almost all (85-100%) of the spawning fish during 2002-2004 in four northern main basin and North Channel tributaries (Garden, St. Marys, Saugeen, and Carp Rivers) and in three Georgian Bay tributaries (Nottawasaga, Beaver, and Sydenham Rivers) (R. Greil, personal communication, 2005; DG, unpublished data). Therefore, we assume that other relatively unobstructed tributaries in Ontario, of which there are many, also contributed highly to production of naturally reproduced adults. In Michigan waters of Lake Huron, wild fish are thought to contribute measurably to recruitment in only the St. Marys, Carp, and Rifle Rivers, because other large cold-water tributaries are dammed near their mouths (Gebhardt et al. 2005). The contribution of shoal spawning to Chinook salmon recruitment remains to be quantified.

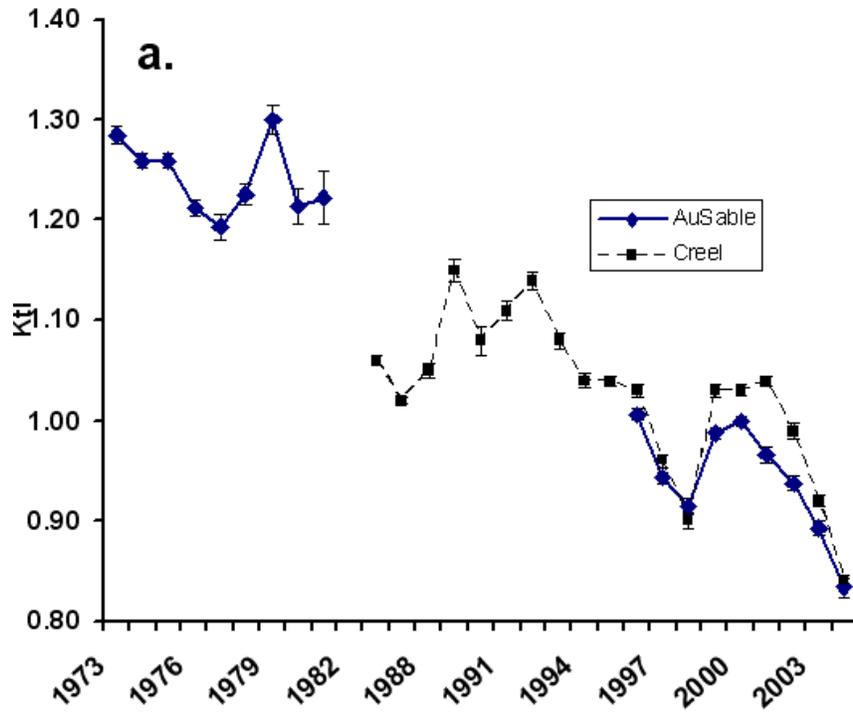
The recreational harvest of Chinook salmon at ten Michigan ports surveyed since 1986 declined in 1998-2001 but remained above 1986-1994 levels (Table 2). Harvest rose again in 2002 and was followed by a steep decline into 2004, when harvest reached its lowest point since 1992. Ontario creel data, available for some ports, indicated similar trends. The cycles of rising and falling rates in both jurisdictions do not appear to be correlated with stocking levels. The commercial yield of Chinook salmon in northern Michigan waters peaked in 1993 and has declined ever since. Total yield, which is reported only for Michigan, reached its second-highest level in 2002 (745,000 kg). However, both commercial and recreational harvests declined subsequently, and by 2004 total yield was less than 50% (322,000 kg) of what it was in 2002.

Table 2. Harvest in numbers of salmonines from ten index ports in the Michigan waters of Lake Huron, 1986 to 2004 (Michigan Department of Natural Resources, unpublished data).

Year	Chinook Salmon	Coho Salmon	Lake Trout	Brown Trout	Pink Salmon	Atlantic Salmon	Rainbow Trout
1986	85,669	6,801	53,530	15,286	104	0	5,090
1987	79,976	3,524	42,430	7,416	9,242	0	6,148
1988	90,134	4,126	39,644	2,730	141	17	2,658
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	18,116	1,685	4,728	0	4,294
1992	40,751	768	13,300	3,312	372	39	5,605
1993	49,115	1,061	6,570	7,765	1,702	158	7,024
1994	55,149	1,360	13,708	12,714	0	0	10,526
1995	96,393	1,897	34,360	14,086	799	301	17,807
1996	84,013	1,970	35,929	9,375	1,286	92	14,472
1997	125,490	2,719	48,142	3,735	751	138	12,146
1998	89,282	1,338	54,539	3,196	742	23	6,267
1999	75,398	5,014	36,810	1,826	1,062	96	8,757
2000	65,351	3,467	27,442	2,697	2,670	143	9,135
2001	58,584	2,003	18,846	1,669	9,332	312	7,546
2002	107,135	12,006	28,209	4,029	3,297	134	7,971
2003	83,376	1,362	43,981	5,743	391	130	4,791
2004	44,350	1,727	60,866	2,200	6,728	110	4,822

Size-at-age and body condition of Chinook salmon have declined since the 1970s (Fig. 4). Lowest values, which occurred in 1997-1998 and 2003-2004, followed times when pelagic prey was at low abundances (see the Prey Fish subsection). Although data are limited, large declines in growth and condition in Ontario waters were similar to those observed in Michigan waters. Chinook salmon now grow slower in Lake Huron than they did in Lake Michigan when a large die-off of salmon was thought to have resulted

from diseases induced by food limitation (Holey et al. 1998). The limited data on the diet of Chinook salmon suggest that alewife and rainbow smelt are the dominant food items, and bioenergetics modeling demonstrated that Chinook salmon were the largest consumer of alewives in the late 1990s (Dobiesz 2003). A population decline in both of these prey species (see the Prey Fish subsection) would have serious implications for Chinook salmon condition and survival.



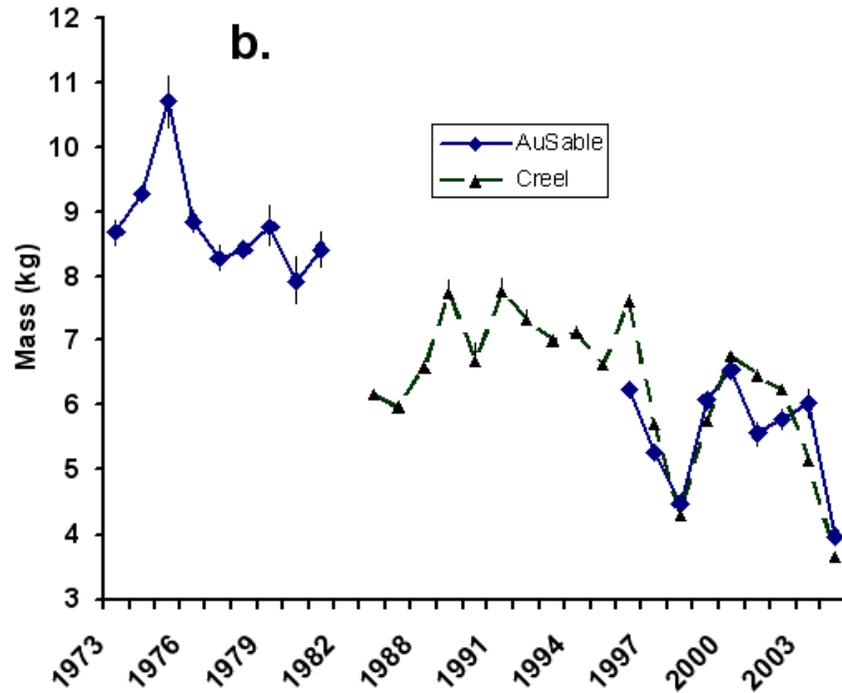


Fig. 4. (a) Body condition (Ktl) and (b) mass at age 3 of Chinook salmon from the recreational catch and fall sampling of the Au Sable River (no data collected 1982-1985).

Rainbow Trout

Stocked and wild rainbow trout (also referred to as steelhead) continued to contribute to a diverse salmonine community and fishery in Lake Huron as they did in 1995-1999 (Woldt et al. 2005a). Stocking of yearling rainbow trout fluctuated during 2000-2004, averaging 107,000 yearlings annually (Fig. 2b). All stockings of rainbow trout in Ontario waters were made by nongovernmental partners, who, in addition to stocking yearlings, planted an average of 313,000 fry annually in tributaries of the main basin and Georgian Bay.

All stocked yearling rainbow trout of the 1995-2004 year-classes were fin clipped to allow for estimation of levels of natural reproduction. During 2000-2004, an average of 42% of the rainbow trout observed in the Michigan creel (resulting from the 1995-2002 year-classes) had fin clips (JEJ, unpublished data). Up to 50% of the rainbow trout sampled at fishways in Ontario's main basin tributaries originated from fish stocked by Michigan, and the remainder were unclipped (Gonder 2005). Natural reproduction is limited in Michigan waters due to the presence of dams on most cold-water streams. Many of the unclipped fish harvested in Michigan waters were suspected of being wild fish produced in Ontario tributaries, although some of these fish could have resulted from fry stockings made in Ontario's waters (fry are not clipped). In Ontario waters, recruitment of wild fish remained substantial during 2000-2004 but was lower than in previous reporting periods.

Recreational harvest at Michigan's ten index ports (commercial harvest is not permitted in either jurisdiction) averaged over 11,000 fish during 1995-1999 (Woldt et al. 2005a) but declined to an average of below 7,000 during 2000-2004 (Table 2). Total yield in Michigan was over 22,000 kg during 2000-2002, which was somewhat above the 20,000 kg average for 1995-1999. Yield then fell to about 12,000 kg for 2003-2004, resulting in an average yield of 18,000 kg during 2000-2004. High exploitation in Ontario waters, despite stricter recreational-fishing regulations initiated in 1999, has contributed to cyclical levels of abundance there. In Georgian Bay, no discernible recovery to former levels of abundance has been observed (Gonder 2005).

In summary, harvest trends and other evidence suggest a possible decline, and certainly no increase, in rainbow trout abundance during the past five years. This species makes up only 1.8% of the total salmonine yield; thus, its current contribution to the desired diverse salmonine fishery is modest.

Brown Trout

Brown trout are stocked in Lake Huron to create diversity in the salmonine community, offer a nearshore fishery less seasonal than that for Chinook salmon, and provide an opportunity for anglers to harvest quality-to-trophy-size fish (Woldt et al. 2005a). Brown trout stocking in all jurisdictions of Lake Huron from 2000 to 2004 averaged 420,000 fish \cdot y⁻¹ (Fig. 2b), a figure similar to the average annual stocking rate in the 1990s. During 2000-2004, average reported yield of brown trout in Michigan waters of Lake Huron was 11,000 kg. Very little catch is reported from Ontario waters.

Although the yield for brown trout during 2000-2004 was approximately one-half that of rainbow trout, harvests had been similar for rainbow and brown trout at index ports in Michigan waters in the late 1980s and early 1990s. In the late 1990s, the harvest of brown trout declined more than did that of rainbow trout (Table 2), despite a series of management changes designed to improve the post-stocking survival of brown trout (Johnson and Rakoczy 2004). In years when large spawning aggregations of alewives occurred inshore at the time brown trout were stocked, survival was better, as evidenced by subsequent contributions to the sport fishery (Johnson and Rakoczy 2004). Stocked brown trout apparently do not migrate offshore to areas where predators may be less abundant, so the alewife may buffer them from predation. In the Thunder Bay area, cormorant predation has been implicated in reducing survival of recently stocked brown trout (Johnson and Rakoczy 2004). Recent drastic declines in alewife abundance could lead to even poorer recruitment of brown trout to the sport fishery.

Atlantic Salmon

Beginning in 1985, the Lake Superior State University, Edison Sault Electrical Company, and MDNR cooperatively stocked Atlantic salmon in the St. Marys River (Woldt et al. 2005a). Annual stocking has averaged about 40,000 yearlings. Since the 1990s, gametes for the stocking program have been taken from adults returning to the river, with the exception of 2000 when, because of losses in the university's hatchery, the MDNR provided young Atlantic salmon originally destined for inland lakes. Reported harvests have been low and fluctuated widely, with a peak of more than 300 fish in 2001 and about 100 fish each year during 2002 to 2004 at the ten Michigan index ports (Table 2). Actual harvest is substantially higher because the main Atlantic salmon fishery, located in the St. Marys River and Detour Island area, is not surveyed each year. In 2001, a creel survey estimated that 488 Atlantic salmon were harvested from the St. Marys River (Fielder et al. 2002).

Coho Salmon

Although no coho salmon have been stocked into Lake Huron since 1989, naturalized populations have continued to survive in several locations, including tributaries on the southern shore of Manitoulin Island and the Alcona, Black and Carp Rivers in Michigan. The harvest of coho salmon at the ten Michigan index ports on Lake Huron peaked in 2002 at more than 12,000 fish, almost double that of any other year. In most years, harvest was less than 2,000 fish (Table 2). Average annual yield during 2000-2004 was

10,000 kg. Without the exceptional yield of 32,000 kg in 2002, the average would be closer to 5,000 kg.

Pink Salmon

Pink salmon naturalized in Lake Huron following an accidental introduction into Lake Superior in the 1950s (Nunan 1967). Pink salmon normally mature and spawn at age 2 before dying (Kwain 1982), but, in recent years, substantial numbers of pink salmon returning to spawn in the St. Marys River have been of ages 3 and 4, a life-history pattern that has not been reported elsewhere (Kennedy et al. 2005). Since 1986, the average Michigan index-port sport-harvest estimate amounted to 2,500 fish (Table 2). A peak harvest of more than 9,000 fish was recorded at the same ports in 2001, but lower harvests followed in 2002 and 2003. In 2004, almost 7,000 fish were harvested, which was the first time a high harvest had occurred in an even-numbered year (Table 2). Average reported yield in Michigan during 2000-2004 was 3,000 kg. Spawning runs in the St. Marys River at one time were dominant in odd-numbered years, then changed to roughly equal numbers each year, and then became dominant in even years (Kennedy et al. 2005).

Burbot

The FCOs for Lake Huron recognize that burbot is important because of its ecological significance; intrinsic value; and social, cultural, and economic benefits (DesJardine et al. 1995). Burbot accounted for roughly 15% of the estimated predator consumption in the main basin of Lake Huron in the late 1990s (Dobiesz et al. 2005). Burbot are caught incidentally in bottom-set graded-mesh gillnet surveys and in the commercial fishery. The commercial fishery harvested nearly 15,000 kg of burbot annually during 1990-1999 (Lake Huron Technical Committee, unpublished data), but only 1,064 kg were reported harvested in 2004.

Burbot inhabit all depths of Lake Huron but are most abundant in waters 20-45-m deep. Large burbot appear to inhabit shallower water than small burbot, as evidenced by a decline in average total length of 628 mm at 0-9 m depths to near 500 mm in depths of 30 m or greater, based on graded-mesh gillnet samples from northwestern waters of the main basin (MH-1) during 1991-2004. Abundance of burbot has declined since 1999 (Schaeffer and Woldt 2005; Stapanian et al. 2008), but the declines occurred primarily in Michigan waters, most markedly in the southern part of the main basin (MH-3, 4, and 5) (Fig. 5).

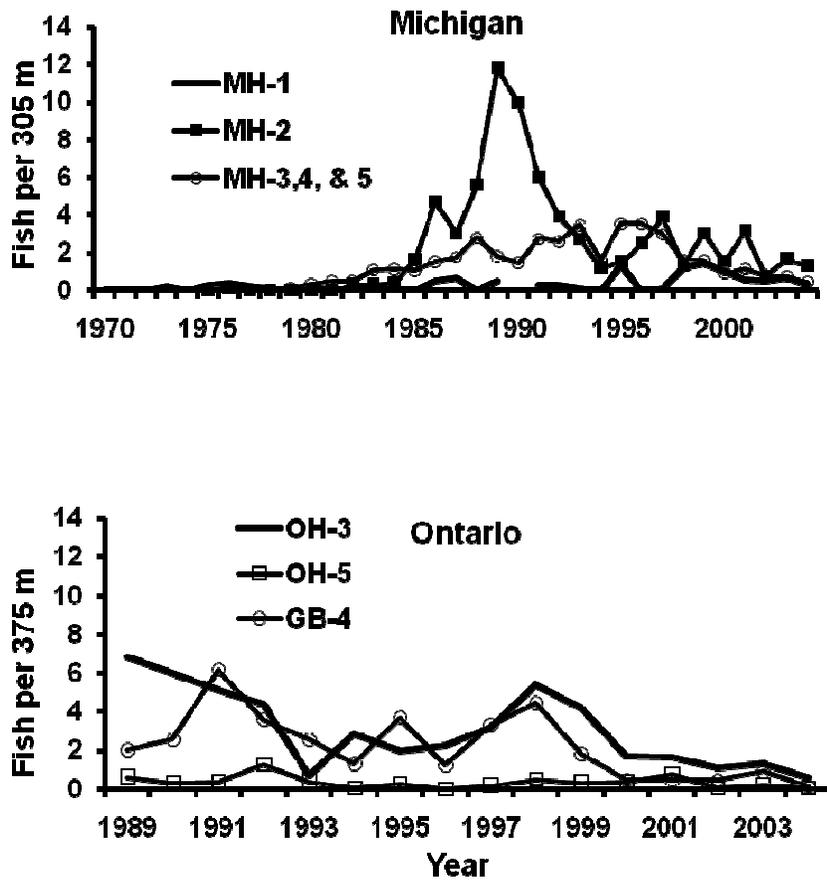


Fig. 5. Catch per effort of burbot in graded-mesh gillnets in Michigan and Ontario statistical districts of Lake Huron (see Fig. 1 for locations).

Burbot from Michigan waters of Lake Huron exhibited a broad age structure indicative of low mortality. From 1997 to 2004, burbot sampled in Michigan waters ranged in age from 3 to 28 y and had a median age of 12 y. Burbot captured in the Northern Refuge (Fig. 1) during the same period had the same age range and a median age of 13 y. The total instantaneous mortality rate of burbot in the Northern Refuge during 1997-2004 was estimated by catch-curve analysis to be $0.21 \cdot y^{-1}$ at ages 13-18 and $0.64 \cdot y^{-1}$ at ages 18-22.

