THE STATE OF LAKE MICHIGAN IN 2005

Great Lakes Fishery Commission

SPECIAL PUBLICATION 08-02

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October 2008

THE STATE OF LAKE MICHIGAN IN 2005

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Citation (entire volume): Clapp, D.F., and W. Horns [EDS.]. 2008. The state of Lake Michigan in 2005. Great Lakes Fish. Comm. Spec. Pub. 08-02.

Citation (individual chapter): Wright, G., Honeyfield, D.C., and Faisal, M. 2008. Fish health. *In* The state of Lake Michigan in 2005. *Edited by* D.F. Clapp and W. Horns. Great Lakes Fish. Comm. Spec. Pub. 08-02. pp. 59-64.

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

October 2008

ISSN 1090-1051

Printed on recycled paper.
SP08-02/10-2008/900

Lake Michigan depicting locations not otherwise identified in this publication. The lake basin is in grey, and treaty-ceded waters are depicted by diagonal lines.

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ABSTRACT

This second state-of-the-lake report for Lake Michigan identifies progress made during 2000-2004 in meeting the fish-community objectives established for the lake in 1995. An oral public report, providing more-extensive data than given here, was made in 2005. During 2000-2004, a geographical information system for the lake and its basin was expanded considerably and is expected to provide a means for establishing priorities for habitat remediation. This system was used in the development of a report, under review, identifying environmental objectives for the lake. Recently introduced invertebrates, particularly dreissenid mussels (*Dreissena* spp.), continued to impact the lake's food web. Their proliferation coincided closely with severe reductions in populations of the amphipod *Diporeia* spp. Round goby (*Neogobius melanostomus*), first reported in the lake in 1995, continued to expand its range and apparently nearly eliminated two inshore species, the johnny darter (*Etheostoma nigrum*) and mottled sculpin (*Cottus bairdi*), but the impact of the goby on other fishes was unresolved. Northern snakehead (*Channa argus*), an aquarium fish, was found in a Chicago harbor, although this specimen did not appear to have been part of an established population. The yield of lake whitefish (*Coregonus clupeaformis*), the most-important commercial fish in the lake, reached a modern low in 2004, falling just below the lower bound (1.8 million kg) of the fish-community objective. Although the abrupt decline in its favorite food, *Diporeia*, had caused a drop in condition of lake whitefish, the recent lower yield of lake whitefish was attributed to reduced fishing effort, not reduced fish abundance. At the time of the first state-of-the-lake report, which covered events through 1999, yield of yellow perch (*Perca flavescens*) was low because of an early life-stage bottleneck and imposition of more-restrictive fishing policies aimed at preserving spawning stocks. Spawning-stock biomass improved during this reporting period due to recruitment of a strong 1998 year-class and better survival of adults. Another strong year-class, produced in 2003, is expected to aid in the recovery of this species. Nonetheless, reductions in the biomass of zooplankton, caused by the filtering activities of dreissenids, make attainment of the objective for yellow perch unlikely. Because the lake sturgeon (*Acipenser fulvescens*) population remained listed as threatened, increased efforts were directed at describing its ecological status and genetic characteristics, improving rearing and stocking methods, and reassessing the need for new regulations. Spawning populations have been confirmed in eight rivers, and reintroductions have been initiated in four rivers. An alarmingly high number of adult sturgeon were found washed up on

beaches. Although the causes of these mortalities have not been confirmed, type E botulism is suspected. The biomass of planktivores (pelagic prey fishes) during this reporting period remained below the target range, similar to what their biomass was at the end of 1999. The energy density of alewife (*Alosa pseudoharengus*), a key planktivore, was 23% less during 2002-2004 than in 1979-1981, making them less nutritious as prey for top predators. This decline in energy density is likely related to the deterioration of *Diporeia* populations. The weight-at-age of Chinook salmon (*Oncorhynchus tshawytscha*), the main consumer of planktivores, reached a recent low in 2003, and poor growth continued on into 2004. During this reporting period, *Renibacterium salmoninarum*, the cause of bacterial kidney disease, continued to be detected in Chinook salmon, and nearly half of the lake trout (*Salvelinus namaycush*) eggs tested expressed early mortality syndrome, which remains a serious threat. The number of naturally reproduced Chinook salmon smolts increased from about 2.5 million in the years just before 2000 to an average of more than 4.0 million during this reporting period. The yield of Chinook salmon was below the objective of 3.1 million kg during 2001-2003 but rose to 3.9 million kg in 2004. The harvest was not considered sustainable, even though stocking was cut in 1999, because growth, ration, and prey abundance were declining. Little progress was made in rehabilitating lake trout during this reporting period—abundance of adults declined as a result of an increased population of sea lampreys (*Petromyzon marinus*). Natural reproduction of lake trout remained inconsequential and is not expected to change until the sea lamprey population is reduced and stocking is increased to recommended levels. Our major recommendations to the Lake Michigan Committee are: (1) develop a process for addressing recommendations in this and previous state-of-the-lake reports, (2) embrace an ecosystem approach to fishery management, (3) oversee completion of the draft environmental objectives for the lake, and (4) revise the lake's fish-community objectives to account for the changes in the lake that occurred after 1995.

INTRODUCTION

This is the second state-of-the-lake report for the fish community of Lake Michigan. It describes progress made during 2000-2004 toward achieving fish-community objectives (FCOs) for the lake—a more-extensive oral report was given in 2005. Goals and objectives for the fish community (Eshenroder et al. 1995) were established pursuant to the provisions of A Joint Strategic Plan for Management of Great Lakes Fisheries (hereafter, Joint Plan) (Great Lakes Fishery Commission 1997), and relevant objectives are provided at the beginning of each chapter in this report. The Joint Plan charged the Lake Michigan Committee (LMC) to define objectives for the fish community and to develop means for measuring progress toward their accomplishment. The LMC is composed of one representative from each of the states of Michigan, Wisconsin, Illinois, and Indiana and from the Chippewa/Ottawa Resource Authority. Reporting on progress serves to focus attention on critical fisheries issues and enhances communication and understanding among fishery agencies, environmental agencies, political bodies, and the public.

The first state-of-the-lake report (Holey and Trudeau 2005) was organized around the lake's FCOs, with chapters highlighting five subcomponent fish communities, nutrient dynamics, plankton communities, fish health, and critical habitat. This report is ordered around nearshore and riverine habitats and their fish communities and around the salmonine community and its forage base. This ordering streamlines reporting on FCOs and serves to organize the changes and progress occurring over the five-year reporting period.

The abbreviated format of this document precludes inclusion of historical reviews, detailed overviews of agency assessments, or in-depth analyses, and some species that are not a major focus within the LMC (e.g., Atlantic salmon, round whitefish) are not discussed (an alphabetical list of common fish names and their corresponding scientific names is given in Table 1). Readers seeking more information can review the 2000 report (Holey and Trudeau 2005) and/or the cited literature in that report and the citations provided here.

