THE STATE OF LAKE HURON IN 1999

SPECIAL PUBLICATION 05-02

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COMMISSIONERS

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THE STATE OF LAKE HURON
IN 1999

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EXECUTIVE SUMMARY

Fish-community objectives (FCOs) for the Lake Huron fish community (DesJardine et al. 1995) were established in response to A Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 1997). This state-of-the-lake report identifies progress in meeting these objectives since the last state-of-the-lake report in 1992 (Ebener 1995), describes the status of fish stocks and their habitat in Lake Huron, makes recommendations to the management agencies regarding actions that should be taken to achieve FCOs, and indicates where FCOs need revision. Creation and maintenance of databases are essential for evaluating FCOs. The Lake Huron Committee (LHC) should ensure that these large databases are created and maintained for future use by all agencies. Lake Huron FCOs are stated below in italics followed by status and progress in achieving them since 1992.

Habitat

Protect and enhance fish habitat and rehabilitate degraded 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.

The open-water and nearshore habitat of Lake Huron remains relatively healthy and unchanged since 1992, but habitat loss continues in embayments, coastal wetlands, and tributaries. Although anthropogenic loading has apparently not increased, the open-water and nearshore habitat still receives aerial input of contaminants, and contaminant burdens in fish flesh continue to generate consumption advisories. Dams remain the primary impediment to rehabilitating tributary habitat, and loss of coastal wetlands hinders achievement of objectives for many Lake Huron fishes, especially esocids and centrarchids. Remedial action has been taken to remove contaminated sediments from the Saginaw River, remediation has been completed for the Collingwood Harbor Area of Concern, and run-of-the-river flow has been established on the Au Sable River in Michigan below Foote Dam.

The open-water habitat has not experienced increased productivity fostered by anthropogenic loadings—as evidenced by the large proportion of diatoms in the summer plankton community. Lack of increased productivity in the open water is positive and necessary to maintain the oligotrophic nature of Lake Huron. Productivity decreased in the nearshore habitat of Saginaw Bay where *Diporeia* spp. populations have decreased substantially since the invasion of zebra mussels, and *Hexagenia* spp. populations still have not recovered as they have in other areas of Lake Huron. Abundance of exotic species, such as zebra and quagga mussels and the round goby, have increased substantially since 1992. Zebra mussels have had the most profound effect on the trophic ecology of Lake Huron.

Inventorying and protecting embayment, tributary, and wetland habitat, and increasing access to tributary habitat should be the primary emphasis of Lake Huron agencies. The Lake Huron global information systems (GIS) database can quantify these habitats to better assess gains and losses and to specify targets for improved fish passage. Access to good tributary habitat is essential for rehabilitation of lake sturgeon and other tributary-dependent fishes. Rehabilitation of the habitat in Saginaw Bay is prerequisite to achieving the FCOs for walleye, yellow perch, channel catfish, and lake herring. Resource agencies should seek information about how much reduction in direct discharge and long-range atmospheric loading of contaminants would be necessary to remove Lake Huron fish from consumption advisories and to meet contaminant objectives of the Great Lakes Water Quality Agreement. Agencies should work more cooperatively to monitor plankton and benthos communities.

Prey Species

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

Overall abundance and the size and age structure of alewife and rainbow smelt populations continue to decline in Lake Huron. Predator-prey models suggest that predator demand may be equal to or exceeding prey-fish production in the main basin. In Saginaw Bay, predator-prey relationships are also out of balance, but the other way—plenty of prey but not enough predators.

Agencies should protect and promote recovery of the indigenous bloater and lake herring as the principal prey species. Reliance on non-indigenous alewife and rainbow smelt limits lake trout rehabilitation, limits diversity of prey species, and greatly complicates achievement of a sustainable abundance of top predators. Agencies should consider management actions to suppress alewife and rainbow smelt and the expanding populations of round goby.

Salmonines

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.

Hatchery fish represent the majority of salmonine predators in Lake Huron, but some progress has been made in lake trout rehabilitation, and natural reproduction by the introduced salmonines has increased. Natural reproduction of lake trout has been detected at six sites, and rehabilitation of a self-sustaining population has been achieved in Parry Sound. Natural reproduction by Chinook and coho salmon has been reported but not quantified, and Chinook salmon remains the dominant salmonine predator. The annual whole-lake harvest of salmonines is unknown, but it is believed to be less than the 2.4-million-kg target stated in the FCO. Salmonine growth rates have declined, particularly for Chinook salmon, indicating that predator populations may be approaching or exceeding the carrying capacity of the prey base. The greatest uncertainty in determining predator-prey dynamics is the lack of reliable information on the amount of natural reproduction of Chinook salmon.

Salmonine FCOs should be based on self-sustainability and prey availability rather than a specific yield, and a concerted effort should be made to determine total annual harvest of important species. Lake trout rehabilitation efforts, especially stocking, should be focused in areas of primary spawning habitat. Numbers stocked annually in these areas should be increased to the recommended four or more yearlings per hectare, or employing a pulse-stocking strategy if the required number of yearlings are not available on an annual basis—stock at the recommended level for several years then no stocking for several years. Lake trout spawning areas should be inventoried to determine quantity and quality. Agencies should coordinate efforts to determine the contribution of naturally produced fish to the salmonine community, especially from Chinook salmon. The lethality of sea lamprey attacks should be determined for various sizes and species, especially top predators such as lake trout and Chinook salmon. Agencies should take into account those food-web factors that influence the high levels of thiaminase in alewife and assess the sub-lethal consequences of low thiamine on fry survival, recruitment, and long-term viability of lake trout and other salmonine populations.

Coregonines

Maintain the present diversity of coregonines. Manage lake whitefish and ciscoes at levels capable of sustaining annual harvests of 3.8 million kg. Restore lake herring to a significant level and protect, where possible, rare deepwater ciscoes.

The harvest objective of 3.8 million kg for the current coregonine community composed of lake whitefish, round whitefish, lake herring, and bloater has been exceeded every year since 1992. Lake whitefish yields comprise 90% of the total coregonine yield, are increasing, and alone exceed 3.8 million kg. However, we are uncertain if these yields can be sustained in the face of declining populations of *Diporeia* spp. and increased abundance of invasive zebra and quagga mussels. Lake herring abundance has increased in northern waters of the main basin and bays of the North Channel and Georgian Bay, but bloater abundance has declined to very low levels throughout the lake, and other species of deepwater coregonines are extremely rare or extinct. Agencies should work cooperatively to develop a lakewide rehabilitation plan for all cisco species currently in the lake and consider reintroduction of those extant in other Great Lakes or elsewhere but extirpated in Lake Huron. Bloater and lake herring harvest levels should be extremely conservative with FCOs revised to reflect their primary role as indigenous prey species.

Percids

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

The walleye is the dominant cool-water predator in many areas of Lake Huron, but the annual yield has remained well below 0.7 million kg during 1993-99. A large population of walleye exists in Saginaw Bay, but it is composed primarily of stocked fish and of wild migrants from outside

Saginaw Bay. Walleye populations remain suppressed in eastern Georgian Bay and in portions of the North Channel because of exploitation, habitat loss, and improper stocking practices.

The Saginaw Bay yellow perch population remains generally healthy with yield commensurate with historical levels. The St. Marys River yellow perch population appears stable, and yellow perch continue to support a commercial fishery in southern Ontario waters. Yellow perch populations in other areas, including the Les Cheneaux Islands and certain areas of the North Channel and Georgian Bay, are declining for unknown reasons.

The percid FCO should be revised to reflect self-sustainability and predator-prey dynamics rather than yield to fisheries. Agencies should determine harvest and the contribution of stocked walleyes for all managed populations and coordinate efforts on shared stocks. Walleye spawning and nursery habitat in Saginaw Bay should be rehabilitated. The effect of cormorant predation on yellow perch should be determined.

Esocids

*Maintain northern pike as a prominent predator throughout its natural range. Maintain muskellunge (*Exox masquinongy*) in numbers and at sizes that will safeguard and enhance its special status and appeal. Sustain a harvestable annual surplus of 0.1 million kg of these esocids.*

Self-sustaining populations of northern pike and muskellunge remain widely distributed throughout the littoral waters of Lake Huron, including Georgian Bay and the North Channel, but their lakewide harvest is unknown. Existing commercial fisheries do not target esocids, and whole-lake estimates of recreational and subsistence fishery harvests are not available. Whether the 0.1 million kg of harvest can be sustained is unknown. The North Channel, Georgian Bay, and St. Marys River populations of northern pike are experiencing high rates of exploitation and have truncated age distributions. Loss of wetland habitat threatens esocid reproduction and achievement of the esocid FCO. Agencies should determine abundance, recruitment, and exploitation of important esocid populations. Genetic diversity should be determined for all muskellunge populations and used in the reestablishment of populations in their native habitats.

Centrarchids

Sustain smallmouth and largemouth bass and the remaining assemblage of sunfishes (*Centrarchidae* spp.) *at recreationally attractive levels over their natural range.*

A diverse self-sustaining centrarchid community persists in nearshore waters throughout Lake Huron, but population levels are largely unknown. Smallmouth bass are highly sought after in the recreational fishery, and a very limited commercial harvest of rock bass and black crappie occurs in Saginaw Bay. The quantity and quality of centrarchid populations may be related to loss of embayment and wetland habitat, increased predation from cormorants, and competition from invasive species. Agencies should obtain more and better information on abundance, recruitment, and exploitation of important centrarchid populations. The effect of cormorant predation on these populations should be determined.

Lake Sturgeon

Increase the abundance of lake sturgeon to the extent that the species is removed from its threatened status in U.S. waters. Maintain and rehabilitate populations in Canadian waters.

Lake sturgeon populations remain greatly depressed relative to historical levels. Barriers on tributaries remain the primary impediment to achieving the lake sturgeon FCOs. Lake sturgeon are harvested commercially in southern Ontario waters. Considerable biological information has been collected from lake sturgeon since 1992, and these data suggest that populations, although depressed, are stable and reproducing. More rivers with spawning populations and more spawning locations in connecting waterways have been identified. Lake sturgeon move throughout Lake Huron and into other Great Lakes, thus pointing out the need for interjurisdictional management of the species. Agencies need a lakewide management plan for lake sturgeon that identifies current populations and areas where lake sturgeon should be reestablished, target abundances for important populations, levels of exploitation that will permit populations to increase, and genetically acceptable brood-stock sources.

Channel Catfish

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

Self-sustaining channel catfish populations remain widely distributed throughout the nearshore waters of Lake Huron with the largest population in Saginaw Bay. The average yield of channel catfish has been well below 0.2 million kg, but this is largely due to low commercial demand. It is not known if channel catfish populations can sustain more harvest. Agencies should determine the exploitation rate and population dynamics for important populations, especially in Saginaw Bay.

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.

A substantial sea lamprey control program was initiated on the St. Marys River in 1998 and expanded in 1999 using an integrated management approach that included the release of sterile males, trapping, and chemical control applications. Sea lamprey-induced mortality continues to be a substantial impediment to achieving the lake trout FCO. A 75% reduction in the abundance of parasitic-phase sea lampreys by 2000 cannot be achieved, but it may be possible to reduce abundance 90% by 2010. The Lake Huron Committee should seek a more-intensive control effort, particularly in the St. Marys River, to further minimize damage to the fish community. Short-term and long-term control strategies, including costs, should be developed and implemented.

Species Diversity

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

Of the 129 fish species originally identified as indigenous to the Lake Huron basin, ten are extinct and 11 are imperiled. Species diversity has increased in recent years due to the accidental introduction of round goby and ruffe via ballast water and discovery of two species previously reported only for other Great Lakes waters (ghost shiner and northern madtom). Agencies should identify locations of rare and imperiled fishes in a shared GIS database so they can be better protected. Extirpated species should be reintroduced, where feasible. The Lake Huron Committee should participate in current efforts by the Great Lakes Fishery Commission to develop strategies for reintroduction of deepwater coregonines, particularly shortjaw cisco and kiyi, both of which are extant in Lake Superior.

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.

Walleye populations in eastern Georgian Bay and the North Channel have lost genetic diversity. Brood-stock selection and rearing practices in Ontario may have imperiled the genetic integrity and future survivability of native stocks of walleye. Lake trout hatchery brood stocks have been developed from remnant stocks in Iroquois Bay and Parry Sound. These brood stocks will facilitate rehabilitation efforts in other areas of Lake Huron and ensure preservation of these irreplaceable genetic strains.

HISTORICAL CONTEXT

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International fishery management on the Great Lakes is coordinated through the Great Lakes Fishery Commission (GLFC). In 1981, the GLFC in cooperation with federal, state, provincial, and tribal natural resource agencies adopted a Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 1992), which was modified in 1994 (Great Lakes Fishery Commission 1997). The GLFC's lake committees are the action arms for implementing the Joint Strategic Plan. The Lake Huron Committee (LHC), which is responsible for this report, is composed of one fishery manager each from the Michigan Department of Natural Resources (MDNR), Ontario Ministry of Natural Resources (OMNR), and Chippewa/Ottawa Resource Authority (CORA). Fish-community objectives (FCOs) adopted by the LHC define objectives for the structure of the fish community and provide means for measuring progress toward their achievement (DesJardine et al. 1995). The overall management objective for Lake Huron is:

Over the next two decades, restore an ecologically balanced fish community dominated by top predators and consisting largely of self-sustaining, indigenous, and naturalized species and capable of sustaining annual harvests of 8.9 million kilograms.

The target of 8.9 million kg is the average annual commercial yield from Lake Huron during 1912-1940, and it is considered to be the best current measure of long-term harvest potential. Historical commercial harvests are, at best, minimum estimates because all fish caught were not reported.

The Lake Huron Technical Committee (LHTC) is charged by the LHC to produce a state-of-the-lake report every five years. The purpose of this reporting is to present an updated status of the fish community, to assess how effective agencies have been in achieving the FCOs and to identify new and emerging issues that will affect future management.

Lake Huron was the first of the Great Lakes discovered by European explorers, who traveled up the Ottawa River to Lake Nippissing, then down the French River to Georgian Bay. At the time, French discoverers knew nothing of other lakes, and called Lake Huron “La Mer Douce,” or the sweet- or fresh-water sea. Although the human population on the shores of Lake Huron is low compared to three of the other four Great Lakes, its close proximity to high-density human population centers in southern Ontario and Michigan makes it a destination for fishing, boating, cottaging, and other forms of recreation. A description of the lake’s morphometry, hydrology, geology, and limnology can be found in various reports, which were summarized in the lake’s FCOs (DesJardine et al. 1995) and first state-of-the-lake report (Ebener 1995). The lake, its three discrete basins (Georgian Bay, North Channel, main basin), designated management areas, and other referenced locations are depicted in Fig. 1.

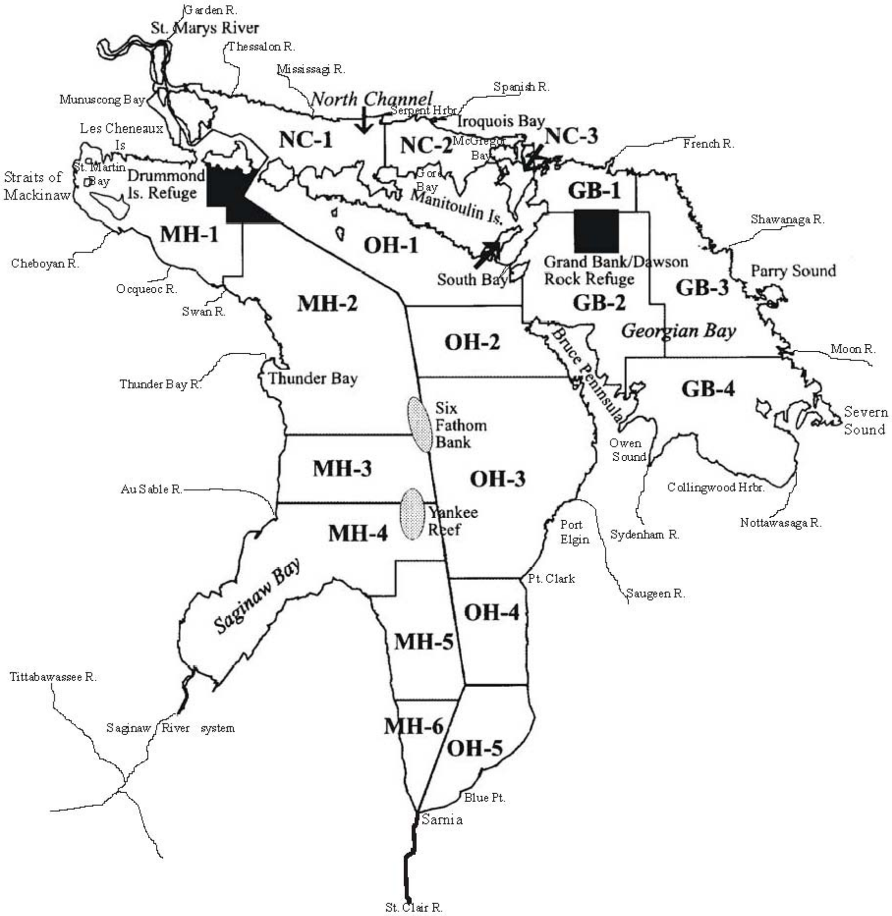

Fig. 1. The Lake Huron basin including designated management areas and major tributaries.

Changes in the composition and abundance of the Lake Huron fish community prior to 1970 have been documented previously by Berst and Spangler (1972), Eshenroder et al. (1995), and Ebener (1995). An alphabetical list of the common fish names and their corresponding scientific names is given in Table 1.

Table 1. Common and scientific names of fishes (Nelson et al. 2004) referenced in this report—asterisk (*) indicates the species is imperiled or endangered, and double asterisk (**) indicates the species is considered extinct in Lake Huron.

Common name	Scientific Name
Native species—cold water:	
Arctic grayling**	*Thymallus arcticus*
bloater	*Coregonus hoyi*
blackfin cisco**	*Coregonus nigripinnis*
brook trout	*Salvelinus fontinalis*
deepwater cisco**	*Coregonus johannae*
deepwater sculpin	*Myoxocephalus thompsonii*
kiyi**	*Coregonus kiyi*
lake herring	*Coregonus artedi*
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
longjaw cisco**	*Coregonus alpenae*
round whitefish	*Prosopium cylindraceum*
shortjaw cisco**	*Coregonus zenithicus*
shortnose cisco**	*Coregonus reighardi*
splake (hybrid)	*Salvelinus fontinalis x S. namaycush*
Native species—cool water:	
black redhorse	*Moxostoma duquesnei*
burbot	*Lota lota*
channel darter*	*Percina copelandi*
eastern sand darter**	*Ammocrypta pellucida*
johnny darter	*Etheostoma nigrum*
lake sturgeon	*Acipenser fulvescens*
muskellunge	*Esox masquinongy*
northern pike	*Esox lucius*
ninespine stickleback	*Pungitius pungitius*
redfin pickerel	*Esox americanus*

Table 1, continued

Common name	Scientific Name
Native species—cool water, continued	
river darter*	*Percina shumardi*
river redhorse*	*Moxostoma carinatum*
sauger*	*Sander canadensis*
slimy sculpin	*Cottus cognatus*
spottail shiner	*Notropis hudsonius*
trout-perch	*Percopis omiscomaycus*
walleye	*Sander vitreus*
yellow perch	*Perca flavescens*
Native species—warm water:	
black crappie	*Pomoxis nigromaculatus*
bluegill	*Lepomis macrochirus*
bullheads	*Ictalurus spp.*
channel catfish	*Ictalurus punctatus*
freshwater drum	*Aplodinotus grunniens*
ghost shiner*	*Notropis buchanani*
lake chubsucker*	*Erimyzon sucetta*
largemouth bass	*Micropterus salmoides*
mooneye*	*Hiodon tergisus*
northern madtom	*Noturus stigmosus*
paddlefish**	*Polyodon spathula*
pugnose shiner*	*Notropis anogenus*
pumpkinseed	*Lepomis gibbosus*
redside dace*	*Clinostomus elongatus*
rock bass	*Ambloplites rupestris*
smallmouth bass	*Micropterus dolomieu*
spotted sucker*	*Minytrema melanops*
weed shiner**	*Notropis texanus*
white crappie	*Pomoxis annularis*

Table 1, continued

Common name	Scientific Name
Non-native species—cold water:	
Atlantic salmon	*Salmo salar*
brown trout	*Salmo trutta*
Chinook salmon	*Oncorhynchus tshawytscha*
coho salmon	*Oncorhynchus kisutch*
Pacific salmon	*Oncorhynchus* spp.
pink salmon	*Oncorhynchus gorbuscha*
rainbow smelt	*Osmerus mordax*
rainbow trout	*Oncorhynchus mykiss*
sea lamprey	*Petromyzon marinus*
Non-native species—cool water:	
alewife	*Alosa pseudoharengus*
threespine stickleback	*Gasterosteus aculeatus*
round goby	*Neogobius melanostomus*
ruffe	*Gymnocephalus cernuus*
Non-native species—warm water:	
gizzard shad	*Dorosoma cepedianum*
common carp	*Cyprinus carpio*

In essence, lake trout was the dominant predator, with walleye and burbot playing a lesser role. The prey community was dominated by lake herring, sculpins, and deepwater ciscoes. Round whitefish, lake whitefish, and ninespine sticklebacks were lesser prey. The structure and function of that fish community began to change in the late 1800s and was radically changed by 1960 through:

- Invasions by sea lamprey, alewife, and rainbow smelt
- Overexploitation of important fishery resources by the commercial fishery
- Habitat degradation in nearshore and tributary areas

Fishery yields from Lake Huron increased substantially since the early 1970s. After reaching a low of 2.0 million kg in 1972, yield reached highs of 7.1 million kg in 1997 and 6.3 million kg in 1999, which is 80% and 70% of the overall harvest objective, respectively. The commercial harvest consists mainly of coregonines (members of the whitefish subfamily), whereas the recreational fishery harvests mostly Chinook salmon and lake trout. Actual yields are greater than reported because of under-reporting by commercial fisheries, incomplete coverage of recreational harvest in Michigan and Ontario waters, and no reporting of commercial and subsistence harvest by many First Nations in Ontario.

The number of predatory fish stocked into Lake Huron has been variable yet relatively consistent since the mid-1980s (Fig. 2). Prior to 1988, Chinook salmon was the primary predator stocked. Since 1988, the number of Chinook salmon, coho salmon, and brown trout stocked decreased, while the number of lake trout and walleye stocked increased. In 1998 and 1999, the numbers of walleye (5.2 and 4.3 million) and lake trout (4.1 and 3.4 million) stocked were greater than the numbers of Chinook salmon (4.0 and 3.3 million) stocked.

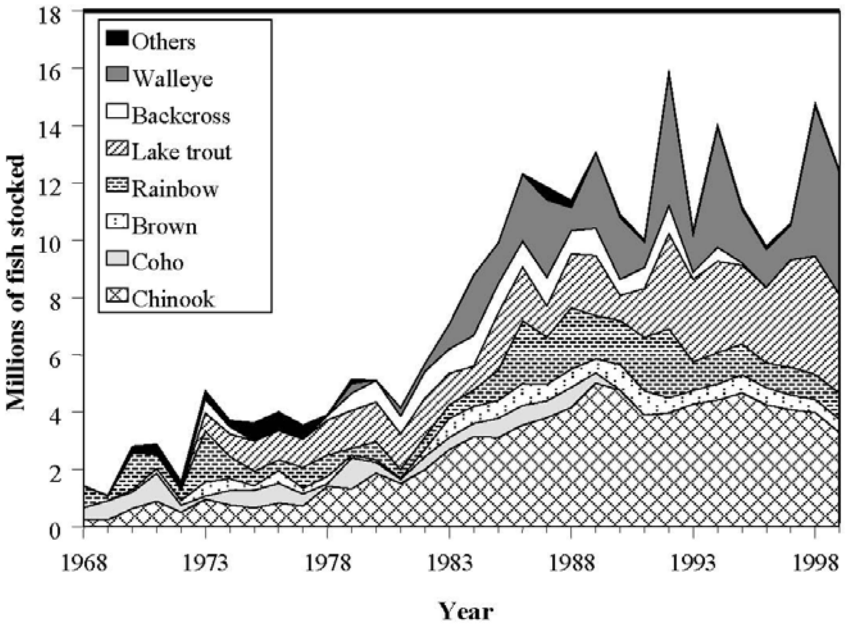

Fig. 2. Millions of predator fish stocked into Lake Huron, 1968-1999. “Others” include brook trout, splake, and Atlantic salmon. Backcross is a splake x lake trout hybrid.

Lake trout populations are not self-sustaining, except in the Parry Sound area (Fig. 1). Although lake trout reproduce successfully in some other areas, this reproduction has not achieved sustainability (Anderson and Collins 1995; Johnson and VanAmberg 1995; Reid et al. 2001).

Non-indigenous species continue to make up a substantial proportion of the Lake Huron fish community, and several new invasive species have established since 1992. Alewife and rainbow smelt are still abundant and are the primary prey of predators. There are more parasitic-stage sea lampreys in Lake Huron than in all of the other Great Lakes combined (Bergstedt et al. 2003), and they continue to kill thousands of lake trout annually (Sitar et al. 1999). Ruffe, round goby, and zebra mussel (*Dreissena polymorpha*) have established and are flourishing (Mills et al. 1993; Nalepa and Schloesser 1993). The effects of ruffe and round goby on the rest of the fish community are unknown, but the abundance and distribution of the round goby is increasing almost annually. Abundance of zebra mussels has increased tremendously since 1991, and they have had a profound impact on the ecology of the aquatic community (Nalepa and Schloesser 1993). On a positive note, the spiny water flea (*Bythotrephes longimanus*) is much less abundant in offshore waters of the main basin than many of the indigenous zooplankters (Barbiero and Tuchman 2001), and its effects on higher trophic levels appears to be minimal.

Of particular concern is the catastrophic decline in abundance of the benthic crustacean *Diporeia* spp. since the early 1990s in western portions of Lake Huron following the establishment of zebra mussels. Many fishes depend upon *Diporeia* as prey and may be affected by this decline (see Coregonine section).