The presence of older-aged burbot in northern parts of the lake may reflect slow growth and the consequent long delay in reaching larger sizes. A sizable amount of size-selective mortality may have been occurring on burbot in MH-1. Only 3% of burbot caught during spring graded-mesh gillnet surveys exceeded 650-mm total length during 1997-2004, as compared to 23% and 58% in MH-2 and MH-3, 4, and 5 (combined), respectively. In MH-1, mean length-at-age of burbot reached an asymptote of roughly 540 mm at age 10. In comparison, length-at-age continued to increase after age 10 in MH-2 and even more so in MH-3. Either growth has been very limited for larger fish in MH-1, or size-selective mortality has removed the largest burbot. Consistent with this latter hypothesis, sea lamprey marking of burbot has been substantially higher in MH-1 than in other statistical districts. Marking on burbot in MH-1 declined from an average of 8.5 marks/100 fish during 1991-1995 to 2.3 marks/100 fish during 1996-2000. Marking then increased to 4.5 marks/100 fish during 2001-2004. The reason for the change in marks per fish remains unclear as this pattern was not like that observed for lake trout.

Double-Crested Cormorant

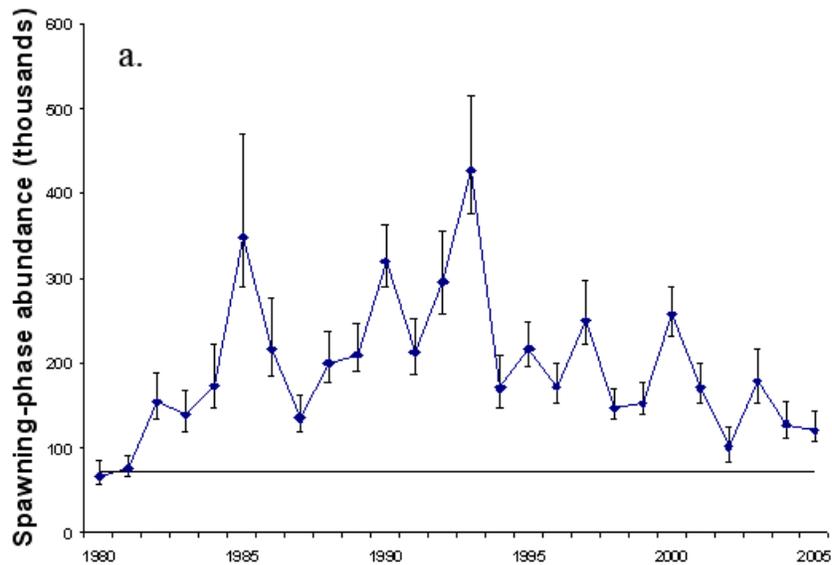
The consumption of prey fish by double-crested cormorants has become large enough that it needs to be considered in estimates of lakewide prey-fish consumption. The population of this piscivorous waterbird declined to low levels by the 1970s due to eggshell thinning and other reproductive anomalies associated with DDT contamination (Ludwig and Summer 1997). Following the ban on DDT, the lakewide population increased, occupying about 45,000 nests by 2000 (DGF, personal communication, 2006; Weseloh et al. 2002), with 38% of nests dispersed around the main basin and the remaining nests divided about equally between the North Channel (including the St. Marys River) and Georgian Bay (Dobiesz et al. 2005). Dobiesz et al. (2005) estimated that resident cormorants in 2000 consumed approximately 13.9 million kg of fish, 5.3 million kg of which was consumed in the main basin. This main basin consumption equaled 18% of the consumption these authors had estimated for the major piscivores (lake trout, Chinook salmon, burbot, and walleye) in the main basin, exclusive of Saginaw Bay in 1996-1998. By 2000-2001, cormorant populations may have been approaching carrying capacity. By 2004-2005, the number of nests declined by about 38% (DGF, personal communication, 2006; Ridgway et al. 2006), possibly in response to declines in alewife abundance (Ridgway et al. 2006). These declines were most marked in the North Channel (including the St. Marys River area) and in Georgian Bay. In the main basin, declines in bird numbers in Ontario waters and in the Les Cheneaux Islands were offset by increases

in Thunder Bay and Saginaw Bay. Control efforts, such as those that began in the Les Cheneaux Islands and used experimentally in the North Channel and Georgian Bay, may cause future declines in cormorant numbers.

Sea Lamprey

Reduce sea lamprey abundance to allow the achievement of other fish-community objectives. Obtain a 75% reduction in parasitic sea lampreys by the year 2000 and a 90% reduction by the year 2010.

The above objectives (DesJardine et al., 1995) were augmented by the LHC in 2004 to include a population reduction of adults to less than 73,000 and a reduction in marking rates on lake trout to five per 100 fish or less. These objectives are indeed ambitious in view of an estimate that, in 1999, the sea lamprey population of Lake Huron exceeded the populations in all the other Great Lakes combined (Morse et al. 2003). Although both adult (spawning-phase) sea lamprey abundance and lake trout marking rates have subsequently declined, they remain above target levels. Average abundance of spawning sea lamprey was 11% lower during 2000-2004 than it was during 1995-1999 (Fig. 6a). A1-A3 marks on lake trout (King 1980; Ebener et al. 2006) declined approximately 40% between these periods (Fig. 6b).



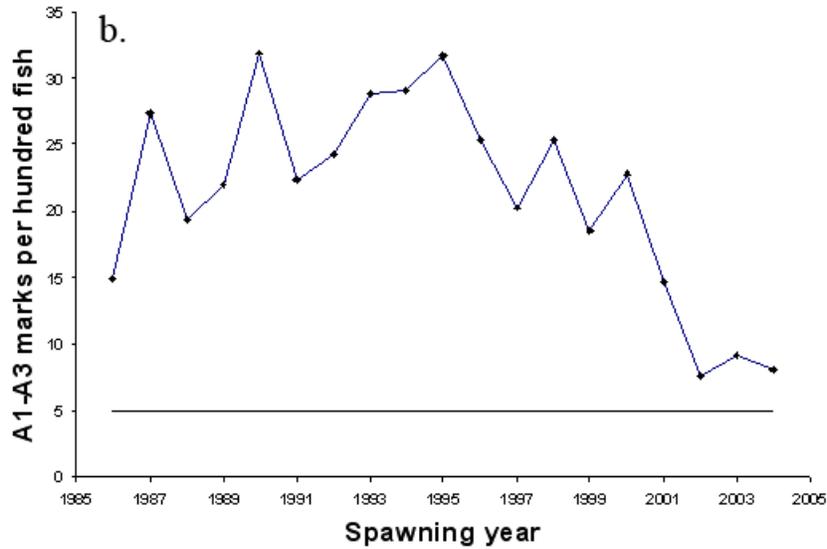


Fig. 6. Population estimates and 95% confidence intervals of spawning sea lampreys in Lake Huron (a), and spring A1-A3 sea lamprey marking rates on lake trout >533 mm total length, 1986-2004 (b). The horizontal lines represent the Lake Huron Committee's targets.

Trends in abundance of recently metamorphosed and parasitic-phase sea lampreys available for 1994-1995 and for 1999-2004 (Bergstedt et al. 2003; Klar and Young 2005) are inconsistent. Taken together, the trends for each life stage do not clearly indicate a decline since the mid-1990s (Young 2005). The contradictory patterns could reflect either large measurement errors in the mark and recapture studies or substantial temporal changes in the survival of transformers. The latter possibility would imply that, in the short term, damage caused by sea lamprey will only weakly correlate with control effort.

During 2000-2004, the GLFC increased its lampricide treatments on nursery streams and maintained its integrated control efforts on the St. Marys River. The TFM lampricide is the primary sea lamprey control tool used in Lake Huron tributaries, exclusive of the St. Marys River (Brege et al. 2003; Morse et al. 2003; Schleen et al. 2003). These TFM-treated tributaries contain approximately 66% of the larval habitat in the basin (GC, unpublished data). The average annual number of streams treated with TFM increased by

approximately 10% from 2000-2004 (16.6 treatments annually) to 1990-1999 (15.0 treatments annually) (Morse et al. 2003; Morse and Young 2005).

Prior to 1995, the production of recently transformed sea lampreys from the St. Marys River, which contains the remaining third of larval habitat in the basin, was virtually unchecked. TFM treatment would have been too costly, and its effectiveness on the St. Marys River was questioned. An integrated control strategy was initiated in 1997 and consisted of targeted Bayluscide applications, enhanced trapping of spawning-phase lampreys, and release of sterilized male lampreys (Schleen et al. 2003; Twohey et al. 2003). Prior to 2000, integrated lamprey control reduced the larval population from 5.2 million to 2.1 million (Morse and Young 2005; J. Adams, personal communication, 2005). An additional 221 hectares of larval habitat have been treated or re-treated with granular Bayluscide since 1999. Also, an average of 10,800 spawning-phase lampreys have been trapped and 30,400 sterile males have been released annually, resulting in an 88% reduction in spawning potential. We believe these control efforts are a major reason why spawning-phase lamprey abundance and sea lamprey marking rates on lake trout have declined in the main basin.

Parasitic-phase sea lampreys move between Lakes Huron and Michigan (Bergstedt et al. 2003), and sea lampreys increased in abundance in Lake Michigan during 2000-2004 (Klar and Young 2005). A newly established population above a disintegrating dam on the Manistique River, a north-shore tributary of Lake Michigan, was identified as a major potential supplier to Lake Huron, but other suppliers remain to be identified. Reducing further the sea lamprey population of Lake Huron, especially in the northern main basin, may depend upon identification and treatment of sources in Lake Michigan.

Barriers have been constructed on some Lake Huron tributaries to deny adult sea lampreys access to spawning habitat, thus reducing the need for TFM treatments. As of 2004, a total of 19 barriers had been built or modified on Lake Huron tributaries (Lavis et al. 2003; Klar and Young 2005). Although no new barriers were constructed during this reporting period, in 2000, the GLFC expanded its partnership with the U.S. Corps of Engineers to build barriers in U.S. tributaries of Lake Huron under authority of the Water Resources Development Act. By 2004, at least four additional barriers were being planned for Lake Huron tributaries.

Prey Fish

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

By the late 1950s, the exotic alewife and rainbow smelt came to dominate the offshore prey-fish community, supplanting a more-diverse assemblage of indigenous species (O’Gorman and Stewart 1999). However, a return to a more-diverse prey community is implied in the above objective (DesJardine et al. 1995). Native (lake trout and walleye) and non-native (Pacific salmon) predator species have been stocked in Lake Huron in an attempt to control the alewife population, which had reached nuisance levels by the 1960s. With high numbers of predators stocked annually in the Great Lakes, concern has been expressed that predator biomass would remain high regardless of prey abundance (Stewart et al. 1981; Jones et al. 1993). Consequently, predator stocking rates occasionally have been adjusted in Lake Huron, an attempt to both maintain predator pressure on alewife and avoid outright prey shortages.

Based on bottom trawling (Argyle 2005), alewife numbers and biomass declined more than 99% between 1999 and 2004, which led to major consequences for the fish community. Adult alewives increased in abundance during 1998-2002 due primarily to strong year-classes produced in 1998 and 1999 (Fig. 7) (Argyle 2005). However, the 2001 year-class suffered an estimated 94% annual mortality (based on a relative abundance of ages-1 and -2 trawl samples), and no fish of this year-class over age 3 were ever collected. The 2002 and 2003 year-classes suffered almost complete mortality during their first year of life, even though the 2003 year-class was exceptionally abundant to begin with. Thus, by 2004, the adult spawning stock was at an all-time low for the series. The 2004 year-class at age 0 was the smallest ever observed in the history of the survey. The failure of three consecutive year-classes, combined with high adult mortality, led to a rapid reduction in both alewife abundance and biomass by 2004.

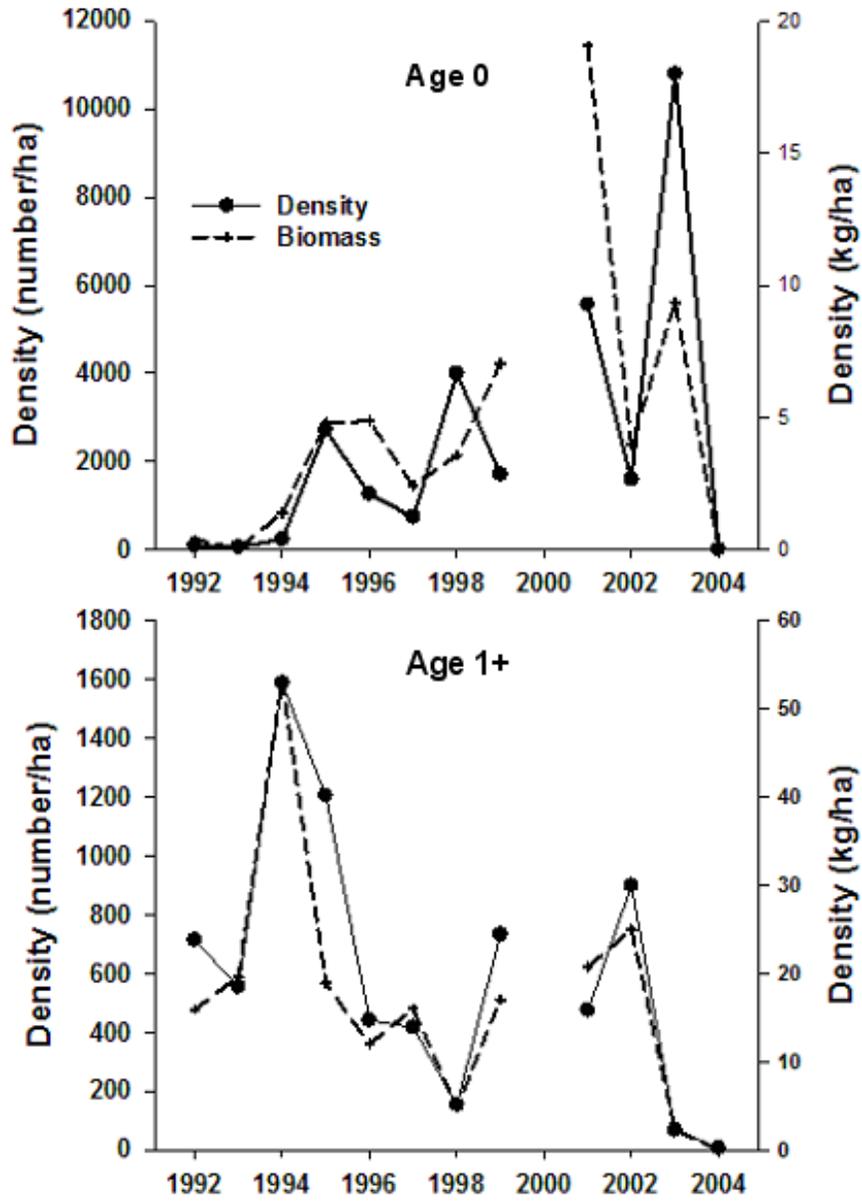


Fig. 7. Density (number/ha) and biomass (kg/ha) of age-0 and age-1 and older (1+) alewife, Lake Huron main basin, 1992-2004. No survey occurred in 2000.

The most-likely reason age-1 and older alewives declined was heavy predation by predators, with Chinook salmon and cormorants having the greatest impact (Dobiesz 2003, Dobiesz et al. 2005), although the winters of 2003-2004 and 2004-2005 were colder than normal and may have resulted in unusually high juvenile mortality (JSS, unpublished data). As predatory demand and mortality on juvenile and adult alewives increased during the 1990s, older and larger alewives began to disappear from the population. By 2001, adults were scarce, and alewife abundance was highly dependent on the number of age-0 fish surviving into their second year. Thus, when the 2003 and 2004 year-classes failed, the age-1 and older population declined rapidly.

Overall prey biomass declined 65% from 1999 to 2004, because no species fully replaced the alewife (Fig. 8). Rainbow smelt, bloater, and deepwater sculpin all exhibited higher recruitment after the alewife population declined. However, these species remained scarce numerically compared to earlier alewife abundances. Rainbow smelt density and biomass, although higher, remained low, and most individuals were less than 100-mm total length in 2004. Rainbow smelt are a preferred prey of salmonines (Diana 1990), but their low numbers and small size probably are inadequate to support robust growth of large salmonines, especially adult lake trout (Martin 1966; Madenjian et al. 1998). Round goby abundance increased through 2003 and then decreased in 2004. Other potential prey species, such as ninespine stickleback and trout-perch, declined in abundance during this reporting period.

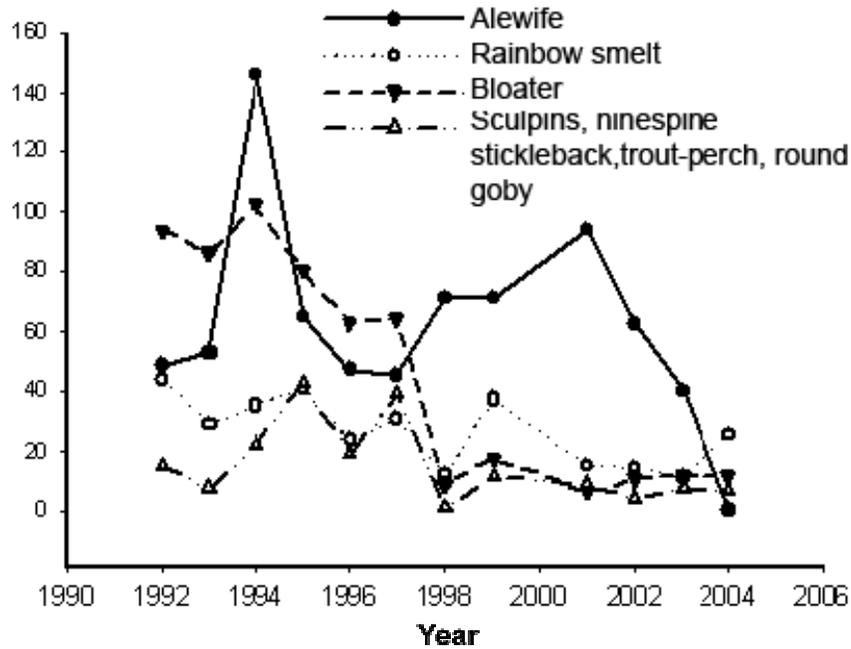


Fig. 8. Biomass of major prey species in U.S. waters of Lake Huron, 1992-2004. No survey occurred in 2000.

Although the alewife population was substantially reduced in abundance by 2004, alewives had not been extirpated from Lake Huron, and they remained abundant in Lake Michigan (Madenjian et al. 2005). Low numbers of adults can produce large year-classes (O’Gorman and Schneider 1986). Thus, alewives have the potential to regain their former abundance, although we suspect that this is unlikely if predator abundance remains similar to that seen during 2000-2004.