In compiling this report, we have not sought to achieve a consensus but have encouraged individual authors to express frankly their own views on management issues. Such views should be taken as those of the authors, not of the LMC.

Table 1. A list of common and scientific fish names used in this publication.

Common name	Scientific name
alewife	*Alosa pseudoharengus*
Atlantic salmon	*Salmo salar*
bighead carp	*Hypophthalmicthys nobilis*
Black Sea silverside	*Aphanius boyeri*
bloater	*Coregonus hoyi*
brown trout	*Salmo trutta*
burbot	*Lota lota*
Chinook salmon	*Oncorhynchus tshawytscha*
ciscoes	*Coregonus* spp.
coho salmon	*Oncorhynchus kisutch*
common carp	*Cyprinus carpio*
deepwater cisco	*Coregonus johannae*
deepwater sculpin	*Myoxocephalus thompsoni*
Eurasian minnow	*Phoxinus phoxinus*
European perch	*Perca fluviatilis*
johnny darter	*Etheostoma nigrum*
lake sturgeon	*Acipenser fulvescens*
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
monkey goby	*Neogobius fluviatilis*
mottled sculpin	*Cottus bairdi*
muskellunge	*Esox masquinongy*
northern pike	*Esox lucius*
northern snakehead	*Channa argus*
Pacific salmon	*Oncorhynchus* spp.
rainbow smelt	*Osmerus mordax*
rainbow trout (steelhead)	*Oncorhynchus mykiss*
round whitefish	*Prosopium cylindraceum*
round goby	*Neogobius melanostomus*

Table 1 (continued).

Common name	Scientific name
ruffe	*Gymnocephalus cernuus*
sea lamprey	*Petromyzon marinus*
silver carp	*Hypophthalmicthys molitrix*
slimy sculpin	*Cottus cognatus*
smallmouth bass	*Micropterus dolomieu*
trout perch	*Percopsis omiscomayus*
tyulka	*Clupeonella cultriventris*
walleye	*Sander vitreus*
white sucker	*Catostomus commersoni*
yellow perch	*Perca flavescens*

LAKE MICHIGAN'S TRIBUTARY AND NEARSHORE FISH HABITATS

Edward S. Rutherford[1]

Background

The importance of preserving and restoring habitat for fish was implicitly recognized in the guiding principles and goals of the Great Lakes Water Quality Agreement (GLWQA) (International Joint Commission 1988), in A Joint Strategic Plan for Management of Great Lakes Fisheries (hereafter, Joint Plan) (Great Lakes Fishery Commission 1997), and most recently in the Great Lakes Regional Strategy (Great Lakes Regional Collaboration 2005). The GLWQA of 1978 called for an ecosystem approach to restore and maintain the chemical, physical, and biological integrity of waters within the Great Lakes basin (Bertram et al. 2005) and recognized the interdependence of living organisms with their physical and chemical habitats (Trudeau 2005). Lake management plans (LaMPs) were established to address critical pollutants and other stresses to each lake and included development of remedial action plans for Areas of Concern (AOCs) that have serious pollution problems impairing beneficial use by humans, fish, or wildlife (U.S. EPA 2004a). In 2000, the Lake Michigan LaMP was developed to comply with provisions in the GLWQA and to guide management practices to maximize achievement of ecosystem goals and restore beneficial use impairments cited in the GLWQA. Many of the subgoals of the management plan (and the environmental indicators used to evaluate those subgoals) address restoration and protection of fish health, biotic integrity, and habitat productivity. Progress towards meeting the goals is reported on a biennial basis (e.g., U.S. EPA 2004b). The Great Lakes Regional Strategy (Great Lakes Regional Collaboration 2005) is a recent wide-ranging, cooperative effort to design and implement a strategy for the

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restoration, protection, and sustainable use of the Great Lakes, with specific suggestions for addressing impairments to fish communities in tributary, coastal wetland, and nearshore habitats.

The Joint Plan called for the development of FCOs for each of the Great Lakes, the identification of environmental issues that may impede achievement of FCOs, and the development of clearly articulated and quantifiable environmental objectives (EOs) to address fish habitat issues. For Lake Michigan, it was recognized that the health and integrity of physical and chemical habitats were critical for protecting or restoring healthy fish populations and sustainable fisheries and for maintaining the biological integrity of the fish community (Eshenroder et al. 1995). The habitat FCOs for Lake Michigan are:

- Protect and enhance fish habitat and rehabilitate degraded habitats
- Achieve no net loss of the productive capacity of habitat supporting Lake Michigan's fish communities; high priority should be given to the restoration and enhancement of historic riverine spawning and nursery areas for anadromous species
- Pursue the reduction and elimination of toxic chemicals, where possible, to enhance fish survival rates and allow for the promotion of human consumption of safe-to-eat fish