DESCRIPTION OF THE FISHERIES

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Commercial Fishery

The commercial fishery on Lake Huron is diverse and has evolved as the fish community and management strategies changed (Van Oosten et al. 1946; Berst and Spangler 1972; Brown et al. 1999). Three events occurred since 1960 that dramatically shaped the commercial fishery. First, Michigan began to manage fish populations primarily for recreational use in the mid-1960s (Kocik and Jones 1999). Similar changes occurred in Ontario, although restrictions on commercial fishing there were not as extensive as in Michigan. Thereafter, commercial fishing was limited to specific areas, the type and amount of gear that could be fished was changed, and the number of operations was reduced (Brege and Kevern 1978; Brown et al. 1999). Second, modernization of the fishery in Ontario in 1984 fundamentally changed the way the commercial fishery was managed and how fish stocks were assessed. Third, assertion of treaty-protected fishing rights by Native Americans in the United States and First Nations in Ontario led to greater allocation of fish resources to tribal fisheries (Doherty 1990; Brown et al. 1999; U.S. *v.* Michigan 2000).

Technological advancements have led to major changes in the ability of the fishery to harvest fish. The most significant changes have been a change in gill-net mesh from nylon multifilament to monofilament, a reduction in diameter of gillnet mesh filament, an increase in height of gillnets, increased mesh size of trapnets, conversion of trapnet mesh from nylon to plastic, and improvements in electronic gear for locating fish and fishing grounds. The conversion from multifilament to monofilament gillnets took place over a

10-year period in the late 1960s (Collins 1979). The shift to thinner diameter mesh filament has been documented for the CORA fishery—diameter decreased from 0.28 mm to 0.20 mm and later to 0.17 mm during the 1970s and 1980s (Chippewa/Ottawa Resource Authority, 179 W. Three Mile Road, Sault Ste. Marie, Michigan, 49783, unpubl. data). The switch from 28- and 36-mesh-deep gillnets to 50-mesh-deep gillnets in 1978-1979 and to 75-mesh-deep gillnets in the early 1990s further increased catchability (Collins 1987; Brown et al. 1999). The use of larger mesh sizes in the lead and the top of the tunnel and pot in trapnets has led to decreased gilling of fish, decreased bycatch of undersize fish, and increased fishing power (efficiency). In the early 1990s, the CORA trapnet fishery began converting from the traditional tarred-nylon mesh to mesh made of plastic or polypropylene. The new "poly" trapnets have increased the efficiency and the number of fishing days for individual trapnets because they require less maintenance than the tarred net. Advancements in electronic and mechanical technologies have added to the fishing power of the commercial fishery. The ability to electronically track the movement of fish; determine exact location of gear; and determine depth, temperature, bottom type, and other features of the lake bed have increased fishing success. Larger, faster and safer boats, better communication, and onboard market information have created a very efficient fleet.

The commercial fishery operates primarily with gillnets and trapnets in all three basins of Lake Huron. The only areas where commercial fishing does not occur is in southern Michigan waters (Fig. 1; MH-5 and MH-6). Gillnet fisheries operate throughout the North Channel, Georgian Bay, Ontario waters of the main basin, and north of Thunder Bay in Michigan waters (Fig. 1). A gillnet fishery for common carp in Saginaw Bay was curtailed in the 1990s because of chemical contaminants. Gillnet effort historically accounted for most of the harvest, and that is still true (Fig. 3). Trapnet fisheries in Michigan are concentrated in main-basin waters north of Thunder Bay and in Saginaw Bay. In Ontario, trapnet fisheries exist in the southern main basin, southwest of Manitoulin Island, and occasionally in the North Channel. Trapnet effort has been relatively stable over the past 20 years but has declined somewhat since 1992 (Fig. 3).

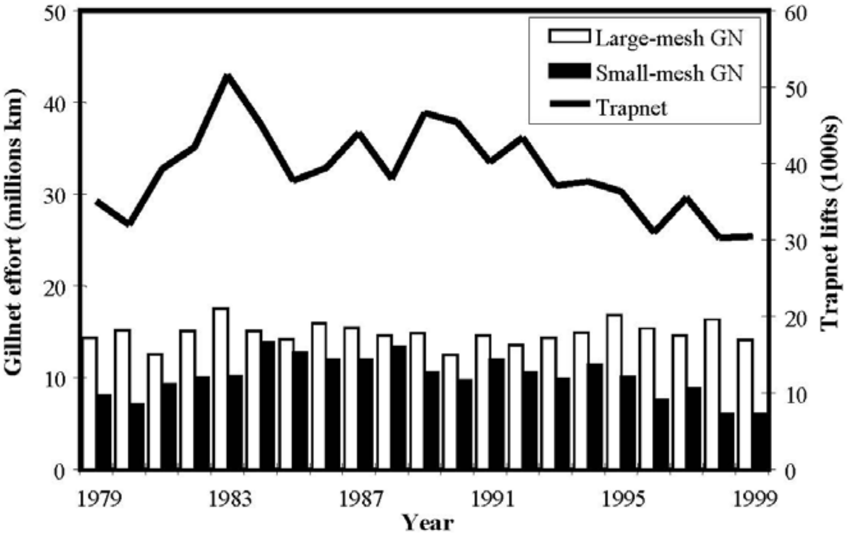

Fig. 3. Large-mesh and small-mesh gillnet effort (bars) and trapnet effort (line) by commercial fisheries on Lake Huron, 1979-1999.

The commercial yield from Lake Huron is, among the Great Lakes, second only to Lake Erie. The main basin produces 80% of the yield, followed by Georgian Bay (13%), and the North Channel (7%). The Ontario commercial fishery harvests 50-65% of the total lakewide yield.

The species composition of the commercial yield was more diverse prior to 1980, but since then, the yield has been dominated increasingly by lake whitefish (Fig. 4). In the early 1970s, yield was made up of bloater and lake whitefish (35%); rough fish such as common carp and suckers (35%); yellow perch and walleye (25%); and channel catfish, bullheads, northern pike, and miscellaneous species (5%). The bloater and lake whitefish contribution increased to 70% by the mid-1980s and to 88% by 1999 (81% lake whitefish).

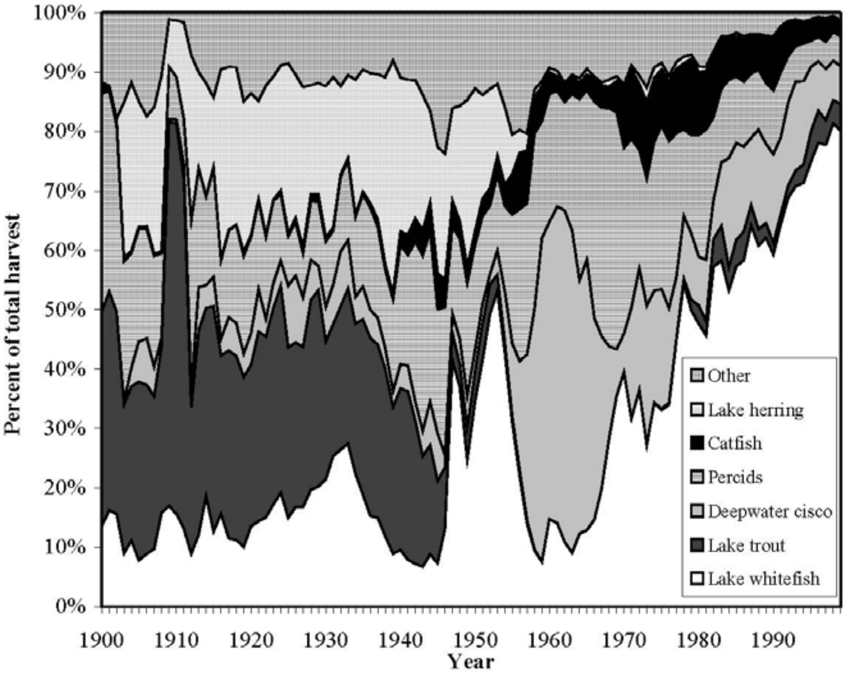

Fig. 4. The percentage composition (%) of fishes in Lake Huron commercial harvests, 1900-1999.

Other important commercially fished species, in order of highest to lowest yield, include channel catfish, lake trout, yellow perch, walleye, freshwater drum, rainbow smelt, suckers, and lake sturgeon. Lake trout is now harvested as bycatch in the large-mesh, gillnet fishery targeted at lake whitefish, which operates primarily in the main basin. Lake trout harvest peaked at just over 260,000 kg in 1996. Commercial yield of yellow perch and walleye is almost entirely from Ontario waters of the main basin. Channel catfish and brown and black bullheads are harvested mostly from Saginaw Bay. Commercial yield of freshwater drum is from the main basin and has increased from 5,000 kg in 1971 to 100,000 kg in 1997. Lake sturgeon is harvested commercially only in Ontario waters, and the catch is almost entirely from the southern main basin and North Channel. The current annual harvest of 5,000 kg is not much different than it was 50 years ago.

Recreational Fishery

Recreational fisheries for lake trout were prominent in Georgian Bay and in the vicinity of Thunder Bay (Fig. 1) prior to the collapse of populations in the 1940s. These early fisheries often employed copper wire line for trolling offshore waters (Berst and Spangler 1972). However, boats large enough to safely navigate the open waters of Lake Huron were relatively scarce then, and most recreational fishing was for other species in protected bays (Bence and Smith 1999). Saginaw Bay supported an important recreational fishery, primarily for yellow perch (Keller et al. 1987). Other important nearshore recreational fisheries for smallmouth bass, lake herring, yellow perch, walleye, muskellunge, and northern pike existed in both Ontario and Michigan waters, but their magnitude was poorly documented (Berst and Spangler 1972). Numerous fishing resorts operated in the Les Cheneaux Islands, St. Marys River, McGregor Bay, and Severn and Parry Sounds.

As human populations and boat ownership (especially of larger boats) increased, fishing shifted to offshore waters. Between 1950 and 1990, the human population of Ontario increased 160% from 4.2 to 10.9 million, while Michigan's population increased 48% from 6.3 to 9.2 million. In 1990, residents of Ontario and the United States spent an estimated 35 million angler days and $1.5 billion on recreational fishing in Lake Huron. The economic value of recreational fishing now exceeds that of commercial fishing in the Great Lakes (Talhelm 1988; U.S. Fish & Wildlife Service and Bureau of Census 1993; Department of Fisheries and Oceans, Canada 1994; Bence and Smith 1999).

Most recreational fisheries are concentrated near shore and within 10-15 km of ports, but the introduction of bigger and safer boats has made the whole basin accessible to recreational fishing. The yellow perch fishery of Saginaw Bay sustained a popular fishery for nearly a century. Other yellow perch fisheries of lesser magnitude are the Les Cheneaux Islands, St. Marys River, and small, isolated locations in all three basins. A major recreational fishery for walleye has re-developed in Saginaw Bay following initiation of stocking in 1972. Since 1991, the yellow perch and walleye fisheries in Saginaw Bay accounted for 58% of the total fishing effort on Michigan waters (Fielder et al. 2000). In Ontario, over 95% of the recreational harvest in 1980 was from nearshore fisheries (Ontario Ministry of Natural Resources 1980). That percentage declined to 76% in 1995, due primarily to increased offshore fishing for trout and salmon in the main basin. Yellow perch and smallmouth bass harvest in 1995, estimated at 0.6- and 0.3-million fish

(Department of Fisheries and Oceans, Canada 1998), made up the bulk of the harvest in nearshore waters, especially in eastern Georgian Bay. Specialized fisheries for species such as muskellunge increased substantially in the North Channel and Georgian Bay. These fisheries are generally catch-and-release and tightly regulated.

A large-scale offshore fishery developed in the 1960s following the introduction of Chinook salmon and coho salmon by Michigan. This fishery also targeted lake trout and rainbow trout. Although initially successful, the coho salmon fishery declined for unknown reasons and the species was no longer stocked after 1989 (Bence and Smith 1999). Lake trout harvest has increased since 1993, particularly in the main basin of the lake—the recreational fishery harvested just over 120,000 kg of lake trout in 1998. The Chinook salmon harvest typically increased in relation to stocking levels through the 1980s, but harvest continued to increase through the late 1990s despite no increase in stocking. This increased harvest is believed due to increased vulnerability of Chinook salmon because of declines in abundance of alewife and to the increased contribution of naturally reproduced Chinook salmon.

The primary trout and salmon fishing areas are located in the main basin and southern Georgian Bay. The main basin yields around 92% of the trout and salmon harvest from Michigan waters (Bence and Smith 1999) and approximately 80% of the harvest from Ontario waters. This fishery is a relatively new phenomenon in Ontario—just ten years ago, trout and salmon made up only 24% of its recreational harvest (Nicol and Mohr 1998). Chinook salmon, rainbow trout, and lake trout make up the bulk of the harvest in Georgian Bay, which averaged 25,000 fish annually in the mid-1990s (Nicol and Mohr 1998).

Total annual recreational yield from Lake Huron averaged about 1 million kg during 1986-1999 and was mostly from Michigan waters (Fig. 5). Approximately 75% of the yield was trout and salmon, and the remainder was largely walleye and yellow perch. The harvest of yellow perch by the recreational fishery declined approximately 60%, while Chinook salmon and lake trout harvest increased. Recreational fishing harvest and effort, though relatively stable throughout most of the 1990s, was lower than in the mid to late 1980s (Fig. 5).

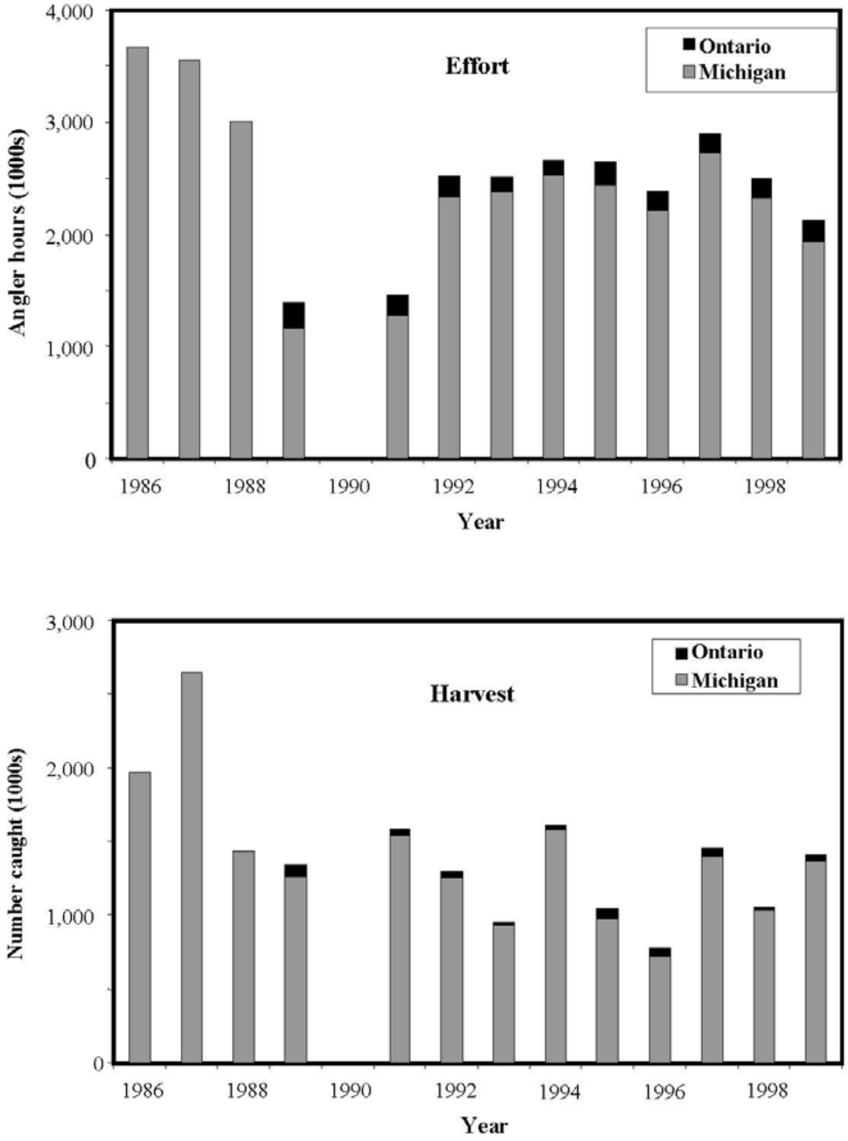

Fig. 5. Recreational fishing effort (angler-hours) and harvest (number of fish) in Michigan and Ontario waters of Lake Huron, 1986-1999 (less 1990).

HABITAT

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The fish-community objectives for habitat are to "protect and enhance fish habitat and rehabilitate degraded habitats, achieve no net loss of the productive capacity of habitat supporting Lake Huron fish communities and restore damaged habitats, and support the reduction or elimination of contaminants."

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The primary habitat zones of Lake Huron are: open water (>73-m depth) and nearshore (<73-m depth, including embayments and wetlands), tributaries, and connecting channels.

Open Water and Nearshore

The most prominent impairments, affecting both open-water and nearshore habitats, have been designated as Areas of Concern (AOCs). Originally, there were seven AOCs on Lake Huron: St. Marys River, Spanish River, Severn Sound, Collingwood Harbor, St. Clair River, Saginaw River, and Saginaw Bay. Collingwood Harbor remains the only AOC to be delisted as of 1999. Severn Sound and the Spanish River are responding well to remedial actions and showing recovery, but there are still significant concerns with degraded water quality and loss of habitat in Saginaw Bay, the Saginaw River, and the St. Marys River.

Tributaries

Fish-community objectives identify restoration of fragmented and degraded streams and restoration of stream-influenced habitats as key needs for increasing populations of salmonines, percids, esocids, and lake sturgeon (DesJardine et al. 1995). Lake Huron was connected to a vast network of rivers, inland lakes, and wetlands prior to human settlement. An estimated 10,069 km of undammed tributary habitat was present in the Michigan portion of the basin, and at least an equivalent amount existed in Ontario. A geographical information systems (GIS)-based database characterizing Michigan tributaries and barriers has been developed for Lake Huron, and the Michigan Department of Environmental Quality maintains a database on barriers. According to the barrier database, there are currently 801 barriers on Michigan tributaries to Lake Huron that have eliminated connection to an estimated 86% of major tributary habitats; only 1,133 of 7,027 total tributary km and 53 of 1,836 km of cold-water-stream reaches are currently connected directly to the lake. This lack of connection necessitates stocking trout and salmon to maintain an ecological balance between predator and prey fishes and to enhance fishing opportunities. Reproduction of lake sturgeon and walleye has suffered due to inaccessibility of spawning habitats in the lower reaches of important Michigan tributaries such as the Au Sable, Thunder Bay, Cheboygan, and Saginaw River systems. Only 6 km of the original 84 km of large-sized, medium-gradient, warm- and cool-water river habitats required for lake sturgeon spawning remain connected to Lake Huron.

Comparable information for Ontario tributaries to Lake Huron is currently unavailable, but a classification program and inventory of barriers is being developed. Most northern tributaries are warm-water streams and have relatively few barriers. Most southern tributaries are cold water and have one or more man-made barriers. Most of the barriers on the lower portions of these streams have built-in fishways, but barriers in upper reaches lack fish passage. The Niagara Escarpment also forms natural barriers on virtually every Lake Huron tributary from the upper reaches of the Nottawasaga River around Georgian Bay to the tip of the Bruce Peninsula and continuing on to the north shore of Manitoulin Island.

Barriers were constructed on Lake Huron tributaries for over a century with little or no regard for the environmental consequences. Today, the environmental costs associated with man-made barriers are better understood. Some barriers represent a liability and their removal provides an opportunity to eliminate a safety hazard and to restore a river ecologically (Kanehl et al. 1997; City of Big Rapids, Michigan, 2000), but others are closely associated with community identity, and any discussion of their modification or removal often becomes contentious (Born et al. 1998).

Blocking upstream migrations of Lake Huron fishes is desirable in some instances. For example, the OMNR supports maintenance of man-made and natural barriers on small streams to protect resident brook trout populations from invasion by non-indigenous trout and salmon. Blocking sea lamprey may be desirable, especially where chemical control is expensive. Also, migration of fish from Lake Huron can expose inland, fish-eating wildlife to higher contaminant levels.

Fisheries agencies should proactively address opportunities for restoring connections between Lake Huron and its tributaries. Michigan’s Au Sable River is one such opportunity. In the 40-year operating license received from the Federal Energy Regulatory Commission in 1994 for dams on the Au Sable River, Consumers Energy agreed to provide for design, construction, operation, and maintenance of upstream and downstream fish passage structures (Zorn and Sendek 2001). Thus, the connection between Lake Huron and the Au Sable River can be partially restored and will provide an opportunity to experiment with passage of lake sturgeon and other species.

Connecting Channels

The St. Marys River is a connecting channel between Lake Superior and Lake Huron and contains a diversity of aquatic habitats and fish communities. The fish populations of the St. Marys River are harvested by Michigan and Ontario anglers, Ontario commercial fisheries, and Native American and Ontario First Nation subsistence and commercial fisheries. The St. Marys River hosts large, open-water bodies, deep- and shallow-flowing channels, high gradient reaches, littoral areas, wetlands, and tributary deltas. The St. Marys rapids, located immediately below the international compensating gates, is a high-gradient reach characterized by high flows and gravel, cobble, boulder, and bedrock substrates. The United States Army Corps of Engineers maintains dredged commercial-shipping channels in the upper and lower portions of the river.

The International Joint Commission designated the St. Marys River as an AOC in 1985, and the Great Lakes Water Quality Agreement (GLWQA) required a Remedial Action Plan to address beneficial-use impairments. Habitat loss has occurred due to dredging and industrial and urban development. Contaminated sediments affect existing water quality as do point- and nonpoint-source pollutants (St. Marys River Remedial Action Plan Team 1992, 2002). Current needs for hydroelectric power and shipping degrade fish habitat and production.

Contaminants

Fish tissue samples have been collected from the Lake Huron watershed and analyzed for bio-accumulative contaminants since the 1970s. These data are used to identify contaminants that have the potential to impact human health or pose ecological risk, to monitor trends, and to identify sources. The samples include edible portions, whole fish, and caged fish. Edible-portion samples are used to set sport fish-consumption advisories and commercial fishing regulations. Whole-fish samples are used primarily to assess temporal and spatial trends and to assess ecological risk to fish-consuming birds or mammals. Caged-fish samples are used to identify sources. The primary contaminants of concern are: PCBs, toxaphene, dioxins, chlordane, mercury, and DDT. These substances continue to exceed some trigger levels for sport fish-consumption advisories set by the Michigan Department of Community Health or the Ontario Ministry of Environment. In lake trout, PCB and DDT concentrations declined dramatically in whole-fish samples since monitoring began in the 1970s, and total chlordane and toxaphene, monitored since 1986, have also declined (Fig. 6). Dioxins remained unchanged, and mercury has been unchanged in some fish or increased in others since monitoring began.

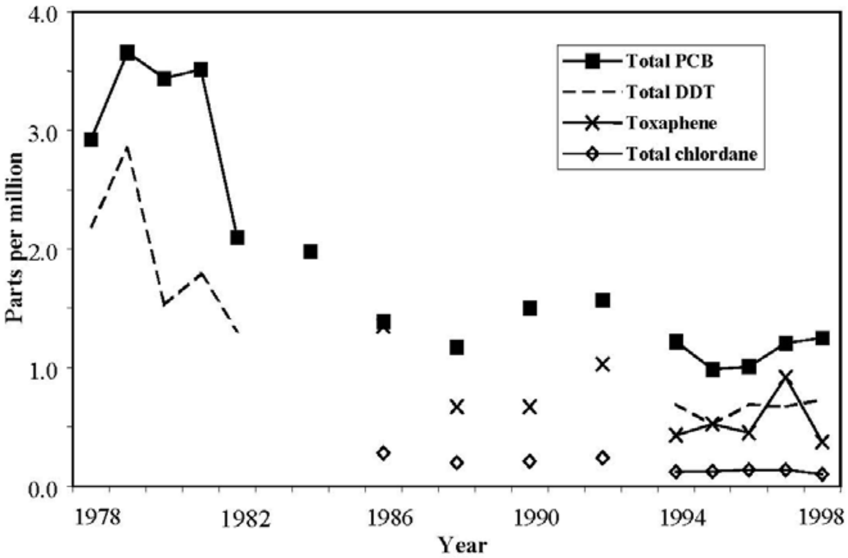

Fig. 6. Concentrations of total PCBs, total DDT, toxaphene, and total chlordane in samples of whole lake trout collected from Lake Huron during 1978-1998 (DeVault et al. 1996; U.S. Environmental Protection Agency, 77 West Jackson Street, Chicago, IL, 60604, unpubl. data).

Recommendations

1. Develop long-term interagency habitat-assessment and monitoring surveys
2. Quantify historical and contemporary aquatic and riparian habitats
3. Complete remedial actions that will lead to the delisting of AOCs
4. Improve water quality and reduce contaminant levels in water, sediments, and fish
5. Inventory, protect, and, where feasible, restore wetland habitats
6. Maintain natural shoreline processes such as long-shore currents and beach building
7. Where feasible, remove barriers from tributaries
8. Install fish-passage facilities when barrier removal is not feasible
9. Educate the public about the need to restore tributary connectivity in the basin
10. Complete development of workable electrical barriers (Swink 1999) or adjustable-crest barriers (Porto et al. 1999) where blocking of certain species during specific times of the year is desirable
11. Where possible, reestablish natural flow regimes in dammed streams

PHYTOPLANKTON, ZOOPLANKTON, AND BENTHOS

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No specific FCOs for phytoplankton, zooplankton, and benthos exist. However, FCOs call for balancing predator abundance with prey-fish production, which is a function of plankton and benthos production. The Great Lakes National Program Office (GLNPO) of the U.S. Environmental Protection Agency has conducted regular surveillance monitoring of Lake Huron since 1983. The monitoring effort is focused on whole-lake responses to changes in loadings of anthropogenic substances, so sampling is restricted largely to the relatively homogeneous offshore waters. Data presented in this report are for phytoplankton and zooplankton communities sampled at 14 sites lakewide during spring (20-21 April) and summer (15-17 August), 1999. Sampling methods and limnological conditions during the surveys are described in Barbiero and Tuchman (2001) and Barbiero et al. (2001). The description of the benthos community is consolidated from a variety of unrelated studies.