The resurgence in recruitment of native prey species, when adult alewives were scarce during 2003-2004, was a major finding. Bloaters produced strong year-classes in both years, and recruitment of wild lake trout and of deepwater sculpin were up in 2004. In Saginaw Bay, walleye and yellow perch produced strong year-classes in both years (see the Nearshore Fish Community section). The native species showing strong responses in recruitment represented four distinct fish families: Salmonidae, Coregonidae, Cottidae, and Percidae. Each species differed ecologically, but

all had a common trait of having pelagic larvae, which are thought to be vulnerable to predation and competition by co-occurring alewife (Smith 1970; Crowder 1980; Eck and Wells 1987), although not all these responses may have been due to the alewife decline (see Madenjian et al. (2008) for additional discussion). These changes are consistent with the FCOs for Lake Huron, but the changes also raise important issues regarding prey availability, ecosystem stability, and the future diversity of the salmonine community.

Ecological Change

The most-striking change in the offshore fish community was the more than 99% decline in alewife abundance and biomass from 1999 to 2004. While the alewife population declined lakewide, recruitment increases were observed in other prey fishes and in wild-born lake trout and, in Saginaw Bay, in walleye and yellow perch (see the Nearshore Fish Community section). Increased recruitment of other prey fishes, however, was not sufficient to replace alewife, and total prey biomass declined. Whether other prey fishes can replace the alewife is not clear. In the short term, the scarcity of prey fish is likely responsible for the decline in Chinook salmon mass-at-age and body condition and for the very low harvest and catch rate in 2004 in the sport fishery. These observations suggest that natural mortality of Chinook salmon increased substantially or large numbers migrated to Lake Michigan, or both. The low abundance of alewife may also have contributed to high post-stocking mortality of brown trout and other salmonines. Larger-sized lake trout have also experienced declines in growth that appear to be related to decreases in the availability of larger prey, although the effect of prey scarcity on recruitment remains to be seen. Primary productivity during 2003-2004 may have been lower than in the past, and prey-fish production may have declined because the production at lower trophic levels is following different pathways (see the Issues Relevant across Fish Communities section). A substantial decline in productivity of prey fish could potentially impede the reaching of lakewide yield goals.

High levels of predatory demand were likely the major factor that contributed to the alewife population decline in Lake Huron and resulted from both continued hatchery releases of salmon, trout, and walleye and increased recruitment of wild Chinook salmon and walleye. The proportion of wild Chinook salmon in the population reached almost 80%, an unexpected level. When wild salmon began to dominate and the extent to which this domination represents a substantial change in total recruitment are unknowns. Regardless, if wild Chinook salmon continue to dominate,

managers will have less ability to reduce predation pressure by reducing stocking. Increased overwinter mortality and changing lower-trophic-level impacts cannot be ruled out as factors that contributed to the decline of the alewife population.

The spread of round gobies, an invasive species (see the Issues Relevant across Fish Communities section), is also of concern. The species established in 1991 (Jude et al. 1992) and became widespread during 1998-2004, extending its range into both deepwater and shallow-water habitats (Schaeffer et al. 2005b). Round gobies have the potential to impact lake trout both as an egg and fry predator and as a source of food. Round goby abundance declined in trawl samples during 2004, perhaps because of predation by walleye, yellow perch, and lake trout.

Recommendations

We recommend an emphasis on determining the causes and consequences of the recent, dramatic decline in prey-fish abundance. Addressing these issues requires continued updating of existing models and assessing of predators, analyzing existing data on prey-fish stock sizes and productivity, and augmenting data collection. We recommend that all stocked fish in Lake Huron be marked so that hatchery-reared and wild-born fish can be distinguished. We also recommend that agencies consider approaches for fishery-independent assessments of predator populations and that prey-fish assessment designs allow for estimating absolute stock sizes and productivity. Such efforts should focus on understanding future responses of the prey-fish community to low alewife abundance.

We recommend aggressive planning for and implementation of actions that might diversify the prey base and the fish community as a whole, including, for example, selected reintroductions of cisco. Reintroductions should take into account many factors, such as genetics, feasibility, spread of disease, and potentially high rates of predation that the introduced fish may face given low prey-fish abundance. We further recommend a review of the current management of Chinook salmon and development of an interagency management plan for this species. Such a review should consider new kinds of data or information that will be required to manage a largely self-sustaining Chinook salmon population.

We recommend a thorough reevaluation of the lakewide status of all salmonines to include stocking rates, prey requirements, wild production, habitat needs, and harvest regimes. For species less impacted by declining prey fish (e.g., rainbow trout), we recommend remediating spawning habitat

and keeping adult mortality rates at sustainable levels. Efforts to diversify the predator community should consider the ability of predators to feed on a diversity of prey, including invertebrates, and to survive periods of low food availability.

We also recommend aggressive action to promote lake trout rehabilitation (Johnson et al. 2004). Of particular importance is increasing the number of yearlings stocked while keeping mortality rates on adults sufficiently low. Sea lamprey control needs to be enhanced to meet the targets for marking rates and sea lamprey abundance. Harvest may need to be reduced in some parts of the lake.

Research and monitoring needs include refinement of fishery-independent lake trout indices of abundance, particularly for age-0 lake trout; continued monitoring of sea lamprey parasitic- and spawning-phase abundance, temporal variation in parasitic-phase survival, and interlake movements; standardization of surveys of spawning lake trout on reefs; improved understanding of factors influencing recruitment of hatchery-reared and wild lake trout; and additional evaluation and refinement of harvest management, including consideration of how life-history changes influence the selection of mortality targets and the effectiveness of lake trout refuges.

WHITEFISHES AND CISCOES

Mark P. Ebener

Inter-Tribal Fisheries and Assessment Program
Chippewa/Ottawa Resource Authority
179 W. Three Mile Road
Sault Ste. Marie, MI, 49783, U.S.A.

Lloyd C. Mohr

Upper Great Lakes Management Unit
Ontario Ministry of Natural Resources
1450 Seventh Ave. East
Owen Sound, ON, N4K 5N7, Canada

Stephen Riley and Edward F. Roseman

U.S. Geological Survey—Great Lakes Science Center
1451 Green Road
Ann Arbor, MI, 48108, U.S.A.

David G. Fielder

Michigan Department of Natural Resources
Alpena Fisheries Research Station
160 E. Fletcher St.
Alpena, MI, 49707, U.S.A.

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 above objective for coregonines from Desjardine et al. (1995) recognizes the historical and continued importance of the whitefish subfamily in the fish community. During this reporting period (2000-2004), the average annual yield of coregonines exceeded 3.8 million kg, the quantity specified in the above objective, although its sustainability is hard to assess. Each year's yield up to 2003 met or exceeded the objective, but, in 2004, the yield of coregonines was slightly under the objective. However,

the average yield for this reporting period was ~1.0 million kg less than the yield of coregonines taken in 1999, the last year of the previous five-year reporting period (Mohr and Ebener 2005b).

Lake Whitefish

The lake whitefish is the most-abundant and widely distributed member of the coregonine subfamily, occupying all three basins at depths up to 80 m, and is the most sought-after commercial species on Lake Huron. The commercial yield of lake whitefish averaged 4.0 million kg during 2000-2004 and comprised more than 80% of the total commercial yield. Commercial yields have declined since the end of the previous reporting period (Fig. 9) (Mohr and Ebener 2005b). The all-time record yield of lake whitefish (4.5 million kg in 1998) occurred just recently (in the previous reporting period) and, although yields were lower in this reporting period, they were still exceptional years in the two-century history of the fishery (Fig. 9).

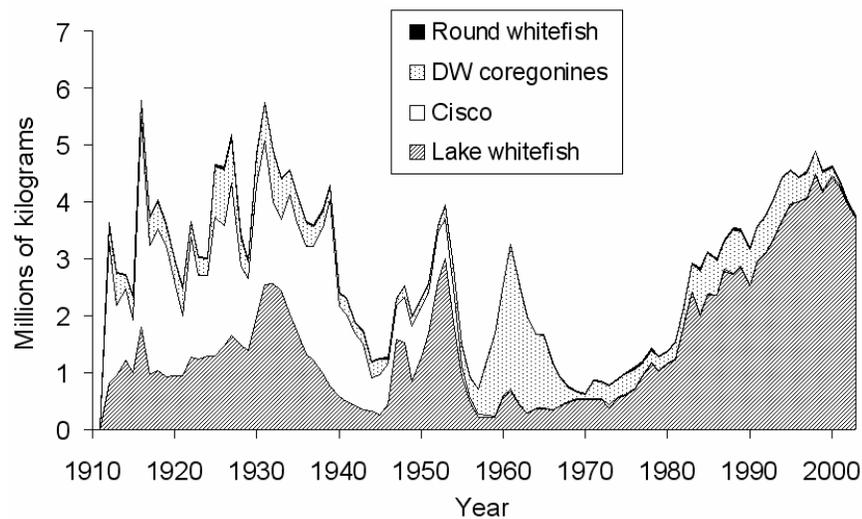
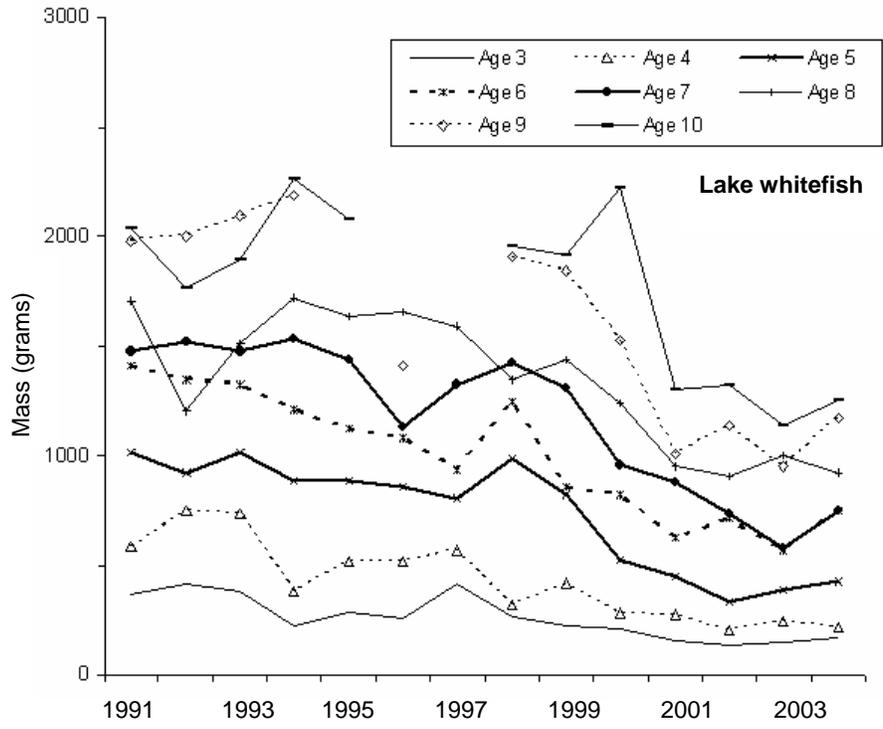
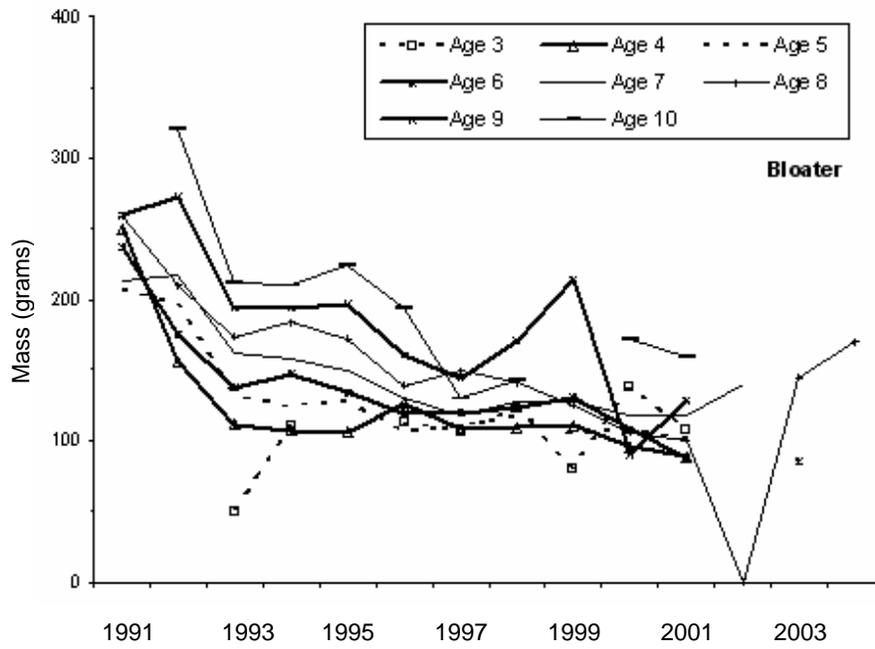


Fig. 9. Commercial fishery yield of coregonines from Lake Huron, 1910-2004. DW coregonines refers to bloater and other deepwater ciscoes. Horizontal line indicates the fish-community objective for sustained yield (3.8 million kg).

A number of factors have contributed to the declining yield of lake whitefish, including reduced commercial-fishing effort associated with recent declines in market prices and declining catchability associated with increased abundance of lake trout, further proliferation of the filamentous algae *Cladophora* spp., and changes in lake whitefish depth distribution (Mohr and Ebener 2005c). Starting in 2000, gillnet fisheries for lake whitefish had to fish nontraditional areas and different components of the main basin population to avoid catching increasingly abundant lake trout (Woldt et al. 2005b). Beginning in 1997, large floating plumes of *Cladophora* spp. have fouled gillnets and trapnets in the southern main basin. During 2000-2004, these plumes were more widespread in the main basin and became common in Georgian Bay. The shift to deeper water by lake whitefish, started in the late 1990s, continued in this reporting period.

Declining individual growth has led to lower biomass of lake whitefish populations. Declines in both average mass-at-age and condition (robustness) of lake whitefish began in the late 1980s and early 1990s (Mohr and Ebener 2005b; Mohr and Ebener 2005c) and continued through 2002. Average mass of age-4-10 lake whitefish declined 30-50% in MH-1 from 1999 to 2004 (Fig. 10). Harvestable biomass of age-3 and older lake whitefish in MH-1 and 2 peaked during 1993-1997 (averaging roughly 22 million kg) and then declined to under 8 million kg in 2003 (Woldt et al. 2005b). Harvestable biomass peaked for many lake whitefish populations during the mid-1990s and then declined to much lower levels during 2000-2004. A few populations may have increased slightly after 2002. Declining growth and condition of lake whitefish may have been due, in part, to nutritional stress (see the Ecological Change subsection).





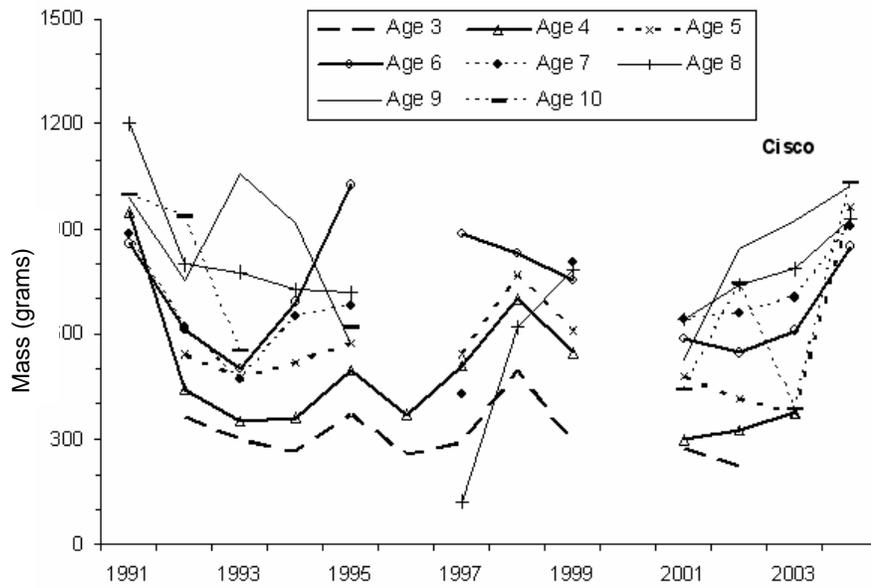


Fig. 10. Mean mass of ages-3-10 lake whitefish, bloater, and cisco captured in graded-mesh gillnet surveys in MH-1 during 1991-2004.

Recruitment of young lake whitefish (evaluated by index netting and age compositions from commercial-fishery samples) also declined during 2000-2004. Year-classes of lake whitefish produced during 1995-1997 and 2000-2002 were weak or of moderate strength at best. While the 1998 and 1999 year-classes were relatively strong, these two year-classes were not abundant enough to prevent an overall decline in lakewide biomass. The 2003 year-class appeared to be exceptionally strong, and it should lead to an increase in yield as it recruits to the fishery during 2007-2010.

Deepwater Ciscoes

The yield of deepwater ciscoes (all species combined) to the commercial fishery declined dramatically in Lake Huron during 2000-2004, a trend that started in 1996. During this reporting period, yield declined from 136,000 kg in 2000 to 11,200 kg in 2004, which was the lowest yield since records began in 1903. By way of contrast, yield of deepwater ciscoes averaged 638,000 kg during 1984-1995. The recent decline in yield was directly proportional to declines in abundance and recruitment observed in surveys (see the Prey Fish subsection in the Offshore Predators and Their Fish Community section).

The bloater and shortjaw cisco are the only two deepwater coregonines known to exist in Lake Huron. The shortjaw cisco was noted as extirpated by Schaeffer and Woldt (2005) in the previous state of the lake report, but it has subsequently been observed in Lake Huron (see the Issues Relevant across Fish Communities section). Its reappearance leaves four deepwater ciscoes as extirpated from the lake: deepwater cisco, blackfin cisco, shortnose cisco, and kiyi.

The bloater is commonly found in all three basins of the lake but is most abundant in the main basin. Its abundance dropped to very low levels after 1997 and remained low from 2000 to 2004. Relatively poor year-classes were observed from 1991 to 1998, and, consequently, they provided very little recruitment during 2000-2004 (Ontario Ministry of Natural Resources 2004). Abundance of adult bloaters increased slightly during 2003 and 2004 (Schaeffer et al. 2005a) due to production of relatively strong year-classes in 1997-2000 (Ontario Ministry of Natural Resources 2004). Bottom-trawl assessments in the main basin suggested that the 2003 and 2004 year-classes were also relatively strong (Schaeffer et al. 2005a). Densities of juvenile bloaters in these surveys were 60 fish•ha⁻¹ in 2003 and 28 fish•ha⁻¹ in 2004.