Status

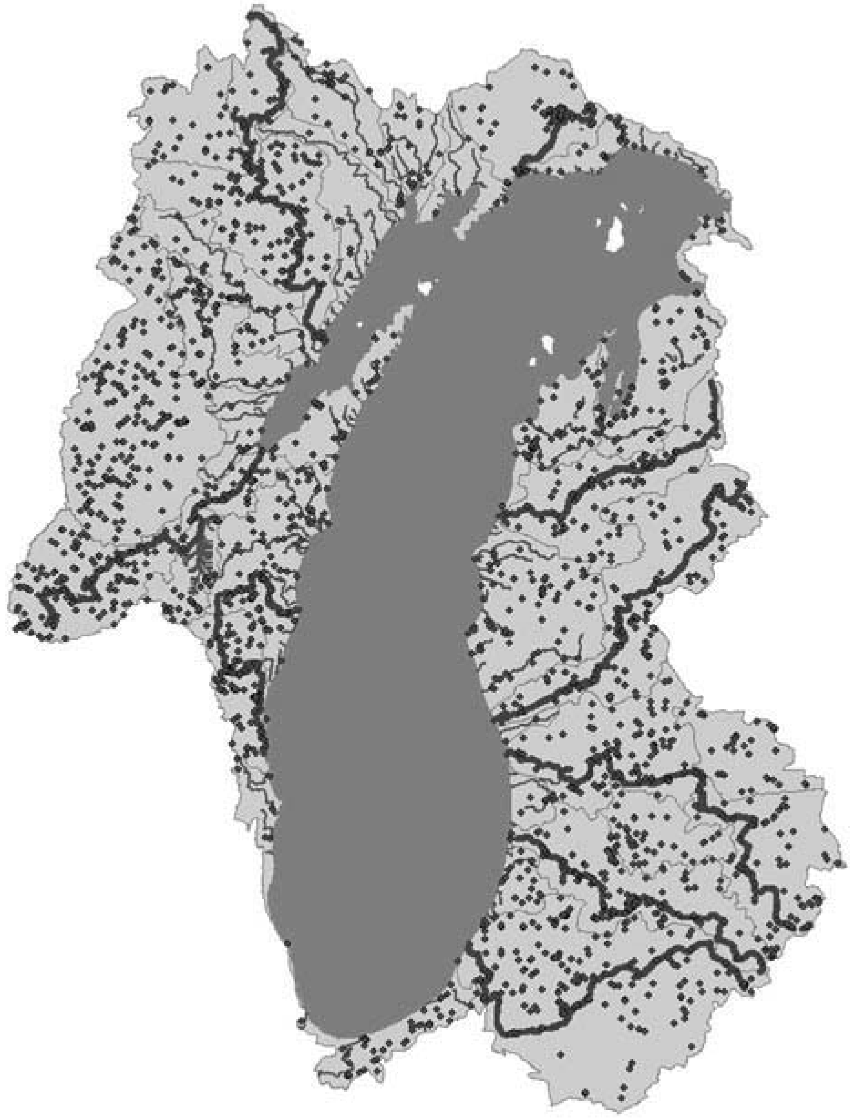
A continuum of habitats stretching from tributaries to the nearshore zone serves as important spawning and nursery habitat for one or more life stages of most Lake Michigan fishes (Wei et al. 2004). High-gradient tributary habitats are used for spawning and nursery areas by salmonines, as well as by native walleye, lake sturgeon (hereafter, sturgeon) and suckers (Catostomidae). Coastal wetland habitats support spawning and early life stages of basses (Centrarchidae), sunfishes (Centrarchidae), northern pike, muskellunge, walleye, and yellow perch, while the nearshore zone provides spawning and nursery habitat for yellow perch, smallmouth bass, and important forage fishes (cyprinids, alewife, bloater, and rainbow smelt) that fuel the growth of piscivorous fishes. Thus, natural and anthropogenic threats that degrade or permanently alter any of these habitats will severely affect fish production.

Tributaries

Most tributaries in the Lake Michigan basin have been significantly impaired through instream activities, such as damming, impoundment, channelization, sedimentation, dredging, eutrophication, and toxic contamination (U.S. EPA 2004b). These impairments have altered tributary hydrology, flow stability, and thermal regimes, thereby compromising their suitability as spawning and nursery habitats. Other physical alterations that have degraded riverine habitats result from various watershed land-use activities and changes, including timber harvest, agriculture, urban development, mining, and removal of large woody debris. Agricultural and urban land uses impose great demands for groundwater withdrawals that can reduce summer base flows and increase river temperatures and flow variability (e.g., Poole and Berman 2001; Foley et al. 2005). To prevent significant adverse impacts from water withdrawals and losses to the basin's ecosystem and its watersheds, The Great Lakes Charter (Council of Great Lakes Governors 1985) and The Great Lakes Charter Annex (Council of Great Lakes Governors 2001) agreements were enacted by the Great Lakes basin states and Canada to protect, conserve, manage, or regulate new or increased withdrawals consistent with basinwide standards (Great Lakes Basin Water Resources Compact 2005). Efforts are under way in each state to develop standards and guidelines for regulating water withdrawals.

Dams currently cause the most-obvious impairments to fish habitat in Lake Michigan tributaries. Nearly every stream draining into the Lake Michigan basin has been dammed (Fig. 1), and all of Lake Michigan's major tributaries (with mean annual discharges exceeding approximately 30 $m^3 \bullet s^{-1}$) are impounded, reducing nearly 30,000 km of available stream habitat to only 5,311 km (Rutherford et al. 2004). Dams interrupt the natural physical processes of a river by altering the flow of water, sediment, nutrients, energy, and biota, all of which affect survival and growth of individual fish and fish-community processes (e.g., Lessard 2001; Hart et al. 2002; Mistak et al. 2003).

Fig. 1. Dams (dots) in the Lake Michigan basin. Major tributaries are indicated with heavy lines.



Limited information exists to relate dam removal or fish passage with habitat and fish-population responses within a river. A geographical information system (GIS)-based, spatially explicit dam database has been compiled for the basin using dam information from state agencies and non-profit groups (e.g., the River Alliance of Wisconsin). Of the estimated 1,947 dams in the Lake Michigan basin, only 19 have some sort of fish-passage structure, and most of these are in Michigan. Dexter and LeDet (1997) summarized fish-passage information at two fish ladders in the St. Joseph River, MI. From 1918 to 2003, 67 dams have been reported removed, 58 in Wisconsin and 9 in Michigan. Wisconsin researchers have shown that the diversity of fishes in the Milwaukee River (see frontispiece for location of rivers) has increased since the removal of the North Avenue Dam in 1997 and the Chair Factory Dam in 2000 (U.S. EPA 2004b; Hirethota et al. 2005). The long-term effects of dam removal on physical attributes and the fishery of the Pine River, a high-gradient tributary of the Manistee River, continue to be studied (e.g., Bednarik 2001; Mistak et al. 2003).

Comprehensive surveys are needed to describe the fish communities and habitats in the lower reaches of Lake Michigan's tributaries. These areas are predominantly non-wadeable and hard to sample. An important but poorly studied feature of lower tributary habitats is occurrence of lateral flow and nutrient transport into and off of flood plains during high-water periods. The benefits of flood-plain habitats for fish foraging and survival are unknown but are potentially large.

Coastal Wetlands and Nearshore Zones

Coastal wetlands make a large contribution to fish health and fisheries productivity despite their relatively small size. Wetlands comprise less than 1% of Lake Michigan's total surface area of 57,800 km^2, yet provide spawning, nursery, or foraging habitat for 40-90% of Great Lakes fish species during some stage of their life cycle, and more than 75 fish species have been documented using wetlands during summer months (Jude et al. 2005a). In particular, the young-of-the-year (YOY) life stages of important forage and commercial/game fishes utilize wetland habitats and adjacent nearshore areas. Wetlands also contribute to primary productivity; provide habitat for other biota; serve as flood storage, groundwater recharge, shoreline anchoring; and assimilate and cycle nutrients and contaminants. Wetlands also serve as conduits for material transported between tributary and nearshore and offshore waters.

Coastal wetlands have been altered naturally and anthropogenically. Variability in lake hydrology is likely the most-dominant form of natural disturbance that wetlands encounter (Jude et al. 2005a). Wetlands experience natural fluctuations in water level at weekly, seasonal, and inter-annual scales. Although wetland communities are well adapted to these natural fluctuations, some natural perturbations, such as storm seiches, can be quite severe and can dramatically alter or destroy wetland communities. Inter-annual fluctuation in lake levels can dramatically change plant communities, which promotes plant and fish habitat diversity.