Phytoplankton

We found 161 phytoplankton taxa in the spring, with a range of 64 to 84 taxa at individual sites. Phytoplankton biomass in spring was relatively uniform among sites, varying only between 0.24 and 0.57 gm•m^{-3} (Fig. 7). The median biomass of 0.44 gm•m^{-3} was similar to that of Lake Michigan (0.62 gm•m^{-3}) and substantially higher than that of Lake Superior (0.065 gm•m^{-3}). All sites were dominated by diatoms, with *Aulacoseira islandica* and the pennate *Tabellaria flocculosa* contributing 67% of the lakewide biomass. Much smaller, but still substantial, populations of *Fragilaria crotonensis* and *A. subarctica* were also found. Non-diatom taxa were represented primarily by the genera *Dinobryon*, *Cryptomonas*, *Oscillatori*a and several genera of Pyrrophyta.

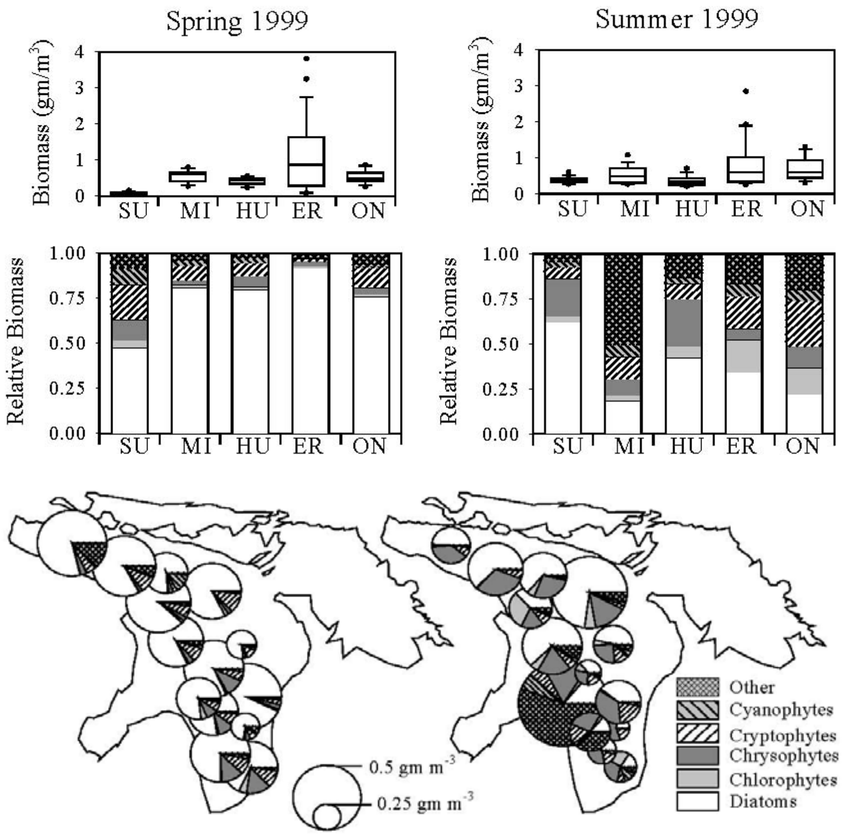

Fig. 7. Upper panel: box plots of phytoplankton biomass across the Great Lakes in spring and summer, 1999. Boxes denote 25th and 75th percentiles; lines denote median; whiskers denote 10th and 90th percentiles; individual points denote outliers. Middle panel: whole-lake average relative biomass of major phytoplankton groups for spring and summer, 1999. Lower panel: biomass of major phytoplankton groups at each site for spring and summer, 1999.

We identified 156 phytoplankton taxa from samples taken during the summer survey; taxa numbers at individual sites ranged between 45 and 66. Although taxa richness decreased slightly from spring to summer on a per-site basis, dominance in summer was distributed over a broader range of species from a greater variety of higher-taxonomic divisions, and diatoms were more prominent at northern sites (Fig. 7). Phytoplankton biomass exhibited a greater difference among sites in summer; biomass ranged between 0.20 and 0.71 gm•m^{-3}, with a median value of 0.34 gm•m^{-3}. This median biomass was lower than in Lake Superior (0.39 gm•m^{-3}) and Lake Michigan (0.58 gm•m^{-3}). Most diatom biomass in Lake Huron was from the typical summer genus *Cyclotella* and the eurytopic *F. crotonensis*. Chrysophytes, which also contributed a large percentage of biomass, were represented by *Chrysosphaerella longispina* and several species of *Dinobryon*. The large dinoflagellate *Ceratium hirundinella* and the cryptophyte *Cryptomonas erosa* also figured prominently at several sites. The large proportion of diatoms in the summer phytoplankton community in Lake Huron can be taken as evidence that the open–water portion of the lake has not experienced the increased productivity fostered by anthropogenic phosphorus loadings reported in Lake Michigan (Schelske 1988).

Zooplankton

Biomass of crustaceans (excluding nauplii) in spring ranged from 1.43 to 3.84 gm dry weight•m^{-2} among sites and was the highest of the five Great Lakes (Fig. 8). The median biomass of 2.30 gm dry weight•m^{-2} was more than twice that of Lake Ontario, nearly four times higher than that of Lake Michigan, and the second-largest crustacean community among the Great Lakes. Crustacean community diversity was low, as is typical in spring, with all sites having 7 or 8 taxa for a lakewide total of 11 taxa. Copepods accounted for nearly all of the non-nauplii crustaceans and were evenly divided between cyclopoids and calanoids. Cyclopoids were represented almost exclusively by *Diacyclops thomasi* and calanoids mostly by the diaptomids *Leptodiaptomus ashlandi, L. minutus,* and *L. sicilis*.

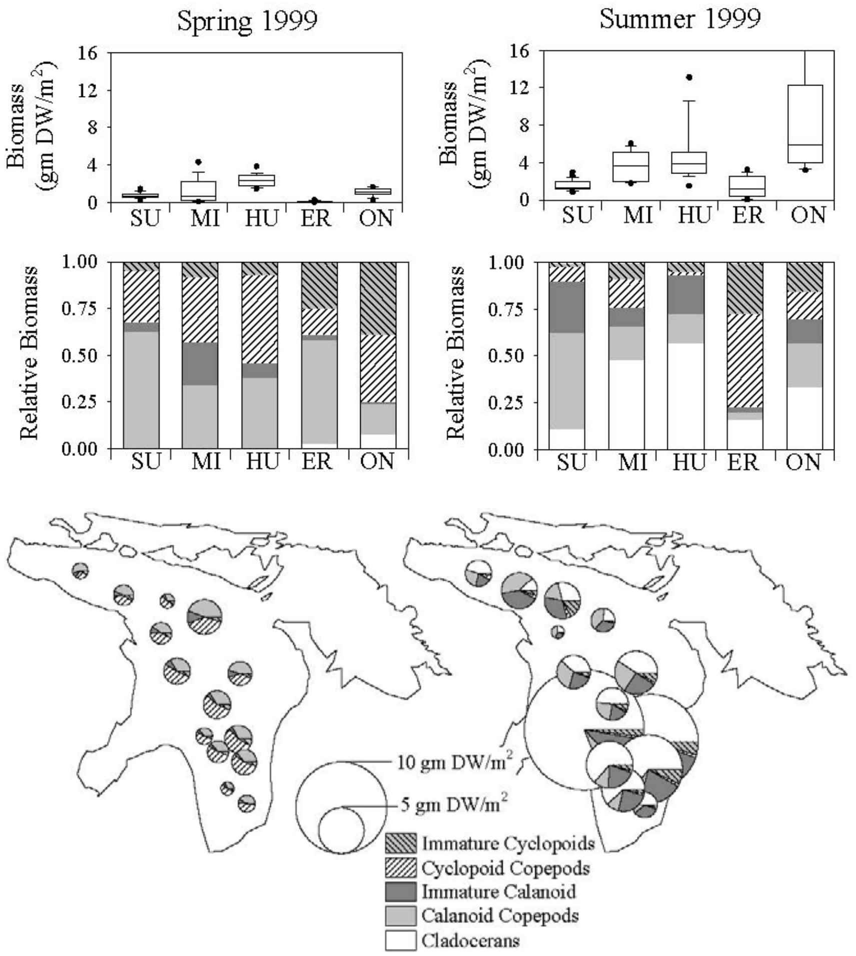

Fig. 8. Upper panel: box plots of zooplankton biomass across the Great Lakes in spring and summer, 1999. Boxes denote 25th and 75th percentiles; lines denote median; whiskers denote 10th and 90th percentiles; individual points denote outliers. Middle panel: whole-lake average relative biomass of major zooplankton groups for spring and summer, 1999. Lower panel: biomass of major zooplankton groups at each site for spring and summer, 1999.

Crustacean biomass increased in summer, ranging between 1.49 and 13.10 gm dry weight•m^{-2} (Fig. 8). The median biomass of 3.92 gm dry weight•m^{-2} was similar to that of Lake Michigan but lower than that of Lake Ontario (highest in the Great Lakes). Crustacean communities were more diverse in the summer (15 taxa) due to the appearance of additional cladoceran taxa. Dominant species included the cyclopoid and calanoid species found in spring and two additional cladoceran taxa (*Daphnia galeata mendotae* and *Bosmina* spp.). These dominant species accounted for over 98% of the non-nauplii crustaceans in summer. The spiny water flea was present at all sites. Abundance was fairly low; the lakewide average of 314 individuals m^{-2} represented less than 0.02% of all crustacean individuals and accounted for only 1-2% of total crustacean biomass.

The differences in crustacean communities between 1998 and 1999 suggest that inter-annual variability in these communities can be substantial. In 1998, the summer cladoceran community was dominated by larger *Daphnia* (Barbiero et al. 2001). The dominance by *Bosmina* spp. in the summer of 1999 and the unusually large cyclopoid populations in the spring were also observed in Lake Michigan in 1999 (J. Cavaletto, Great Lakes Environmental Research Laboratory, 2205 Commonwealth Blvd., Ann Arbor, Michigan, 48105, personal communication).

Benthos

The benthic macroinvertebrate community of Lake Huron has been the least studied in the Great Lakes. Some studies were conducted in the main basin or in specific bays during the early 1970s (Batchelder 1973; Schelske and Roth 1973; Shrivastava 1974; Loveridge and Cook 1976). More recently, two sampling programs were initiated to examine distributions and temporal trends in macroinvertebrate populations. In 1987-1996, annual surveys were conducted in Saginaw Bay to assess the response of the macroinvertebrate community to nutrient abatement efforts and to colonization by the zebra mussel. In 1997, GLNPO began annual surveys of macroinvertebrates in main-basin waters 45 m and deeper.

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

There were large fluctuations in densities of some major groups in the inner bay during 1987-1996, which were related to the introduction and rapid expansion of zebra mussels. Zebra mussel populations were first found in the bay in 1990, increased in 1991, peaked in 1992, and then declined to stable levels during 1993-1996 (Nalepa et al. 1999). At sites with hard substrates (sand, gravel) in the inner bay, the most significant change after the peak in zebra mussel abundance in 1992 was a six-fold increase in the density of the amphipod *Gammarus* spp. Density increased from a mean of $65•m^{-2}$ during 1987-1990 to $400•m^{-2}$ during 1993-1996. *Gammarus* benefited from the habitat complexity created by zebra mussel clusters and/or from increased food availability from mussel biodeposits (Ricciardi et al. 1997). Oligochaete densities at sites with a soft bottom (silt) decreased from $22,000•m^{-2}$ in 1988 to $1,200•m^{-2}$ in 1994, then returned to near pre-zebra mussel levels by 1996. Because these soft-bottom sites are located in the deeper depositional zone of the bay, the filtering activities of the peak zebra mussel populations in the shallower regions resulted in diminished organic inputs to the depositional zone and fewer oligochaetes.

Only a few individuals of the burrowing mayfly *Hexagenia* spp. were collected during the entire 1987-1996 sampling period. This important fish-food organism was abundant in the bay until the mid-1950s. At that time, populations essentially disappeared because of pollution and lakebed degradation. A similar decline occurred in western Lake Erie in the mid-1950s, but these populations recovered to former densities by the mid-1990s (Schloesser et al. 2001). There was no indication of a similar recovery of *Hexagenia* in Saginaw Bay as of 1996.

In the outer bay, the most significant change after zebra mussels became established was a decreased abundance at the sites greater than 20- to 30-m deep of the amphipod *Diporeia* spp. Mean density of *Diporeia* was $800•m^{-2}$ in the pre-zebra mussel period but declined to $80•m^{-2}$ by 1996. *Diporeia* biomass declined from 0.24 g ash-free dry weight (AFDW) $•m^{-2}$ and 54% of total benthic biomass to 0.02 g $AFDW•m^{-2}$ and just 11% of total benthic biomass.

The benthic community of the main basin is typical of that found in offshore waters of the other upper lakes. At depths below the thermocline (>30 m), amphipods (*Diporeia* spp.) are dominant, and oligocheates, sphaeriids, and chironomids follow in order of importance (Table 2). During 1997-1999, *Diporeia* densities generally decreased, but there were no consistent trends among densities of the other benthic groups. Densities of benthic groups, including *Diporeia*, in 1997-1999 were comparable to densities at similar depth intervals sampled in the early 1970s (Nalepa and Tuchman 2000). However, densities at similar depths in the early 1970s were highly variable, making it difficult to define a baseline.

Table 2. Mean (+ 2SE) densities of the major macroinvertebrate groups in the main basin of Lake Huron, 1997-1999. Numbers in parenthesis indicate the number of sites in each of the three depth intervals.

Depth (m)	Species	1997	1998	1999
30-50	*Diporeia* spp.	2,610 ± 469	3,429 ± 414	2,945 ± 294
(2)	Oligochaeta	617 ± 109	493 ± 182	1,730 ± 864
	Sphaeridae	89 ± 46	61 ± 4	67 ± 35
	Chironomidae	73 ± 16	124 ± 3	86 ± 54
51-90	*Diporeia* spp.	3,353 ± 464	2,274 ± 696	1,027 ± 299
(5)	Oligochaeta	516 ± 115	368 ± 107	737 ± 254
	Sphaeridae	231 ± 85	185 ± 63	169 ± 61
	Chironomidae	31 ± 8	33 ± 14	25 ± 7
>90 m	*Diporeia* spp.	4,266 ± 738	2,949 ± 570	2,067 ± 235
(3)	Oligochaeta	520 ± 254	340 ± 154	756 ± 203
	Sphaeridae	33 ± 8	25 ± 4	18 ± 10
	Chironomidae	98 ± 33	59 ± 26	26 ± 10

Recommendations

1. Continue monitoring the status of plankton and benthos at index sites in offshore waters
2. Expand current monitoring of plankton and benthos to nearshore waters
3. Establish regular monitoring programs for plankton and benthos in the North Channel and Georgian Bay
4. Analyze all historical data on plankton and benthos
5. Develop better communication and coordination between researchers working on crustaceans and those working on fish

PREY FISHES

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The fish-community objective for prey fishes is to "maintain a diversity of prey species at population levels matched to primary production and to predator demands" (DesJardine et al. 1995). Prey species indigenous to Lake Huron include ninespine stickleback, slimy and deepwater sculpins, trout-perch, bloater, and various cyprinids. Non-indigenous species include rainbow smelt, alewife, threespine stickleback, and gizzard shad. Annual trawl surveys of prey fish populations were initiated in United States waters in 1973 (Argyle 1982). A 12-m bottom trawl was used to conduct the surveys during 1973-1991, but a 21-m bottom trawl became the standard in 1992. Unless otherwise stated, the catch and biomass data for 1973-1991 have been adjusted for this change in trawling gear.

Rainbow Smelt

Rainbow smelt were first reported in Lake Huron in 1925 (Van Oosten 1937), and they increased in abundance until the winter of 1942-1943 when the population collapsed (Van Oosten 1947). Following the collapse, rainbow smelt populations began to rebuild, and they were a component of the commercial catch by the late 1940s. The commercial yield of rainbow smelt from Lake Huron (primarily from Saginaw Bay) averaged about 75,000 kg annually during the 1950s and about 18,000 kg annually during the 1960s (Baldwin et al. 1979).

The current population of adult rainbow smelt is mostly comprised of young fish; ages 1 and 2 make up more than 80% of the adult population, fewer than 10% are older than age 3, and ages 4 and 5 never make up more than 3%. Year-class strength (based on abundance of age-1 fish) has been highly variable. Strong year classes, usually apparent in the fall as young of the year (YOY), were produced in 1978, 1980, 1982, 1984, and 1990 (Fig. 9).

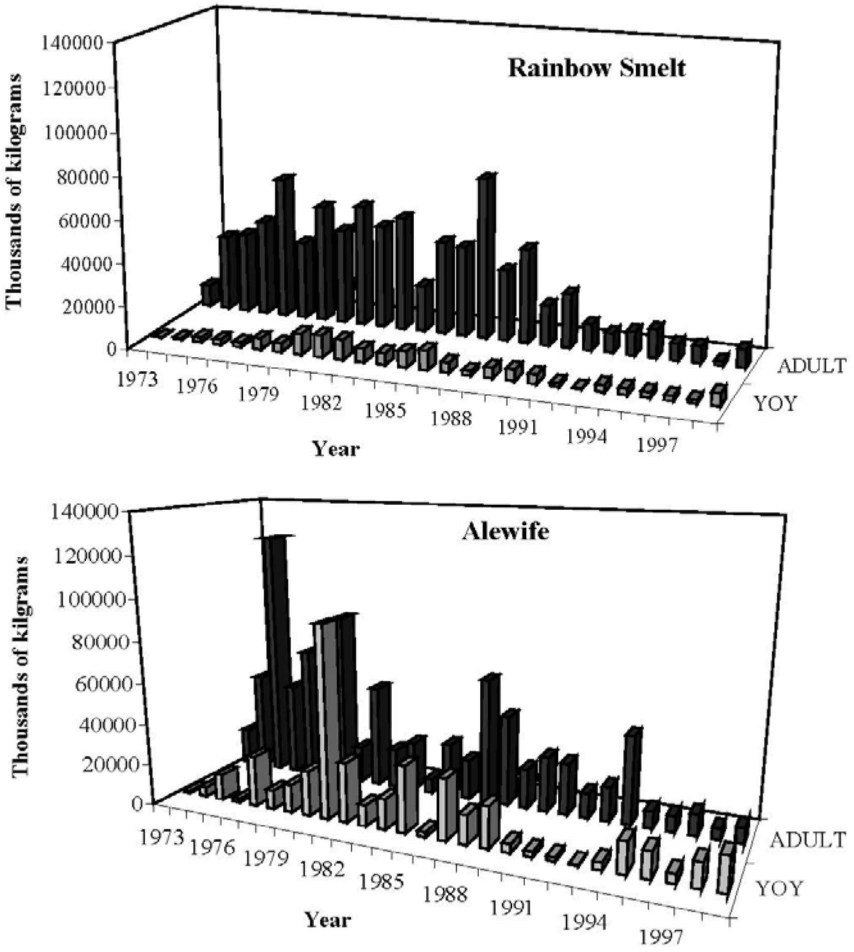

Fig. 9. Estimated biomass of young of the year and adult rainbow smelt and alewife based on bottom-trawl surveys in Lake Huron during the fall, 1973-1999.

The rainbow smelt population was remarkably stable throughout the 1970s and most of the 1980s. However, the catch of adults began to decline in the late 1980s and early 1990s, despite moderately good year classes of juveniles (Fig. 9). Biomass declined in 1990, rose slightly in 1991 because of the recruitment of the 1990 year class, remained low during 1992-1998, and then increased slightly in 1999. The mean weight of adult rainbow smelt decreased from about 16 g in the early 1970s to about 10 g by the late 1990s. The decrease in average weight does not appear related to a decline in condition but rather to a decrease in growth and a lack of older fish in the population. Based on how the population has responded to changes since the early 1970s, rainbow smelt should continue as a major component of the prey-fish community, but the population will likely continue to be mostly young fish.

Alewife

The abundance of adult alewives (>119 mm, total length) fluctuated substantially during 1973-1999 and reached its lowest levels in the early to mid-1980s and during 1995-1999 (Fig. 9). The age structure of the alewife population has also fluctuated during 1973-1999. Mean age of age-1 and older alewives was 2.9 y from 1973 to 1981 and then decreased to 1.8 y in the mid- to late 1980s. Mean age has generally continued to decrease since the 1980s, except for a brief increase during 1993-1995 when several strong year classes recruited to the population.

Recent changes in the age and size structure of the alewife population suggest a decline in abundance of older alewives during and since the mid-1990s. The trend in the abundance of large alewives (>150 mm, total length) during the same period paralleled changes in mean age, and, by 1999, few of these large fish were present in trawl catches. As the adult population declined after 1995, strong year classes were frequently produced, indicating a density-dependent response. However, many of these year classes failed to recruit well to the adult population. For example, the large numbers of age-0 alewives present in 1995 were not very abundant as 3-year-olds in 1998 (Fig. 9). Whether predation or other factors caused the poor recruitment is unknown.

Sculpins

Deepwater sculpin make up most of the sculpin biomass in the main basin (Fig. 10), and their populations have been moderately stable until the past few years. Their standing stocks declined in 1998 and 1999 following several years of very good catches, and the present biomass is well below historical levels. Slimy sculpins have never been as abundant in survey catches or as extensively distributed across depths in Lake Huron as they are in Lake Ontario (Owens and Bergstedt 1994). The biomass of slimy sculpins averaged about 50,000 kg through most of the 1970s, declined to an average of about 10,000 kg during the 1980s, and rose again to about 50,000 kg in the 1990s.

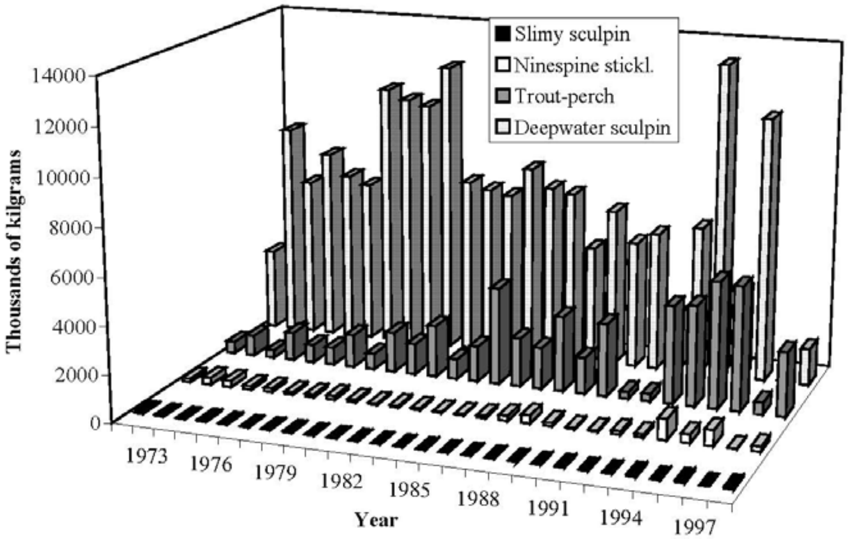

Fig. 10. Biomass of slimy sculpin, ninespine stickleback, trout-perch, and deepwater sculpin in the main basin of Lake Huron based on bottom-trawl surveys during the fall, 1973-1999.

Other Prey Species

Ninespine sticklebacks and trout-perch are an important part of the prey-fish community. Biomass of ninespine sticklebacks decreased during the late 1970s to mid-1990s but has increased in recent years (Fig. 10). Trout-perch have gradually increased in abundance during 1973-1999.

THE OPEN-WATER PREDATOR COMMUNITY

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The salmonine fish-community objective for Lake Huron is to "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" (DesJardine et al. 1995). The salmonine community includes lake trout, Chinook salmon, coho salmon, pink salmon, Atlantic salmon, rainbow trout, brown trout, and brook trout. Lake trout and brook trout are the only species indigenous to Lake Huron.

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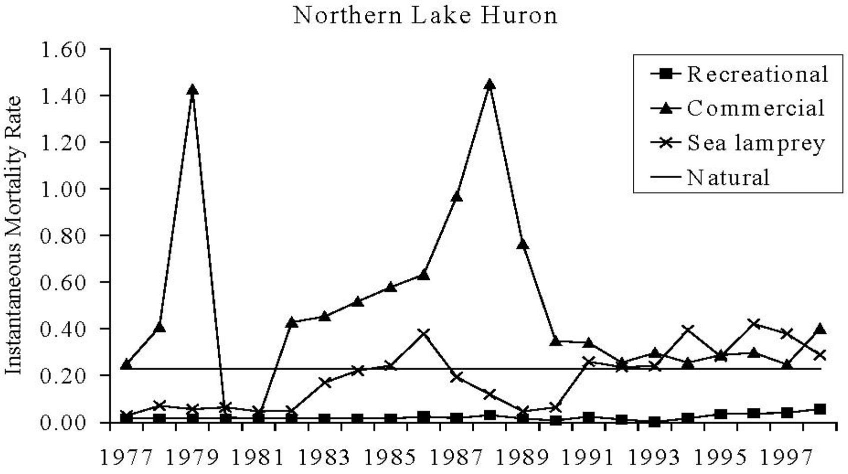
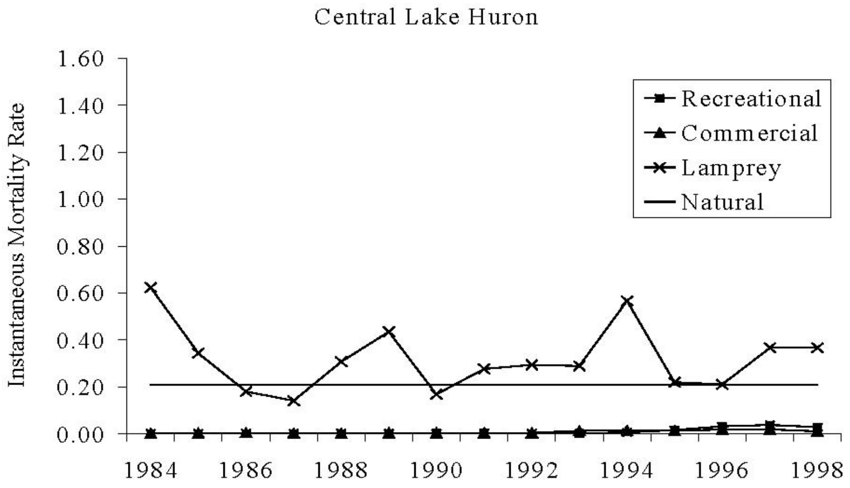
Lake Trout

Statistical catch-at-age (SCAA) stock-assessment models were developed for lake trout in the main basin during 1998-1999 to assist management and to evaluate rehabilitation. The SCAA models were used to estimate mortality and abundance of lake trout and to partition total mortality into its sea lamprey-induced, commercial fishing, recreational fishing, and natural components (Sitar et al. 1999). The SCAA models were constructed for three areas within the main basin by combining existing management units or statistical districts in Michigan and Ontario (Fig 11): Northern Lake Huron (MH-1, OH-1), Central Lake Huron (MH-2, OH-2, and OH-3), and Southern Lake Huron (MH-3, MH-4, OH-4, and OH-5).