Bloaters appear to exhibit density-dependent growth in Lake Huron, similar to that reported in Lake Michigan (Szalai et al. 2003). Mean mass-at-age of bloaters in Lake Huron declined continuously from the early 1980s to the mid-1990s as abundance peaked. Mass-at-age stabilized after about 1998 when the bloater population began to crash and appeared to have increased marginally since 2002, even though yield remained low (Fig. 9). The condition of bloaters declined in Lake Huron from the early 1990s to 1999, paralleling somewhat the decline in growth (Mohr and Ebener 2005b).

Other Coregonines

The commercial yield of round whitefish, which inhabits all three basins primarily in waters less than 46 m deep, has been relatively low but stable since the mid-1960s. The average yield during the 2000-2004 period was 36,300 kg, higher than the 40-year average of 25,900 kg. In MH-1 during 2000-2004, round whitefish were common in graded-mesh gillnet catches at depths from 3 to 37 m and were most abundant in the 9- to 24-m depth range. Abundance declined rapidly in catches at depths greater than 37 m.

The cisco, (referred to as lake herring in previous state of the lake reports) a pelagic nearshore coregonine, is found in all three basins, but its distribution was much more restricted during the reporting period than that of round whitefish. The cisco was common in the St. Marys River and North Channel, in waters between the Straits of Mackinac and Drummond Island, and in isolated areas of eastern Georgian Bay. It was not found in Michigan waters south of the Straits of Mackinac but was occasionally caught in Ontario's southern and central waters of the main basin. The total commercial yield of cisco in Lake Huron was 30,800 kg in 2004.

The abundance of the cisco appeared to be slowly increasing, and its range appeared to be expanding in Ontario waters. It remained absent from Saginaw Bay, where it was formerly abundant. The cisco made up 45-49% of gillnet catches in the Drummond Island Refuge (Fig. 1) during 1991-2004, specifically along the south side of the island. Abundance there increased fourfold from 1991-1997 to 1998-2004. At five index sites located across all three basins in Ontario waters, relative abundance of the cisco increased from a mean of one fish per gillnet set in 1991 to 11 fish per gillnet set in 2003 (LCM, unpublished data). The change in relative abundance from the 1995-1999 to the 2000-2004 reporting periods was less dramatic—it increased 1.6 times. Growth rates of the cisco appear to have been relatively stable during 1991-2004 (Fig. 10). Hoping to take advantage of a collapsing alewife population and the resultant vacant niche, the LHTC in 2004 began developing a guide to foster a recovery of the cisco.

Ecological Change

In this reporting period, the lake's coregonine fishes continued to respond to changes in the food web, especially to invasive species, in ways described in the previous reporting period (1995-1999). For example, the declines in growth and condition of lake whitefish and bloater in the main basin that began sometime after 1992 (Mohr and Ebener 2005b; Mohr and Ebener 2005c) continued during 2000-2004 (Fig. 10). These declines occurred while abundance declined, suggesting that density-dependent growth was not a factor. The decline of *Diporeia* spp. (hereafter, diporeia as a common name) populations (Nalepa et al. 2005) has left lake whitefish and bloater populations more dependent on energy-deficient prey, such as dreissenid mussels, and on alternative prey, such as *Mysis relicta*, resulting in lake whitefish lipid levels that are lower in Lake Huron than in populations in Lake Michigan. Lake whitefish from the Detour and Cheboygan areas of MH-1 had average total lipid levels of 16-17% from October 2003 through September 2004, whereas, two stocks in northern Lake Michigan had lipid levels of 17-20% (M.L. Jones, personal communication, 2006). Although slight, these differences in lipid content are meaningful at the individual level and suggest that lake whitefish from Lake Huron may be deficient in some essential fatty acids (M. Arts, personal communication, 2006).

In the northern waters of the main basin, from 30% to 90% of the lake whitefish sampled from fall 2003 through summer 2004 tested positive for *Renibacterium salmoninarium*, the causative agent of bacterial kidney disease (BKD), and 0-20% of the fish had active clinical signs of the disease (M. Faisal, personal communication, 2005). The high prevalence of the BKD-causative bacterium in lake whitefish (and also in bloater) suggests that coregonine fishes are stressed, and their populations may become less productive.

Dreissenid mussels appear to have driven much of the ecological change seen offshore (see the Issues Relevant across Fish Communities section). Bloater and lake whitefish abundance peaked in the mid-1990s shortly after dreissenid mussels became established in Lake Huron. Mussel populations expanded rapidly and were abundant by the mid-1990s (Nalepa et al. 2005), when the abundance of the bloater and lake whitefish began to decline. The growth and condition of both species did not improve as their abundance declined; rather, growth and condition declined further and have only recently improved modestly.

Concurrent with the increase in abundance of dreissenid mussels was a sizable increase in water clarity and in production of *Cladophora* spp. Lake whitefish responded apparently by inhabiting deeper water (Mohr and Ebener 2005a). This shift in depth probably exacerbated the declines in growth and condition associated with the severe reduction in diporeia populations. Increased production of *Cladophora* spp. was followed by substantial increases in dead and dying *Cladophora* spp. in the pelagic zone, which fouled commercial-fishing gear. Linkages among coregonine fishes, dreissenid mussels, and *Cladophora* spp. are not clear, but the fouling of commercial gear, combined with reduced lake whitefish growth and condition that affected market prices, all worked together to suppress yields.

The apparent collapse of the alewife population (see the Offshore Predators and Their Fish Community section) may be having a positive affect on the recruitment of cisco and bloater, an outcome suggested by Ebener (1997) and Dobiesz et al. (2005) (but see Madenjian et al. 2008). As the alewife population declined, bloater recruitment increased beginning with the 2000 year-class, and lake whitefish recruitment increased beginning mainly with the 2003 year-class. We anticipate that a similar increase will occur in cisco.

Recommendations

Most of the changes in coregonine fishes appear to be related to changes in the food web driven by the continuing proliferation of dreissenids. These changes cannot be directly controlled by fishery-management actions. This reality leads to three overarching recommendations:

1. Work to gain an improved understanding of how these invaders are altering the productive capacity of coregonines
2. Develop revised FCOs that are more in line with the new realities of fish productivity
3. Encourage a more-aggressive approach for reducing the likelihood that new exotics become established in Lake Huron

We also recommend an aggressive approach to cisco rehabilitation as is being developed by the LHTC. Prompt action is needed in light of the current low abundance of alewife. Maintaining sustainable levels of total mortality on highly sought commercial fishes is also recommended.

NEARSHORE FISH COMMUNITY

David G. Fielder

Michigan Department of Natural Resources
Alpena Fisheries Research Station
160 E. Fletcher St.
Alpena, MI, 49707, U.S.A.

Arunas Liskauskas and Lloyd C. Mohr

Upper Great Lakes Management Unit
Ontario Ministry of Natural Resources
1450 Seventh Ave. East
Owen Sound, ON, N4K 2Z1, Canada

James Boase

U.S. Fish and Wildlife Service
Alpena Fishery Resources Office
145 Water St., Rm. 204
Alpena, MI, 49707, U.S.A.

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.

The total yield of walleye from all sources during the 2000-2004 reporting period averaged 0.24 million kg or approximately 35% of the above objective (DesJardine et al. 1995) and was essentially unchanged from the previous five-year reporting period (Fielder et al. 2005) (Fig. 11). Moreover, the 2000-2004 yield is not appreciably different than that reported since detailed record keeping resumed in the late 1980s (Krueger et al. 1995). Walleye are harvested lakewide by sport fisheries and by localized commercial fisheries in Ontario waters. Limited tribal (U.S.) and First Nation (Canada) subsistence harvesting also occurs. The lakewide subsistence harvest and sport harvest in Ontario waters are not routinely quantified and are not included in the yield estimates provided here. These unmeasured harvests are presumed to be low, so the true yield is still believed to be well below the objective.

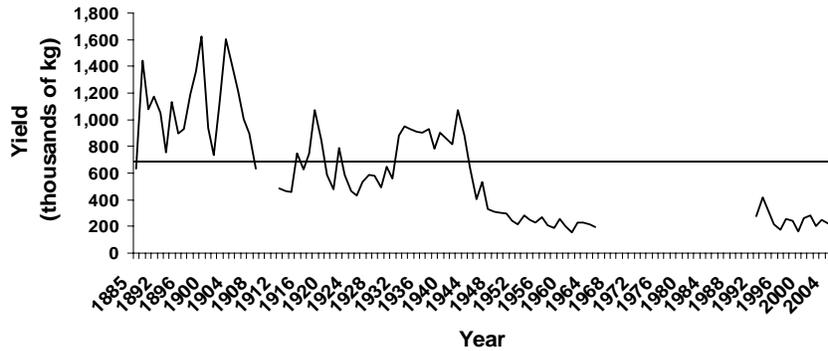


Fig. 11. Reported walleye yield in Lake Huron from 1885 to 2004. Horizontal line indicates the fish community objective for sustained yield (0.7 million kg).

Historically, Saginaw Bay was home to the largest walleye population within Lake Huron and sustained the second-largest walleye commercial fishery in the Great Lakes (Schneider and Leach 1979). That population is considered partially recovered but still undergoing rehabilitation (Fielder and Baker 2004). Production of age-0 walleye in Saginaw Bay was exceptionally high in 2003 and 2004, a sign that rehabilitation is progressing (Fielder and Thomas 2006). Trawl catch rates in 2003 were as much as 4.8 times greater than the previous record high, which was for the exceptionally strong 1998 year-class. The 2003 increase was attributed primarily to ideal climatic conditions and a coincidental decline or near absence of adult alewives (Fielder and Thomas 2006; see the Offshore Predators and Their Fish Community section). Alewives can be formidable predators on and competitors with larval fishes, and, although direct evidence of these effects on walleye larvae is lacking (Brooking et al. 1998), alewives have been reported as a potential obstacle to walleye recovery in Lake Ontario (Bowlby et al. 1991).

In Saginaw Bay, the increased number of age-0 walleye in 2003 did not produce proportionally large increases in the catch of age-1 fish in 2004 (Fielder and Thomas 2006). As yearlings, the 2003 year-class was strong but equivalent only to that of the 1998 year-class. The average total length of the 2003 year-class was shorter than that of previous year-classes, and smaller size may have reduced the ability of individuals in this year-class to reach their second year of life.

Both Saginaw Bay and the St. Marys River received large annual stockings of walleye fingerlings during 2000-2004. If natural reproduction continues to increase in these locations, walleye recovery objectives may be reached (Fielder and Baker 2004), resulting in adjustments to stocking plans.

Stocking remained sporadic in eastern Georgian Bay, and the net benefits of these efforts were unclear. Most walleye populations in the North Channel and eastern Georgian Bay are below historical levels of abundance. These populations experience high mortality, and recruitment has been low and variable due to habitat limitations (Liskauskas 2002), including access to spawning grounds in rivers. In 2003, more-restrictive sport-harvest regulations were implemented in the North Channel and Georgian Bay to encourage population recoveries.

Yellow Perch

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

The total yield of yellow perch from all sources during the five-year reporting period, 2000-2004, averaged 0.22 million kg, less than half (44%) of the above objective from DesJardine et al. (1995) (Fig. 12) and a decline from the average annual yields of 0.30 and 0.33 million kg reported for the two previous reporting periods (Krueger et al. 1995; Fielder et al. 2005). Most of the lake's harvest is from sport fisheries dispersed throughout the lake and from commercial fisheries concentrated in the North Channel, Ontario's waters of the southern main basin, and Saginaw Bay. Additionally, various Indian tribes and First Nations make subsistence harvests. Because of subsistence harvest and the lack of data on Ontario's recreational harvest, the true yield was somewhat greater than indicated by the figures given above.

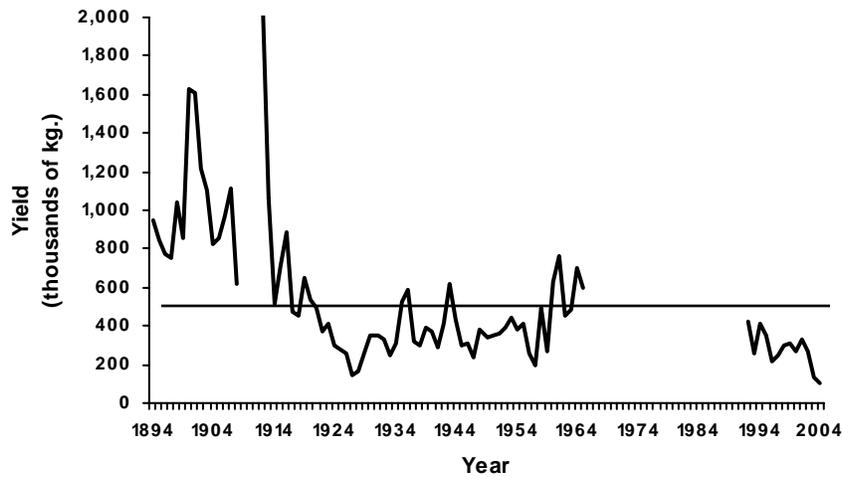


Fig. 12. Reported yellow perch yield in Lake Huron from 1894 to 2004. Horizontal line indicates the fish community objective for sustained yield (0.5 million kg).

The commercial yield of yellow perch from the main basin declined in 2003 and 2004 to levels not seen since the 1920s. The yield of yellow perch from the North Channel and Georgian Bay has been greatly depressed and showed no sign of recovery through 2004. However, strong year-classes produced in 2003 and 2004 would not be expected to recruit to the commercial fishery until 2005 and 2006.

The reasons for the declining yellow perch yields are not fully understood. Recruitment in the main basin dropped dramatically following the relatively strong 1998 year-class (Ontario Ministry of Natural Resources 2004). That cohort sustained the fisheries in the main basin until 2002. The production of age-0 yellow perch increased in 2003 and 2004 in the main basin and included dramatic increases in Saginaw Bay. However, in Saginaw Bay, the 2003 year-class survived poorly and, in the following year, did not appear strong. The prospects for the 2004 year-class also appeared to be poor as the size of age-0 fish in 2004 was smaller than average, just like it was in 2003—reflecting possible overabundance in both years. Small size may have exacerbated the influences of predation and overwinter thermal stress, resulting in poor survival (Fielder and Thomas 2006).

Recent investigations in Georgian Bay and the North Channel suggest that predation by double-crested cormorant has led to the disruption of the fish community, especially near rookeries (J. Casselman, personal communication, 2005). Cormorant predation has been implicated also in declines of yellow perch in the Les Cheneaux Islands region of northern Lake Huron (Fielder 2004). Netting surveys conducted in 2004 in this region detected a resurgence of yellow perch that coincided with the implementation of cormorant control (DGF, unpublished data).

The harvest of small, immature yellow perch has been suggested as an impediment to better recruitment in Ontario's waters of the main basin. To better understand the effects of exploitation from these fisheries, an analysis of commercial and recreational harvests is being conducted.

Future management of yellow perch populations and fisheries will require consideration of not just yellow perch, but the whole aquatic community and the effects that other species, such as the alewife and double-crested cormorants, have on yellow perch production.

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.

When DesJardine et al. (1995) identified the above objective, lake sturgeon had an environmental listing, that of Threatened Species, only in the state of Michigan. Since then, it was listed as a Species of Concern in Ontario's waters of Lake Huron and is in the process of being listed as a Species of Concern by the U.S. and Canadian governments. Lake sturgeon spawn in only a few of the lake's tributaries because dams and other structures block access. Access is a problem in almost all (otherwise suitable) Michigan tributaries and in many Ontario tributaries. Lake sturgeon inhabit a surprisingly large number of Ontario tributaries, but spawning has only been documented in five: the Garden, Mississauga, Nottawasaga, Spanish, and St. Clair (includes Michigan waters) Rivers. The presence of an age-0 lake sturgeon in Michigan's Rifle River in 2002 (J. Weisser, personal communication, 2005) suggests that spawning may have occurred there, which is encouraging.

Mark-recapture data collected from 1995 to 2004 suggest that the abundance of lake sturgeon in Ontario waters of Lake Huron was greater than originally thought, and limited recruitment continued to occur in all three of the lake's basins. Exploitation rates were below 2% in both the North Channel and the main basin (LCM, unpublished data), which is within recommended levels (Hay-Chmielewski and Whelan 1997). However, exploitation may have been inhibiting rehabilitation efforts elsewhere (Baker and Borgeson 1999), especially given the low population levels.

The average annual commercial harvest of lake sturgeon in Ontario's waters was 4,900 kg during 2000-2004 and came primarily from the southern main basin and the North Channel. Michigan's waters of Lake Huron are closed to recreational and commercial harvest of lake sturgeon. Recreational harvest occurred in the St. Clair River and in a few of Ontario's major tributaries. Lake sturgeon were also harvested for subsistence purposes by Ontario's First Nations. This subsistence harvest and recreational catches in Ontario's waters were not documented.

During 1995-2004, more than 3,500 lake sturgeon were tagged and released in Lake Huron, and 231 of these fish were recaptured at least once. Locations where lake sturgeon have been tagged include the St. Marys River, the North Channel, southern Georgian Bay, Saginaw Bay, southern Lake Huron, and the St. Clair River. Recaptures indicate that most fish remain relatively close to the tagging location. However, fish tagged in Lake Huron have been recaptured in western Lake Erie, the Detroit and St. Clair Rivers, Lake St. Clair, and western Lake Michigan. Similarly, sturgeon tagged outside of Lake Huron and the St. Clair River have been recaptured in Lake Huron.

Telemetry studies conducted from 2002 to 2004 revealed movements of lake sturgeon between the St. Clair River system, Saginaw Bay, and southern Lake Huron. These movements reflect, in part, migration patterns related to spawning and the location of spawning sites in the St. Clair River, one at Algonac, MI, and one at Port Huron, MI. Therefore, spawning sites and feeding sites may not be in the same lake basin.

Genetics data collected in 2002 and 2003 from known spawning populations in Lake Huron revealed similarities between these populations and those in downstream water bodies. The Mississauga River, Spanish River, and Lake Nipissing populations were genetically similar, and the Nottawasaga River and three downstream populations (St. Clair, Detroit, and Niagara Rivers) were also genetically similar (Welsh 2006). A basinwide approach will clearly be needed for lake sturgeon conservation. In support of this need, a

partnership between the United States Fish and Wildlife Service (USFWS), OMNR, MDNR, and commercial fishermen continued to coordinate assessments begun in 1995 and was expanded to include other state and federal agencies, academic institutions, and Ontario's First Nations.