Coastal wetland loss has been extensive and widespread in Lake Michigan. Along the southern and western shores of Green Bay, coastal wetlands have been reduced by 60-75%, and the extensive network of wetlands along the eastern shore also has experienced dredging, ditching, draining, and backfilling (Wilcox 2005). Despite this loss, wetlands in the Green Bay area are recognized as the most-extensive fringing coastal wetland habitat in the Great Lakes basin (Jude et al. 2005a). Anthropogenic factors contributing to wetland loss or degradation include dredging, dyking, ditching, filling, shoreline hardening (i.e., sea walls, riprap), artificial manipulation of water levels, contamination, beach grooming, and increased nutrient and sediment loadings from watersheds. Beach grooming during periods of low lake levels may significantly reduce potential fish recruitment when lake levels rise.

Development-related hardening of shorelines and contamination of waters may negatively affect fish-community diversity and relative abundance (Brazner 1997). Turbidity and its negative effects on plant diversity and structure are the primary disturbance factors influencing fish and invertebrate assemblages in coastal wetlands (Uzarski et al. 2005). Turbidity lowers macrophyte cover, reduces invertebrate diversity and biomass, and decreases water clarity.

Wetlands also have been severely impacted by invasions from non-indigenous plant species but less so from non-indigenous fishes. Disruption of natural hydrologic cycles favors monocultures of plants intolerant of water-depth change (i.e., purple loosestrife) that result in lower fish biomass and species richness. Although common carp can degrade wetlands by disturbing sediments and increasing turbidity during spawning, other species including zebra mussels (*Dreissena polymorpha*), ruffe, and round goby do not appear to have impacted wetland habitats, as they are not as abundant in these habitats as in nearshore or tributary habitats.

Contaminants

Understanding the processes controlling the cycling of nutrients, sediment, and contaminants has been the focus of several studies in Lake Michigan. The Lake Michigan Mass Balance (LMMB) study has measured and modeled contaminant cycling and availability in biota and habitats within the Lake Michigan ecosystem, including fishes. Results from the LMMB study show that the greatest external inputs of PCBs are from atmospheric and tributary inputs, and the greatest losses are from volatilization and deep burial in lake sediments (McCarty et al. 2004). Because of their proximity to developed areas situated on lower rivers, the ten AOCs within the drainage have the highest concentrations of contaminants and heavy metals. The Fox, Grand Calumet, and Kalamazoo Rivers still contribute the largest tributary loads of PCBs to Lake Michigan (McCarty et al. 2004). The LaMP has identified and prioritized pollutants for removal and monitoring (U.S. EPA 2004b).

Water Quality

The water quality in Lake Michigan is generally good (U.S. EPA 2004b). Nutrient concentration trends since 1983 have shown a slow and steady decline in pelagic (offshore) phosphorus and increases in chloride, nitrogen, and silica. Reductions in pelagic phosphorus have resulted from efforts to reduce loadings, while increases in chloride, nitrogen, and silica have resulted from both increased loadings and biological cycling (Warren and Kreis 2005). In nearshore waters, zebra mussels (and, more recently, quagga mussels (*D. bugensis*)) are thought to have changed the dynamics of phosphorus cycling and increased water clarity, which, with increased tributary loadings of phosphorus from agriculture and urban areas, are stimulating blooms of *Cladophora* spp., a benthic algae (Hecky et al. 2004). The potential consequence of algal blooms for fishes are degradation of nearshore spawning and nursery habitats.

Progress towards Meeting Objectives

Draft EOs have been completed for review by the Lake Michigan Committee (Rutherford et al. 2004). The EOs were developed as guidelines to protect and restore the health and function of aquatic habitats in support of achieving the FCOs. The document identifies environmental issues and their impacts on fish species and life-history stages, summarizes current and historic information on habitats, and identifies priorities and possible future directions required to ensure achievement of the FCOs. The document is supported by the Lake Michigan GIS project (Great Lakes Fishery Commission 2005), which contains a database and map layers to assist the public, managers, and scientists in monitoring, modeling, and analyzing fish habitats. Maps and websites of interest for fishery managers include ecoregion classifications of offshore and nearshore habitats, the U.S. Fish and Wildlife Service (USFWS) spawning and nursery atlas for Lake Michigan fishes, and the Lake Michigan Fish Atlas.

Inventory, classification, and establishment of reference conditions are necessary precursors for protecting and restoring fish habitats. Since 2000, much progress has been made using GIS software and databases. Tributary habitat inventory, classification, and modeling soon will be available for nearly the entire basin through Michigan's Digital Water Atlas, the National Hydrography Database, the Michigan Rivers Inventory, and a project funded by the Environmental Protection Agency's STAR Grant program (U.S. EPA 2005). Spatial gradients in river habitats are correlated with landscape-scale variables, such as drainage area, gradient, and soil geomorphology, which structure groundwater contributions and flows (Seelbach and Wiley 2005). Such landscape-scale variables also correlate well with fish-species abundance and community composition (Zorn et al. 2002) and, as a consequence, can be used to estimate fish habitat suitability and production potential for areas not sampled, including river habitats above dams.

Restoring additional spawning habitat to adfluvial and potamodromous fishes may be accomplished by identifying specific barrier removals or fish-passage provisions that would yield the highest spawning benefits. For example, if fish passage was provided at the Croton Dam on the Muskegon River, the reach between the Croton and Hardy Dams would produce an estimated additional 4,000 brown trout, 5,700 steelhead, 2,200 white suckers, and 21,500 Chinook salmon (Creque 2002). Providing passage on the Manistee River from Tippy to Hodenpyle Dams would produce an estimated additional 20,400 brown trout, 29,700 steelhead, 11,500 white suckers, and 109,000 Chinook salmon (Creque 2002). While potentially important, the benefits of fish passage must be balanced against the negative impacts of increased nursery habitat for sea lamprey and increased contaminant transport upstream by migrating Great Lakes fishes (Creque 2002).

Progress is being made on classification of wetland and nearshore habitats and development of indices of biotic integrity and anthropogenic disturbance. Albert and Minc (2001) identified ecoreaches of coastal Lake

Michigan using wetland types, geomorphology, and floral composition. Simon et al. (2005) and Wilcox (2005) reported classification schemes for Lake Michigan wetlands based on hydrologic influence with further sub-classification based upon geomorphic features and shoreline processes. The Great Lakes Environmental Indicators project (http://glei.nrri.umn.edu/default/) classified wetland types based on hydrology and geology and developed a suite of physical and biological indicators of ecosystem health, including fish. Recently, Uzarski et al. (2005) developed a fish-based index of biotic integrity and anthropogenic disturbance for wetlands.