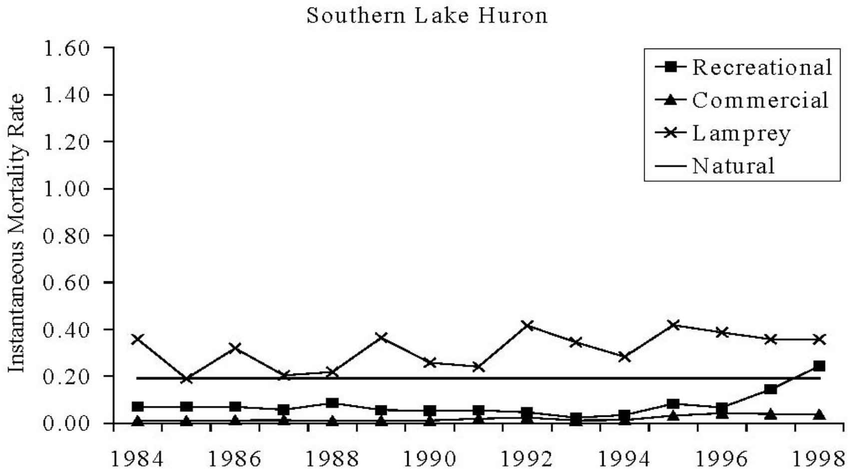


Fig. 11. Statistical-catch-at-age model estimates of instantaneous mortality rates (recreational fishing, commercial fishing, sea lamprey, and natural) for lake trout in the northern main basin (1977-1998) and central and southern main basin (1984-1998) of Lake Huron. Natural mortality was assumed to equal 0.20.

Northern Lake Huron

Instantaneous mortality rates have been relatively high in northern Lake Huron (Fig. 11). Commercial fishing was the greatest source of mortality during 1977-1990. Since 1990, commercial-fishing mortality decreased and sea lamprey-induced mortality increased. Through the 1990s, commercial-fishing instantaneous mortality averaged $0.30 \bullet y^{-1}$, and sea lamprey-induced instantaneous mortality averaged $0.29 \bullet y^{-1}$. Recreational-fishing mortality was low in all years relative to commercial fishing and sea lamprey mortality.

The high rates of commercial-fishing and sea lamprey-induced mortality truncated the age structure of lake trout in northern waters so few female fish survived to reach sexual maturity, which occurs at around age 7 (Fig. 12), and spawning-stock biomass remained extremely low (Fig. 13). Total biomass has remained relatively stable at around 432,000 kg during 1977-1998 (Fig. 13). A projection model using SCAA estimates of abundance and mortality indicates that suppressing sea lamprey populations, reducing commercial fishing mortality by 60%, and implementing a 61-cm (24-inch) minimum-size limit on recreational fishing will reduce total annual mortality of adult lake trout to the negotiated management goal of 45% or less by 2020 (U.S. *v*. Michigan 2000).

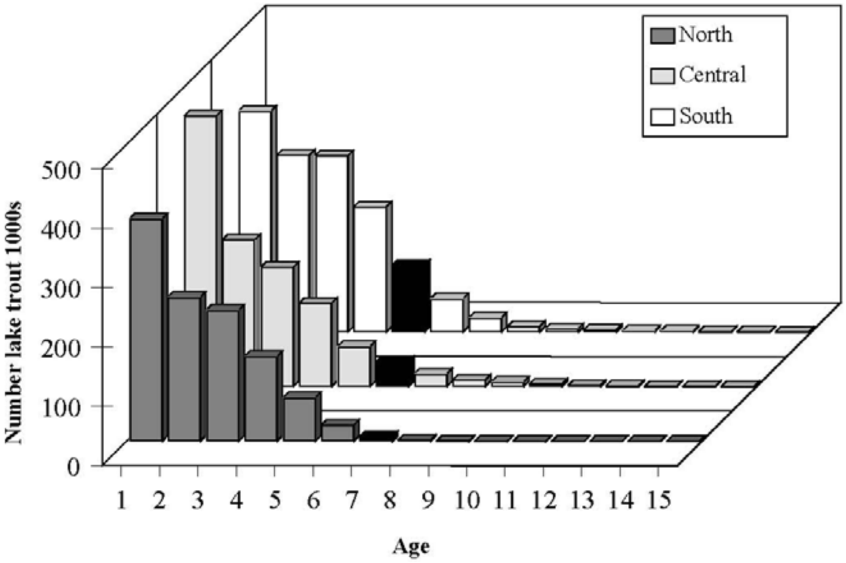
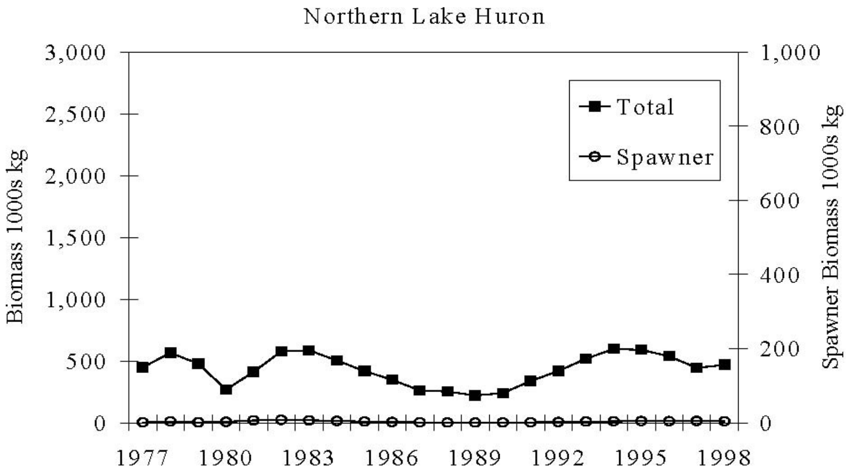
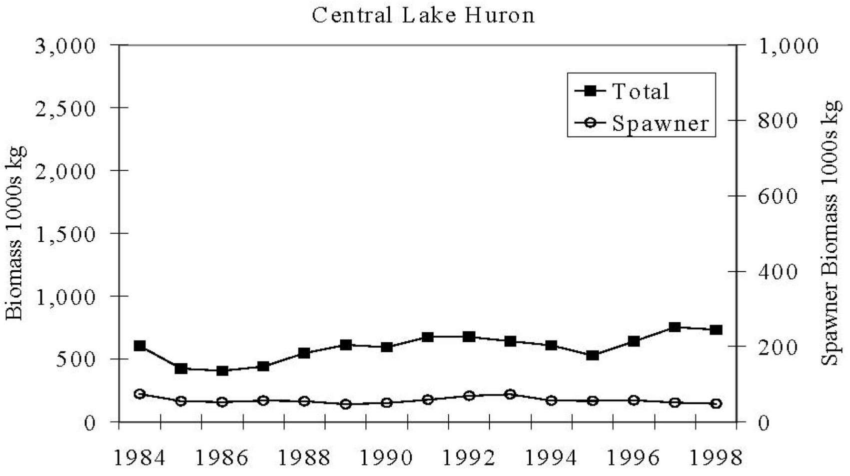


Fig. 12. Statistical catch-at-age estimates of mean age structure for lake trout in the northern, central, and southern main basin of Lake Huron, 1994-1998. Black bars indicate age of earliest maturity of female fish.


Northern Lake Huron
3,000
2,500
2,000
1,500
1,000
500
0
Biomass 1000s kg
1,000
800
600
400
200
0
Spawner Biomass 1000s kg
Total
Spawner
1977
1980
1983
1986
1989
1992
1995
1998


Central Lake Huron
3,000
2,500
2,000
1,500
1,000
500
0
Biomass 1000s kg
1,000
800
600
400
200
0
Spawner Biomass 1000s kg
Total
Spawner
1984
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1996
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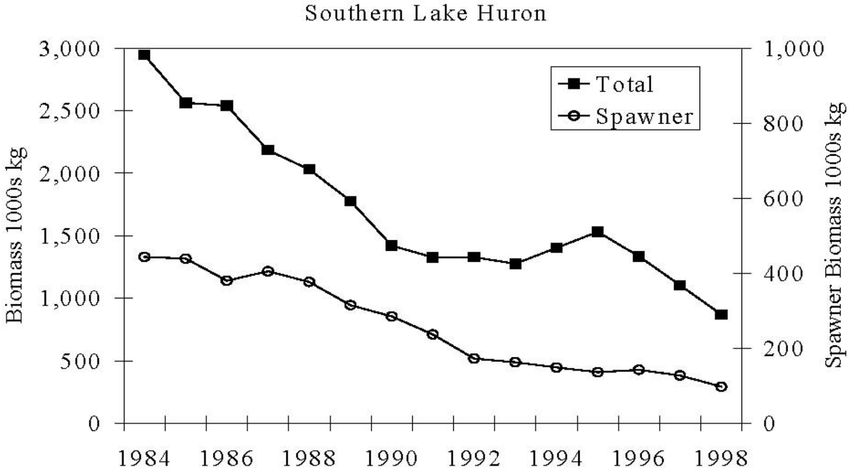

Fig. 13. Statistical-catch-at-age model estimates of total lake trout biomass and spawning-stock biomass in the northern main basin (1977-1988) and central and southern main basin (1984-1998) of Lake Huron.

Central Lake Huron

Predation by sea lamprey was the largest source of mortality for lake trout in central Lake Huron during 1984-1998, except in 1986, 1987, and 1990 when natural mortality was the largest (Fig. 11). Sea lamprey-induced mortality peaked in 1989, 1994, and 1997 and averaged $0.31 \cdot y^{-1}$.

The sea lamprey-induced mortality rate in central Lake Huron was large enough to truncate the age structure of lake trout so that few female fish reached sexual maturity (Fig. 12). As a result, spawning-stock biomass (58,000 kg) has been low (Fig. 13). Total biomass estimates have been relatively stable and averaged around 593,000 kg during the last 15 years (Fig. 13). The projection model indicates that suppressing sea lamprey populations and implementing a 61-cm minimum-size limit on the recreational fishery will achieve the rehabilitation goal of 40% total annual mortality on adult lake trout by 2020 (Ebener 1998; U.S. *v.* Michigan 2000).

Southern Lake Huron

Predation by sea lamprey was the largest source of mortality on adult lake trout in southern Lake Huron during 1984-1998 (Fig. 11) (Sitar et al. 1999). It averaged 0.34•y^{-1} during 1990-1998. Recreational-fishing mortality increased during 1994-1998, but commercial-fishing mortality was uniformly low in all years.

Lake trout age structure in southern Lake Huron was similar to that in the other areas, but the earliest age of maturity for females was age 5 in the south compared to age 6 in central waters and age 7 in the north. As a result of this earlier maturity, spawning-stock biomass (168,000 kg) was higher in the south (Fig. 13). However, the majority of the historical lake trout spawning habitat is located in northern and central Lake Huron (Eshenroder et al. 1995; Ebener 1998), which may explain why no reproduction has been detected in the south. Total and spawning-stock biomass steadily declined during 1984-1998 in southern Lake Huron perhaps because of reduced stocking or decreased survival of stocked fish.

The SCAA projection model indicates that suppressing sea lamprey populations and placing a 61-cm minimum-size limit on recreational fisheries will permit reaching the rehabilitation goal of 40% total annual mortality on adult lake trout by 2020. In addition, reducing commercial-fishing mortality by 50% would speed rehabilitation and increase spawning stock biomass 18% by 2020.

Natural Reproduction of Lake Trout

Measurable natural reproduction of lake trout has been detected at six locations in Lake Huron: two in Michigan (Six Fathom Bank, Thunder Bay) and four in Ontario (Gravelly Bay, South Bay, Parry Sound, Iroquois Bay) (Fig. 1). Natural reproduction at Six Fathom Bank, Thunder Bay, Gravelly Bay, and South Bay resulted from stocking hatchery-reared fish because no native stocks were present at these sites. Residual stocks of native lake trout in Parry Sound and Iroquois Bay may account for the reproduction there.

Parry Sound (approximately 8,000 ha) has been the most successful site for lake trout rehabilitation in Lake Huron (Reid et al. 2001). The abundance of wild lake trout increased in Parry Sound since 1988, and major increases were observed in 1995, 1996, and 1998 (Fig. 14). The management tactics employed in Parry Sound were good sea lamprey control, prohibition of commercial fishing, tight control of sport fishing, stocking progeny of native Parry Sound lake trout at levels exceeding 4.5 yearlings per ha, and cessation of stocking when wild fish became abundant. Too many sea lampreys and an overexploitive sport fishery apparently kept lake trout numbers depressed in Parry Sound through the 1960s and 1970s. Sea lamprey marking rates in 1958 were 45-times higher than levels observed in 1988-1998 (Reid et al. 2001). However, the absence of commercial fishing in Parry Sound may have been a factor in the persistence of lake trout until sea lamprey control was initiated in the early 1960s (Johnson 1988). Tighter restrictions on the sport fishery were implemented during 1981-2000 (Reid et al. 2001). Lake trout rehabilitation in Parry Sound may have been further delayed because non-native strains of lake trout and lake trout hybrids were initially stocked. Splake were stocked initially, but these efforts were unsuccessful. In 1979, gametes were first collected from the few remaining wild lake trout. Starting in 1981, progeny from these wild fish were stocked together with a splake-lake trout backcross. Backcross stocking was terminated in 1991 due to poor survival and concerns about the genetic effects on the native lake trout. Lake trout were not stocked during 1989-1991 due to an outbreak of epizootic epitheliotrophic disease in the Great Lakes (Bradley et al. 1989). Although there is evidence that hatchery fish played an important role in the rehabilitation of Parry Sound lake trout (Reid et al. 2001), stocking was terminated in 1997 due to an adequate and increasing level of natural reproduction and knowledge that cessation of stocking can enhance natural reproduction of lake trout once a viable spawning population has been established (Evans and Willox 1991; Dunlop and Brady 1998).

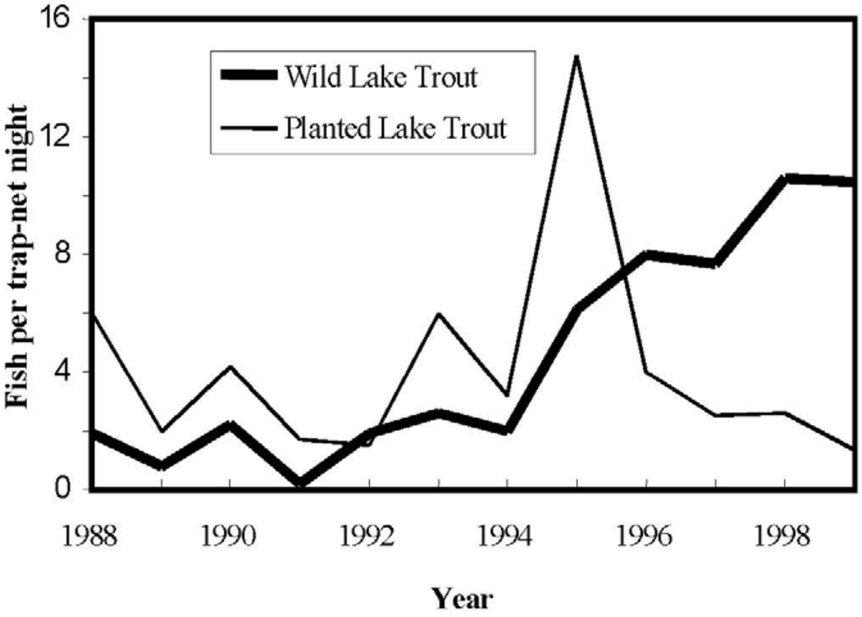

Fig. 14. Relative abundance of spawning lake trout caught in trapnets at Horse Island in Parry Sound, Ontario, 1988-1999.

Iroquois Bay is home to the only other native population of lake trout in Lake Huron, and it currently mimics the Parry Sound population of the late 1960s. The adult population is estimated at between 80 and 200 fish now. This bay is deep and isolated, similar to Parry Sound but much smaller (496 ha). Different strains of lake trout have been stocked into the bay over the years, but only progeny from the Iroquois Bay brood stock have been stocked since 1995. In 1999, a public advisory committee helped to enact sport-fishing regulations for Iroquois Bay that were more restrictive than those in Parry Sound—a daily limit of one lake trout of hatchery origin only (identified by a fin clip) less than 51-cm total length. Competition with Chinook salmon for spawning habitat (Powell and Miller 1990) may constrain rehabilitation of lake trout in Iroquois Bay.

South Bay on Manitoulin Island is another deep basin with a restricted opening to the main lake and, at 8,600 ha, is approximately the same size as Parry Sound. Different strains of lake trout have been stocked in South Bay, but only the Lake Manitou strain (from an inland lake on Manitoulin Island) has been stocked since 1995. Harvest by First Nation and sport fisheries was very high during 1979-1983, although First Nation exploitation decreased during 1984-1992. Naturally reproduced lake trout were first observed in 1986 (Anderson and Collins 1995). The first sizable natural year class of lake trout since 1948 was produced in 1990. In 1988, brook trout genes were detected in the wild-origin lake trout (indicating some genetic input from backcross), but none were detected in 1991 and 1992 (Anderson and Collins 1995). Little monitoring of the population occurred after 1993, but we believe that the present level of reproduction is insufficient to achieve a rehabilitated population and that additional harvest controls are needed.

The abundance of lake trout on spawning shoals in Gravelly Bay in Owen Sound has been surveyed since 1994. Initially, only hatchery (fin-clipped) lake trout were encountered, but, since 1998, substantial numbers of unclipped, presumably wild, lake trout have been captured. The abundance of unclipped fish in the catch remained stable during 1998-1999. The age range of unclipped fish was from 4 to 7. The survey results at Gravelly Bay are preliminary but encouraging.

Natural reproduction by lake trout has been documented since 1981 in Michigan waters in the vicinity of Thunder Bay (Fig. 1; Nester and Poe 1984). At North Point (mouth of Thunder Bay), YOY lake trout have been taken consistently since 1984 using a 30-ft bottom trawl (Johnson and VanAmberg 1995). The best catch was 2.6 per tow in 1986. Catch rates have been 1.0 or less since then and 0.1 or less since 1994. Limited numbers of YOY were also collected in 1992, 1993, and 1994 from Mischley Reef, located in the center of Thunder Bay (Johnson and VanAmberg 1995). Substantial numbers of mature unclipped lake trout were caught on Mischley Reef during the falls of 1991-1993 and 1997-1998 (Michigan Department of Natural Resources, Alpena Fisheries Research Station, 160 E. Fletcher Street, Alpena, MI, 49707, unpubl. data). Very few of these fish were older than age 7, and they were likely the progeny of hatchery lake trout. Many other reefs in the same area were surveyed, but no evidence of natural reproduction was found.

The Six Fathom Bank-Yankee Reef complex was a historically important spawning area for lake trout (Eshenroder et al. 1995). During 1985-1998, Six Fathom Bank was stocked annually with five strains of yearling lake trout (≈180,000 of each strain) that were marked with separate coded-wire tags. Lake trout YOY have been collected on Six Fathom Bank every year during 1993-1998 except 1996—number per tow ranged from around 70 in

1994 to less than 5 in 1993, 1997, and 1998 (U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI, 48105, unpubl. data).

Future Efforts and Coordination

The OMNR is undertaking a five-year review of its 1996 Lake Trout Rehabilitation Plan. The review is based on new knowledge, the need for a reduction in exploitation by the commercial and sport fisheries, and the need to focus efforts in protected bays (Reid et al. 2001). High-priority areas for rehabilitation in Ontario would include locations with native stocks or research sites: Parry Sound, Iroquois Bay, Owen Sound, and South Bay. Because they harbor wild lake trout, these areas would have the highest level of protection from exploitation and the highest priority for assessment. Other sites where natural reproduction has not been observed but where lake trout spawning habitat exists would be a moderate priority. Proposed management options for high-priority areas include refuges where commercial and sport fishing is limited and a buffer area of less-restrictive regulations.

Lake Huron waters within the 1836 treaty-ceded area in Michigan waters of Lake Huron (Fig. 1, MH-1) have been co-managed since 1985 by the MDNR and the CORA. A 20-year agreement for future co-management was being negotiated during 1999. The preliminary agreement addresses strategies to promote lake trout rehabilitation including:

- Reducing commercial-fishing mortality by converting existing gillnet fisheries to trapnet fisheries
- Increasing stocking to levels called for in the lake trout rehabilitation guide (Ebener 1998)
- Achieving total annual mortality of not more than 45%
- Allocating the lake trout harvest among commercial and sport fisheries
- Reducing the sea lamprey population in the St. Marys River

Rehabilitation of lake trout throughout Lake Huron has been hindered by excessive sea lamprey and exploitation mortality. The recent treatment of the St. Marys River with lampricides should reduce sea lamprey-induced mortality and increase survival of lake trout. Managers need to ensure that a reduction in sea lamprey mortality is not offset by increases in commercial and sport fishing to levels that exceed the target mortality rate (Ebener 1998). All of the successes in fostering lake trout natural reproduction in Lake Huron highlight the need for stringent controls on mortality.

Chinook Salmon

There is no specific fish-community objective for Chinook salmon. The MDNR introduced Chinook salmon to control overabundant alewife and rainbow smelt populations and to convert this non-indigenous prey into an economically important resource (Keller et al. 1990). Chinook salmon are stocked as spring fingerlings only a few months after hatching, and, thus, are very cost-effectively reared compared to the other salmonines, which are usually stocked as yearlings.

Chinook salmon were first stocked in Lake Huron in 1968 by the MDNR in the Ocqueoc and Thunder Bay Rivers. The initial egg sources were Columbia River, Oregon, and Puget Sound, Washington (Keller et al. 1990). Since 1970, the Michigan egg sources have been Michigan tributaries: currently the Swan River, a small tributary to northwest Lake Huron, and the Little Manistee River, a tributary in eastern Lake Michigan.

All Chinook salmon stocked in Ontario waters are raised at Community Fisheries Involvement Program hatcheries, which are staffed by volunteers, licensed by the OMNR, and located at Sarnia and Port Elgin on the main basin, Owen Sound in Georgian Bay, and Gore Bay in the North Channel. The egg sources for these hatcheries are the Sydenham River in Owen Sound and the local streams of Manitoulin Island.

Lakewide stocking rates peaked at 5 million fish in 1989 and have since averaged near 4.5 million fish annually. Fishery agencies became concerned that Chinook salmon abundance, combined with increasing numbers of other piscivores, could exceed the capacity of Lake Huron’s prey base. By interagency agreement, stocking levels of predator species were capped at 1990 levels (see the Predator-Prey Interactions, this publication). Initial results of a predator-prey modeling effort suggested predation rates by Chinook salmon, lake trout, walleye, and burbot had exceeded pre-sea lamprey levels, and, consequently, Chinook salmon stocking was reduced by nearly 20% in 1999.

Prior to the 1980s, no reproduction by Chinook salmon had been detected in Michigan tributaries (Carl 1982) or elsewhere in Lake Huron. However, during 1985-1987, mature Chinook salmon and their eggs and fry were observed on historically important lake trout spawning reefs in the North Channel, indicating that shoal spawning occurred in Lake Huron (Powell and Miller 1990). Chinook salmon spawning and wild age-0 progeny have been observed in tributaries to Lake Huron since 1988 (Powell and Miller 1990; Johnson et al. 1995). Natural reproduction is thought to contribute between 10% and 30% of fish harvested in Michigan (Johnson et al. 1995).

Harvest and Abundance

Chinook salmon are not captured during agency surveys in numbers sufficient to assess their abundance, so catch rate in the recreational fishery has been the best available index of abundance. Chinook salmon harvest and catch rates at nine ports surveyed since 1986 (no data 1989-1991) were fairly stable during 1986-1994 and then increased from 1995 through 1997 (Fig. 15). Harvest and catch rates declined in 1998-1999 but remained above the 1986-1997 average. The decline in recent years does not appear to be related closely to changes in stocking levels. Stocking peaked in 1989 and should have produced a peak harvest in 1992 rather than in 1997. Other factors that probably contributed to the higher catch and catch rates in the mid- to late 1990s include increased vulnerability to the sport fishery due to a declining prey supply, increased natural reproduction, and increased survival of stocked fish. In recent years, the MDNR, in partnership with sport-fishing groups, has used net-pens to acclimate Chinook salmon to natural environments immediately prior to stocking. Studies suggest that 3-4 weeks of rearing in acclimation pens may double post-release survival and/or result in better homing to stocking sites (Michigan Department of Natural Resources, Alpena Fisheries Research Station, 160 E. Fletcher Street, Alpena, MI, 49707, unpubl. data).