Esocids (Northern Pike and Muskellunge) and Centrarchids (Basses and Sunfishes)

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.

Esocids

The approximately 6,000 northern pike harvested recreationally from the St. Marys River in both 2000 and 2001 represented the bulk of the catch from Lake Huron in those years and amounted to about 16% of the above objective from DesJardine et al. (1995). However, about the same number of northern pike were estimated to have been caught just from Michigan's side of the river in 1999, the last year of the previous five-year reporting period (Fielder et al., 2005). Moreover, the average harvest from both sides of the river was approximately four times this amount during the earlier 1988-1992 reporting period (Fielder et al. 2002). Gillnet surveys in 2002 also suggested a substantial decline in northern pike abundance since 1995 (Fielder et al. 2004). Although these fragmentary data suggest a population reduction may have occurred near the start of the current reporting period, a 610-mm minimum length limit instituted in 1993 in Michigan's waters of the river may account, in part, for the lowered harvests following the 1988-1992 reporting period.

The Severn Sound area of southern Georgian Bay supports a recreational fishery for northern pike somewhat smaller than that of the St. Marys River—about 3,400 fish were harvested there in 2001 (AL, unpublished data). Fish-community surveys in Severn Sound show that the abundance of northern pike has declined substantially from levels observed throughout the 1980s and 1990s (Gonder 2003). Relative abundance increased in 2000, due primarily to a strong 1997 year-class, but abundance has since fallen substantially. Low water levels since 2000 may have suppressed northern pike recruitment by constraining their access to flooded vegetation, which is

required spawning and nursery habitat. To reduce their mortality and protect trophy-sized fish, northern pike were afforded greater protection from recreational fishing in Georgian Bay and the North Channel beginning in 2003.

Surveys in Ontario's waters have identified important spawning wetlands for muskellunge in Georgian Bay and the North Channel. Catch rates of 0.11 to 1.53 fish per trapnet night are within the range of values encountered during surveys going back to 1996 (AL, unpublished data). In 2001, a Record Class Fishery designation resulted in a minimum size limit of 137 cm (54 inches) for these waters, which should further protect these populations. In Michigan's waters, Great Lakes-type muskellunge are absent from Saginaw Bay and are encountered only occasionally in the Les Cheneaux Islands area or St. Marys River. The St. Marys River appears to offer ideal habitat for Great Lakes-type muskellunge, but some unknown factor apparently limits this population.

Centrarchids

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

The above qualitative objective from DesJardine et al. (1995) is being met, although the supporting data are limited. Recreational fisheries for smallmouth and largemouth bass continue to exist throughout the basin. Some locations, such as Severn Sound in Georgian Bay, attract considerable angler effort. High catch rates and large average size of bass have made this area attractive to competitive catch-and-release bass fishing events. Creel surveys of the St. Marys River, however, suggest that bass fishing is a relatively small component of the fishery in those waters (Fielder et al. 2002).

Fish-community surveys in Severn Sound during 2000-2004 showed that smallmouth bass had moderate mortality rates (Liskauskas 2004). Similar surveys conducted in other parts of Georgian Bay and the North Channel confirmed the relatively high abundance and longevity of smallmouth bass. The recent establishment of round goby in the Severn Sound area of Georgian Bay could have negative impacts on the reproductive success of smallmouth bass (Tran 2007).

Abundance of rock bass, pumpkinseed, and black crappie continue to be low throughout Georgian Bay and the North Channel. Among these species, the black crappie population has changed the most and now is much lower than

in the 1980s (Gonder 2003). Centrarchids continue to be widespread and support recreational harvests as well as small amounts of commercial harvest in Saginaw Bay.

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.

Of the remaining nearshore species to be discussed here, only the channel catfish has a quantitative objective as given above (DesJardine et al. 1995). Reported annual yield of channel catfish during 2000-2004 averaged 0.12 million kg lakewide, amounting to about 65% of the objective, and was not changed from the previous five-year reporting period (Fielder et al. 2005). Nearly all the harvest is commercial, coming from Ontario's waters of the main basin and from Saginaw Bay.

Suckers are mentioned in DesJardine et al. (1995) only in connection with a general species-diversity objective, which calls for their conservation. Average annual yield of suckers was 60,900 kg during 2000-2004 and came mostly from Ontario's waters of the southern main basin and from Saginaw Bay. Yield has been extremely low in the North Channel and eastern Georgian Bay since the 1980s, possibly due to a proliferation of cormorant colonies in those areas.

In Saginaw Bay, trawl assessments for forage species indicated one change in abundance associated with the invasion of round gobies. The abundance of johnny darter had declined (Fielder and Thomas 2006), while that of spottail shiners and trout-perch appeared unchanged. Emerald shiners continued to be at a low abundance, although this species may be negatively affected by zebra mussels (*Dreissena polymorpha*) that colonized just before the round goby (Fielder and Thomas 2006). Small-fish surveys conducted in all basins in Ontario's nearshore waters revealed high species diversity (14-30 species per site) in 2003 and 2004.

Harvest by bait-fish industries of small-bodied nearshore species is of concern to fishery managers, as is overconsumption by double-crested cormorants, although, by 2004, cormorant abundance appeared to have begun to decline from its peak.

Ecological Change

Major changes in abundance of invasive species likely had a major influence on the nearshore fish community during the reporting period and will continue to do so in the future, although these influences are poorly understood. Round gobies continued to expand their range in both the nearshore waters and elsewhere in the lake, dreissenid mussels remained abundant in the nearshore benthos, and the drastic decline of alewife populations in 2003 and 2004 coincided with increased recruitment of native cool-water species, in particular of yellow perch and walleye. Predation by the double-crested cormorant continues to have an impact on nearshore fishes, especially those with populations nearest major rookeries. Declining water levels and subsequent habitat loss is a growing concern, particularly in inshore areas of Georgian Bay, the North Channel, and the St. Marys River (see the Habitat subsection in the Issues Relevant across Fish Communities section).

Recommendations

We recommend that an interagency, lakewide recovery plan be developed for lake sturgeon. Regional recovery plans should also be developed for depressed walleye populations. The Saginaw Bay walleye recovery plan could be used as a starting point for the design, and it should continue to be implemented.

More-conservative harvest regulations should be implemented for those yellow perch populations that are believed to be recruitment limited to conserve existing populations until conditions are more favorable. Management should address situations where fish stocks are believed to be adversely affected by cormorant predation.

Tributary habitat is deemed limiting for both walleye and lake sturgeon. Access to spawning, overwintering, and nursery habitat would likely enhance recovery of both of these native species. Coordination of efforts to review dam removals and improve fish passage is recommended to provide for improved access to tributary habitat while denying access to sea lampreys.

Assessment of nearshore fish populations is inadequate. In particular, we recommend studies to better quantify mortality rates of depressed walleye, northern pike, and yellow perch populations. More information is needed also on the effects of exploitation on lake sturgeon, their habitat needs, and their genetic structure. We also recommend enhanced surveys to determine

the status of yellow perch and of other nearshore species in the main basin. Lastly, improved and expanded assessments of the inshore forage base, including the effects of bait-fish extractions, need to be implemented.

ISSUES RELEVANT ACROSS FISH COMMUNITIES

Arunas Liskauskas

Ontario Ministry of Natural Resources
Upper Great Lakes Management Unit
1450 Seventh Ave. East
Owen Sound, ON, N4K 5N7, Canada

Jerry R. McClain

United States Fish and Wildlife Service
Alpena Fishery Resources Office
Federal Building, Room 203, 145 Water Street
Alpena, MI, 49707, U.S.A.

Stephen Gile

Ontario Ministry of Natural Resources
Upper Great Lakes Management Unit
1450 Seventh Ave. East
Owen Sound, ON, N4K 2Z1, Canada

Edward F. Roseman and Wendylee Stott

U.S. Geological Survey—Great Lakes Science Center
1451 Green Rd.
Ann Arbor, MI, 48105, U.S.A.

Mark P. Ebener

Chippewa/Ottawa Resource Authority
179 W. Three Mile Rd.
Sault Ste. Marie, MI, 49783, U.S.A.

James E. Johnson

Michigan Department of Natural Resources
Alpena Great Lakes Fisheries Station
160 E. Fletcher Street
Alpena, MI, 49707, U.S.A.

Kim T. Scribner

Department of Fisheries and Wildlife and Department of Zoology
Michigan State University
13 Natural Resources Building
East Lansing, MI, 48824, U.S.A.

Chris Wilson
Ontario Ministry of Natural Resources
Aquatic Research and Development Section
Trent University
1600 West Bank Drive
Peterborough, ON, K9J 8N8, Canada

DesJardine et al. (1995) identified non-species-specific “challenges and impediments” that could prevent achievement of Lake Huron’s FCOs. These challenges and impediments included changes in fish-species diversity, detrimental effects of invasive species, changes in genetic diversity, and habitat-management needs. This section provides an update of these issues from previous state of the lake reports (Ebener 1995; Ebener 2005).

Fish-Species Diversity

Recognize and protect the array of other indigenous fish species because they contribute to the richness of the fish community...ecological significance; intrinsic value; and social, cultural, and economic benefits.

We address two aspects related to the above objective from DesJardine et al. (1995). First, we consider the status of rare and endangered species. Second, we present information on the status of work describing fish distributions.

All fishery-management agencies on Lake Huron, as well as researchers and other interested agencies, were polled for new occurrences of rare, threatened, or endangered fishes in their collections. Of note were occurrences of shortjaw cisco and one capture of a spotted gar. A single shortjaw cisco was captured in a bottom-trawl tow made off of Hammond Bay on November 13, 2002, and approximately 25 more were caught subsequently off the Bruce Peninsula (N. Mandrak, personal communication, 2004). This species was considered extirpated from Lake Huron as of 1999 (Ebener 2005). The spotted gar is considered rare in Lake Huron, and the single specimen captured in southeastern Georgian Bay in 2004 was the first sighting in recent years.

Of the several species mentioned as rare by Schaeffer and Woldt (2005), three (lake chubsucker, pugnose shiner, and black redhorse) were observed in low numbers at more than one location in 2003 and 2004. There was no evidence of new fish additions or losses in Lake Huron or a change in the

status of species listed as threatened or endangered. Few studies target rare fishes in Lake Huron, and most occurrences of these fishes are incidental, which makes detection of change difficult.

Schaeffer and Woldt (2005), in the previous state-of-the-lake report, recommended continued monitoring of species distributions as well as development of a spatial database that links populations with habitat descriptors. The Lake Huron Geographical Information System (GIS) was built, starting in 2003, to provide researchers and resource managers with a basinwide, centralized collection of distribution and habitat-characteristic datasets for fishes, which now includes information on nearly every species found in the basin (Geddes 2006). This GIS is intended to be updated on a regular basis. This project is complementary to other databases that provide information on Lake Huron fish distributions (e.g., Mandrak 2004).

Invasive Species

Invasive species have the potential to impact the maintenance and rebuilding of Lake Huron's fish communities (DesJardine et al. 1995). We first provide an update on the status of high-profile aquatic nuisance fish species, as reported by McClain and Bredin (2005). We then turn to other (non-fish) invasive species.

High-Profile Invasive Fish Species

Ruffe were discovered at the mouth of the Thunder Bay River in Alpena, MI, in August 1995 and have been monitored since then. Age-0 ruffe were collected in the falls of 1997-2000 in bottom trawls. In 1999, the catch per unit effort of ruffe in Thunder Bay was 11.5 times greater than in 1998 due to a strong 1999 year-class (98% of the catch was age 0), and abundance in this region appeared to be headed to a rapid increase like that documented in western Lake Superior (Bronte et al. 1998). Although production of another year-class was documented in 2000, and age-0 fish represented 87% of those captured, overall abundance decreased. No age-0 fish have been captured since 2000. In 2002, the USFWS began an intensive gillnet removal effort for adult ruffe on known spawning grounds in the Thunder Bay River. In 2004, no ruffe of any age were captured. Removals of adults likely contributed to the disappearance of ruffe in this location. The Thunder Bay region remains the only location where ruffe have been documented in Lake Huron.

The round goby has the potential to disrupt native fish communities (Jude 1997). First established in Lake Huron in 1991 (Jude et al. 1992), round gobies have been seen in numerous new locations within Lake Huron since 1999 (McClain and Bredin 2005). In 2002, round gobies were present in all GLSC trawl stations, except for offshore areas in the northern main basin (Schaeffer et al. 2005b). Gobies are consumed by lake trout, burbot, and walleye in Lake Huron (JH, personal communication, 2006; LCM, unpublished data). Because adult round gobies feed predominantly on zebra mussels, which often have high contaminant levels in their tissues, concerns have been expressed that predators may be exposed to high levels of contaminants by consuming gobies (Hanari et al. 2004; Kwon et al. 2006).

By 2004, round gobies were routinely captured at all USFWS surveillance stations in the main basin, MDNR trawling stations in Saginaw Bay, and offshore GLSC trawling stations. Their abundance increased rapidly, and, in many locations, round gobies became the most-abundant species observed in bottom-trawl surveys. Reduced catches, however, were observed in GLSC trawls in 2004. In Canadian waters, round goby colonized the southern main basin first and, by 2004, had spread northward to the top of the Bruce Peninsula. They have been captured at three locations outside of the main basin: Severn Sound in 1999 and again in 2003; Owen Sound (Fig. 1) starting in 2002; and Bayfield Sound, North Channel, starting in 2002. Populations were well established by 2004 in all three of these locations. Inasmuch as these three populations were isolated from the main basin population, they were likely established by ship ballast water or by bait transfer.

Other Invasive Species

Zebra and quagga mussels (*D. bugensis*) (collectively dreissenids), which spread throughout Lake Huron in the late 1980s, are viewed as a serious threat to the aquatic community. Consumption of dreissenids by native fish has been documented and raises concerns regarding the cycling of contaminants in the food chain (see the Nearshore Fish Community section). Zebra mussels are commonly observed in the stomachs of lake whitefish and occasionally observed in the stomachs of lake trout, burbot, lake sturgeon, and round whitefish.

Zebra mussels, in particular, colonize mostly hard substrates, which often serve as preferred spawning locations for native fish species and/or habitat for invertebrates and small-bodied fishes. This modification of habitat has the potential to limit reproductive capacity and habitat availability at several trophic levels.

Zebra mussels (along with round gobies) may be contributing to the death of large numbers of aquatic birds, although an exact mechanism has not yet been demonstrated (Yule et al. 2006; McLaughlin 2003). At times, in recent years, hundreds of fish-eating birds (including common loons, cormorants, and gulls) have been found dead or dying at locations mainly along the shoreline of the south-central main basin, typically during late summer and fall. In several instances, the cause of death has been confirmed to be type E botulism poisoning.

When dreissenid mussels reach high densities, as they have in Lake Huron (Nalepa et al. 2007), they have the potential to divert productivity from pelagic to benthic pathways and/or divert productivity from offshore to inshore waters (Johannsson et al. 2000; Hecky et al. 2004; Nalepa et al. 2005; Nalepa et al. 2007). From 1999 to 2004, in Lake Huron, benthic invertebrate abundance declined, zebra mussel populations stabilized, and quagga mussel populations increased, especially in deeper waters (Nalepa et al. 2007). These changes are important because DesJardine et al. (1995) called for matching predator abundance with prey-fish production, which, in turn, is a function of plankton and benthos production.

Very little is known about the recent distribution of the rusty crayfish (*Orconectes rusticus*) in Lake Huron. The 1999 state of the lake report gives no indication of range (McLain and Bredin 2005). This new invasive species is most often spread by anglers who use it as bait. It is known to displace native crayfish, destroy aquatic vegetation, and impact invertebrate and fish populations (Gunderson 2005). New sightings were reported in 2002 and 2004 in the North Channel (Ontario Federation of Anglers and Hunters 2005), hundreds of kilometers from the nearest previous sighting, which is an indication that the distribution of this species is expanding with human help.

Anecdotal observations by anglers suggest that the spiny water flea (*Bythotrephes longimanus*), another invader, has become common throughout Lake Huron and has now been joined by the fishhook water flea (*Cercopagis pengoi*), one of the most-recent invasive species in the lake. Both species have been commonly observed in fish stomachs. They add another trophic level to the lake and have the potential to reduce the efficiency with which productivity is transferred to higher trophic levels (Hart 2002). Barbiero and Tuchman (2004) argued that these two zooplankters have led to reductions in the abundance of cladocerans (e.g., *Daphnia* spp.) in Lake Huron.

Eurasian watermilfoil is now one of the most-common aquatic plants in Saginaw Bay and in numerous inland waters of the basin (McLain and Bredin 2005). In nutrient-rich lakes, watermilfoil can form thick underwater stands of tangled stems and vast vegetative mats at the water's surface that can crowd out native plants and, at times, interfere with boating, fishing, and swimming (McLain and Bredin 2005). Purple loosestrife is also impacting native vegetation and threatens the biotic integrity of wetland ecosystems (Stuckey 1989). Purple loosestrife was introduced and spread by plant nurseries and by the use of solid ship ballast as fill along shorelines (Stackpole 2000). Chemical, physical, and biological control efforts are now being employed to counteract these invasive plant species. However, as of 2004, there was no measurable evidence of success.

Lower Trophic Levels

Dreissenids appear to be linked to declines in the abundance of benthic invertebrates, especially of the amphipod *Diporeia* spp. (hereafter, diporeia as a common name), an important food for many fishes. By 1999, there was clear evidence of substantial declines in diporeia populations in Saginaw Bay (Barbiero et al. 2005; Dobiesz et al. 2005; Nalepa et al. 2005). Surveys during 2000 and 2003 throughout the main basin showed that all major benthic invertebrates, other than dreissenids, declined from 1972 to 2000. By 2003, diporeia populations had fallen to less than half their 2000 abundance and were absent from large regions of the lake where they were formerly abundant (Nalepa et al. 2007).

No substantial changes in the offshore phytoplankton community or in primary productivity were evidenced through 1999, although substantial eutrophication and some increased productivity occurred in Saginaw Bay and in other inshore locations (Dobiesz et al. 2005). Barbiero et al. (2005) reported that offshore zooplankton biomass was substantially higher during 1998-2002 than in the 1980s, but, by 2004, biomass had declined to levels more like those of the 1980s. This oscillation likely resulted from increases and then decreases in planktivory. Their data also suggest that offshore total spring phosphorus concentrations and offshore summer algal biomass were lower in 2003 and 2004, indicating a decline in primary productivity.

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.