Monitoring of coastal wetlands is critical for assessing wetland losses from development and is the basis for protecting wetlands. In 2000, the Great Lakes Wetlands Consortium was established to develop and begin implementation of protocols to monitor wetland status and trends. Efforts are ongoing to establish bio-indicators of wetland health. Wetland restoration efforts are concentrating on reducing sources of turbidity and increasing macrophyte production, which should result in more-diverse biotic communities. Future work must assess the potential impacts of exotic species, cultural development, and climate change on wetland function and area. Basic work remains to be done on quantitative sampling and monitoring of habitat characteristics and fish communities in nearshore areas.

Technology exists for continuous monitoring of physical, chemical, and biological components of aquatic habitats at temporal and spatial scales appropriate for fishes (http://www.glerl.noaa.gov/res/Programs/eos/). Aerial photography can provide measures of habitat change, and satellite imagery can provide estimates of surface temperature, turbidity, and chlorophyll *a* (http://www.glerl.noaa.gov/pubs/brochures/coastwatch/coastwatch.pdf). Acoustics can provide maps of gradient, depth, substrate composition, and sediment transport (Cochrane and Lafferty 2002); in-situ and towed cameras (Sprules et al. 1998) and hydroacoustics can estimate biomass of fishes and their prey in horizontal and vertical dimensions (http://www.glerl.noaa.gov/pubs/brochures/fishecology/fishacoustics.pdf). Fish otoliths also may provide a record of water chemistry and temperature, thus providing clues to habitat dependence. Using these techniques, Brazner et al. (2004) were able to distinguish wetland vs. nearshore habitat dependence for yellow perch in Lake Superior. Dufour et al. (2005) documented thermal histories and habitat use of alewife recruits in Lake Michigan, while Wurster et al. (2005) documented thermal histories of Chinook salmon in Lake Ontario. Analysis of stable isotope geochemistry in fish otoliths has been used to determine natal habitats of steelhead juveniles in Lake Michigan watersheds (ESR, unpublished data).

Additional inventory work is needed to address the large data gaps that exist for fish communities and habitats in most coastal areas outside of the AOCs. In addition to establishment of habitat reference conditions, much work is needed to quantify fish habitat quality. Traditional measures of habitat quality have documented presence/absence or relative abundance of fish, but an understanding of habitat importance to fish growth, survival, and reproduction is also required (Brandt et al. 1992; Minns et al. 1996). Recent examples of comprehensive survey and modeling approaches to habitat quality and importance include the Muskegon River Mega Model Project, a multi-university modeling-based framework for integrated fish habitat management of watershed, wetland, and nearshore fisheries habitats (Wiley 2005).

Significant progress has been made towards reducing and eliminating toxic substances. Thousands of kilograms of contaminated sediments have been removed from the AOCs in Lake Michigan under sponsored projects identified in Annex 2 of the GLWQA. Financial support for cleanup was increased by recent passage of the Great Lakes Legacy Act (U.S. EPA 2006), which provides funding for contaminant removal and remediation of the AOCs. In the Fox River, cleanup is being funded by paper mill companies through the Superfund process. Detailed descriptions of remediation activities completed for each AOC can be found at http://www.epa.gov/glnpo/aoc/. Although significant progress has been made in removal of contaminants from the ten AOCs in Lake Michigan, as of 2004, all AOCs were still plagued by low water quality, high suspended solids, and contaminant loads, especially of PCBs and dieldrin.

Progress has been made in the reduction of contaminant loadings and burdens in fishes and other indicator species. Murphy and Whittle (2004) reported consistent declines in total DDT and total PCB concentrations in lake trout tissues from Lake Michigan starting in the 1970s, although there has been very little change in recent years. While total DDT concentrations have remained near or below the GLWQA criteria since 1986, total PCBs in lake trout remain above the criteria. Agreements have been reached to reduce mercury concentrations entering Lake Michigan by 50% (U.S. EPA 2004b). Concentrations of atrazine, an herbicide used to control weeds in agriculture, have increased but still are well below regulatory limits for human health concerns and proposed criteria for ambient water quality (Brent and Warren 2005).

The presence of new persistent toxics represents an emerging threat to the health of the Great Lakes ecosystem. These compounds include the brominated flame retardants (BFRs), which are heavily used globally in the manufacturing of a wide range of consumer products and building materials. Flame retardants are bioaccumulating in Great Lakes fish and in breast milk of North American women (Murphy and Whittle 2004; Environmental Working Group 2006). Assessment of the occurrence and fate of these new compounds has recently been incorporated into surface water, suspended sediment, and bottom-sediment monitoring programs (Murphy and Whittle 2004). Levels of polybrominated diphenyl ethers (PBDEs), which are a major class of BFRs, have increased since the late 1980s, a trend also seen for PBDEs in lake trout in the Great Lakes (Murphy and Whittle 2004).

In summary, significant progress has been made towards addressing the habitat-related objectives within the FCOs. Efforts are under way to restore and protect critical habitats in tributary, nearshore, and wetland habitats. Reduction of contaminant burdens has occurred in many key indicator species, and work continues on rehabilitating degraded habitats in the AOCs. Recognition of the importance of watershed connectivity to lake health and function has focused efforts on watershed management and dam removal. Future work should improve habitat monitoring and surveying and lead to improved understanding of habitat function and its importance to fisheries. Efforts also should focus on quantifying habitat alterations caused by exotic species and separating effects of anthropogenic sources from natural environmental changes.

IMPACTS OF RECENT INVASIVE SPECIES ON NEARSHORE FISHES

John M. Dettmers[2], Charles P. Madenjian, Paul J. Allen, Steven A. Pothoven, and Thomas F. Nalepa

Introduction

Invasive species have impacted Lake Michigan's fisheries for 70 years. The passage through the Welland Canal by sea lamprey, after it invaded Lake Ontario, led to its establishment in Lake Michigan where it was first seen in 1936 (Christie and Goddard 2003). A combination of overfishing and sea lamprey predation led to the extirpation of lake trout (Coble et al. 1990; Hansen 1999) and to the extirpation or extinction of several deepwater ciscoes endemic to the Great Lakes (Coon 1999). Alewives, probably through interference with reproduction, likely caused the decline in abundances of deepwater sculpins and yellow perch during the 1960s and may have delayed the recovery of burbot in Lake Michigan until the 1980s (Madenjian et al. 2002). From 1959 to 1999, the rate of new introductions into the Great Lakes has increased to more than one species per year

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(Grigorovich et al. 2003), resulting in the establishment of numerous invaders during the past 20 years. In this report, we focus on (1) the status of six recent invasive species during 2000-2004, (2) the identity of other species that could invade in the near future, (3) examples of their impacts on the nearshore fish community, and (4) the implications for fishery management.