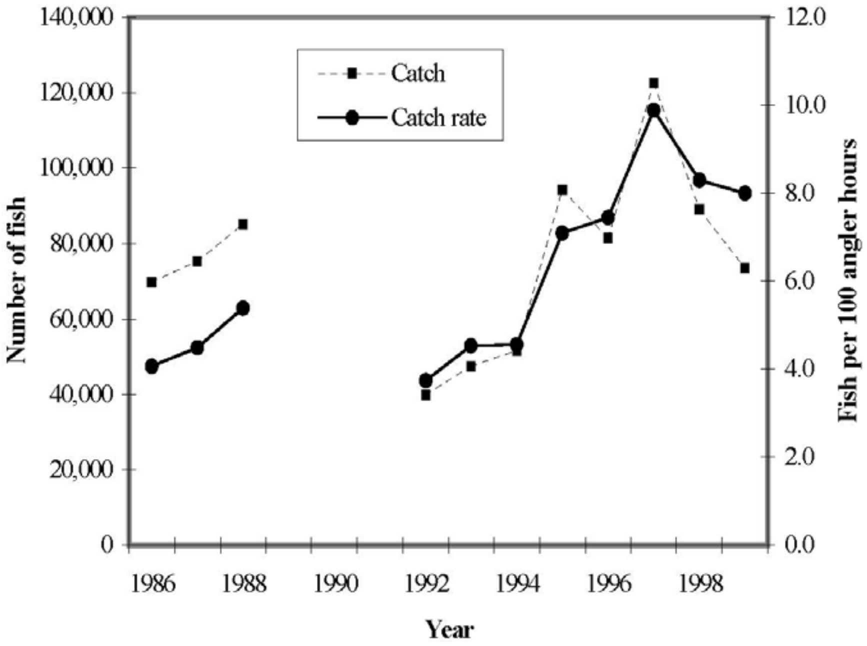

Fig. 15. Catch (numbers) and catch rate (fish per 100 angler hours) of Chinook salmon at nine index ports in Michigan waters of Lake Huron, 1986-1999.

Growth

Based on age-specific weights and lengths of mature Chinook salmon collected from the Au Sable River during 1974-1981 and 1996-1999, growth has declined in recent years. The fish collected in 1974-1981 were aged using scales from the caudal peduncle area and fin-ray sections. During 1996-1999, Chinook salmon were aged using vertebrae or coded-wire tags. Mean weights-at-age for ages 1-4 were significantly lower during 1996-1999 than during 1974-1981 (*t* test, $p < 0.001$ and *t* test for unequal variances, $p < 0.015$). Chinook salmon were significantly older during 1996-1999 with more fish of age 3 or 4 than in the earlier sampling period. The reduction in growth during 1996-1999 was accompanied by older age at maturity. Weights at ages 2-4 declined significantly each year during 1996-1998 (*t* test, $p < 0.05$), but then recovered to near-1996 weights in 1999. Condition factors also were significantly lower during 1996-1999 than during 1974-

1981 (*t* test, $p < 0.001$), declined each year during 1996-1998 then recovered to near-1996 levels in 1999.

Food Habits

Alewife and rainbow smelt are the primary prey of Chinook salmon in Lake Huron. Alewives made up 73%, rainbow smelt made up 19%, and lake whitefish made up 8% by weight of identifiable food items in the diet of Chinook salmon collected from central Michigan waters during 1997-1999. Spiny water fleas were also found, but contributed little weight to the diet.

Rainbow Trout

The rainbow trout is a Pacific salmonine that was first stocked in Lake Huron in 1876 in Michigan waters (Smedley 1938). Rainbow trout spread throughout the lake and were reported in Ontario waters in 1904 (Radforth 1944). Their abundance increased since the 1950s because of three factors: the collapse of lake trout populations and accompanying initiation of sea lamprey-control reduced predation on adults (Berst and Wainio 1967), heavy rains associated with Hurricane Hazel in 1956 cleared many rivers of both barrier dams and debris and created more spawning habitat, and the intentional removal of additional dams and the creation of fishways on several large river systems increased access to spawning habitat.

The numbers of rainbow trout stocked annually decreased lakewide through the 1970s, increased in the 1980s, and have been relatively stable at 300,000-400,000 yearlings during the 1990s. The increase in the mid-1980s in Ontario waters was due in part to development of private hatcheries (Community Fisheries Involvement Program). Most of the rainbow trout stocked in the main basin are stocked by the MDNR. The MDNR stocked domestic stains prior to 1994, but since then has stocked mainly the Little Manistee River (Lake Michigan) strain. This change in strains is believed responsible for the increased catch rates of rainbow trout in Michigan waters after 1994.

The bulk of Lake Huron’s cold-water streams accessible to anadromous salmonines are in Ontario waters (southern Georgian Bay, southern main basin, and on the southern shore of Manitoulin Island), and most rainbow trout natural reproduction occurs in these tributaries. Very few streams in Michigan are suitable for rainbow trout reproduction and survival of young.

As rainbow trout abundance increased in the 1970s, Ontario created sanctuaries, reduced open seasons, reduced bag limits, and increased stocking, especially in spawning streams, to offset the effect of increasing angler effort. However, the development of an offshore salmon fishery in Ontario waters in the mid- to late 1980s resulted in a substantial increase in the harvest of rainbow trout. Despite stricter regulations, anglers were reporting declines in catches of adults in Georgian Bay and Manitoulin Island streams by the late 1980s and early 1990s. The numbers of rainbow trout that passed through fishways declined during the 1980s and 1990s in southern Georgian Bay (Fig. 16A), but the numbers passed through main-basin fishways, and the proportion of hatchery fish increased (Fig. 16B). Stocking may have masked the loss of natural populations in main-basin tributaries. The MDNR fin clipped all of the rainbow trout they stocked in 1997 to assess natural reproduction and distribution of the stocked fish. Prior to 1997, unclipped fish that were caught in Ontario waters and streams of the main basin were presumed wild, but they may have been stocked by Michigan. As these marked Michigan fish recruited to the spawning population, their proportion increased in Ontario tributaries of the main basin.

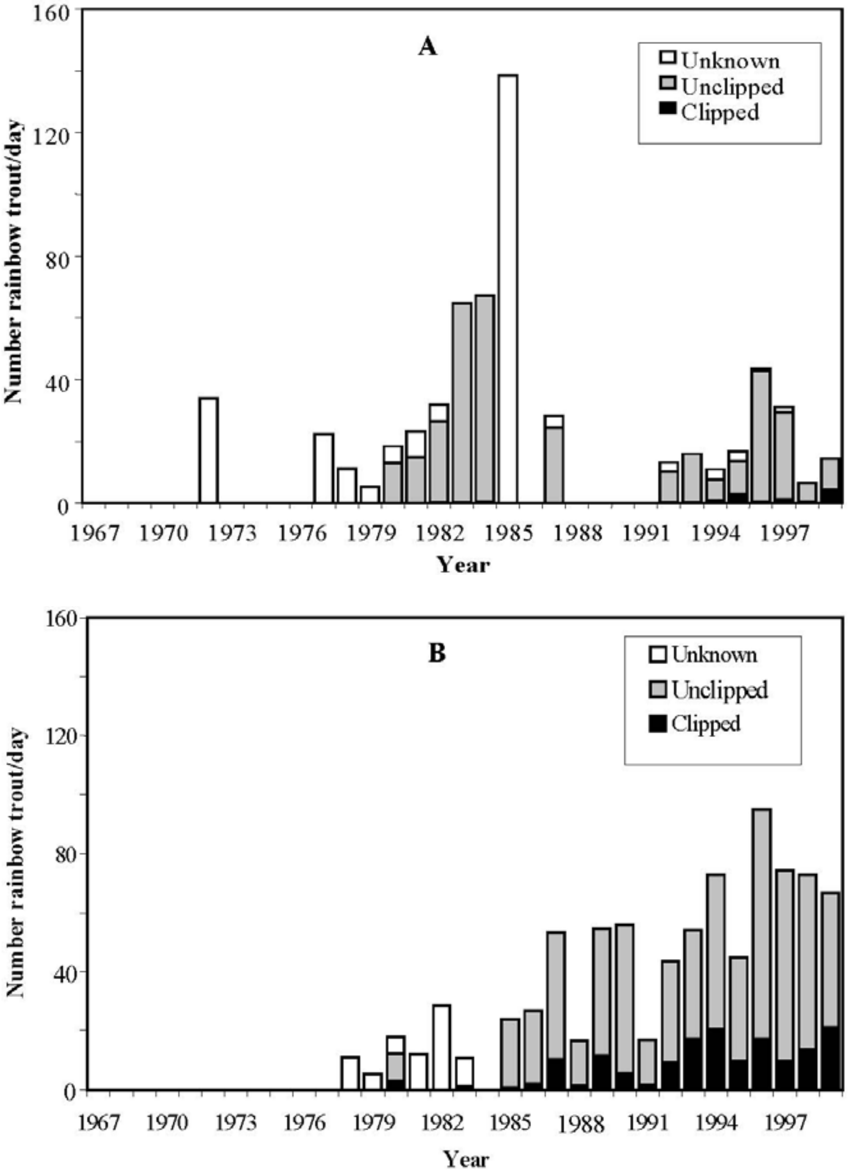

Fig. 16. Number of rainbow trout that passed through fishways on Ontario's Lake Huron tributaries to southwestern Georgian Bay during 1972-1999 (A) and the main basin during 1978-1999 (B). Years lacking bars indicate no assessment conducted.

Brown Trout

Small naturalized populations of brown trout occur in many tributaries of Lake Huron as a result of prior stocking (MacCrimmon and Marshall 1968). However, brown trout abundance is much lower than that of rainbow trout, and natural reproduction occurs mostly in Ontario tributaries because of their greater suitability for this species. Although stocking in tributaries began in the late 1800s, stocking directly into the lake only began in 1970 in Michigan waters and in 1983 in Ontario waters. Current lakewide stocking levels are ≈400,000 per year. Brown trout are stocked to diversify the salmonine community, offer a nearshore fishery that is less seasonal in nature than the Chinook salmon fishery, and provide an opportunity for anglers to harvest quality- to trophy-sized brown trout.

Evaluation of brown trout stocking has been focused in Thunder Bay (Fig. 1) where Michigan stocks over a third of its total Lake Huron allotment. Return to the sport fishery of brown trout stocked as yearlings averaged nearly 5% in Thunder Bay during 1974-1987, then declined to less than 1%. Annual harvest in Thunder Bay during 1974-1987 varied as a function of the number stocked the previous year. Despite increased stocking during the 1990s, annual harvest decreased from 4,000 fish in 1993 to only 162 fish in 1999 (Fig. 17). Possible reasons for this decline include changes in strains stocked, increased predation by walleye and double-crested cormorants (*Phalacrocorax auritus*), and decreased abundance of alewife. Seeforellen and Wild Rose strains of brown trout produced better returns to the sport fishery than the more-recently used Plymouth Rock strain. Stocking during May-June, when alewife abundance was highest, appeared to buffer predation and result in higher brown trout survival (Johnson 2000).

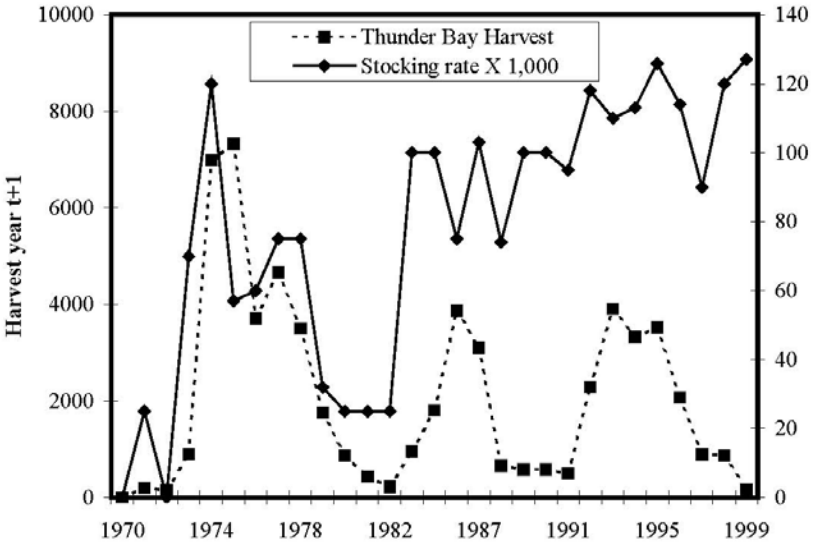

Fig. 17. Harvest of brown trout in Thunder Bay, Michigan, and number of brown trout stocked the previous year in Thunder Bay, 1970-1999.

Pink Salmon

Pink salmon established in Lake Huron in the late 1960s and early 1970s (Parsons 1973; Johnson et al. 1995). The largest spawning population is believed to be in the St. Marys River. Pink salmon typically spawn every two years, but a few do not spawn until the third year resulting in the establishment of both odd- and even-year spawning runs. The annual harvest in the Michigan sport fishery ranged from 148 kg to 1,300 kg during 1992-1999. Pink salmon-Chinook salmon hybrids have been caught regularly in the St. Marys River and in northern Lake Huron since 1993 (Rosenfield 1998; Rosenfield et al. 2000). This hybrid has not been reported elsewhere in Lake Huron or from other Great Lakes.

Atlantic Salmon

Atlantic salmon in Lake Huron are the result of a cooperative stocking program involving Lake Superior State University (LSSU), Edison Sault Electric Company, and the MDNR. Each year about 40,000 Atlantic salmon are reared by LSSU personnel at the Edison Sault hydroelectric facility and stocked as yearlings in the St. Marys River. These fish support a sport fishery in the St. Marys River, and annual harvest in the Michigan sport fishery has ranged from 55 kg to 709 kg since 1992. Atlantic salmon have also been caught sporadically in the recreational fishery of southern Georgian Bay.

Coho Salmon

The fish-community objectives for Lake Huron (DesJardine et al. 1995) state that coho salmon are currently present in low numbers in the lake. They may persist because of limited natural reproduction or immigration but will not be stocked because of potential conflicts with other riverine species, their relatively short period of availability for fishing, and poor returns from past stocking. Coho salmon were stocked annually during 1968-1988 (Tody and Tanner 1966). Despite stocking almost one million fish in some years, the return of coho to the angling fishery was poor, and it appears they would never play a major role in the Lake Huron sport fishery (Rakoczy and Rogers 1990). Although no coho salmon have been stocked in Lake Huron in over a decade, small numbers of them appear regularly in the sport catch. Their catch at nine Michigan ports in 1999 was 5,026 fish, which was second only to the catch in 1986 (Michigan Department of Natural Resources, Charlevoix Fisheries Research Station, 96 Grant Street, Charlevoix, MI, 49711, unpubl. data). The catch of coho salmon in the Ontario sport fishery increased in South Bay and Province Bay during 1995-1999 despite a 50% reduction in fishing effort (Ontario Ministry of Natural Resources, Upper Great Lakes Management Unit, 1450 Seventh Ave. East, Owen Sound, Ontario, Canada, N4K 2Z1, unpubl. data). Coho salmon are occasionally harvested in southern Lake Huron and in southern Georgian Bay as an incidental catch in the Chinook salmon sport fishery.

Natural reproduction is the most likely explanation for the continued presence of coho salmon in Lake Huron. In Ontario waters, spawning runs occur in several tributaries along the south shore of Manitoulin Island including Blue Jay, Shrigley, Timber Bay, and Hughson Creeks and the Manitou River. The spawning run on Blue Jay Creek varies in number from

24 to 50 pairs (Paul Methner, Ontario Ministry of Natural Resources, Blue Jay Creek Fish Culture Station, RR#1, 242 Highway 542, Tehkummah, Ontario, P0P 2C0, personal communication).

Recommendations

1. Concentrate lake trout rehabilitation efforts, at least initially, in isolated bays

2. Reduce total annual mortality rates on lake trout to 40%

3. Establish additional refuges for lake trout where commercial and sport fishing is prohibited or severely restricted; existing refuges have been effective in both Lake Huron (Reid et al. 2001) and Lake Superior (Schram et al. 1995)

4. Increase stocking rates to more than four yearlings per hectare in areas containing the best lake trout spawning habitat or concentrate large number of yearlings in good habitat for several consecutive years and then cease stocking for several years (pulse-stocking)

5. Cease stocking lake trout when reproduction meets rehabilitation criteria described in Ebener (1998)

6. Increase assessment of lake trout populations in rehabilitation zones

7. Increase funding assessment of additional factors other than sea lamprey and fishing mortality, such as early mortality syndrome and predation on eggs and young that limit reproduction of lake trout

8. Estimate the amount of natural recruitment of Chinook salmon

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The fish-community objectives for coregonines (DesJardine et al. 1995) are to:

- Maintain the present diversity of coregonines
- Manage lake whitefish and ciscoes at levels capable of sustaining annual harvests of 3.8 million kg
- Restore lake herring to a significant level
- Protect, where possible, rare deepwater ciscoes

The coregonine community of Lake Huron is made up of lake whitefish, lake herring, bloater, and round whitefish. Each is harvested primarily for commercial purposes. Total annual harvest of these species during 1993-1999 has surpassed the yield target of 3.8 million kg (Fig. 18). Lake whitefish is the primary commercial species, contributing about 90% of the current coregonine harvest, and it is followed in importance by bloater, round whitefish, and lake herring. Deepwater ciscoes, mainly bloaters, made up approximately 74% of the coregonine harvest in the early 1960s but have contributed only about 8% during the past 5 years. Although lake herring made up the majority of the commercial harvest (51%) during the first half of the 1900s, they now contribute less than 1%. Round whitefish likewise account for less than 1% of the coregonine harvest.

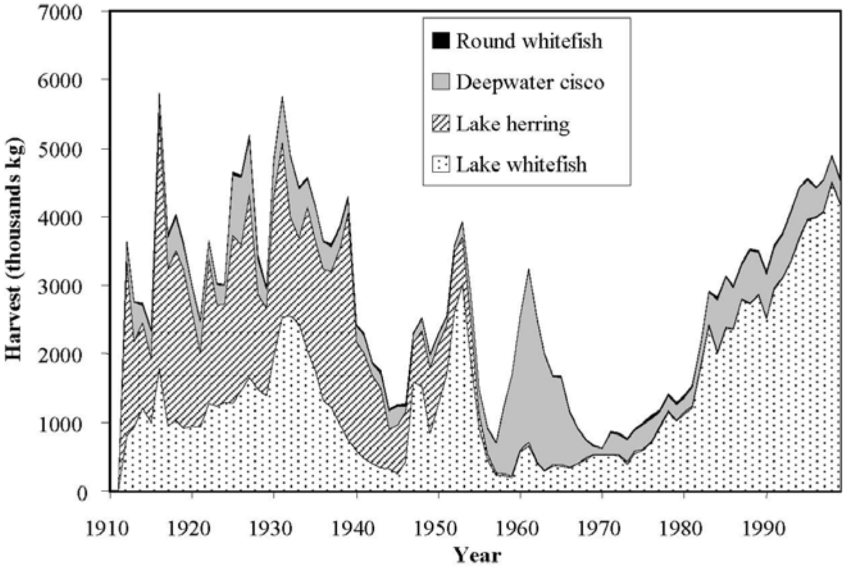

Fig. 18. Commercial harvest of coregonines from Lake Huron, 1912-1999.

Lake Whitefish

Lake whitefish harvest was low during the late 1950s to early 1970s, but it increased to record levels by the late 1980s (Fig. 18). The increase in harvest was due to an extraordinary recovery of lake whitefish populations (Reckahn 1995; Ebener 1997) attributed to control of the sea lamprey, which reduced predation (Spangler and Collins 1980); stocking of salmonines that led ultimately to reduced predation on lake whitefish larvae by alewife and rainbow smelt (Reckahn 1995; Ebener 1997); better management of commercial fishing; and colder winters and warmer springs favorable for survival of lake whitefish eggs and larvae (Taylor et al. 1987).

The increased commercial harvest of lake whitefish and recovery of the populations has occurred in all three basins (Fig. 19), but the occurrence was later and of lesser magnitude in Georgian Bay and the North Channel. Commercial harvest lakewide increased since the 1970s, reaching 4.5 million kg in 1998 and 4.1 million kg in 1999. Over half of this lakewide harvest was from Ontario waters (59%-47% from the main basin) and the remaining 41% came from Michigan waters.

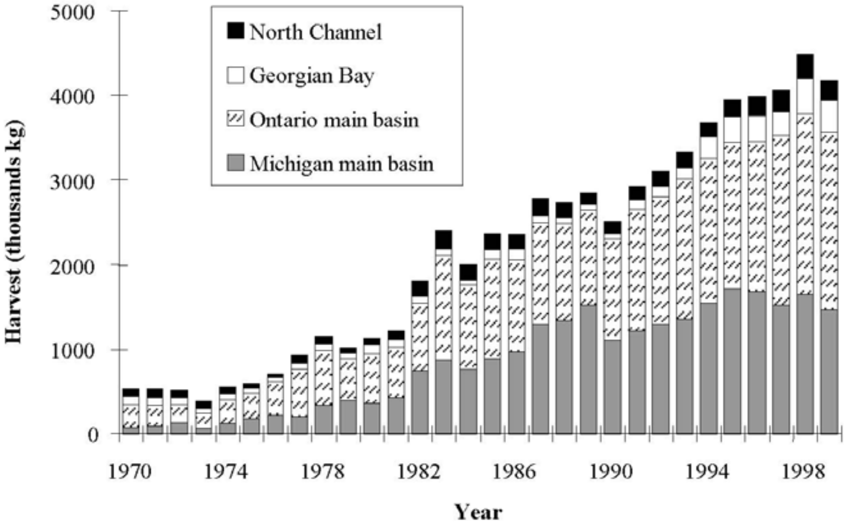

Fig. 19. Commercial harvest of lake whitefish from the three basins of Lake Huron, 1970-1999.

Abundance of lake whitefish, expressed as catch per unit effort (CPUE), steadily increased in virtually all areas since the late 1970s. The greatest increase has been in Ontario's southern main basin where CPUE in commercial gillnets increased from 85 kg•km^{-1} in 1979 to 373 kg•km^{-1} in 1998. Similarly, CPUE in the trapnet fishery increased from 48 kg•net^{-1} in 1992 to 538 kg•net^{-1} in 1999. The CPUE in the Michigan trapnet fishery in northern Lake Huron increased from 107 kg•net^{-1} in 1976 to 322 kg•net^{-1} in 1993 then declined slightly during 1994-98. The increased abundance and yield of lake whitefish during the last 30 years have been driven mainly by increased recruitment; consistently strong year classes were produced lakewide on a regular basis, and especially abundant year classes were produced during 1986-1991. Abundance of the 1992-1996 year classes declined lakewide, but, if initial surveys are correct, the 1998-1999 year classes are still abundant and should support the fisheries into the next decade.

As the abundance of lake whitefish increased, their growth and condition decreased substantially and increased at maturity. Mean weight of lake whitefish ages 3, 5, 7, and 10 from southern waters of the main basin decreased during 1975-1999 (Fig. 20). Mean weight also decreased in northern waters, and condition of lake whitefish in northern waters (Fig. 1, MH-1), expressed as empirical mean weight at a given length, has declined—lake whitefish 460-, 500-, and 550-mm total length weighed less in 1999 than in any other year during 1986-1999 (Fig. 21). Age at maturity of lake whitefish from Ontario waters of the main basin increased substantially during the last decade. In 1989, 50% of female lake whitefish were sexually mature by age 4 in Georgian Bay and the main basin, but, by 1999, the 50% maturity rate was not reached until age 7 in the southern part of the basin (OH-4/5) and age 8 in northern waters (OH-1). Age at 50% maturity has remained at age 4 in Georgian Bay where recovery of whitefish populations has been slower.

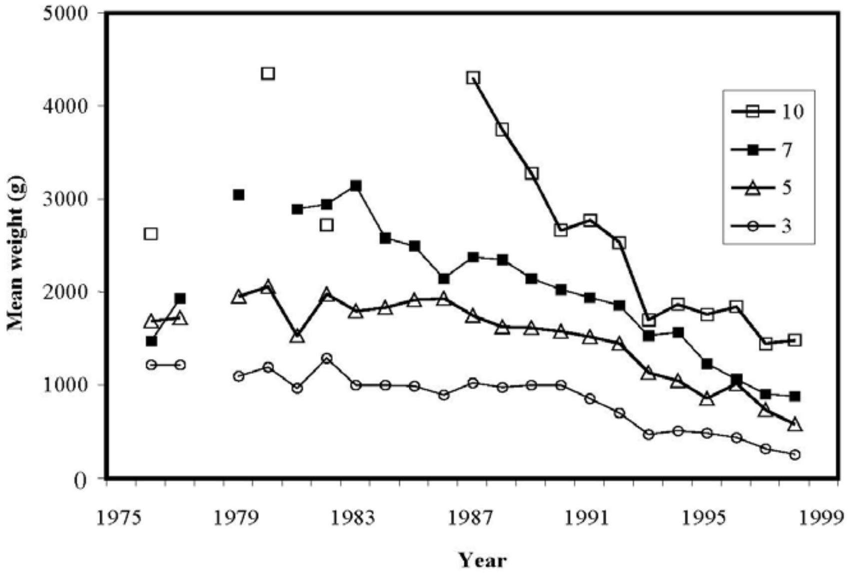

Fig. 20. Mean weight (g) at ages 3, 5, 7, and 10 years for lake whitefish caught in the commercial fishery from Ontario waters of the southern main basin of Lake Huron, 1975-1998.

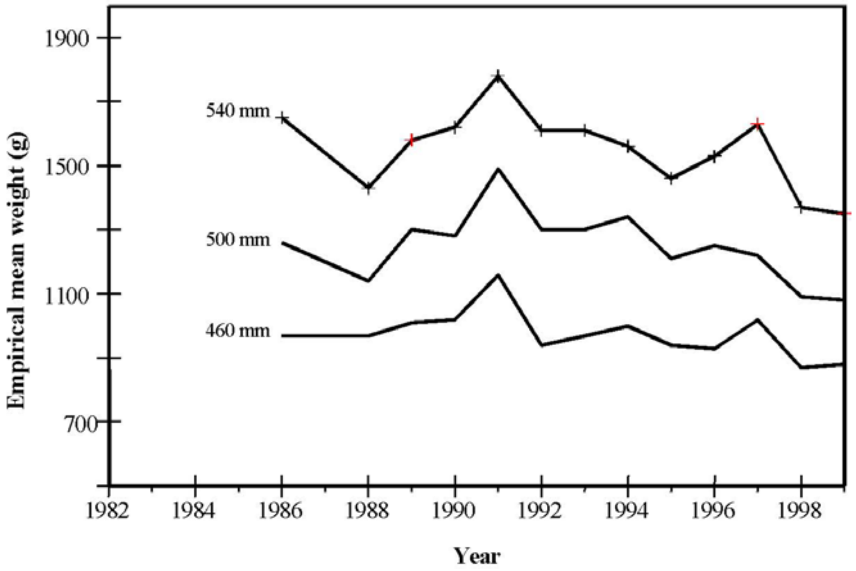

Fig. 21. Empirical mean weight (g) of three lengths of lake whitefish caught in CORA trapnet fisheries from Lake Huron management area MH-1, 1986-1999.