Consistent with the above objective from DesJardine et al. (1995), studies continued on the genetic stock structure of key species undergoing rehabilitation, including walleye and lake trout. Studies have even been expanded since the last state of the lake report (Scribner and Liskauskas 2005) to include assessment of lake sturgeon, muskellunge, and lake whitefish as well as of forage species, such as deepwater sculpin, slimy sculpin, and ninespine stickleback. Molecular markers and novel methods of statistical inference have also been used recently to examine parentage, to estimate variance in recruitment, and to chronicle likely patterns of invasion by non-native species.

Procedures for genetic stock identification have been applied to lake trout samples from around the lake to assess the contribution of different strains to production of wild fish. Results indicate that 80-100% (depending on year and method) of naturally produced lake trout sampled in the main basin of Lake Huron were progeny of Seneca Lake-strain fish, as compared with expectations of 14-60% based on the composition of the spawning population (Page et al. 2003; WS, unpublished data). Georgian Bay-derived hatchery strains contributed disproportionately more (relative to expectations based on numbers stocked) to the naturally produced lake trout population in the bay, although 70% were classified as interstrain hybrids (Stott et al. 2004). These results are consistent with earlier recommendations (Burnham-Curtis et al. 1995; Desjardine et al. 1995; Krueger and Ihssen 1995) that lake trout strains used for rehabilitation should be matched with local environments, when possible.

Genetic relationships among extant populations of walleye in the Great Lakes waters of Michigan, in inland locales in Michigan formerly connected to the Great Lakes, and in waters immediately adjoining the state have been evaluated using microsatellite markers (KS, unpublished data). The genetic characteristics of Saginaw Bay-area spawning runs were found to be very similar to those of the Muskegon River (Lake Michigan), suggesting that the restoration of spawning stocks of walleye in the Saginaw Bay region resulted from stocking mostly Muskegon River fish in the bay.

Genetic studies of walleye from Georgian Bay and Manitoulin Island were used to guide a stocking program administered by the province's Community Fish and Wildlife Improvement Program. Concerns had been raised regarding removing walleyes from a spawning population at Whitefish Falls, a tributary in the eastern end of the North Channel. Microsatellite analysis identified alternative populations, including Lake Manitou on Manitoulin Island, as potential gamete sources based on their low interpopulation divergence and similar compositions (CW, unpublished data).

Substantial effort continues to be directed toward understanding the parentage and stock structure of lake sturgeon in Lake Huron. Research since 1998, using microsatellite DNA from fish in the Black River (a tributary of the Cheboygan River; Fig. 1), has provided information on spawning activity and success rates (P. DeHaan, personal communication, 2006). DeHaan et al. (2006) found that lake sturgeon samples from Michigan waters of the main basin had high genetic affinities to populations in eastern Lake Michigan, but differed significantly from populations in western Lake Michigan and from Lake Superior. Differences have also been found between spawning populations in Ontario's waters of Lake Huron. Interestingly, similarities were also detected among Lakes Huron, Erie, and Ontario populations (Welsh 2006; Welsh et al. 2008) (see the Nearshore Fish Community section).

OMNR researchers have used mitochondrial and microsatellite DNA markers to examine genetic stock structure of muskellunge in Georgian Bay and in the Saugeen and Sydenham Rivers (Fig. 1). While mitochondrial DNA showed insufficient variation for identifying stock structure, microsatellite loci showed moderate variation within and among populations (CW, unpublished data). Data from this study will be used as baseline information to assess the success of rehabilitative stocking in the Spanish River (Fig. 1).

The GLSC is involved currently in a lakewide analysis of lake whitefish stock structure in Lake Huron. Significant differences in microsatellite allele frequency were observed among most collection locations up to 2004. These results will be compared with data from a tagging study of lake whitefish in the main basin, with patterns in commercial catches, and with previous genetic analyses, in an effort to better identify separate reproductive stocks. This research should aid resource agencies in managing this important commercial species.

Ongoing studies on forage fishes using mitochondrial DNA and microsatellites are documenting the degree of spatial genetic structure and of major genetic discordance. Preliminary results for deepwater sculpin, slimy sculpin, and ninespine stickleback indicate less structuring than has been seen in their predators, although a distinct genetic break exists between Lake Superior and Lakes Huron/Michigan. Spatial structuring was most pronounced in the slimy sculpin, and smaller spatial-scale effects related to factors, such as hydrology and species diversity, were important for this species (WS and KS, unpublished data).

While the amount of genetic work being done continues to grow, we are far from having a full accounting of Lake Huron fish stocks with local adaptations. In the past, theories that embraced concepts of genetic diversity were not universally translated into management actions. The emphasis was on the use of “strains” (implying recruitment from anthropogenic sources) in stocking programs, rather than on the conservation of native “stocks” (local populations that are reproductively isolated and that have become adapted to local conditions (Waples 1991)). The recent information will hopefully bring about a change in management philosophy.

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 habitats. Support the reduction or elimination of contaminants.

Progress towards achievement of the above objective from DesJardine et al. (1995) is difficult to evaluate, because no specific quantitative measures or indicators have been developed to assess changes, with the exception of changes in contaminants. Government agencies in Michigan and Ontario collect and analyze various fish species for levels of chemical contaminants that may be harmful to humans. Concentrations of chemicals that tend to bioaccumulate, such as polychlorinated biphenyls (PCBs), mercury, dioxins, and toxophene, declined substantially from the 1970s to the early 1990s in top predators, but, by 2004, the downward trends in PCBs and mercury had leveled off (Lake Huron Binational Partnership 2004). The persistence of chemical contaminants in sediments containing old industrial wastes, airborne particulates, industrial and municipal discharges, and land runoff means that, for the foreseeable future, fish will carry chemical burdens of varying degrees. As a result, fish consumption restrictions and advisories

continued in place for a number of fish species in Lake Huron (Lake Huron Binational Partnership 2004).

Progress towards achievement of the habitat objective was made in 2004 with the completion by a working group of the LHTC of a draft Environmental Objectives (EOs) document. This report recommends three EOs that are largely habitat related (Liskauskas et al. 2007). The first EO calls for the maintenance, protection, and restoration of fish spawning and nursery habitats in coastal wetlands, in tributaries, and around reefs. The second EO stresses the importance of reestablishing natural water exchanges, circulations, and flows along shorelines, because these processes greatly influence nearshore habitats. The last habitat-related EO highlights the need to protect and restore water quality throughout the basin, especially in Areas of Concern (AOCs). It also stresses the need to reduce or eliminate contaminant burdens in fish, in particular by addressing their sources. After the draft document is completed, it should serve as a guide for planning and assessing habitat improvements in Lake Huron.

Of the original seven AOCs in Lake Huron, one (Collingwood Harbor) was delisted during the previous reporting period (Gebhardt et al. 2005) and another, Severn Sound, has been delisted since then. AOCs are defined as areas with prominent habitat impairments that have directly affected local aquatic communities.

Tributary monitoring and mapping continues across the lake as recommended by Gebhardt et al. (2005). However, a comprehensive GIS layer has yet to be completed for Lake Huron. Through 2004, there have been no known barrier removals, modifications, or additions of fish-passage facilities in the Lake Huron basin beyond those reported in the last state of the lake report. Monitoring of wetland habitats across eastern Georgian Bay and the North Channel began in 2003 and is expected to continue.

Recommendations

Although some Lake Huron fishes are adequately monitored on an ongoing basis, rare or imperiled species, with the exception of lake sturgeon, tend to be ignored. Nearshore small-bodied fishes are rarely sampled, creating a large information gap. We advocate broad-based surveys of fish communities in all habitat types, including in the nearshore zone, (McClain et al. 1995) to better evaluate their status, understand their structure, and enhance the maintenance of biodiversity. Species richness and community-structure measures should be reported in future state of the lake reports.

We also recommend an increased emphasis on research aimed at understanding the role and impact of dreissenid mussels and other abundant exotic species on fish production and community structure. The specter of continued introduction and proliferation of aquatic nuisance species lends urgency to the need to develop and implement an enforceable strategy for halting further introductions, regardless of origin. A rapid-response protocol to address new introductions and an active public education program on invasive species are also needed.

Genetic monitoring of fish populations should be expanded. This is particularly important for species undergoing rehabilitation, such as lake trout, walleye, and lake sturgeon, where the determination of strain performance, possible introgression, and the appropriate brood source is critical. Researchers (Stott 1998; Page et al. 2003; Page et al. 2004; Page et al. 2005; Stott et al. 2004; CW, unpublished data) have compiled databases of microsatellite DNA variation for the hatchery strains of lake trout currently stocked in Lake Huron. These databases should be consolidated and standardized. Attention should begin to focus on other issues besides the success of hatchery strains, such as the potential effects of outbreeding depression.

The absence of standardized sampling to assess the total amounts and quality of different types of habitat makes it difficult to establish or identify trends in losses or gains. Thus, we recommend additional efforts to inventory habitat quality and quantity and to also identify critical habitat types for fishes. Lastly, we recommend that the LHC approve the draft EO document and that it be reviewed and revised on an ongoing basis.

STATE OF LAKE HURON: CURRENT AND FUTURE

James R. Bence

Department of Fisheries and Wildlife
Michigan State University
East Lansing, MI, 48824, U.S.A.

Lloyd C. Mohr

Upper Great Lakes Management Unit
Ontario Ministry of Natural Resources
1450 Seventh Ave. East
Owen Sound, ON, N4K 2Z1, Canada

The fish community of Lake Huron has changed dramatically over this five-year reporting period and shows signs of more change soon to come. Major shifts in predator and prey biomass and community structure have moved the community in the direction envisioned in the FCOs (DesJardine et al. 1995). The reasons for the changes are not fully understood, but their existing and potential impacts have been reviewed in earlier sections, and we summarize them in this overview.

Predator-Prey Issues

Indigenous predator species, such as lake trout and walleye have increased in abundance in Lake Huron, and, by the end of the five-year period, lake trout dominated the reported yield from the salmonine community, just as envisioned in the FCOs. Lake trout stocking has remained relatively unchanged since 1992, suggesting that the increased abundance is due to increased survival. Mortality on lake trout due to sea lamprey has decreased (primarily due to treatment of the St. Marys River), and improved management practices have decreased the likelihood of overfishing of lake trout. Increases in the recruitment of wild-born indigenous species, including lake trout, are encouraging, as is the increased natural-based recruitment of introduced predators, such as Chinook salmon. Declining abundance of some predators, most notably Chinook salmon and burbot, suggests a decline in total predator abundance because the increased abundance of lake trout and walleye has not fully compensated for the declines in Chinook salmon and burbot. Overall, however, the fish community appears to have

moved closer to the FCO of a system dominated by indigenous top predators.

Simultaneous with the decline in overall abundance of top predators, the abundance of dominant prey species declined, too, substantially altering previously existing predator-prey interactions. Alewives, in particular, became almost undetectable in 2004. The large lakewide decline in abundance of this species is notable because the alewife was formerly the most-utilized prey by the lake's top predators. The decline in prey biomass has had a negative effect on growth of top predators, thereby reducing the likelihood of achieving predator yield objectives. However, for a variety of reasons, declines in the abundance of the alewife and smelt appear to be having positive effects on other fishes and may, in fact, be promoting especially the recovery of native species other than the walleye and lake trout and a more ecologically balanced fish community. The improved recruitment of native species, apparently in response to the decline of the alewife population, is broader than some would predict (Madenjian et al. 2008), but the timing of these events is striking and unlikely to be coincidental.

Strong year-classes of several prominent species, in particular those with pelagic larvae, were produced in 2003 and 2004. Yellow perch and walleye year-classes in 2003 were the biggest on record in the main basin. The 2003 year-class of lake whitefish also appears to have been of record size in the main basin. Moreover, the near elimination of the alewife from the lake trout diet should markedly reduce the effects of early mortality syndrome on this species and, thereby, increase its reproductive success. The decline in alewife abundance also opens a potential niche for native pelagic fishes. Increased bloater recruitment in 2003 and 2004 and increasing cisco abundance in recent years point towards a negative interaction between native and introduced planktivores. The resurgence of native predators and prey fishes in the face of declining non-indigenous prey indicates substantial progress towards achievement of the lake's FCOs.

Yield-Based Fish-Community Objectives

While the new composition of the fish community can be viewed as positive, the sustainable yield levels specified in the FCOs for all species, particularly for predators, appear to be increasingly unrealistic. The total reported yield declined during the 2000-2004 period and, by 2004, was at about 60% of the FCO of 8.9 million kg. The reported salmonine yield averaged 1.0 million kg during the 2000-2004. Even after doubling the reported recreational Chinook salmon yield to acknowledge substantial extractions by the Ontario

recreational fishery, the adjusted average yield of salmonines of 1.6 million kg was well below the 2.4-million-kg FCO. Likewise, lake trout yield averaged about 0.5 million kg during 2000-2004, as compared with the desired range of 1.4 to 1.8 million kg. Increases in walleye recruitment in Saginaw Bay have not, as of 2004, translated into increased fishery yields. The average walleye yield of 0.2 million kg since 2000 is well below the FCO of 0.7 million kg. Lake whitefish continued to dominate the commercial fishery, and coregonine yields during the 2000-2004 period remained steady near the FCO of 3.8 million kg. Lake trout, Chinook salmon, and lake whitefish populations have all shown declines in growth and condition, suggesting that, under current ecological conditions, substantial increases in the abundance of these species are unlikely, and, even if such increases were possible, would not lead to correspondingly large increases in yields.

Historical-yield levels might now not be sustainable for reasons discussed in detail by Bence et al. (2005): first, the historical yields (1912-1940), upon which the FCOs are based, might not have been sustainable back then; and, second, the current prey-fish community is less likely to be able to harness the primary and secondary productivity of the lake than was the more-diverse historical prey-fish community dominated by coregonines. These concepts led Bence et al. (2005) to recommend intensive efforts to restore a more-diverse coregonine community, particularly of the cisco and of deepwater ciscoes. With respect to the cisco, this recommendation was made in an earlier section. Here we endorse the broader recommendation from Bence et al. (2005), involving reintroduction of deepwater cisco species, to better utilize the lake's productivity.

The growing and now dominant concern regarding potential yield reflects a situation where bottom-up factors have led to the decreased primary and secondary productivity available to fishes. Concerns about how declines in populations of *Diporeia* spp. (hereafter, diporeia as a common name) would impact the achievement of FCOs were previously expressed by Bence et al. (2005) and Mohr and Ebener (2005b). During 2001-2004, the pattern of declines in diporeia populations, while dreissenid mussels proliferated, has become even more evident. Hecky et al. (2004) proposed a linkage between these changes and *Cladophora* spp. blooms, which foul nets and directly interfere with fishing. Furthermore, recent surveys suggested that phytoplankton and zooplankton in the offshore pelagia of Lake Huron reached unusually low levels by 2004. Zooplankton groups showing the largest declines were, unfortunately, those most often consumed by fishes. While the causes of the changing lower-trophic levels are poorly understood, the import of such changes to achievement of objectives is unmistakable.

Although comparing current yields with the historical benchmarks used in the FCOs is illustrative, we believe that a primary emphasis on such comparisons is misplaced. From first principles, one would expect a range of sustainable yields that can be supported by a given fish population or by an aggregate of populations comprising multiple species. When populations are depleted or overfished, they can sustain little yield without further declines, but this is also true when populations are abundant and strong compensation is occurring, and, thus, peak sustainable yields occur at intermediate population sizes. Historically, much fishery management focused on maintaining fish populations near levels that maximized sustainable yields, while, more recently, this goal has been modified to account for competing ecological and economic objectives (usually towards higher levels of fish abundance and somewhat lower yields). This issue is recognized in the FCOs themselves, which, in the introduction, states that quantitative yield objectives “are viewed—not as targets—but as an indication of [fish] community response” (DesJardine et al. 1995). We believe this kind of thinking should become more explicit, so that new quantitative FCOs incorporate target abundance levels within the feasible range and/or define harvest policies that specify acceptable exploitation rates, given abundance. Fishery managers may wish to strive toward ecological states that allow higher sustainable yields at given abundance levels. When incorporating this suggestion into new FCOs, however, we believe one also needs to consider to what extent and through what means yield curves can be altered.

Ecosystem Integrity

The species present in Lake Huron in 2004 were essentially the same as reported in the 1999 state of the lake report, and the status of at-risk species has not changed either. Lake sturgeon abundance has increased slightly, but much more progress is needed before this species can be delisted, especially in Michigan waters. Unfortunately, invasive species continue to expand their range in Lake Huron. By 2004, the round goby had spread outside the main basin into southern Georgian Bay and the North Channel. The rusty crayfish also continued to expand its range and is now found in all three basins. While both of these species (especially round goby) are more common in the diets of native predators, the long-term impacts they are having on the whole fish community are still poorly understood and need to be a priority research topic. Steps also need to be taken to reduce the likelihood of new invasions. Agencies need to better recognize the ecological and economic impacts of existing invasive species to become more diligent about halting new introductions.

Substantial genetic research and evaluation have occurred during the past five years, in particular with respect to recovering native species: walleye, lake sturgeon, and lake trout. Genetic monitoring is likely critical as populations recover from low population sizes.

Notwithstanding a substantial effort to summarize available information on essential fish habitat, we believe little progress has been made on the recommendations of Bence et al. (2005) with regard to fish habitat and biodiversity. Those recommendations included identifying better defined or high-priority habitats in need of protection or at-risk populations with specialized habitat needs. Bence et al. (2005) also argued that the no-net-loss habitat objective was not realistic, and the habitat and species diversity FCOs would benefit from revision.

RECOMMENDATIONS

Specific recommendations were made in each section. Here we attempt to pull together the major recommendations common throughout this report.

1. First and foremost, we believe the time has come to revisit the FCOs. This is driven, in part, by a realization that the current FCOs may not be realizable. Or, if they were to be realized, the cost to objectives for other species would need a reappraisal. This recommendation is also driven by concerns regarding the logical underpinnings of the current FCOs, in particular their dependence upon yield measures. Other metrics exist that are likely more useful in evaluating ecosystem integrity, even at the species level.
2. Promote and support research to better understand how lower trophic-level processes have changed, how they may change even more, and the likely consequences for production of desirable fishes. Such research starts at the prey-fish level and continues down to plankton. While some studies implicate top-down food-web effects, other information suggests that bottom-up effects are also occurring.
3. Continue to promote effective control of sea lamprey as an essential backdrop for achieving other objectives. The maintenance of a self-sustaining, indigenous, top-predator community is the backbone of the lake's FCOs. Sea lamprey control is essential to ensure that top predators, particularly lake trout, survive at sustainable levels. The challenge of potentially competing objectives for other native species (e.g., lake sturgeon, northern brook lamprey, and walleye) needs to be addressed to establish priorities.
4. Identify high-priority habitat for rehabilitation or protection. The development of environmental objectives by the LHTC and the habitat-inventory work has been beneficial. However, critical-habitat mapping in support of rehabilitation planning is missing in many instances and needs to be completed before any meaningful success will be observed.