Status

Spiny Water Flea

Bythotrephes longimanus was first recorded in Lake Michigan in 1986 (Evans 1988). Native to the Ponto-Caspian region of Europe, this predatory cladoceran has been implicated in the reduction of small-bodied daphnids since the 1980s (Lehman 1991). Although few regular estimates of lakewide densities are available, mean density of *Bythotrephes* averaged across eight sites was $570/m^2$ in offshore waters during September 2000 (Pothoven et al. 2003). Except for being implicated in reduced diversity of the offshore *Daphnia* species complex (Lehman and Cáceres 1993), this invader has had little apparent impact on nearshore fishes.

Zebra and Quagga Mussels

Zebra mussels were first documented in Lake Michigan in 1989 (Marsden 1992) and rapidly increased their population size in nearshore rocky habitats (Marsden 1992). Quagga mussels were first documented in Lake Ontario (May and Marsden 1992) and were present in Lake Michigan by 1997 (Nalepa et al. 2001). Although little quantitative monitoring of zebra mussels is conducted in Lake Michigan, an estimate of lakewide biomass is available from U.S. Geological Survey fall bottom-trawl assessments. Between 1999 and 2004, lakewide biomass of zebra and quagga mussels ranged from 14 kt (1,000s of metric tones) in 1999 to a peak of 43 kt in 2001 and returned to 14 kt in 2003 (Madenjian et al. 2005a). These lakewide estimates are likely conservative because trawls are not fished over the hard substrate on which zebra mussels prefer to attach (Fleischer et al. 2001; Coakley et al. 2002). Zebra mussel biomass was not separated from quagga mussel biomass in these trawl surveys, but observations suggest that the proportion of quagga mussels has been increasing in recent years.

Round Goby

This invader was first reported from Lake Michigan in 1993 (Charlebois et al. 1997). Since then it has spread slowly through southern Lake Michigan and most likely was transported via commercial shipping to ports farther north in the lake (Mills et al. 1993; Jude 2001), where it has further spread northward and eastward (Clapp et al. 2001). As round gobies spread into the lake, assessment trawls documented their increased relative abundance. Trawling by both the Michigan Department of Natural Resources (DNR) at Grand Haven and by Ball State University (BSU) in Indiana waters first detected round gobies in 1997 (Michigan DNR) and 1998 (BSU). Catch rates rose by two orders of magnitude within two years and, since then, have generally remained at similarly high levels (Lauer et al. 2004).

Fishhook Water Flea

Cercopagis pengoi, the fishhook water flea, was first recorded in Lake Michigan in 1999 (Charlebois et al. 2001). Like *Bythotrephes longimanus*, its relative, this invasive predatory cladoceran from the Ponto-Caspian region feeds on zooplankton. Unlike its relative, *Cercopagis* feeds primarily on smaller zooplankton, including rotifers, juvenile copepods, and small cladocerans (Vanderploeg et al. 2001; Benoit et al. 2002; Laxson et al. 2003). The abundance of this species, although variable, has trended upwards (Witt et al. 2005). Its impacts on the food web remain uncertain. Improved monitoring of its population dynamics and community impacts remains important to fully understand whether this invader will exert strong impacts on the nearshore food web.

Ruffe

Ruffe, a Eurasian fish, was first documented in Lake Michigan at Little Bay de Noc in 2002. It was found there again in 2003 and 2004 and since has spread to Big Bay de Noc. In other targeted and routine sampling around the lake, no other populations of ruffe have been reported. It is unclear why this species has expanded relatively slowly after introduction into Lake Michigan. The pattern of slow spread observed in Lake Superior, about 200 miles in eight years from 1987 to 1994 (Gunderson et al. 1998), may result from the apparent negative relationship between ruffe abundance and system productivity (Ogle 1998). Ruffe may initially colonize a location via commercial shipping but, once established, do not aggressively immigrate into new areas. This behavior may provide a control method if ports are at risk.

Species on the Doorstep

Other potential invaders could arrive during the next few years. Of special concern is the possibility that silver carp or bighead carp, collectively known as Asian carp, could enter Lake Michigan through the Chicago Sanitary and Ship Canal (CSSC), the live food trade, or by other means. A permanent electric barrier is being constructed in the CSSC to deter movement across this artificial connection between the Mississippi River and Great Lakes drainages. Similarly, efforts among U.S. and Canadian agencies and legislative bodies are seeking to eliminate the trade in live Asian carp.

The northern snakehead is another potential invader. This species escaped into the Potomac River basin, most likely from aquarium releases. Specimens have been collected by the Wisconsin DNR and Michigan DNR on the non-Great Lakes waters of these states. One snakehead was collected by an angler while fishing in a Chicago harbor in October 2004. Based on an intensive sampling effort in the harbor, best estimates suggest that this snakehead was released from an aquarium and is not part of an established population. However, additional monitoring of Chicago harbors will continue to provide critical early warning.

Kolar and Lodge (2002) recently developed quantitative models of invasability characteristics of fishes from the Ponto-Caspian region. Based on their models, other fishes that could rise to pest status if they do establish in the Great Lakes include tyulka, Eurasian minnow, Black Sea silverside, European perch, and monkey goby.

Direct and Indirect Impacts

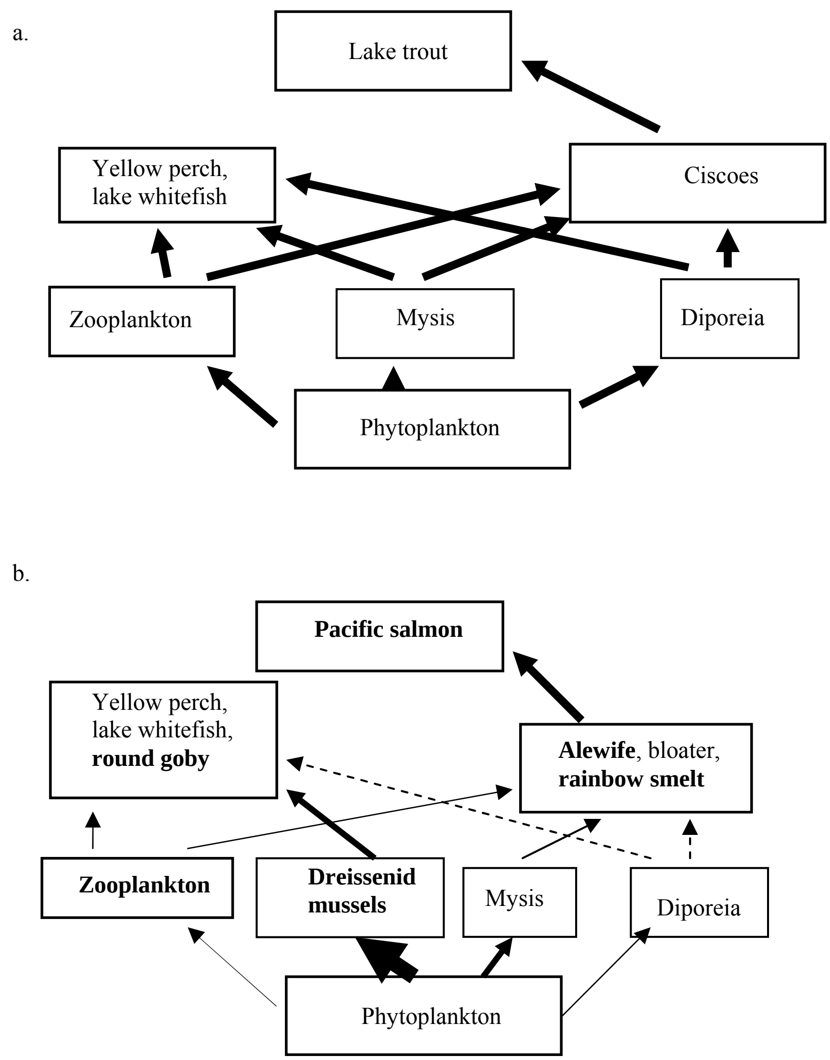
Invasive species affect Lake Michigan fishes both directly and indirectly. We illustrate direct impacts using round goby as an example and indirect impacts using dreissenid mussels, because few effects of the other species are known.