Deepwater Ciscoes

The annual commercial harvest of deepwater ciscoes fluctuated considerably during the 1900s, peaking at slightly above 2.5 million kg in the early 1960s then declining to only 250,000 kg just 7 years later. Harvest remained relatively stable at 267,000 kg through the 1970s then more than doubled, primarily in Ontario waters of the main basin, during 1984-1995. Harvest has declined lakewide since 1995; harvest was 330,000 kg in 1999. The bloater was the only deepwater cisco found in commercial catches in 1999, but other forms such as the shortnose cisco may still exist in Lake Huron.

The resurgence in bloater harvests during the 1980s and early 1990s was due to increased recruitment that began in the 1970s (Argyle 1995; Johnson et al. 1995). By the late 1980s, bloaters were the most abundant fish in the deepwater community. Catches in bottom trawls indicated recruitment was increasing throughout the main basin, but gill-net surveys from Ontario suggested that year-class strength was variable within the main basin and Georgian Bay. Bloater year-class strength was lower in Georgian Bay than the main basin during 1976-1988; after 1988, bloater reproduction increased in Georgian Bay but decreased in the main basin. Condition of bloaters in northern Lake Huron (MH-1) declined during the 1990s; bloaters 310-mm total length weighed about 270 g in 1991 but only about 150 g in 1999. The decline in condition of bloater occurred across all sizes from 250 to 310 mm. Mean weight at age also declined during the same time period (MPE, unpubl. data).

Lake Herring

Lake herring populations and the associated commercial harvest have yet to recover to historical levels. During 1970-1999, annual lake herring yield averaged 18,000 kg•y^{-1}, most of which has been from Ontario waters (90%), mainly from Georgian Bay and the North Channel. Commercial harvest has increased since 1996 in northern Michigan waters of the main basin because of a strong 1994 year class; the harvest in 1999 was the highest reported in over 30 years. A sport-fishery harvest of lake herring occurs in the St. Marys River where it was the second-most harvested species in 1999 (Fielder et al. 2002).

Round Whitefish

The historical commercial harvest of round whitefish during 1912-1940 averaged just over 28,000 kg•y^{-1}. Commercial yields fluctuated with no definite trend during the 1960s, 1970s, and 1980s then declined during the 1990s. Yield shifted from almost entirely Ontario waters in the 1970s to mostly Michigan waters in the mid-1980s and early 1990s but has been equally split between the jurisdictions since 1992.

Recommendations

1. Identify structure, spatial distribution, and sustainable fishing rates of lake whitefish

2. Determine the diet of lake whitefish and how diet is affected by food-web changes

3. Develop stock-specific indices of year-class strength for lake whitefish, bloater, and lake herring

4. Determine if lake herring populations are recovering in response to food-web changes

5. Develop management policies that encourage rehabilitation of lake herring

6. Develop a lakewide rehabilitation plan for deepwater ciscoes, including restoration of extirpated species that are extant elsewhere

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Walleye

Historically, the main predator of nearshore habitat in Lake Huron was the walleye, and annual commercial yield averaged over 860,000 kg between 1885 and 1945 (Baldwin et al. 1979). The fish-community objective is to “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” (DesJardine et al. 1995). The average total yield from all fisheries during 1993-1999 was 255,000 kg, well short of the 700,000 kg yield target specified in the fish-community objective. Numerous walleye populations have been identified from around the lake where they are almost always associated with tributaries (Schneider and Leach 1977; Schneider and Leach 1979; Reckahn and Thurston 1991). The largest walleye population was in Saginaw Bay, and it would often produce commercial yields in excess of 680,000 kg. By the mid-1900s, many of Lake Huron's walleye populations and their fisheries were in severe decline (Schneider and Leach 1977; Schneider and Leach 1979) due to loss or degradation of habitat, declining water quality, overfishing, and predation and competition from rainbow smelt and alewife. Abundance of all walleye populations and their yields are currently below historical levels. Throughout the watershed, dams and spillways impede the spawning migrations of walleye and other migratory fishes. Overall production of walleye would be higher if the species had access to spawning habitat above obstacles.

Stocked fish have aided in the maintenance of many walleye populations and fisheries, especially in Saginaw Bay where walleye historically spawned in tributaries and on reefs (Schneider and Leach 1979; Fielder 2002a). Today, natural recruitment occurs only in the lower areas of two tributaries to the Saginaw River (Tittabawassee and Flint Rivers) (Fielder 2002b). Walleye stocking will remain a widely used management practice in Lake Huron for the foreseeable future. An average 904,000 fingerlings have been stocked per year in Michigan waters during 1993-1999, mostly in Saginaw Bay. Smaller numbers of fingerlings are also stocked in Ontario waters.

Although stocked fish have been important in the maintenance of Lake Huron walleye populations, stocking could inhibit walleye recovery in some areas. Several walleye populations in Georgian Bay exhibited reduced genetic diversity largely attributable to fish-culture practices (Gatt 1998). In recognition of genetic concerns, the MDNR discontinued in 1996 the use of Lake Michigan walleye brood sources for stocking in Lake Huron and now depends on walleye from the Tittabawassee River. Similarly, CORA began its own walleye egg collection from the Munuscong River, a tributary of the St. Marys River, to supply its northern Lake Huron propagation program.

The contribution of walleye to the Lake Huron population from the Lake Erie/Lake St. Clair corridor has been quantified in recent studies. Walleyes tagged on spawning areas in western Lake Erie and Lake St. Clair migrated annually into southern Lake Huron and Saginaw Bay (Haas et al. 1988). Although these recaptures were only a small percentage of the Lake Erie population, they represented hundreds of thousands of walleye and a substantial contribution to Lake Huron fisheries. A study of the genetic makeup of walleye caught in Ontario's southern Lake Huron commercial fishery assigned 60-70% of the catch to Lake Erie origins and another 10-20% to the Thames River in Lake St. Clair (McParland 1996).

Yellow Perch

The fish-community objective for yellow perch is to maintain it "as the dominant near-shore omnivore while sustaining a harvestable annual surplus of 0.5 million kg." Historically, yellow perch were found throughout Lake Huron and were especially abundant in Saginaw Bay where the commercial yield averaged 419,000 kg annually during 1891-1960 (Baldwin et al. 1979). Saginaw Bay continues to support the largest yellow perch fishery in Lake Huron. The location of other notable yellow perch fisheries include the Les Cheneaux Islands, St. Marys River, Bay of Islands, and the southeastern main basin lakeshore from Blue Point to Point Clark (Fig. 1). The yield of yellow perch from all sources during 1993-1999 averaged 295,000 kg. The sport harvest of yellow perch from Ontario waters is underestimated due to a lack of comprehensive creel surveys, so the true harvest is likely much greater than 295,000 kg.

Most yellow perch populations and fisheries along the shore of the main basin in Michigan waters declined or disappeared since the early 1980s. However, populations and fisheries along the southeastern shore (Ontario waters) have remained strong. Why this difference has occurred is not fully understood.

Abundance of yellow perch was very high in Saginaw Bay during the mid- to late 1980s, and, consequently, growth was very slow (Haas and Schaeffer 1992). The slow growth was also partly due to a low abundance of large invertebrate prey. Yellow perch abundance has since decreased due to lower recruitment resulting in improved growth (Fielder et al. 2000). Recruitment has remained low in recent years, and managers are concerned that the population is in jeopardy of declining to an undesirably low level.

The yellow perch population in the Les Cheneaux Islands area of northern Lake Huron has increased since 1992 (Lucchesi 1988; Schneeberger and Scott 1997). That population supported substantial fisheries dating back to the early 1900s, and the peak yellow perch harvest in 1986 was estimated at around 389,000 fish. However, the harvest in recent years was similar to years prior to 1986 (Schneeberger and Scott 1997). The yellow perch population did decline from the early 1980s to 1993, but relative abundance nearly doubled from 1993 to 1995. A previous study in the area did confirm that double-crested cormorants prey heavily on yellow perch at certain times of the year (Maruca 1997), but a direct link between cormorant predation and the yellow perch population decline has not been established.

Esocids

The fishery objectives for esocids are "maintain the northern pike as a prominent predator throughout its natural range, maintain the muskellunge in numbers and at sizes that will safeguard and enhance its special status and appeal, and sustain a harvestable annual surplus of 0.1 million kg of these esocids" (DesJardine et al. 1995). Three species of esocids inhabit Lake Huron: northern pike, muskellunge, and redfin pickerel. The redfin pickerel is least abundant and is found only in tributaries of the southern main basin and of Georgian Bay.

The muskellunge is a top predator and a barometer of the health of nearshore fish habitat. The nearshore waters of eastern Georgian Bay and the North Channel support numerous small, natural muskellunge populations. The abundance of islands, submerged reefs, deepwater refuges, shallow productive embayments, and river deltas provide the habitat diversity required by this species. Naturally reproducing populations of muskellunge are also found in the St. Marys River.

Because of a dearth of information on muskellunge, the OMNR, with the support of several volunteer groups, conducted muskellunge spawning surveys during 1996-1999 in the Moon River and Severn Sound areas of Georgian Bay and in the Serpent Harbor, Bay of Islands, and McGregor Bay areas of the North Channel. The average size of muskellunge from each site did not vary significantly—females averaged 1,175-mm (46.3 inches) total length and males averaged 1,006-mm (39.6 inches) total length. The relative abundance of muskellunge varied across sampling sites, ranging from 0.26 to 0.55 fish per trapnet night (Fig. 22). We do not know if the abundance of these populations has changed over time.

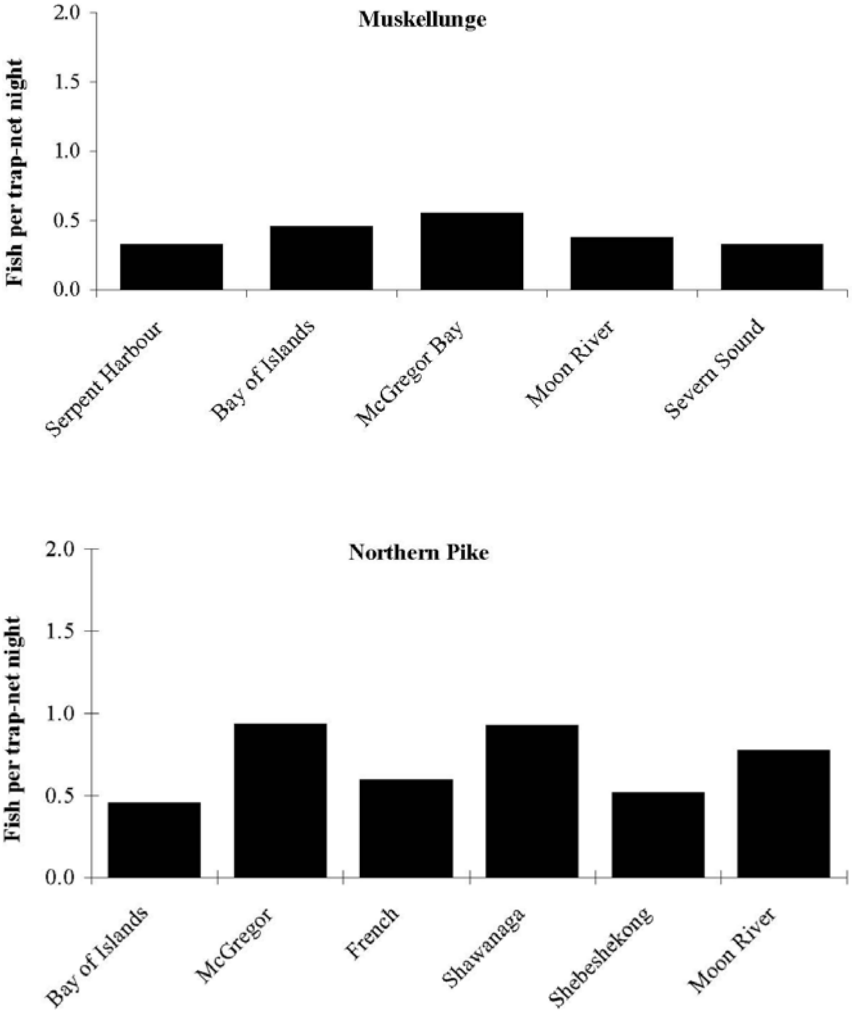

Fig. 22. Numbers of muskellunge and northern pike caught per trapnet night in nearshore, trapnet surveys at sites in the North Channel (Serpent Harbor, Bay of Islands, McGregor Bay) and Georgian Bay (Moon River, Severn Sound, Shawanaga River, French River, Shebeshekong River) during 1996-1999.

Northern Pike

Northern pike populations are found in littoral and riverine habitats throughout Lake Huron. The largest populations are found primarily in eastern Georgian Bay, St. Marys River, Les Cheneaux Islands, the north shore of the North Channel, and Saginaw Bay. Commercial fisheries harvested northern pike historically, but there is little commercial harvest today; commercial harvest, primarily from the North Channel, averaged 1,800 kg during 1993-1999. First Nation subsistence fisheries do target this species, but the amount of this harvest is unknown.

The most abundant northern pike populations in Michigan waters are found in the St. Marys River where 5,400 were harvested in 1999 (Fielder et al. 2002). Based on graded-mesh gillnet surveys, no appreciable change in northern pike abundance occurred between 1975 and 1995 (Fielder and Waybrant 1998). These northern pike grew slowly and the survey catches were dominated by smaller individuals with a mean age of 2.3 years (few were more than age 5) and a mean total length of 488 mm. Northern pike captured in spring fykenet surveys in 1998 and 1999 in Munuscong Bay (Fig. 1) were older (mean age 5.1 years) and larger (mean total length 543 mm) than reported by Fielder and Waybrant, but this was because the spring surveys targeted spawning fish (MPE, personal communication).

Northern pike populations in Lake Huron are dominated by young fish, and many populations are experiencing high levels of annual mortality. Relative abundance of northern pike in six areas of Georgian Bay and the North Channel varied from 0.45 to 0.93 fish per trapnet-night during 1996-1999 (Fig. 22), placing these populations in the low to moderate range of abundance relative to Ontario benchmarks for inland lakes (Brereton 2000). The mean age of these northern pike ranged from 3.5 to 4.6 years with very few fish older than 5 years, and annual mortality rates averaged 54%, which suggests high exploitation.

Centrarchids

The fishery objective for centrarchids (basses and sunfishes) is to “sustain smallmouth bass and largemouth bass and the remaining assemblage of sunfishes at recreationally attractive levels over their natural range” (DesJardine et al. 1995).

Smallmouth bass are found throughout the nearshore waters of Lake Huron, especially along the eastern shore of Georgian Bay and in Saginaw Bay. The annual harvest of smallmouth bass in Michigan's main-basin sport fishery was estimated to range from 928 to 3,788 fish during 1992-1999 with no trend (Michigan Department of Natural Resources, Charlevoix Fisheries Research Station, 96 Grant Street, Charlevoix, Michigan, 49711, unpubl. data). In the St. Marys River, the sport fishery harvested 1,499 smallmouth bass in 1999, and the catch rate was 0.0027 fish•h^{-1}. Harvest rates for smallmouth and largemouth bass are usually quite low in sport fisheries because anglers tend to catch and release these species. In the Bay of Islands and McGregor Bay, both in the North Channel, catch and release rates were 841 and 60% and 1,410 and 65%, respectively, during 1996-1998.

Smallmouth bass caught in surveys in Georgian Bay and North Channel during 1996-1998 encompassed a broad range of ages from age 1 to age 13 (Fig. 23). Common attributes among all populations surveyed were the presence of a weak 1992 year class and similar average ages. The relative abundance of smallmouth bass differed among sampling sites, and abundance was primarily in the low to moderate range compared to provincial benchmarks (Brereton 2000). The similar age compositions of smallmouth bass populations in eastern Georgian Bay and the North Channel, which are separated by hundreds of kilometers of shoreline, suggest that their population dynamics may be governed to a large extent by climatic factors. In Michigan waters of the St. Marys River, smallmouth bass size-at-age was similar among the sample sites (Fielder and Waybrant 1998). Smallmouth bass in the St. Marys River grew slower than smallmouth bass in Georgian Bay and the North Channel. A number of strong year classes of smallmouth bass have been produced lakewide since 1995 due to a series of warm springs and optimal summer growing conditions.

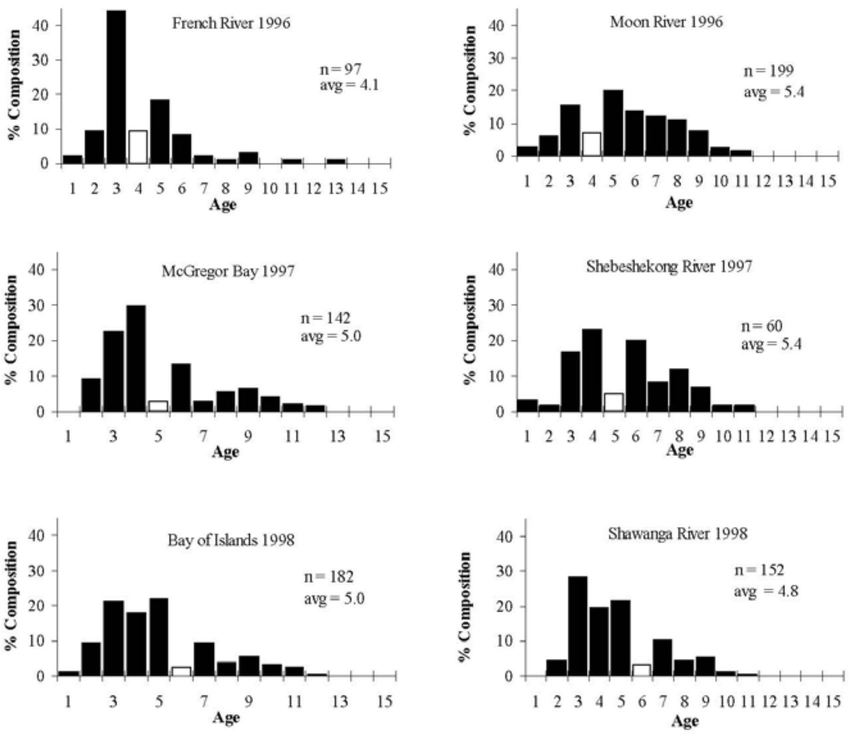

Fig. 23. Age composition (%), sample size, and average age in years of smallmouth bass captured in trapnet surveys at various sites in Georgian Bay (French River, Moon River, Shawanga River, Shebeshekong River) and North Channel (McGregor Bay, Bay of Islands), Lake Huron, during 1996-1998. White bars represent the 1992 year class.

Largemouth bass, rock bass, pumpkinseed, bluegill, black crappie, and white crappie are widely distributed throughout Lake Huron, but their population status is unknown. These species are popular with recreational anglers in many locations and comprise 29-61% of the total centrarchid sport-fish harvest in Michigan waters during 1992-1999 (Michigan Department of Natural Resources, Charlevoix Fisheries Research Station, 96 Grant Street, Charlevoix, Michigan, 49711, unpubl. data). A limited commercial fishery for rock bass and black crappie exists in Saginaw Bay (1,500 kg and 900 kg harvested, respectively, in 1992). Nearshore, fish-community surveys conducted in Georgian Bay and the North Channel suggest that the abundance of centrarchids is low to extremely low compared to provincial benchmarks for inland lakes.

Lake Sturgeon

The fish-community objectives for lake sturgeon are to "increase the abundance of lake sturgeon to the extent that the species is removed from its threatened status in U.S. waters, and maintain or rehabilitate populations in Canadian waters." The lake sturgeon is currently listed as either threatened or endangered by 19 of the 20 states encompassing its original range within the United States—Wisconsin is the exception.

Lake sturgeons historically were found widely distributed in Lake Huron and its larger tributaries. Indigenous people inhabiting the basin depended on lake sturgeon for sustenance and fished for them in the Mississaugi River, the Severn River (Needs-Howarth 1996), the islands of Lake Huron (Kinietz 1940), and elsewhere. The colonial commercial fishery initially treated lake sturgeon as pests, but lakewide commercial landings exceeded 470,000 kg by 1985. Commercial landings declined to less than 40,000 kg by 1905 and continued to decline to the present. Overharvest by commercial fisheries, construction of barriers on tributaries historically used for spawning, and deterioration of spawning and juvenile habitat were the key contributors to the rapid decline of lake sturgeon (Ono et al. 1983). Water quality has improved and some habitat has been restored, but the lake sturgeon is still limited in distribution because of blocked access to spawning habitat, particularly in Michigan tributaries. Lake sturgeons currently inhabit a surprisingly large number of Ontario tributaries, but spawning populations have been identified in only three: Garden, Mississaugi, and Nottawasaga Rivers.

Lake sturgeons tagged in Lake Huron moved extensively within the lake and into other Great Lakes. During 1995-1999, a total of 1,466 lake sturgeons were tagged and released as part of a movement study, and 123 have been recaptured at least once. Fish tagged in Lake Huron have been recaptured in western Lake Erie, Lake St. Clair, St. Clair River, and western Lake Michigan. Lake sturgeons tagged in the North Channel have been recaptured in the northeastern waters of the main basin. Lake sturgeons tagged in Georgian Bay have not been recaptured elsewhere. Lake sturgeons tagged in

Lake Erie, Lake St. Clair, and the St. Clair River have been recaptured in southern Lake Huron.

Lake sturgeons are currently harvested by commercial fisheries in Ontario, primarily in the southern main basin and the North Channel and by recreational fisheries in both Ontario and Michigan. Commercial harvest has changed little over the past 15 years, averaging 4,900 kg annually since 1985. Most lake sturgeons are caught as bycatch in commercial gillnets and trapnets fished for walleye, yellow perch, and lake whitefish. They are also harvested by First Nations for subsistence purposes in some of the larger Ontario tributaries. The recreational harvest of lake sturgeon occurs primarily in streams throughout the Lake Huron basin, including the Mississaugi and Thessalon Rivers in the north and the St. Clair River in the south. In 1995, a coordinated effort was initiated between the U.S. Fish & Wildlife Service (USFWS), the OMNR, the MDNR, and commercial fishermen to compile biological information on lake sturgeon in Lake Huron. Between 1995 and 1999, this working group expanded to include partners from other state and federal agencies, academic institutions, and First Nations in Ontario. By the end of 1999, just over 2,370 lake sturgeon had been captured and sampled lakewide. Ages of captured lake sturgeon ranged from yearlings to 60 years, the modal age was 14 years, and weight ranged from 60 g to 39.1 kg. Mark-recapture data suggests that the abundance of lake sturgeon is more robust than previously thought and that recruitment is occurring in all three basins. Population estimates for southern Lake Huron are highest and suggest an exploitation rate of 2.0% in 1999. Estimates for the North Channel suggest a much smaller population with an exploitation rate of 1.6%. No estimates are available for Georgian Bay. The current harvest levels do not appear to be excessive.

Channel Catfish

The fish-community objective for channel catfish is to “maintain it as a prominent predator throughout its natural range while sustaining a harvestable surplus of 0.2 million kg” (DesJardine et al. 1995). Channel catfish inhabit the nearshore waters of Lake Huron and are most abundant in Saginaw Bay, North Channel, Georgian Bay, and St. Marys River. Sport and commercial fisheries for channel catfish occur in Michigan and Ontario waters. Commercial fisheries, mainly those in Saginaw Bay, account for about 88% of the total annual yield. The annual commercial harvest ranged from 54,000 to 368,000 kg during 1952-1977 (Baldwin et al. 1979) and averaged 85,104 kg during 1993-1999. The annual sport harvest is estimated to be about 12,000 kg. This current yield is well below the harvestable surplus specified in the fish-community objective, but harvest in the commercial fishery is driven largely by demand, not supply, and not all sport fisheries are surveyed.

In Saginaw Bay, the abundance of channel catfish has been relatively stable or increased slightly during 1989-1997 (Fielder et al. 2000). Most channel catfish captured in surveys were age 6 and younger, but individuals up to age 19 were caught. The total annual mortality averaged 42% during 1997-1999 (DGF, unpubl. data).

Recommendations

Walleye

1. Remove barriers to fish passage on tributaries historically used for spawning

2. Maintain adequate tributary flows during spawning and egg incubation

3. Reduce the abundance of alewife and rainbow smelt to decrease mortality on walleye fry

4. Improve fish-culture practices

5. Use only brood stocks of Lake Huron origin as sources of walleye for stocking

6. Identify the exploitation and distribution of depressed stocks in mixed-stock fisheries

7. Harmonize harvest regulations and management objectives for shared stocks

8. Determine the contribution of stocked walleye to populations in Lake Huron

Yellow perch

1. Develop better indices of yellow perch recruitment for major populations

2. Develop better estimates of harvest for major fisheries

3. Harmonize regulations and management of shared stocks

4. Protect shoreline wetlands and minimize their fragmentation to ensure adequate spawning and nursery habitat

5. Quantify double-crested cormorant predation

Esocids

1. Identify and protect critical nearshore spawning and nursery habitats

2. Determine exploitation rates for sport and subsistence fisheries

3. Investigate the level of genetic diversity in muskellunge populations

4. Reestablish populations of muskellunge in their original habitats in Saginaw Bay and the Spanish River

Centrarchids

1. Determine harvests and exploitation rates

2. Inventory and protect critical nearshore habitats

3. Assess the effects of predation by double-crested cormorants on smallmouth bass

Lake Sturgeon

1. Determine accurate estimates of harvest
2. Determine sustainable levels of exploitation
3. Provide upstream passage of adults and downstream passage of juveniles, especially in Michigan tributaries
4. Identify and quantify major spawning stocks in tributaries
5. Complete genetic analysis of spawning stocks before initiation of stocking
6. Develop an interagency lakewide management plan

Channel Catfish

1. Continue to monitor populations in Saginaw Bay
2. Measure age structure and total annual mortality rate of major populations to determine harvestable surplus

PREDATOR-PREY INTERACTIONS

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Balancing predator forage demand and availability of forage fish is now and has been a major concern for Lake Huron fishery managers. In 1991, the LHC capped stocking of all salmonines except lake trout to that needed to produce 4.8 million pounds of harvestable surplus. The LHC also asked the LHTC to determine appropriate stocking levels using a bioenergetics approach, given lake trout rehabilitation goals and their historical harvest of four million kg (8.9 million pounds).