5. More direct management of native species both for rehabilitation and preservation has been identified as a major recommendation in several sections. The result of these actions will, hopefully, speed the process of achieving the FCOs or, at a minimum, of understanding what actions are required for their achievement.

REFERENCES

- Argyle, R.L. 2005. Prey fishes. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 43-46.
- Baker, E.A., and Borgeson, D.J. 1999. Lake sturgeon abundance and harvest in Black Lake, Michigan, 1975-1999. *North Am. J. Fish. Manage.* **19**: 1080-1088.
- Barbiero, R.P., and Tuchman, M.L. 2004. Changes in the crustacean communities of Lakes Michigan, Huron, and Erie following the invasion of the predatory cladoceran *Bythotrephes longimanus*. *Can. J. Fish. Aquat. Sci.* **61**: 2111-2125.
- Barbiero, R.P., Nalepa, T.F., and Tuchman, M.L. 2005. Phytoplankton, zooplankton, and benthos. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 33-42.
- Bence, J.R., Ebener, M.P., and Eshenroder, R.L. 2005. A critique of fish community objectives. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 119-123.
- Bergstedt, R.A., McDonald, R.B., Mullett, K.M., Wright, G.M., Swink, W.D., and Burnham, K.P. 2003. Mark-recapture population estimates of parasitic sea lampreys (*Petromyzon marinus*) in Lake Huron. *J. Great Lakes Res.* **29**: 283-296.
- Berst, A.H., and Spangler, G.R. 1972. Lake Huron: effects of exploitation, introductions, and eutrophication on the salmonid community. *J. Fish. Res. Board Can.* **29**: 877-887.
- Bowlby, J.N., Mathers, A., Hurley, D.A., and Eckert, T.H. 1991. The resurgence of walleye in Lake Ontario. *In* Status of walleye in the Great Lakes: case studies prepared for the 1989 workshop. *Edited by* P.J. Colby, C.A. Lewis, and R.L. Eshenroder. Great Lakes Fish. Comm. Spec. Pub. 91-01. pp.169-205.
- Brege, D.C., Davis, D.M., Genovese, J.H., McAuley, T.C., Stephens, B.E., and Westman, R.W. 2003. Factors responsible for the reduction in quantity of the lampricide, TFM, applied annually in streams tributary to the Great Lakes from 1979 to 1999. *J. Great Lakes Res.* **29**(Suppl. 1): 500-509.
- Bronte, C.R., Evard, L.M., Brown, W.P., Mayo, K.R., and Edwards, A.J. 1998. Fish community changes in the St. Louis River Estuary, Lake Superior: is it ruffe or population dynamics? *J. Great Lakes Res.* **24**: 309-310.
- Brooking, T.E., Rudstam, L.G., Olson, M.H., and VanDeValk, A.J. 1998. Size dependent alewife predation on larval walleyes in laboratory experiments. *North Am. J. Fish. Manage.* **18**: 960-965.

- Burnham-Curtis, M., Krueger, C.C., Schreiner, D.R., Johnson, J.E., Stewart, T.J., Horrall, R.M., MacCallum, W.R., Kenyon, R., and Lange, R.E. 1995. Genetic strategies for lake trout rehabilitation: a synthesis. *J. Great Lakes Res.* **21**(Suppl. 1): 477-486.
- Carl, L.M. 1982. Natural reproduction of coho salmon and Chinook salmon in some Michigan streams. *North Am. J. Fish. Manage.* **2**: 375-380.
- Crowder, L.B. 1980. Alewife, rainbow smelt, and native fish in Lake Michigan: competition or predation? *Environ. Biol. Fishes* **5**: 225-233.
- DeHaan, P., Libants, S.T., Elliott, R.F., and Scribner, K.T. 2006. Genetic population structure of remnant lake sturgeon populations in the upper Great Lakes basin. *Trans. Am. Fish. Soc.* **135**: 1478-1492.
- DesJardine, R.L., Gorenflo, T.K., Payne, R.N., and Schrouder, J.D. 1995. Fish community objectives for Lake Huron. *Great Lakes Fish. Comm. Spec. Pub.* 95-01.
- Diana, J.S. 1990. Food habits of angler-caught salmonines in western Lake Huron. *J. Great Lakes Res.* **16**: 271-278.
- Dobiesz, N.E. 2003. An evaluation of the role of top piscivores in the fish community of the main basin of Lake Huron. Ph.D. dissertation, Michigan State University, East Lansing, MI.
- Dobiesz, N.E., McLeish, D.A., Eshenroder, R.L., Bence, J.R., Mohr, L.C., Henderson, B.A., Ebener, M.P., Nalepa, T.F., Woldt, A.P., Johnson, J.E., Argyle, R.L., and Makarewicz, J.C. 2005. Ecology of the Lake Huron fish community 1970-1999. *Can. J. Fish. Aquat. Sci.* **62**: 1432-1451.
- Ebener, M.P. [ED.]. 1995. The state of Lake Huron in 1992. *Great Lakes Fish. Comm. Spec. Pub.* 95-02.
- Ebener, M.P. 1997. Recovery of lake whitefish populations in the Great Lakes. *Fisheries* **22**: 18-20.
- Ebener, M.P. [ED.]. 1998. A lake trout rehabilitation guide for Lake Huron. *Great Lakes Fish. Comm. Misc. Pub.*, August 1998.
- Ebener, M.P. [ED.]. 2005. The state of Lake Huron in 1999. *Great Lakes Fish. Comm. Spec. Pub.* 2005-02.
- Ebener, M.P., King, Jr., E.L., Edsall, T.A. 2006. Application of a dichotomous key to the classification of sea lamprey marks on Great Lakes fish. *Great Lakes Fish. Comm. Misc. Pub.* 2006-02.
- Eck, G.W., and Wells, L. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of alewife *Alosa pseudoharengus*. *Can. J. Fish. Aquat. Sci.* **44**(Suppl. 2): 53-60.
- Eshenroder, R.L., Payne, N.R., Johnson, J.E., Bowen, II, C., and Ebener, M.P. 1995. Lake trout rehabilitation in Lake Huron. *J. Great Lakes Res.* **21**(Suppl. 1): 108-127.

- Fielder, D.G., Johnson, J.E., Weber, J.R., Thomas, M.V., and Haas, R.C. 2000. Fish population survey of Saginaw Bay, Lake Huron, 1989-97. Mich. Dept. Nat. Resour. Fish. Res. Rep. No. 2052. Lansing, MI.
- Fielder, D.G., Bowen, A.K., Gebhardt, K.J., and Greenwood, S.J. 2002. Harvest of fishes in the St. Marys River, May, 1999 through March 2000 [online]. Available from glfc.org/lakecom/lhc/HarvestReport.pdf [accessed 11 June 2008].
- Fielder, D.G. 2004. Collapse of the yellow perch fishery in the Les Cheneaux Islands, Lake Huron, and possible causes. *In* Proceedings of the Percis III: the third international percid fish symposium. *Edited by* T.P. Barry and J.A. Malison. Univ. Wisconsin Sea Grant Inst., Madison, WI. pp. 129-130.
- Fielder, D.G., and Baker, J.P. 2004. Strategies and options for the recovery of walleye in Saginaw Bay, Lake Huron. Mich. Dept. Nat. Res., Fish. Spec. Rep. No. 29. Lansing, MI.
- Fielder, D.G., Borgeson, D.J., Bowen, A.K., Koproski, S.R., Greenwood, S.J., and Wright, G.M. 2004. Population dynamics of the St. Marys River Fish Community 1975-2002 [online]. Available from glfc.org/lakecom/lhc/SMR2002rpt.pdf [accessed 11 June 2008].
- Fielder, D.G., Baker, J.P., Mohr, L.C., Liskauskas, A., and McClain, J.R. 2005. The nearshore fish community. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-2. pp. 77-90.
- Fielder, D.G., and Thomas, M.V. 2006. Fish population dynamics of Saginaw Bay, Lake Huron 1998-2004. Mich. Dept. Nat. Resour., Fish. Res. Rep. No. 2083. Lansing, MI.
- Gebhardt, K., Bredin, J., Day, R., Zorn, T.G., Cottrill, A., McLeish, D., and MacKay, M.A. 2005. Habitat. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Fish. Comm. Spec. Pub. 05-02. pp. 27-32.
- Geddes, C. 2006. The Lake Huron GIS [online]. Available from glfc.org/glgis/support_docs/html/GIS_help/fact_sheets/LHGIS_fact_sheet.pdf [accessed 11 June 2008].
- Great Lakes Fishery Commission [ED.]. 2007. A joint strategic plan for management of Great Lakes fisheries (adopted in 1997 and supersedes 1981 original). Great Lakes Fish. Comm. Misc. Pub. 2007-01.
- Gonder, D.J.A. 2003. Dynamics of the Severn Sound fish community with emphasis on walleye (*Stizostedion vitreum*). Ont. Min. Nat. Resour. Upper Great Lakes Manage. Unit Manage. Rep. MR-LHA-2003-01., Owen Sound, ON.
- Gonder, D.J.A. 2005. Status of rainbow trout (*Oncorhynchus mykiss*) in southern Georgian Bay and Lake Huron. Ont. Min. Nat. Resour. Upper Great Lakes Manage. Unit Manage. Rep. MR-LHA-2005-01. Owen Sound, ON.

- Gunderson, J.L. 2005. Rusty crayfish: a nasty invader—biology, identification and impacts. Minn. Sea Grant Fact Sheet X34, Duluth, MN [online]. Available from seagrant.umn.edu/publications/X34 [accessed 6 June 2008].
- Hanari, N., Kannan, K., Horii, Y., Taniyasu, S., Yamashita, N., Jude, D.J., and Berg, M.B. 2004. Polychlorinated naphthalenes and polychlorinated biphenyls in benthic organisms of a Great Lakes food chain. *Arch. Environ. Contam. Toxicol.* **47**(1): 84-93.
- Hart, D.R. 2002. Intraguild predation, invertebrate predators, and trophic cascades in lake food webs. *J. Theory Biol.* **218**(1): 111-128.
- Hay-Chmielewski, E. and Whelan, G.E. 1997. Lake sturgeon rehabilitation strategy. Mich. Dept. Nat. Resour., Fisheries Div. Spec. Rep. No. 18. Lansing, MI.
- He, J.X., Bence, J.R., Johnson, J.E., Clapp, D.F., and Ebener, M.P. 2008. Modeling variation in mass-length relations and condition indices of lake trout and Chinook salmon in Lake Huron: a hierarchical Bayesian approach. *Trans. Am. Fish. Soc.* **137**: 801-817
- Hecky, R.E., Smith, R.E.H., Barton, D.R., Guildford, S.J., Taylor, W.D., Charlton, M.N., and Howell, T. 2004. The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. *Can. J. Fish. Aquat. Sci.* **61**: 1285-1293.
- Holey, M., Elliott, R., Marcquenski, S., Hnath, J., and Smith, K. 1998. Chinook salmon epizootics in Lake Michigan: possible contributing factors and management implications. *J. Aquat. Animal Health* **10**(2): 202-210.
- Johannsson, O.E., Dermott, R., Graham, D.M., Dahl, J.A., Millard, E.S., Myles, D.D., and LeBlanc, J. 2000. Benthic and pelagic secondary production in Lake Erie after the invasion of *Dreissena* spp. with implications for fish production. *J. Great Lakes Res.* **26**: 31-54.
- Johnson, J.E., and Rakoczy, G.P. 2004. Investigations into recent declines in survival of brown trout stocked in Lake Charlevoix and Thunder Bay, Lake Huron. Mich. Dept. Nat. Resour., Fish. Res. Rep. No. 2075. Lansing, MI.
- Johnson, J.E., He, J.X., Woldt, A.P., Ebener, M.P., and Mohr, L.C. 2004. Lessons in rehabilitation stocking and management of lake trout in Lake Huron. *In* Propagated fish in resource management. *Edited by* M. Nickum, P. Mazik, J. Nickum, and D. MacKinlay. *Am. Fish. Soc. Symp.* **44**: 161-175.
- Johnson, J.E., Dewitt, S.P., and Clevenger, Jr., J.A. 2007. Investigations into causes of variable survival of Chinook salmon stocked into Lake Huron. Mich. Dept. Nat. Resour., Fish. Res. Rep. No. 2086. Ann Arbor, MI.
- Jones, M.L., Koonce, J.F., and O’Gorman, R. 1993. Sustainability of hatchery-dependent salmonine fisheries in Lake Ontario: the conflict between predator demand and prey supply. *Trans. Am. Fish. Soc.* **122**: 1002-1018.

- Jude, D.J., Reider, R.H., and Smith, G.R. 1992. Establishment of the Gobiidae in the Great Lakes Basin. *Can. J. Fish. Aquat. Sci.* **49**: 416-421.
- Jude, D.J. 1997. Round gobies: cyberfish of the third millennium. *Great Lakes Res. Rev.* **3**: 27-34.
- Kennedy, A.J., Greil, R.W., Back, R.C., and Sutton, T.M. 2005. Populations, characteristics and spawning migration dynamics of pink salmon in U.S. waters of the St. Marys River. *J. Great Lakes Res.* **31**: 11-21.
- King, Jr., E.L. 1980. Classification of sea lamprey (*Petromyzon marinus*) attack marks on Great Lakes lake trout (*Salvelinus namaycush*). *Can. J. Fish. Aquat. Sci.* **37**: 1989-2006.
- Klar, G.T., and Young, R.J. 2005. Integrated management of sea lampreys in Lake Huron 2004. *In* Minutes of the 2005 Annual Meeting of the Lake Huron Committee, Attach. No. 4.b., pp. 35-53. Great Lakes Fishery Commission, Ann Arbor, MI.
- Krueger, K.M., Schrouder, K.S., Baker, J.P., Ebener, M.P., and McClain, J.R. 1995. Status of cool-water fishes in 1992. *In* The state of Lake Huron in 1992. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 95-02. pp. 73-85.
- Krueger, C.C., and Ihssen, P.E. 1995. Review of genetics of lake trout in the Great Lakes: history, molecular genetics, physiography, strain comparisons, and restoration management. *J. Great Lakes Res.* **21**(Suppl. 1): 348-363.
- Kwain, W. 1982. Spawning behaviour and early life history of pink salmon (*Oncorhynchus gorbuscha*) in the Great Lakes. *Can. J. Fish. Aquat. Sci.* **39**: 1353-1360.
- Kwon, T.D., Fisher, S.W., Kim, G.W., Hwang, H., Kim, J.E. 2006. Trophic transfer and biotransformation of polychlorinated biphenyls in zebra mussel, round goby, and smallmouth bass in Lake Erie, U.S.A.. *Environ. Toxicol. Chem.* **25**(4): 1068-1078.
- Lake Huron Binational Partnership. 2004. 2004 Binational Partnership Action Plan [online]. Available from epa.gov/greatlakes/lakehuron/LH%202004.pdf [accessed 11 June 2008].
- Lavis, D.S., Hallett, A., Koon, E.M., and McAuley, T.C. 2003. History and advances in barriers as an alternative method to suppress sea lampreys in the Great Lakes. *J. Great Lakes Res.* **29**(Suppl. 1): 362-372.
- Liskauskas, A.P. 2002. Georgian Bay and the North Channel walleye assessment update: 2002. Ont. Min. Nat. Resour. Upper Great Lakes Manage. Unit Tech. Rep. TR-LHA-2002-01. Owen Sound, ON.
- Liskauskas, A.P. 2004. Severn Sound end of spring trap netting (ESTN) survey: summary report, 2004. Ont. Min. Nat. Resour. Upper Great Lakes Manage. Unit Program Series Rep. PS-LHA-IA04-251. Owen Sound, ON.

- Liskauskas, A., Johnson, J., McKay, M., Gorenflo, T., Woldt, A., and Bredin, J. 2007. Environmental objectives for Lake Huron [online]. Available from glfc.org/lakecom/lhc/lheo.pdf [accessed 11 June 2008].
- Ludwig, J.P., and Summer, C.L. 1997. Population status and diet of cormorants in Les Cheneaux Islands area. *In* History, status, and trends in populations of yellow perch and double-crested cormorants in Les Cheneaux Islands, Michigan. *Edited by* J.S. Diana, G.Y. Belyea, R.D Clark, Jr. Mich. Dept. Nat. Resour., Fish. Div. Spec. Rep. No. 16. Lansing, MI. pp.5–25.
- Madenjian, C.P., DeSorcie, T.J., and Stedman, R.H. 1998. Ontogenetic and spatial patterns in diet and growth of lake trout in Lake Michigan. *Trans. Am. Fish. Soc.* **127**: 236-252.
- Madenjian, C.P., Bunnell, D.B., Desorcie, T.J., Holuszko, J.D., and Adams J.V. 2005. Status and trends of prey fish populations in Lake Michigan. *In* Minutes of the 2005 Annual Meeting of the Lake Michigan Committee, Attach. No. 10. B., pp. 67-78. Great Lakes Fishery Commission, Ann Arbor, MI.
- Madenjian, C.P., O’Gorman, R., Bunnell, D.B., Argyle, R.L., Roseman, E.F., Warner, D.M., Stockwell, J.D., and Stapien, M.A. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. *North Am. J. Fish. Manage.* **28**: 263-282.
- Mandrak, N.E. 2004. Development of a Great Lakes fish distribution database and web-based atlas of Great Lakes fishes [online]. Available from glfc.org/research/reports/Mandrak.pdf [accessed 22 July 2008].
- Martin, N.V. 1966. The significance of food habits in the biology, exploitation, and management of Algonquin Park, Ontario, lake trout. *Trans. Am. Fish. Soc.* **95**: 415-422.
- McClain, J.R., and Bredin, J.H. 2005. Recent invasive species. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-2. pp. 115-118.
- McClain, J.R., Ebener, M.P., and Johnson, J.E. 1995. Status of species diversity, genetic diversity and habitat in 1992. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 109-26.
- McLaughlin, G. 2003. Conference overview. *In* Botulism in Lake Erie workshop proceedings [online]. Available from seagrant.sunysb.edu/botulism/pdfs/Botulism-Proc03.pdf [accessed 11 June 2008].
- Mohr, L.C., and Ebener, M.P. 2005a. Description of fisheries. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 19-26.
- Mohr, L.C., and Ebener, M.P. 2005b. Coregonine community. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 69-76.