Round gobies can exert both positive and negative impacts on the nearshore fish community. They serve as prey for nearshore fishes, such as yellow perch (Truemper and Lauer 2005) and smallmouth bass, whose growth rates at age 0 have increased in Lake Erie since round gobies became abundant (Steinhart et al. 2004). Similarly, lake whitefish, lake trout, burbot, brown trout, and coho salmon have been reported to consume round gobies. Although consumption of round gobies could be positive for predators, negative impacts of consumption of round gobies are also likely. Specifically, because round gobies >50 mm in length consume primarily dreissenid mussels, biomagnification of toxic substances, such as polychlorinated biphenyls and polychlorinated naphthalenes, through the food web is likely (Hanari et al. 2004).

Round gobies have essentially eliminated important nearshore benthic fishes, such as mottled sculpin and johnny darter (Janssen and Jude 2001; Lauer et al. 2004). The mechanisms behind this displacement include agonistic interactions for refuges (Dubs and Corkum 1996) and egg predation by round gobies on mottled sculpin nests (Janssen and Jude 2001). Because round gobies are voracious egg predators, they may negatively affect restoration efforts for native fishes by eating their eggs and fry (e.g., Chotkowski and Marsden 1999). For example, sturgeon eggs are consumed by round gobies (J. Nichols, unpublished data). Furthermore, round gobies are both more numerous and more-effective lake trout egg predators than native predators, such as crayfish (*Orconectes* spp.) and mottled sculpin (Fitzsimons et al. 2003).

Because dreissenid mussels filter phytoplankton from the water column, they compete directly with zooplankton for food (Fig. 2). Since dreissenid mussels invaded Lake Michigan, zooplankton densities, when first-feeding of yellow perch larvae occurs, have declined by an order of magnitude (Dettmers et al. 2003), indirectly resulting in reduced numbers of age-0 yellow perch in the fall (Clapp and Dettmers 2004).

Fig. 2. Simplified food-web structure of Lake Michigan in 1900 (a) and 2004 (b). Arrows represent the relative energy flow from one group to another, with thicker arrows representing greater energy flow. Dashed lines represent the reduced and declining contribution of *Diporeia* spp. to the trophic level immediately above. Species in **bold** text are invaders or intentionally introduced species that have established themselves in the food web.



The recent decline in *Diporeia* spp. (hereafter, diporeia as a common name) populations in southern Lake Michigan is another apparent indirect effect of dreissenid mussels. Although no specific mechanism for the decline has been demonstrated, diporeia populations did not start declining until zebra mussels were first detected (1989), and, by 1993, diporeia populations declined by over an order of magnitude in parts of the lake (Nalepa et al. 1998). This decline is relevant to the health of nearshore fishes because diporeia is an energy-rich food source and an important prey for several fishes, including alewife, yellow perch, and slimy sculpin (Wells 1980). Alewife condition declined by about 14% after 1995 (Madenjian et al. 2003), suggesting a link between reduced alewife condition and diporeia abundance. More recently, Madenjian et al. (2006) (also see the Status of Planktivore Populations chapter) reexamined the energy density of alewife using bomb calorimetry. Peak energy density of alewife >150 mm in length in the fall declined by 21%, from 9,641 J/g in 1979-1981 (Stewart and Binkowski 1986) to about 7,680 J/g in 2002-2003. In contrast, peak energy density of juvenile alewives, which do not consume diporeia, has remained at about 4,600 J/g. Salmonines must now consume greater numbers of large alewife than they did 30 years ago to achieve the same growth. This constraint may have important repercussions for the entire ecosystem as fishery managers seek optimal levels of predation by salmonines on alewives.

Numerous invasive species have established in Lake Michigan during the last 20 years (Fig. 2), and some of them exert strong impacts on the food web (Jude et al. 2005b). Although some invaders like the spiny water flea have limited discernable impacts, and others like the round goby can have positive impacts, the majority of impacts of invaders appears to be negative. The mechanisms for negative interactions are direct predation, as on lake trout eggs, or competition, as with other nearshore benthic fishes. Indirect interactions of dreissenid mussels, mediated through the food web, have probably negatively affected the recruitment of yellow perch and the condition of alewives. These indirect interactions have the potential for far-ranging impacts on the entire fish community (Fig. 2). Furthermore, after an invader has established itself, fishery managers are largely at the mercy of community interactions to determine if an invader will be a pest. Fishery managers face a very difficult task trying to manage fisheries that are part of an ever-changing set of food-web linkages mediated by invasive species.

Because there is great concern among fishery managers throughout the basin about the potential for new invaders to disrupt the existing community structure, an important emerging need will be tools to (1) predict which species are likely to invade, (2) predict which species are likely to become pests, and (3) especially prevent establishment of those likely to become pests. Without effective prevention measures, including but not limited to (1) eliminating transport by ballast water, (2) preventing planned introductions to other parts of the country that then spread through connecting waterways, and 3) establishing effective rapid-response plans for areas, such as ports and connecting channels, that are potential entry points, the fish community will remain at risk of disruption by invasive species.

LAKE WHITEFISH

Mark P. Ebener[3], Greg M. Wright, Philip J. Schneeberger, and Randall M. Claramunt

The expected annual yield of lake whitefish should be from 1.8-2.7 million kg (4 to 6 million pounds).

In the first state-of-the-lake report (Schneeberger et al. 2005b), which covered the status of lake whitefish through 1998, yield had been within or exceeded the above target range (Eshenroder et al. 1995) going back as far as 1981. After reaching a peak of 3.2 million kg in 1993, however, yield declined steadily and reached 1.7 million kg in 2004, which was the lowest yield since 1980 and slightly below the fish-community-objective target. Despite this recent decline, the average commercial yield of 1.9 million kg during this reporting period (2000-2004) was within the target range.