Stocking has been widespread since the mid-1960s and is the major source of recruitment for several key predators, including Chinook salmon and lake trout. With hatchery fish contributing over 50% of the recruitment of these predators, natural limitations on recruitment may not prevent their exceeding the capacity of the forage base. Increased natural reproduction by predators would further intensify forage demand. Conversely, excessive abundance of exotic forage fish, such as alewife, appear to adversely impact recruitment of native predator species (Fisher et al. 1996); therefore an abundance of predators may be necessary to keep exotic prey species in check.

In this section, we provide estimates of the consumption of forage fish by the key predators in the main basin, compare these estimates to estimates of consumption by historical lake trout populations, and project the effects of various management actions on consumption. We also review preliminary estimates of consumption by the key predators in Georgian Bay and North Channel.

Using a suite of stock-assessment models, we tracked abundance-at-age over time for the key predators (burbot, Chinook salmon, lake trout, and walleye) in the main basin (Bence and Dobiesz 2000). Estimates of age-specific population abundance and mortality rates from these models, together with information on weight-at-age, were used to estimate gross production. Production estimates were divided by gross conversion efficiency estimates using the production-conversion-efficiency method (Ney 1990, 1993) to compute year- and age-specific consumption. Age-specific gross conversion efficiency was estimated using the Wisconsin bioenergetics model (version 3.0b) (Hewett and Johnson 1995) and Lake Huron-specific values for water temperature, diet composition, and caloric content of predators and prey (Bence and Dobiesz 2000). Consumption by pre-collapse lake trout in the main basin was estimated with these same methods using historical data for growth, diet, and natural mortality estimates from the upper Great Lakes. Abundance and mortality of key predators in Georgian Bay and the North Channel were not available. Therefore, we estimated prey consumption by Chinook salmon and lake trout in these areas by multiplying their recruitment by recent main basin estimates of consumption-per-recruit. In estimating recruitment in Georgian Bay and the North Channel, we did not include wild recruitment of lake trout and assumed that wild recruitment of Chinook salmon was 45% of the total recruitment for 1990-1993. We also included an estimate of consumption by double-crested cormorants (McLeish 1996).

Main Basin

According to our models, from 1984 to 1998, burbot and Chinook salmon biomass increased, walleye biomass was stable, and lake trout biomass decreased (Fig. 24), but consumption differed substantially among the predators (Fig. 25). Lake trout and Chinook salmon, on average, consumed 77% of the total available prey (e.g., alewife, rainbow smelt, sculpins, sticklebacks, trout-perch). The mean total consumption in the main basin was 34 million kg during 1984-1998.

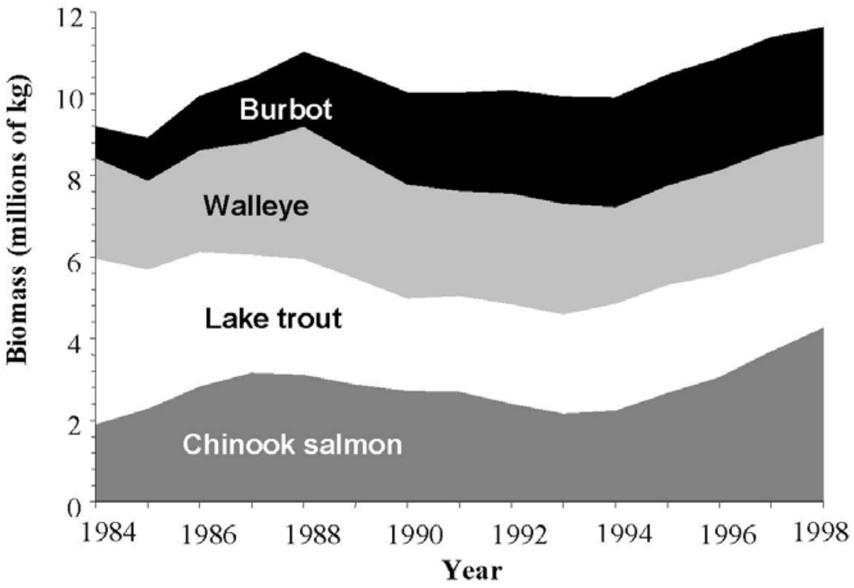

Fig. 24. Estimated biomass (millions of kilograms) of Chinook salmon, lake trout, walleye, and burbot in the main basin of Lake Huron, 1984-1998.

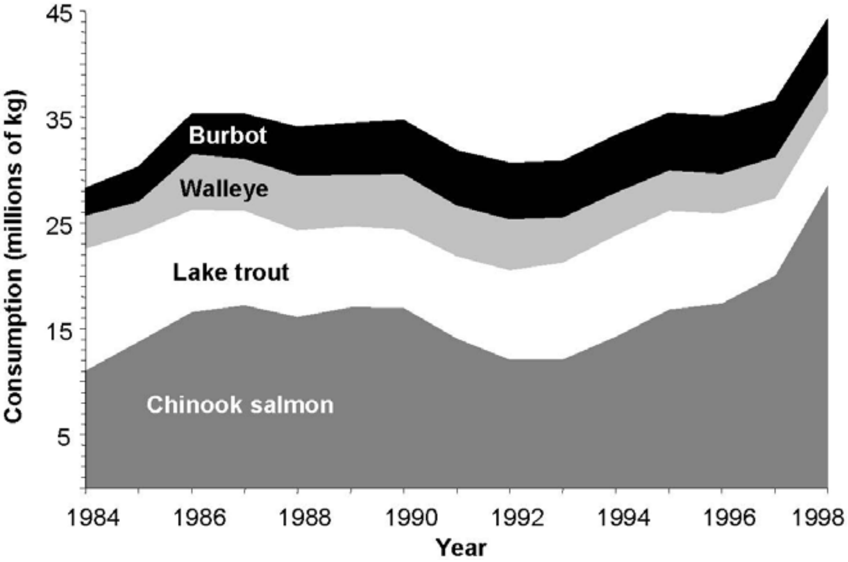

Fig. 25. Estimated consumption of forage fish (millions of kilograms) by Chinook salmon, lake trout, walleye, and burbot in the main basin of Lake Huron, 1984-1998.

Consumption by Chinook salmon in recent years has increasingly exceeded the combined consumption by all other predators (Fig. 25). Consumption increased from 1968 through the mid-1980s as Chinook salmon abundance increased in response to increased stocking. Consumption and biomass then leveled off and declined during the late 1980s and early 1990s, but increased again during the remainder of the 1990s. The increased consumption during the 1990s appears to be the result of increased stocking during the first half of the decade and improved stocking methods (e.g., net pens) thereafter.

The biomass of prey consumed by native lake trout during the last period of reasonably stable populations (1912–1940) was estimated at 24 million kg, which was lower than current total consumption (34 million kg) by all key predators. Two important caveats affect this comparison. First, we did not estimate consumption by burbot and walleye, which were historical as well as current predators. Second, diet composition historically was dominated by ciscoes that have higher energy content than alewife and rainbow smelt—species that currently dominate consumption.

We compared consumption of alewife and rainbow smelt by the key predators during 1984-1998 with estimates of combined alewife and rainbow smelt biomass obtained from the U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, Michigan, 48105 (unpubl. data). Consumption of alewife and rainbow smelt was substantially lower than the available prey biomass until the early 1990s, but, since then, consumption has approached the estimated level of prey abundance more closely and apparently exceeded it in 1998 (Fig. 26). Prey biomass, however, was likely underestimated. Prey biomass was a single point in time, standing-stock estimate, and these are often less than annual production estimates. In addition, trawl swept-area surveys tend to underestimate prey biomass, and biomass of other prey species was not included in these estimates.

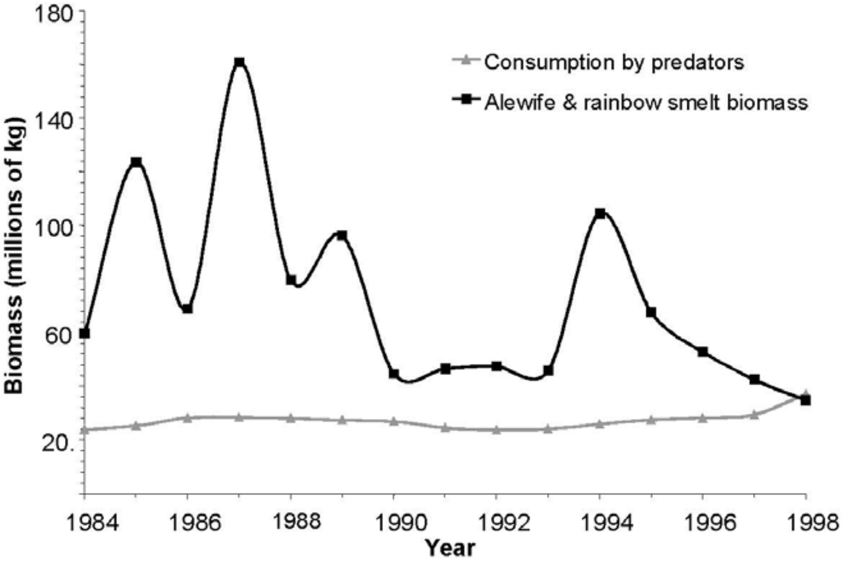

Fig. 26. Combined alewife and rainbow smelt biomass and consumption of alewife and rainbow smelt by Chinook salmon, lake trout, walleye, and burbot in the main basin of Lake Huron, 1984-1998.

During 1996-1998, the annual mean consumption by all key predators was 38.5 million kg, of which over 31 million kg (81%) was alewife and rainbow smelt (Table 3). In this simplified scenario, alewife and rainbow smelt were the primary prey of Chinook salmon, lake trout, and walleye (87%, 96%, and 60% of their diets, respectively). The burbot diet included substantial amounts of invertebrates and sculpins and lesser amounts of alewife and rainbow smelt.

Table 3. Estimated mean annual consumption (millions of kg) of prey fish by burbot, Chinook salmon, lake trout, and walleye in the main basin of Lake Huron during 1996-1998.

	Burbot	**Chinook**	**Lake Trout**	**Walleye**	**Total**
Prey fish					
Alewife	1.5	13.6	3.9	1.6	20.6
Rainbow smelt	1.1	5.7	3.4	0.5	10.7
Other	2.7	2.8	0.3	1.4	7.2
Total	5.3	22.1	7.6	3.5	38.5
Alewife + smelt	2.6	19.3	7.3	2.1	31.3

Projections for the Main Basin

Projecting consumption by key predators under various management scenarios can improve an understanding of how these scenarios can affect prey biomass. We project first, as a designated baseline scenario, an annual consumption of 47 million kg and roughly constant predator abundance through the year 2020 (Fig. 27). This scenario includes the changes to lake trout stocking and harvest regulations resulting from the 2000 Consent Decree for the 1836 treaty-ceded waters of Michigan (U.S. *v.* Michigan 2000) and the 20% reduction in Chinook salmon stocking that began in

1999. All other factors that affect abundance and consumption are held constant at 1998 levels during the projection period of 2002-2020.

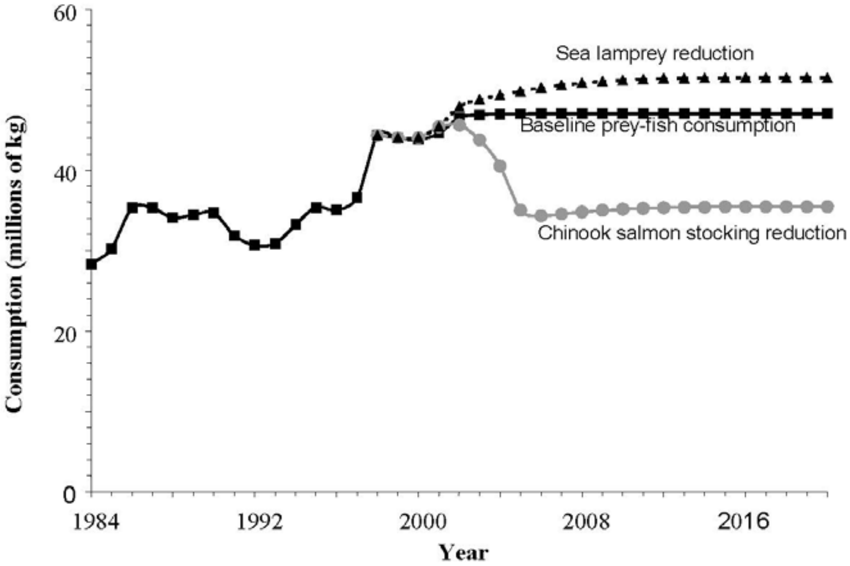

Fig. 27. Projected consumption of prey fish by Chinook salmon, lake trout, walleye, and burbot in the main basin of Lake Huron through 2020 under three management scenarios. In scenario one (baseline), prey-fish consumption is assumed to be 47 million kg annually, and predator abundance is assumed constant. Scenario two assumes an 85% reduction in sea lamprey abundance due to enhanced sea lamprey control in the St. Marys River. Scenario three includes both a 50% reduction in numbers of Chinook salmon stocked beginning in the year 2002 and an 85% reduction in sea lamprey abundance.

Our second scenario explores the effects of the projected 85% reduction in sea lamprey abundance resulting from the recently enhanced efforts to control sea lamprey in the St. Marys River (Schleen et al. 2003). Reducing sea lamprey abundance reduces lake trout, Chinook salmon, and burbot mortality, thereby increasing their abundance and consumption. However, the reduction in sea lamprey mortality was only applied to the lake trout and burbot consumption models in this scenario. Mean consumption in this scenario is 51.5 million kg, representing an increase of 9% over the baseline (first) scenario.

Our third scenario explores the consequences of decreased Chinook salmon abundance. This scenario includes the projected 85% reduction in sea lamprey abundance and adds a 50% reduction in numbers of Chinook salmon stocked beginning in the year 2002. Mean total consumption for the period 2010-2020 under this scenario is 35.5 million kg annually, which is 31% less than the second scenario, which focused on fewer sea lampreys, and 25% less than the baseline scenario.

Georgian Bay and North Channel

The key predators in Georgian Bay and the North Channel are Chinook salmon, lake trout, and double-crested cormorant. Consumption by double-crested cormorants substantially affects the forage base in Georgian Bay and the North Channel but has a much smaller impact in the main basin (McLeish 1996). The estimated prey consumption by these key predators in Georgian Bay and North Channel was 8.1, 5.7, and 3.5 million kg, respectively, during 1996-1999; whereas consumption by these predators in the main basin was 7.6, 22.1, and 0.7 million kg, respectively. Total consumption of 17.3 million kg by the key predators in Georgian Bay and the North Channel falls substantially below our main-basin estimate (30.4 million kg), reflecting the lower numbers of Chinook salmon stocked in these waters. This difference hinges on our assumption that the proportion of wild recruits of Chinook salmon is similar (45%) in all three basins.

Recommendations

1. Continue to monitor both predator and prey abundance

2. Determine seasonal diets of predators

3. Maintain predator-prey models

4. Estimate condition factors for predator and prey fishes

SPECIES DIVERSITY

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The fish-community objective for species diversity in Lake Huron calls for protection of other indigenous fishes, those not addressed previously, because they contribute to community richness; have ecological significance and intrinsic value; and provide social, cultural, and economic benefits (DesJardine et al. 1995). The most rare of these "other" fishes are a concern because they are infrequently monitored and their extirpation would represent a loss of biodiversity for the lake (Cudmore-Vokey and Crossman 2000).

Extirpated and Imperiled Species

Historical surveys identified 79 fish species in Lake Huron proper and about 50 additional species in tributaries (Bailey and Smith 1981). Of those 129 species, 20 are now considered extirpated or imperiled based on the Nature Conservancy's conservation ranking system applied to the number of populations, individual abundance, and range size (Jenkins 1988; Master 1991).

Extirpated species include Arctic grayling, paddlefish, weed shiner, eastern sand darter, deepwater cisco, blackfin cisco, longjaw cisco (thought to be synonymous with the shortjaw cisco), shortjaw cisco, shortnose cisco, and kiyi. Arctic grayling inhabited nearly all cold-water streams in Michigan's northern Lower Peninsula and two streams in the western Upper Peninsula (Hubbs and Lagler 1964). They were ubiquitous within Lake Huron tributaries before being extirpated around 1900. Factors believed responsible for this extirpation include logging, fishing, and competition from introduced trout (Hubbs and Lagler 1964). Attempts to reintroduce Arctic grayling in Michigan have failed (Nuhfer 1992). The eastern sand darter formerly occurred in southern Lake Huron but may be present now only in tributaries of the St. Clair River (Scott and Crossman 1973; Gilbert 1980; Michigan Department of Natural Resources 2001). The deepwater cisco, blackfin cisco, shortjaw cisco, and kiyi did not survive intensified commercial fishing during the 1950s (Eshenroder and Burnham-Curtis 1999). The shortnose cisco persisted until at least 1985, but recent surveys suggest that the species is now extinct (Webb and Todd 1995).

Paddlefish, mooneye, and sauger are extirpated in all or parts of Lake Huron. Paddlefish were never abundant in any of the Great Lakes. Some authors suggested that tributary barriers blocked access to spawning habitat and extirpated the only population in Lake Huron (Hubbs and Lagler 1964; Trautman 1981; Becker 1984). Mooneyes were formerly considered rare in Lake Huron, and their decline here and elsewhere in the Great Lakes was likely due to dams that blocked spawning migrations, and possibly increased turbidity (Scott and Crossman 1973; Trautman 1981). Saugers were a substantial component of the Saginaw Bay commercial fishery during 1926-1936, but landings declined precipitously after 1936, and the fishery collapsed by 1950 (Baldwin et al. 1979). Saugers are thought to require access to upper reaches of rivers to spawn (Fritz and Holbrook 1978), and spawning runs may have been blocked by dam construction within the Saginaw River watershed. Saugers continue to be caught in the southern main basin by the Ontario commercial fishery, and some saugers are still found in southern Georgian Bay (LCM, personal communication).

The weed shiner, pugnose shiner, spotted sucker, and lake chubsucker are associated with clear-water, heavily vegetated habitats. The weed shiner formerly inhabited the Saginaw River watershed but has since been extirpated from Michigan (Latta 1998). The pugnose shiner is known throughout the Great Lakes region, and it is thought to have declined throughout its range due to increased turbidity and wetland loss (Hubbs and Lagler 1964; Trautman 1981; Becker 1984). Spotted suckers are usually associated with slow-moving, clear streams (Gilbert 1980; Trautman 1981; Becker 1984) but are also present in Lake Huron proper (Scott and Crossman 1973). Spotted suckers are at their northern range limit in Michigan (Gilbert 1980) and may be uncommon for that reason (Scott and Crossman 1973). Lake chubsuckers are rare within the Lake Huron watershed having been collected on only a few occasions in Michigan and

Ontario (Michigan Department of Natural Resources 2001; Environment Canada 2001).

Six species have declined appreciably due to loss of clear-water stream habitat: the river redhorse, river darter, black redhorse, redside dace, eastern sand darter, and channel darter. The river redhorse and river darter are associated with pristine large-river habitats (Trautman 1981); the river redhorse has been collected rarely within Michigan's Au Sable River (Evers 1994), whereas the river darter occurred in the Saginaw River drainage but was extirpated from the system during the 1940s (Latta 1998). The black redhorse is associated with pristine high-gradient streams (Trautman 1981) and occurs in only a few isolated areas within the Lake Huron watershed (Michigan Department of Natural Resources 2001; Environment Canada 2001). Redside dace exist as isolated populations in cool headwater streams (Gilbert 1980); they have been found in a single Ontario tributary to Lake Huron, and their existence is tenuous (McKee and Parker 1982). The channel darter occurs in a number of Michigan tributaries to Lake Huron (Michigan Department of Natural Resources 2001). This species is poorly documented in Lake Huron proper but was abundant in shallow areas of Lake Erie before turbidity increased during the 1950s (Scott and Crossman 1973; Gilbert 1980; Trautman 1981).

Although native species have been lost, diversity in Lake Huron may increase. Northern madtoms were discovered in the St. Clair River in 1993, and ghost shiners were discovered there in 1998 (Michigan Department of Natural Resources 2001). Whether these discoveries represent recent colonization or simply discovery of previously unknown resident species is not known, but these species may eventually be discovered in Lake Huron since the St. Clair River drains Lake Huron. Cudmore-Vokey and Crossman (2000) suggested that the spotted sucker, lake chubsucker, and northern madtom represent recent additions to the fauna, having extended their range northward due to global warming.

Burbot

The burbot is the only other indigenous top predator besides lake trout found in the Lake Huron open-water fish community, but it also occupies tributaries and nearshore waters. Burbot are caught in bottom-set, graded-mesh survey gillnets in the main basin and in Georgian Bay. From 1970 to 1985, burbot abundance was uniformly low in Michigan's main basin, averaging 0.3 fish•305 m^{-1} of survey gillnet (Fig. 28). Burbot abundance gradually increased after 1985, peaked in the late 1980s and early 1990s, then declined to about 2 fish•305 m^{-1} in the late 1990s. In Ontario waters, burbot abundance in both the south-central main basin (OH-3 and OH-5) and in southern Georgian Bay was relatively stable during 1989-1999, averaging 0.9 fish•305 m^{-1} and 1.0 fish•305 m^{-1}, respectively (Fig. 28). Most burbot (79%) captured in the gillnet surveys in Michigan waters during 1996-1999 contained food items including rainbow smelt, slimy sculpin, alewife, crayfish (Decopoda), ninespine stickleback, deepwater sculpin, zebra mussels, threespine stickleback, trout-perch, johnny darter, round goby, yellow perch, spottail shiner, mayflies, terrestrial insects, and unidentified fish remains. The burbot diet by mass was 22% rainbow smelt, 21% alewife, 18% sticklebacks, 13% sculpins, 13% unidentified fish remains, 12% crayfish, and 1% miscellaneous. Burbot were aged by otolith examination, and ages ranged from 3 to 17 with a median age of 11 years. Burbot length and weight increased steadily with age until reaching an asymptote at age 12.

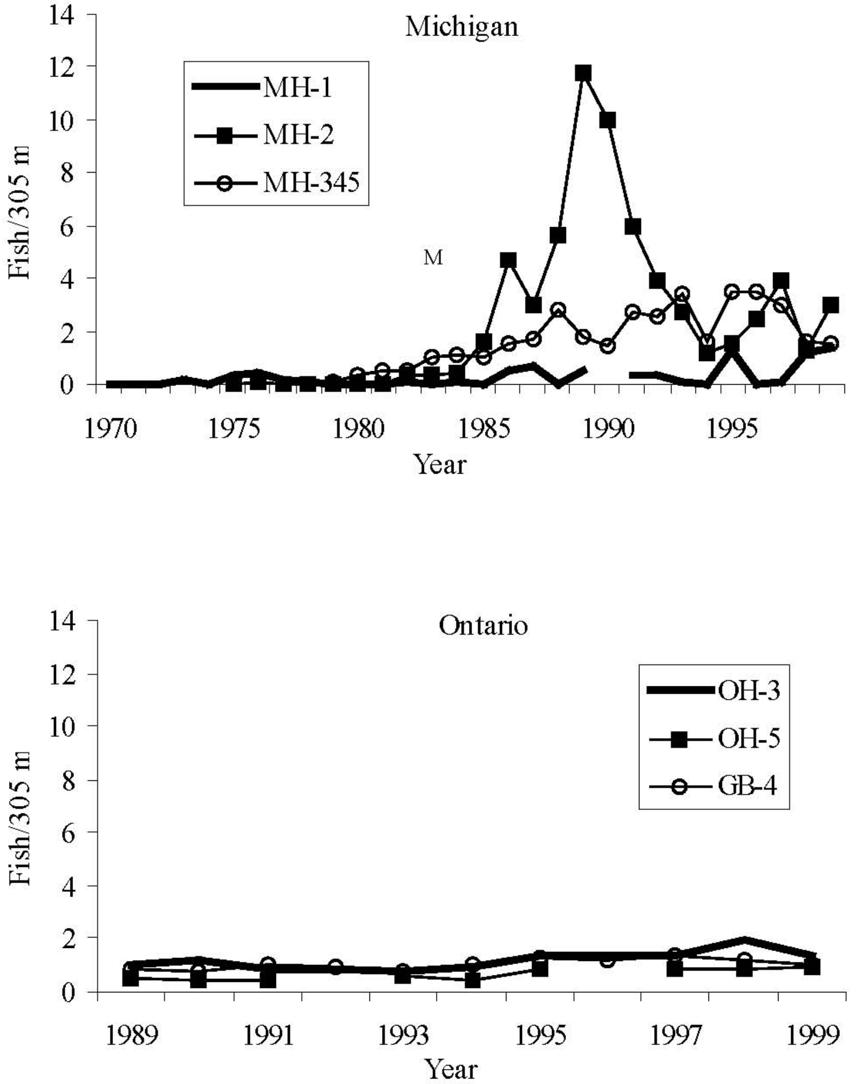

Fig. 28. Relative abundance of burbot (number per 305 m of net) in bottom-set, graded-mesh gillnets in Michigan and Ontario management areas of Lake Huron, 1970-1999.

Recommendations

1. Develop spatial databases that link information on the distribution of rare and endangered fish species and their habitats

2. Continue to monitor abundance, age structure, food habitats, and other life-history characteristics of burbot

GENETIC DIVERSITY

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The fish-community objectives for genetic diversity are to maintain and promote genetic diversity by conserving locally adapted strains and by ensuring that strains of fish being stocked are matched to the environments they are to inhabit. Fish-community objectives for Lake Huron (DesJardine et al. 1995) embrace the ecological concepts of stability, balance, and sustainability. Management plans recognize the need to preserve biodiversity because of the ecological significance of complexity (Tilman 1999) and because of social, cultural, and economic values.