- Mohr, L.C., and Ebener, M.P. 2005c. Status of lake whitefish (*Coregonus clupeaformis*) in Lake Huron. *In* Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great Lakes. *Edited* by L.C. Mohr, and T.F. Nalepa. Great Lakes Fish. Comm. Tech. Rep. 66. pp. 105-125.
- Morse, T.J., Ebener, M.P., Koon, E.M., Morkett, S.B., Johnson, D.A., Cuddy, D.W., Weisser, J.W., Mullett, K.M., and Genovese, J.H. 2003. A case history of sea lamprey control in Lake Huron: 1979-1999. *J. Great Lakes Res.* **29**(Suppl. 1): 599-614.
- Morse, T.J., and Young, R.J. 2005. Sea lamprey. *In* The state of Lake Huron in 1999. *Edited* by M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 111-113.
- Nalepa, T.F., Fanslow, D.L., and Messick, G. 2005. Characteristics and potential causes of declining *Diporeia* spp. populations in southern Lake Michigan and Saginaw Bay, Lake Huron. *In* Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great Lakes. *Edited* by L.C. Mohr, and T.F. Nalepa. Great Lakes Fish. Comm. Tech. Rep. 66. pp. 157-188.
- Nalepa, T.F., Fanslow, D.L., Pothoven, S.A., Foley, III, A.J., and Lang G.A. 2007. Long-term trends in benthic macroinvertebrate populations in Lake Huron over the past four decades. *J. Great Lakes Res.* **33**(2): 421-436.
- Nelson, J.S., Crossman, E.J., Espinosa-Pérez, H., Findley, L.T., Gilbert, C.R., Lea, R.N., and Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. *Am. Fish. Soc. Spec. Pub.* 29.
- Nunan, P.J. 1967. Pink salmon in Lake Superior. *Ont. Fish. Wildl. Rev.* **6**(3-4): 9-14.
- Ontario Federation of Anglers and Hunters. 2005. Invading species awareness program [online]. Available from invadingspecies.com/indexen.cfm [accessed 11 June 2008].
- O’Gorman, R., and Schneider, C.P. 1986. Dynamics of alewives in Lake Ontario following a mass mortality. *Trans. Am. Fish. Soc.* **115**: 1-14.
- O’Gorman R., and Stewart, T.J. 1999. Ascent, dominance, and decline of the alewife in the Great Lakes: food web interactions and management strategies. *In* Great Lakes fisheries policy and management: a binational perspective. *Edited* by W.W. Taylor and C.P. Ferreri, Mich. State U. Press, East Lansing, MI. pp. 489-513.
- Ontario Ministry of Natural Resources. 2004. Offshore index assessment program, 2003 summary report. *Ont. Min. Nat. Resour. Upper Great Lakes Manage. Unit Prog. Series Rep.* PS-LHA-IA03-SUM. Owen Sound, ON.
- Page, K.S., Scribner, K.T., Bennett, K.R., Garzel, L.M., and Burnham-Curtis, M.K. 2003. Genetic assessment of strain-specific sources of lake trout recruitment in the Great Lakes. *Trans. Am. Fish. Soc.* **132**: 877-894.

- Page, K.S., Scribner, K.T., and Burnham-Curtis, M.K. 2004. Assessing levels and partitioning of genetic diversity in wild and hatchery lake trout populations: relevance for lake trout management and restoration in the Great Lakes. *Trans. Am. Fish. Soc.* **133**: 674-691.
- Page, K.S., Scribner, K.T., Bast, D., Holey, M., and Burnham-Curtis, M. 2005. Influences on the genetic diversity in the lake trout hatchery program used for restoration efforts in the upper Great Lakes. *Trans. Am. Fish. Soc.* **105**: 872-891.
- Powell, J.J., and Miller, M. 1990. Shoal spawning by Chinook salmon in Lake Huron. *North Am. J. Fish. Manage.* **10**: 242-244.
- Ridgway, M.S., Milne, S.M., Middel, T., and Casselman, J.M. 2006. Double-crested cormorant and coastal fish monitoring and assessment in the North Channel and Georgian Bay, Lake Huron [online]. Available from milnettechnologies.ca/MilneTech_Docs/DCCO%20Methodology%20Final.pdf [accessed 11 June 2008].
- Reid, D.M., Anderson, D.M., and Henderson, B.A. 2001. Restoration of lake trout in Parry Sound, Lake Huron. *North Am. J. Fish. Manage.* **21**: 156-169.
- Schaeffer, J.S., and Woldt, A. 2005. Species diversity. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 99-104.
- Schaeffer, J.S., Roseman, E.F., Riley, S.C., Faul, C.S., O'Brien, T.P., and Fouilleroux, A. 2005a. Status and trends of the Lake Huron deepwater fish community. *In* Minutes of the 2005 Annual Meeting of the Lake Huron Committee, Attach. No. 6, pp. 103-116. Great Lakes Fishery Commission, Ann Arbor, MI.
- Schaeffer, J.S., Bowen, A., Thomas, M., French, III, J.R.P., and Curtis, G.L. 2005b. Invasion history, proliferation, and offshore diet of the round goby *Neogobius melanostomus* in western Lake Huron, U.S.A.. *J. Great Lakes Res.* **31**: 414-425.
- Schleen, L.P., Christie, G.C., Heinrich, J.W., Bergstedt, R.A., Young, R.J., Morse, T.J., Lavis, D.S., Bill, T.D., Johnson, J.E., and Ebener, M.P. 2003. Development and implementation of an integrated program for control of sea lampreys in the St. Marys River. *J. Great Lakes Res.* **29**(Suppl. 1): 677-693.
- Schneider, J.C., and Leach, J.H. 1979. Walleye stocks in the Great Lakes 1800-1975: fluctuations and possible causes. *Great Lakes Fish. Comm. Tech. Rep.* No. 31.
- Scribner, K.T., and Liskauskas, A.P. 2005. Genetic diversity. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. Great Lakes Fish. Comm. Spec. Pub. 05-02. pp. 99-104.
- Smith, S.H. 1970. Species interactions of the alewife in the Great Lakes. *Trans. Am. Fish. Soc.* **100**:754-765.

- Stackpoole, S. 2000. Purple loosestrife in Michigan: biology, ecology, and management [online]. Available from miseagrant.umich.edu/downloads/ais/fs-97-501_purple_loosestrife.pdf [accessed 11 June 2008].
- Stapanian, M.A., Madenjian, C.P., Bronte, C.R., Ebener, M.P., Lantry, B.F., and Stockwell J.D. 2008. Status of burbot populations in the Laurentian Great Lakes. *In*. Burbot: ecology, management, and culture. *Edited by* V. Paragamian and D. Bennett. *Am. Fish. Soc. Symp.* **59**: 111-130.
- Stewart, D.J., Kitchell, J.F., and Crowder, L.B. 1981. Forage fish and their salmonid predators in Lake Michigan. *Trans. Am. Fish. Soc.* **110**: 751-763.
- Stott, W. 1998. Genetic variation within and among Ontario hatchery stocks of lake trout (*Salvelinus namaycush*) as measured by three molecular marker systems: applications to rehabilitation and hatchery management. Ph.D. thesis. McMaster Univ., Hamilton, ON.
- Stott, W., Reid, D.M., and Johnson, J. 2004. Natural lake trout strain identification in Lake Huron [online]. Available from glfc.org/research/reports/Stott_LHuron_LAT.html [accessed 22 July 2008].
- Stuckey, R.L. 1989. Western Lake Erie aquatic and wetland vascular plant flora: its origin and change. *In* Lake Erie estuarine systems: issues, resources, status, and management. *Edited by* K.A. Kreiger. NOAA Estuary-of-the-Month Seminar Series No. 14. Dept. Commerce, Washington, DC. pp. 205-256.
- Szalai, E.B., Fleischer, G.W., and Bence, J.R. 2003. Modeling time varying growth using a generalized von Bertalanffy model with application to bloater (*Coregonus hoyi*) growth dynamics in Lake Michigan. *Can. J. Fish. Aquat. Sci.* **60**: 55-66.
- Tran, J.L.-A. 2007. Nearshore small fishes of Lake Huron: maximizing the detection of species in sampling surveys, demography of an invasive species, round goby, and nest defense of native smallmouth bass against round gobies. M.Sc. thesis, Dept. Zool., Univ. Toronto, Toronto, ON.
- Twohey, M.B., Sorensen, P.W., and Li, W. 2003. Possible application of pheromones in an integrated sea lamprey control program. *J. Great Lakes Res.* **29**(Suppl. 1): 410-423.
- United States vs. Michigan. 2000. Consent Decree August 8, 2000. United States District Court, Western District of Michigan, Southern Division, Case No.2:73 CV 26 [online]. Available from 1836cora.org/pdf/2000consentdecree.pdf [accessed 11 June 2008].
- Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. *Can. J. Fish. Aquat. Sci.* **48**:124-133.
- Welsh, A.B. 2006. Lake sturgeon conservation in the Great Lakes: scaling it up from genetics to policy. Ph.D. dissertation, Dept. Animal Sci., Univ. California, Davis, CA.

- Welsh, A.B., Hill, T., Quinlan, H., Robinson, C., and May, B. 2008. Genetic assessment of lake sturgeon population structure in the Laurentian Great Lakes. *North Am. J. Fish. Manage.* **28**: 572-591.
- Weseloh, D.V.C., Pekarik, C., Havelka, T., Barrett, G., and Reid, J. 2002. Population trends and colony locations of double-crested cormorants in the Canadian Great Lakes and immediately adjacent areas, 1990-2000: a manager's guide. *J. Great Lakes Res.* **28**(2): 125-144.
- Whelan, G.E., and Johnson, J.E. 2004. Successes and failures of large scale ecosystem manipulation using hatchery production: the Upper Great Lakes experience. *In* Propagated fish in resource management. *Edited by* M.J. Nickum, P.M. Mazik, J.G. Nickum, and D.D. MacKinlay. *Am. Fish. Soc., Symp.* **44**: 3-32.
- Woldt, A.P., Reid, D.M., and Johnson, J.E. 2005a. Status of the open-water predator community. *In* The state of Lake Huron in 1999. *Edited by* M.P. Ebener. *Great Lakes Fish. Comm. Spec. Pub.* 05-02. pp. 47-68.
- Woldt, A.P., Sitar, S.P., Bence, J.R., and Ebener, M.P. 2005b. Status of lake trout and lake whitefish populations in the 1836 treaty-ceded waters of Lakes Superior, Huron and Michigan in 2003, with recommended yield and effort levels for 2004 [online]. Available from michigan.gov/documents/2004StatusLT&LakeWhitefishPop_126360_7.pdf [accessed 11 June 2008].
- Young, R.J. 2005. Integrating heterogenous survey data to characterize the success of the Lake Huron sea lamprey (*Petromyzon marinus*) control program. Ph.D. Dissertation, Mich. State U., East Lansing, MI.
- Yule A.M., LePage V., Austin J.W., Barker I.K., and Moccia, R.D. 2006. Repeated low-level exposure of the round goby (*Neogobius melanostomus*) to *Clostridium botulinum* type E neurotoxin. *J. Wildl. Diseases* **42**: 494-500.

- 88-4 The international Great Lakes sport fishery of 1980. 1988. D. R. Talhelm. 70 p.
- 89-1 A decision support system for the integrated management of sea lamprey. 1989. J. F. Koonce and A. B. Locci-Hernandez. 74 p.
- 90-1 Fish community objectives for Lake Superior. 1990. Edited by T. R. Busiahn. 24 p.
- 90-2 International position statement and evaluation guidelines for artificial reefs in the Great Lakes. 1990. Edited by J. E. Gannon. 24 p.
- 90-3 Lake Superior: the state of the lake in 1989. 1990. Edited by M. J. Hansen. 56 p.
- 90-4 An ecosystem approach to the integrity of the Great Lakes in turbulent times (proceedings of a 1988 workshop supported by the Great Lakes Fishery Commission and the Science Advisory Board of the International Joint Commission). 1990. Edited by C. J. Edwards and H. A. Regier. 302 p.
- 91-1 Status of walleye in the Great Lakes: case studies prepared for the 1989 workshop. 1991. Edited by P. J. Colby, C. A. Lewis, and R. L. Eshenroder. 222 p.
- 91-2 Lake Michigan: an ecosystem approach for remediation of critical pollutants and management of fish communities (report of a round table sponsored in 1990 by the Great Lakes Fishery Commission, the Science Advisory Board of the International Joint Commission, and the Lake Michigan Federation). 1991. Edited by R. L. Eshenroder, J. H. Hartig, and J. E. Gannon. 58 p.
- 91-3 The state of the Lake Ontario fish community in 1989. 1991. S. J. Kerr and G. C. LeTendre. 38 p.
- 93-1 Great Lakes fish disease control policy and model program. 1993. Edited by J. G. Hnath. 38 p. Protocol to minimize the risk of introducing emergency disease agents with importation of salmonid fishes from enzootic areas. 1993. Edited by R.W. Horner and R. L. Eshenroder. 15 p.
- 94-1 The state of Lake Superior in 1992. 1994. Edited by M. J. Hansen. 110 p.
- 94-2 An introduction to economic valuation principles for fisheries management. L. G. Anderson. 98 p.
- 95-1 Fish-community objectives for Lake Huron. 1995. R. L. DesJardine, T. K. Gorenflo, R. N. Payne, and J. D. Schrouder. 38 p.
- 95-2 The state of Lake Huron in 1992. Edited by M. P. Ebener. 140 p.
- 95-3 Fish-community objectives for Lake Michigan. R.L. Eshenroder, M.E. Holey, T.K. Gorenflo, and R.D. Clark, Jr. 56 p.
- 99-1 Fish-community objectives for Lake Ontario. T.J. Stewart, R.E. Lange, S.D. Orsatti, C.P. Schneider, A. Mathers, M.E. Daniels. 56 p.
- 03-01 Fish-community objectives for Lake Superior. W.H. Horns, C.R. Bronte, T.R. Busiahn, M.P. Ebener, R.L. Eshenroder, T. Gorenflo, N. Kmiecik, W. Mattes, J.W. Peck, M. Petzold, D.R. Schreiner. 86 p.
- 03-2 Fish-community goals and objectives for Lake Erie. P.A. Ryan, R. Knight, R. MacGregor, G. Towns, R. Hoopes, W. Culligan. 56 p.
- 05-01 The state of Lake Michigan in 2000. Edited by M. E. Holey and T. N. Trudeau. 114 p.
- 05-02 The state of Lake Huron in 1999. Edited by M. P. Ebener. 140 p.
- 07-01 The state of Lake Ontario in 2003. Edited by B. J. Morrison and S. R. LaPan. 108 p.
- 07-02 The state of Lake Superior in 2000. Edited by M. P. Ebener. 126 p.

Special Publications

- 79-1 Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. 1979. E. L. King and T. A. Edsall. 41 p.
- 82-1 Recommendations for freshwater fisheries research and management from the Stock Concept Symposium (STOCS). 1982. A. H. Berst and G. R. Spangler. 24 p.
- 82-2 A review of the adaptive management workshop addressing salmonid/lamprey management in the Great Lakes. 1982. Edited by J. F. Koonce, L. Greig, B. Henderson, D. Jester, K. Minns, and G. Spangler. 58 p.
- 82-3 Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. 1982. Edited by N. A. Auer. 744 p. (Cost: \$10.50 U.S., \$12.50 CAN)
- 83-1 Quota management of Lake Erie fisheries. 1983. Edited by J. F. Koonce, D. Jester, B. Henderson, R. Hatch, and M. Jones. 40 p.
- 83-2 A guide to integrated fish health management in the Great Lakes basin. 1983. Edited by F. P. Meyer, J. W. Warren, and T. G. Carey. 262 p.
- 84-1 Recommendations for standardizing the reporting of sea lamprey marking data. 1984. R. L. Eshenroder and J. F. Koonce. 22 p.
- 84-2 Working papers developed at the August 1983 conference on lake trout research. 1984. Edited by R. L. Eshenroder, T. P. Poe, and C. H. Olver.
- 84-3 Analysis of the response to the use of "Adaptive Environmental Assessment Methodology" by the Great Lakes Fishery Commission. 1984. C. K. Minns, J. M. Cooley, and J. E. Forney. 22 p.
- 85-1 Lake Erie fish community workshop (report of the April 4-5, 1979 meeting). 1985. Edited by J. R. Paine and R. B. Kenyon. 58 p.
- 85-2 A workshop concerning the application of integrated pest management (IPM) to sea lamprey control in the Great Lakes. 1985. Edited by G. R. Spangler and L. D. Jacobson. 98 p.
- 85-3 Presented papers from the Council of Lake Committees plenary session on Great Lakes predator-prey issues, March 20, 1985. 1985. Edited by R. L. Eshenroder. 134 p.
- 85-4 Great Lakes fish disease control policy and model program. 1985. Edited by J. G. Hnath. 24 p.
- 85-5 Great Lakes Law Enforcement/Fisheries Management Workshop (report of the 21, 22 September 1983 meeting). 1985. Edited by W. L. Hartman and M. A. Ross. 26 p.
- 85-6 TFM vs. the sea lamprey: a generation later. 1985. 18 p.
- 86-1 The lake trout rehabilitation model: program documentation. 1986. C. J. Walters, L. D. Jacobson, and G. R. Spangler. 34 p.
- 87-1 Guidelines for fish habitat management and planning in the Great Lakes (report of the Habitat Planning and Management Task Force and Habitat Advisory Board of the Great Lakes Fishery Commission). 1987. 16 p.
- 87-2 Workshop to evaluate sea lamprey populations "WESLP" (background papers and proceedings of the August 1985 workshop). 1987. Edited by B. G. H. Johnson.
- 87-3 Temperature relationships of Great Lakes fishes: a data compilation. 1987. D. A. Wismer and A. E. Christie. 196 p.
- 88-1 Committee of the Whole workshop on implementation of the Joint Strategic Plan for Management of Great Lakes Fisheries (reports and recommendations from the 18-20 February 1986 and 5-6 May 1986 meetings). 1988. Edited by M. R. Dochoda. 170 p.
- 88-2 A proposal for a bioassay procedure to assess impact of habitat conditions on lake trout reproduction in the Great Lakes (report of the ad hoc Committee to Assess the Feasibility of Conducting Lake Trout Habitat Degradation Research in the Great Lakes). 1988. Edited by R. L. Eshenroder. 13 p.
- 88-3 Age structured stock assessment of Lake Erie walleye (report of the July 22-24, 1986 Workshop). 1988. R. B. Deriso, S. J. Nepszy, and M. R. Rawson. 13 p.