Sustainability of Lake Huron's fishery resources relies on production from wild or naturalized populations and on stocked fish. The importance of maintaining the viability, integrity, and diversity of natural stocks and the successful implementation of enhancement programs underlies the need for greater awareness of genetic concepts and for an effective lakewide genetics policy. Guidelines based on population genetics theory should be compatible with agency goals of satisfying constituent needs and desires and with mandated stewardship responsibilities relating to ecosystem diversity and viability.

At first glance, all goals appear to be quite compatible and should be universally achieved through existing policies and management practices. In the above statement on objectives, however, the emphasis on "strains" (implying anthropogenic-generated recruitment) rather than "stocks" (i.e., recognizable or manageable local populations that are reproductively isolated and that over time become adapted to local conditions; Waples 1991) suggests a degree of disconnection between theory and practice.

Recent advances in molecular genetic technology and statistical methods of analysis offer a viable alternative for analysis of harvest composition. If the genetic attributes (i.e., allele frequencies) of different populations vary, then it is possible to estimate the proportional contribution of each breeding population when individuals occur within mixtures (Millar 1987; Pella and Milner 1987; Xu et al. 1994). Statistical approaches have also been developed to assign individuals to populations/strains of origin on the basis of genotype and the likelihood of observing the genotype in each population/strain (Waser and Strobeck 1998).

Walleye Genetic Diversity in Ontario

Recently, the OMNR supported a number of studies aimed at examining the genetic structure of walleye populations throughout the Ontario waters of Lake Huron. The eastern shore of Georgian Bay and the north shore of the North Channel comprise a vast littoral habitat that has historically supported numerous walleye populations. Most of these walleye populations have been closely associated with river systems that drain into the area. Efforts to rehabilitate many of the walleye populations in the area began in earnest during the mid-1980s with the advent of the Community Fisheries Involvement Program (CFIP). The OMNR identified the need to determine the genetic "health" of existing walleye populations and whether CFIP efforts to rehabilitate local walleye populations through stocking were having beneficial effects.

Gatt et al. (2002) recently completed a study that examined both the spatial and temporal distributions of mitochondrial DNA (mtDNA) haplotypes in walleye from eastern Georgian Bay and the North Channel of Lake Huron (Fig. 1). Variation in mtDNA was established from archival scale samples collected from spawning walleye during 1965-1998 and gill filaments and fingerling walleye collected during 1995-1998. The results of the study indicated that walleye stocks from eastern Georgian Bay, including the French River complex, currently exhibit relatively low levels of mtDNA differentiation. Stocks in eastern Georgian Bay typically had the least amount of mtDNA variation compared to walleye sampled from the French River complex and North Channel. Temporal losses of mtDNA variation were evident from Moon River and Shawanaga River stocks in eastern Georgian Bay, whereas mtDNA variation increased in the French River stock. The stocked (pond-reared) walleye consistently showed reduced mtDNA variation compared to their parental sources. Results of these studies indicate historical loss of genetic variation in walleye stocks from eastern Georgian Bay. Efforts aimed at rehabilitating these populations have been primarily focused on stocking, but current brood-stock selection and culture practices do not appear to be effective in maintaining the integrity and diversity of these populations.

In Ontario waters of the southern main basin, walleye have been subjected to commercial fishing for over a century. Walleye inhabiting this portion of the lake are thought to be using the area for seasonal feeding (Ferguson and Derkson 1971) and likely represent a mixture of stocks originating from Lakes Erie, St. Clair, and Huron. A genetic study by McParland et al. (1999) used allozymes and mtDNA to determine whether spawning populations of walleye from the three areas are genetically differentiated and to estimate their contributions to the commercial fishery in southern Lake Huron. Significant differentiation among walleye from the three areas was detected; walleye from western Lake Erie were the major contributors (60-70%), whereas Lake Huron and Lake St. Clair sources each contributed 10-20%.

Walleye Genetic Diversity in Michigan

Stock structuring of walleye in Michigan waters of Lake Huron is evidenced by significant differences in allozyme (Todd and Haas 1995) and mtDNA allele frequencies. Population models suggest that the average abundance of walleye in Saginaw Bay, which historically supported a large population of walleye, exceeds that which could reasonably be produced by known stocking and natural reproduction (J. Bence, Department of Fisheries and Wildlife, Michigan State University, 13 Natural Resources Building, East Lansing, Michigan, 48824, personal communication). The naturally produced population of walleye presently in Saginaw Bay is derived from different spawning locales, including tributaries to Saginaw Bay, Lake St. Clair, and Lake Erie (Fielder et al. 2000; Fielder 2002). Protein electrophoretic comparisons of Tittabawassee River and Muskegon River walleye, which constitute the two main sources of walleye stocked into Saginaw Bay, suggest that hatchery walleye have made substantial contributions to the Saginaw Bay population over the last ten years (T. Todd, U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, Michigan, 48105, personal communication).

Lake Trout

Historically, lake trout of the upper Great Lakes were ecological dominants and biologically diverse. The size of the Great Lakes basin, heterogeneous nature of the lakes, and contributions from multiple glacial refugia (Wilson and Hebert 1996) promoted geographical and eco-phenotypic variation among lake trout stocks. Strategies for the stocking of lake trout juveniles derived from six brood stocks have emphasized stocking fish from multiple brood stocks and the need to correlate ecological and behavioral traits of brood stocks to the receiving habitats (Krueger et al. 1983; Krueger and Ihssen 1995). Ecological and phenotypic characteristics of progenitor wild stocks used to develop hatchery brood stocks have, in part, been used to design stocking strategies.

The lack of success in restoring viable and self-sustaining populations of lake trout has stimulated efforts to reevaluate assessment and research needs. Current stocking strategies utilize indirect genetic considerations such as brood-stock source and environmental origin. Population genetic investigations (Page 2001) have provided:

- Much-needed data on the extent of genetic differentiation between hatchery brood stocks and remnant wild populations
- Predictions on the genetic implications for the simultaneous release of progeny from multiple brood stocks
- Recommendations for the preservation of the genetic variation that remains in wild and domestic brood stocks

Evidence for population bottlenecks and loss of genetic variation was also evident in their comparisons of genetic characteristics of contemporary and historical populations. Successful restoration efforts should be based on biologically sound criteria, founded on a better fundamental understanding of the relationship between genetic diversity of lake trout brood stocks (both historical and contemporary), and extant native populations.

Recommendations

1. Stocked fish should be from brood-stock sources matched ecologically to conditions at release sites

2. Use of brood-stock sources from outside the basin should be discouraged

3. Once genetically appropriate strains of lake trout have been identified for a locale, other strains should no longer be stocked

4. Programmatic issues related to maintenance of genetic variability in hatcheries and distributions of offspring and gametes for release (reviewed in Page 2001) should be a major consideration in fish stocking

5. Rehabilitative walleye stocking should employ stocking practices that take into account genetic stock structure of the stocked fish and of the receiving population, especially if the receiving population is a mixture of stocks subject to substantial fishing

SEA LAMPREY

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The fish-community objectives for sea lamprey in Lake Huron (DesJardine et al. 1995) are to reduce its abundance to allow the achievement of other fish-community objectives and obtain a 75% reduction in parasitic sea lampreys by the year 2000 and a 90% reduction by the year 2010. Morse et al. (2003) identified Lake Huron as having a population of parasitic-phase sea lampreys that exceeded the combined populations of all the other Great Lakes. The Lake Huron population increased from approximately 250,000 in the early 1980s to approximately 450,000 in 1994 (Bergstedt et al. 2003). The increase in parasitic-phase numbers was also evident in increased abundance of spawning-phase sea lampreys: 37,000 in 1977; 328,000 in 1985; 202,000 in 1986; and 153,000 to 431,000 annually thereafter, (mean = 220,000) (Mullett et al. 2003).

Sea lampreys, especially those from the St. Marys River, continue to have a devastating effect on the Lake Huron fish community, especially on lake trout. Sea lampreys are believed to be the primary source of lake trout mortality in Lake Huron (Sitar et al. 1999). Koonce and Pycha (1985) reported that the probability of age-7 to age-9 lake trout in Lake Superior surviving an attack was only 14%. In laboratory experiments, Swink (1990) found that single attacks on lake trout-induced mortalities ranging from 43% on large fish (660–825 mm) to 64% on smaller fish (469-557 mm). Although lake trout were the primary target for sea lamprey attacks, 16 species of fish bore sea lamprey-attack marks in St. Martin Bay during the springs of 1991-1995 (Morse et al. 2003).

The presence of substantial sea lamprey populations has delayed some lake trout restoration efforts in Lake Huron. In 1993, the LHTC recommended cessation of stocking of lake trout in northern Lake Huron until the GLFC submitted a plan and time frame for controlling the population of sea lamprey larvae in the St. Marys River. Stocking was discontinued from 1994-1997 and resumed in 1998 when an integrated plan for sea lamprey control in the St. Marys River was implemented.

Control

Control—Lampricide

Between 1960 and 1999, some 620 applications of the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) were conducted on 92 Lake Huron tributaries. These applications used 38% less TFM per year in the 1990s compared to the 1980s (Brege et al. 2003). The average number of tributaries treated annually decreased from $22 \cdot y^{-1}$ during 1970-1979 to $15 \cdot y^{1}$ during 1990-1999, a reduction of 32% in the number of tributaries treated and a 42% decrease in the length of tributaries treated. These reductions in lampricide used and effort were due to:

- Failure of sea lampreys to reestablish in some tributaries after initial treatments
- Reductions in treatment staff in the United States and Canada
- Fewer Lake Huron treatments to accommodate new efforts in Lake Ontario and Lake Erie
- Construction of barrier dams to reduce the stream area requiring treatment
- Changes in the criteria used to select tributaries for treatment
- Development of more-precise estimates of effective TFM application rates by accounting for differences in pH and total alkalinity
- Selecting streams for treatment based on larval and transformer abundance (Christie et al. 2003) rather than on time since last treatment and presence or absence of larvae

Control—Barriers

Denny’s Dam, constructed on the Saugeen River in 1970, was the first barrier built specifically to block sea lampreys in a Lake Huron tributary. By 1999, 17 structures had been either constructed specifically for control or were modified to more-effectively block sea lampreys. Such barriers block sea lampreys from more than 450 km of tributaries and have been effective in 92% of 246 barrier-years of operation. However, Porto et al. (1999) observed an average reduction of 2.5 fish species in streams with sea lamprey barriers compared to streams without barriers, and construction of barriers to stop movement of sea lampreys may be contrary to efforts to remove barriers to improve passage of other fish.

St. Marys River

Prior to its treatment in 1998, the St. Marys River (Fig. 1) was the largest untreated source of sea lampreys in Lake Huron (Morse et al. 2003). In 1997, the GLFC approved and implemented a management plan for the St. Marys River (Schleen et al. 2003). The plan calls for a reduction in larval sea lampreys through the application of granular Bayluscide and the introduction of sterilized males. In 1998 and 1999, spot treatments with granular Bayluscide removed 45% of the sea lamprey larvae from 840 ha in the upper portions of the river, and males captured from streams throughout the Great Lakes were sterilized and released into the river (Twohey et al. 2003).

The effect of the St. Marys River control effort is projected to reduce parasitic populations 85% by 2010, which, combined with control efforts in other tributaries, should achieve the sea lamprey objective of a 90% reduction lakewide by 2010. A reduction of 85% in sea lamprey abundance would boost the prospects for lake trout rehabilitation. Sitar (1999) estimated that, for MH-1, an 85% reduction in the number of parasitic-phase sea lampreys would increase the number of mature female lake trout 232% by 2010.

Recommendations

1. Continue to apply control in the St. Marys River

2. Estimate damage to the fish community caused by sea lampreys

RECENT INVASIVE SPECIES

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The Great Lakes ecosystem has been dramatically and forever changed by the invasion of aquatic nuisance species (ANS). Since the 1800s, at least 160 species of fauna and flora have been introduced into the Great Lakes ecosystem, and as many as 80 of these occur in Lake Huron (Mills et al. 1993). The introduction of ANS into Lake Huron has altered the fish community and the ecological processes that support the community. The threats posed by ANS to the fish community are recognized in Lake Huron's fish-community objectives (DesJardine et al. 1995). This section provides an update on the status, trends, and potential impacts of high-profile ANS.

Ruffe

The ruffe is a small Eurasian percid that was introduced into the Great Lakes during the 1980s apparently via ballast discharges from trans-Atlantic ships into the St. Louis River, a Lake Superior tributary near Duluth, Minnesota. In the Great Lakes, ruffe are believed to have a competitive advantage over native fish for food and habitat because they can spawn more than once a year allowing quick proliferation, and they are aggressive (Busiahn and McClain 1995).

In Lake Huron, three ruffe were captured by trawling in Michigan waters at the mouth of the Thunder Bay River (Fig. 1) in August 1995 (Kindt et al. 1996). This is the only instance where ruffe have been found outside of Lake

Superior as of 1999. The USFWS has been monitoring the population of ruffe in the Thunder Bay River with bottom trawls in the fall, and has documented recruitment of year classes since 1997. The abundance of ruffe was low prior to 1999 and showed no sign of the exponential increase documented in western Lake Superior. In 1999, however, the average number of ruffe caught per minute of bottom trawling (CPUE) increased 11.5 times over that in 1998 due to a strong 1999 year class, which made up more than 98% of the ruffe catch. In addition, the percentage of ruffe in the total catch of all species increased from 3% in 1998 to nearly 19% in 1999. However, overwinter survival of this population has been scant, and relative abundance is dependant upon YOY, which may explain their failure thus far to expand their range in Lake Huron.

Round Goby

The round goby has origins in the Black and Caspian Seas, and it is believed to have been introduced into the Great Lakes from ballast water discharged by trans-Atlantic ships. Round gobies were first identified in the St. Clair River in 1990 (Fig. 1; Jude et al. 1992). They are a small-bodied fish that feed on mollusks, crustaceans, small fish, and fish eggs (Jude 1996). Round gobies have a well-developed lateral-line system that enables them to feed effectively in complete darkness.

Since their discovery in Lake Huron in 1994, round gobies have become abundant throughout the lake. They are now captured routinely at all USFWS surveillance locations in Lake Huron. The CPUE of round goby in fall trawling surveys in Thunder Bay increased from 1.0 fish•min^{-1} in 1998 to 5.8 fish•min^{-1} in 1999, and they have become the most abundant species in the trawl catch. Round gobies have been captured in forage-assessment trawls in offshore waters up to 73 m deep (U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI, 48105, unpubl. data).

Recreational anglers use round gobies for bait and may be spreading them via escapement or dumping of unused bait into the other Great Lakes and inland waters. Round gobies are believed to have been introduced via this manner into the headwaters of the Shiawassee River, a Saginaw River tributary (Jude 1997).

Zebra Mussel

The zebra mussel was discovered in Lake St. Clair in the spring of 1988 and may have entered via the ballast water of trans-Atlantic freighters that had previously visited a port in eastern Europe where this mollusk is common. Zebra mussels have since spread to all five Great Lakes and are found in other areas of eastern North America (Mills et al. 1993). Zebra mussels readily attach to most submerged surfaces, including boats, rocky shoals, water intake pipes, navigational buoys, docks, piers, and indigenous mussels and clams. Zebra mussels reproduce rapidly and affix themselves to shells of their own species, and thus are able to form dense layered colonies of over one million per square meter.

Zebra mussels are a serious threat to the Lake Huron ecosystem because they compete with native species. They have tremendous filtering capacity for particles in the water column, especially phytoplankton (Fanslow et al. 1995). In some areas of the Great Lakes, zebra mussels have caused a decrease in turbidity, which has led to increased abundance of higher aquatic plants at the expense of phytoplankton and planktivorous-fish communities (Skubinna 1995). Populations of phytoplankton in Lake Erie and Saginaw Bay declined and light penetration increased after zebra mussels became established. Higher aquatic plants such as *Vallisneria americana* and *Chara* spp. were more abundant and occupied deeper waters after the introduction of zebra mussels. Zebra mussels have devastated native mussel and clam populations, some of which were already threatened and endangered. Zebra mussels contribute to the cycling of contaminants by removing PCBs from the sediments and reintroducing them into the food web (Jude 1996).

Spiny Water Flea

The spiny water flea was first discovered in Lake Huron in 1984 and has now colonized all offshore waters. It is believed to have entered the Great Lakes through discharged ballast water from ocean-going ships (Mills et al. 1993). Although its average length is rarely more than 1.5 cm, this predacious crustacean can have a profound effect on a lake's plankton community by feeding on smaller zooplankton and by competing directly with native crustaceans and young fish for food (Hart et al. 2000). Despite their protective spine, spiny water fleas are still consumed by many fish species.

Other Aquatic Nuisance Species

The rusty crayfish (*Orconectes rusticus*), which is spread by anglers who used them as bait, and the white perch, a native of Atlantic coastal regions, compete with native species. *Cercopagis pengoi*, the fishhook water flea, is a crustacean native to the Caspian, Azov, and Aral Seas and is one of the most recent invasive species in Lake Huron. It was originally discovered in Lake Ontario in August 1998 and likely entered through a ballast-water discharge. *Cercopagis* are a problem because they foul lines used by recreational and commercial fishers and are a consumer of zooplankton.

Eurasian watermilfoil (*Myriophyllum spicatum*) reached the midwestern United States sometime between the 1950s and 1980s, and it is now one of the most common aquatic plants in Saginaw Bay. In nutrient-rich lakes, Eurasian watermilfoil can form thick underwater stands of tangled stems and vast mats of vegetation at the water's surface that can crowd out native plants, and these dense stands can sometimes interfere with recreation activities such as boating, fishing, and swimming.

Purple loosestrife *(Lythrum salicaria*) is a perennial wetland plant native to Europe and Asia that was introduced into the eastern United States in the early 1800s. Purple loosestrife was introduced and spread by plant nurseries and by the use of solid ship ballast as soil to fill in low areas along shorelines (Stackpoole 2000). Purple loosestrife is impacting Lake Huron wetland ecosystems by changing their structure, function, and productivity. The plant forms dense monocultures that can be hundreds of acres in size. Purple loosestrife can displace native vegetation and threaten the biotic integrity of wetland ecosystems (Stuckey 1989). This displacement of native plants has eliminated natural foods and cover essential to many wetland wildlife species. A beetle that consumes purple loosestrife has been introduced into areas with dense stands as a biological control agent.

Recommendations

1. Develop and implement, with public and private stakeholders, a strategy to address the problem of ANS introductions via ballast water

2. Identify pathways for ANS introductions and interrupt them

A CRITIQUE OF FISH-COMMUNITY OBJECTIVES

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Two state-of-the-lake reports for Lake Huron, including this one, have been published since the FCOs were published in April of 1995. We believe that a constructive critique of these objectives, along with associated management initiatives and assessment and research needs, is needed to keep these important efforts focused. The authors of the objectives recognized that "significant challenges and impediments exist and may prevent achievement of the fish-community objectives." Our goal here is to identify these challenges and impediments so that they can be better dealt with in the future. We follow the order of subjects in this report.

Habitat

Achievement of no net loss of habitat is a well-accepted resource policy, but nearly non-existent reporting of losses, especially loss caused by illegal modifications and changes in land use, make the policy unrealistic. Restoration of previously degraded habitats is, in reality, probably not attainable because of political and socioeconomic limitations. Revisions to fish-community objectives should reflect the reality of habitat issues, and managers should opt for goals that can be attained and will allow restoration of indigenous species.

The emphasis in this report is on the need to improve fish passage in tributaries, an especially acute problem in Lake Huron's main basin, and to quantify and protect shoreline wetlands. We recommend that the LHC make specific FCO targets for fish passage, identifying amounts and types of stream reaches to be made accessible using the Lake Huron GIS database. Rehabilitation of tributary habitat is essential to achievement of the habitat FCOs and of the FCOs for species like lake sturgeon that depend upon tributaries during some phase of their life. In particular, sufficient flow should be maintained in tributaries to provide spawning and nursery habitat. The GIS database can also be used to discern and quantify wetland habitat and should be used in prioritizing specific areas for protection and to monitor loss or gain of wetlands.

Achievement of FCOs for species such as walleye, yellow perch, channel catfish, and lake herring cannot be achieved without rehabilitation of aquatic habitat in Saginaw Bay. Historical yields of these species were primarily from Saginaw Bay, and its degraded habitat is currently limiting their recovery. For example, large burrowing mayflies such as *Hexagenia* spp., an important food source, are still not abundant in the bay. Reefs in the innermost portion of the bay, historically used for spawning by walleyes, have been degraded by silt to the point that walleye reproduction is no longer successful (Schneider and Leach 1979; Fielder 2002).

Lastly, there is a need to evaluate how much of a reduction in direct discharge and long-range atmospheric loading of contaminants will be necessary to remove Lake Huron fish species from consumption advisories and to meet the whole-fish contaminant objectives of the GLWQA. It is possible that, despite our best efforts to achieve load reduction targets, these targets may not be sufficient to remove fish from consumption advisories.

Prey Fishes and Predatory-Prey Interactions

We are concerned that the FCOs for top predators, which are based on historical yields, cannot be achieved due to changes in the prey and predator community. The non-indigenous alewife and rainbow smelt are less likely to be fully utilizing the primary and secondary production of the lake than the historical, highly diverse, mainly coregonine, indigenous prey-fish community. If this is the case, it may explain why consumption by lower-than-historical predator populations could be approaching or exceeding the available production of prey fish. Restored walleye and lake trout populations would put further demands on prey fish and likely limit the capacity of Lake Huron to sustain substantial populations of introduced salmonines. Although the salmonine FCO is consistent with a concept of moving toward the historical fish community, the societal importance of non-indigenous salmonines and prey-fish species will continue to limit complete lake trout rehabilitation. Without recovery and/or reestablishment of some of the native ciscoes, the objective of maintaining a diversity of prey species at population levels matched to predator demands may not be met.

Open-Water Predators

Progress toward achievement of FCOs tied to potential yield levels is difficult to measure, and the FCOs will be difficult to achieve because they are based on commercial yields, whereas contemporary yields of most top predators are from sport fisheries. We believe that the LHC should ultimately move toward more functionally defined objectives. Objectives based on yield are operationally attractive because historical information on yield is available, and current levels of yield can be determined from available data without complex assumptions. Unresolved issues, however, remain. First, the once common assumption that the apparently stable yield of lake trout during the historical period was sustainable now appears to be questionable (Coble et al. 1990; Eshenroder et al. 1992; Eshenroder et al. 1995). Second, while ascertaining the current yield is straightforward, establishing that it is sustainable poses many challenges (Jones et al. 1993). The intent of the overall FCO was to seek a fish community approximating the historical one. Self-sustaining populations of top predators dominated this structure. We believe that a focus on this underlying functional objective, i.e., self-sustainability, rather than a specific amount of yield, will better indicate the status of the lake's top predators.

Coregonines

The need to diversify the lake's coregonine community cannot be overemphasized. We urge the LHC to commit to developing lakewide rehabilitation plans for lake herring and deepwater ciscoes. The fact that lake herring populations are rebounding in northern waters suggest that strategies should be developed to foster a continuation of this promising trend. Development of a FCO recognizing the importance of lake herring as a prey fish would be a start.

We have essentially failed to protect deepwater ciscoes. Management of deepwater ciscoes has been ineffective, allowing extirpation of all except the bloater. Harvest of deepwater ciscoes should be conservative and allowable catches should take into account the cyclic recruitment that these species exhibit in the lake.

Species Diversity/Genetic Diversity

The next step, now that Lake Huron's imperiled fish species have been identified, should be to identify locations of rare fishes in an accessible GIS so that they can be better protected. The LHC should also promote efforts to reintroduce, where feasible, extirpated species. Two of five species of deepwater ciscoes extirpated from Lake Huron (shortjaw and kiyi) are extant in Lake Superior and could serve as a brood stock for a reintroduction effort. We recommend that the LHC participate in current efforts within the GLFC to develop strategies for reintroduction of these deepwater ciscoes. The issue of within-species genetic diversity can be addressed with the use of within-lake genotypes for walleye and Pacific salmon. More experimentation with lake trout genotypes, especially with deepwater forms, is also recommended in view of the continuing failure to achieve a sustainable level of reproduction in the main basin.

Sea Lampreys and Other Invasive Species

We urge the LHC to seek immediately a finding as to whether the control operations initiated on the St. Marys River in 1998 will result in the 90% reduction in sea lamprey numbers projected for the main basin. If this target is not met, the LHC should seek an intensification of control efforts in the St. Marys River to minimize damage to the fish community.

Alewife may be suppressing recruitment of lake trout, coregonines, and yellow perch through egg and fry predation and competition. Consumption of alewives results in nutritional and reproductive problems in salmonine predators. Continued reliance of alewife as the primary prey of salmonines is undesirable and may require some direct effort to suppress alewife populations. Recent invaders, particularly zebra and quagga mussels, round gobies, spiny water flea, white perch, and ruffe, have introduced substantial uncertainty regarding achievement of FCOs. For example, populations of *Diporeia* spp., an important invertebrate food for lake trout and lake whitefish, have declined sharply in association with proliferating invasive mussels. The spate of recent introductions could cause upheavals in community structure. The LHC should be prepared to make timely changes in management policy to minimize such impacts.

Research Priorities

Achievement of fish-community objectives and rehabilitation of many indigenous species will require aggressive management founded on well-organized and focused research. We have provided some suggestions for management such as rehabilitation of depleted species and reintroduction of extirpated species. Beyond those ideas, each section of this state-of-the-lake report makes recommendations for management or research. We have consolidated these many recommendations into the following specific research questions that should be given high priority for funding:

- What specific habitats should be given priority for rehabilitation?
- Which historical lake trout spawning reefs are not being used, and what should be done to achieve their colonization?
- What is the production and sustainability of the prey-fish community?
- What is the amount of natural recruitment for lake trout, stream-spawning salmonines, and walleyes, and where does the recruitment originate?
- How have non-indigenous species affected the sustainability of coregonine, walleye, salmonine, and percid populations?

Lastly, creation and maintenance of databases will be essential for evaluating and measuring achievement of FCOs. Information on fish stocking, harvest, habitat, coded-wire-tag recoveries, predator diets, and prey abundance are all currently used to model fish populations and describe their status. As time passes and agencies change staff, these databases may become too large, fragmented, and sometimes useless. The LHC should begin the process of making sure these large databases are housed at one location and maintained for future sharing.

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