Fishing effort directed at lake whitefish has declined considerably since 1976, although the harvest continues to be substantial. Large-mesh gillnets and trapnets are the two primary gears used to harvest lake whitefish. Large-mesh-gillnet effort declined from its peak of 19.05 million m in 1977 to 3.55 million m in 2004 (Fig. 3). Trapnet effort increased from 6,400 lifts in 1976 to 13,900 lifts in 1984, varied between 11,200 and 13,600 lifts over the next 14 years, and then declined to 6,600 lifts in 2004. A trawl fishery harvested upward of 0.45 million kg of lake whitefish annually since 1976, but it is confined to fishing Michigan's waters of Green Bay. Pound net effort has

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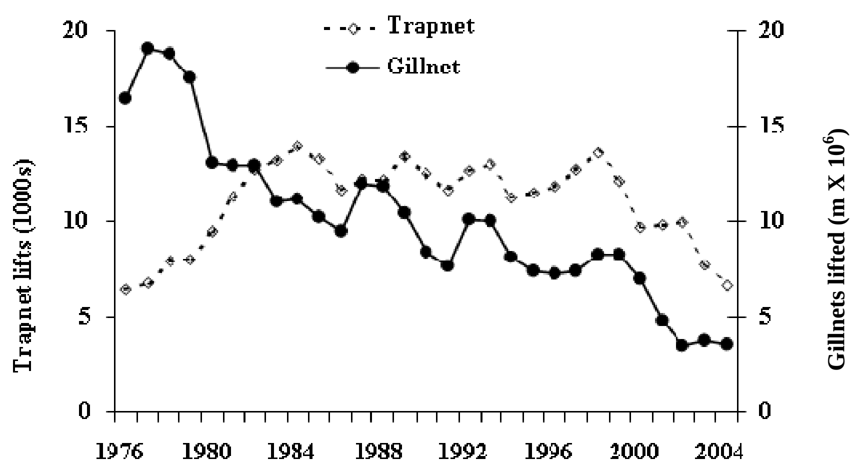
been insignificant and less than 100 lifts annually since 1987. Gillnets historically accounted for most of the lake whitefish yield from Lake Michigan, but, in 2003, trapnets accounted for 71% of the yield in Wisconsin and 83% of the yield in Michigan. These changes in fishing resulted from declining market prices for lake whitefish; a preference for fillets over dressed fish; negotiated settlements between tribal governments and the state of Michigan; establishment of individual transferable quotas (ITQs) in Wisconsin; measures to protect lake trout and promote their restoration; effects of dreissenid mussels on fishing gear and gear efficiency; ecological effects of dreissenid mussels on the food, growth, and spatial distribution of lake whitefish; and the changing abundance of lake whitefish.

Fig. 3. Annual commercial large-mesh gillnet and trapnet fishing effort used to capture lake whitefish in Lake Michigan, 1976-2004.



Wisconsin has three quota zones for lake whitefish, and, in Michigan, there are ten management units based on stock delineation (Ebener and Copes 1985; Scheerer and Taylor 1985; Walker et al. 1993; Ebener et al. 2005). Total allowable catch (TAC) and limited entry are the primary management tools used to control harvests of lake whitefish in Wisconsin, whereas TACs and constrained entry are the primary management tools in Michigan waters. In 1989, Wisconsin established ITQs, which initially were set at 0.52 million kg and then increased gradually to 1.12 million kg during 1999-2005. The 2000 negotiated settlement between Native American tribes and the state of Michigan established TACs as the primary tool for controlling commercial harvests in Michigan's 1836-ceded waters (see frontispiece) of Lake Michigan (Bence and Ebener 2002; Ebener et al. 2005). TACs in the combined management units in the 1836 treaty-ceded waters were set at 3.0 million kg in 2001 and, by 2005, reached 2.97 million kg (Woldt et al. 2004). The TAC/quota for lake whitefish in Wisconsin and Michigan waters combined was 4.1 million kg in 2005, which was twice the yield obtained in 2004. Yields have been less than the projected TACs because of the issues identified previously.

Fishery agencies on Lake Michigan since 1999 have expanded their capacity to more-intensively manage lake whitefish. Statistical catch-at-age analysis is being used to estimate absolute levels of abundance, recruitment, biomass, growth, and mortality of lake whitefish in Wisconsin and Michigan waters (Ebener et al. 2005). Timely estimates of these population parameters allow fishery agencies to set harvest limits based on biological information (Ebener et al. 2005). In addition, agencies in Michigan waters have developed and implemented a fishery-independent survey of each lake whitefish stock that will provide input to the catch-at-age models.

The arrival and rapid expansion of dreissenid mussels in Lake Michigan has markedly changed the lake whitefish fishery. Filamentous algae and dreissenid mussels routinely foul trapnets and gillnets, dramatically reducing catchability of lake whitefish in both gears. As water clarity increased due to filtration by dreissenid mussels, most lake whitefish populations moved into deeper water outside the reach of trapnet fisheries and into depths not typically frequented by lake whitefish (e.g., Mohr and Ebener 2005; P. Peters, personal communication, 2005). Lake whitefish may also spend more time than usual feeding in the water column on vertically migrating invertebrates (e.g. *Mysis relicta)* than prior to the arrival of dreissenid mussels.

Dreissenid mussels have indirectly affected the food, growth, and condition of lake whitefish in Lake Michigan. The abundance of lake whitefish peaked in 1992-1993 when mussel populations exploded in the lake (Pothoven et al. 2001; Schneeberger et al. 2005a). Abundance of the amphipod *Diporeia*, spp., an important food item for lake whitefish, declined severely in most areas of the lake following establishment of the dreissenids. In many areas, lake whitefish have shifted from being a predominately benthic-feeding fish to feeding on pelagic organisms like *Mysis* and zooplankton (Pothoven et al.

2001; Pothoven 2005). Growth and condition of lake whitefish began to decline after 1992 (Madenjian et al. 2003; Schneeberger et al. 2005a, 2005b), and that decline continued through roughly 2002—after which both growth and condition of lake whitefish appeared to stabilize and even increase slightly. Unfortunately, the presence of dreissenid mussels and an altered food web will likely continue to suppress growth and condition of lake whitefish.

Pathogens

The initial findings of a multi-disciplinary study of lake whitefish from Lakes Michigan and Huron indicate the presence of multiple systemic diseases. *Renibacterium salmoninarum,* previously discovered in Lake Michigan lake whitefish, was detected in lake whitefish at all four sampling sites: Big Bay de Noc (see frontispiece for location of ports) and Naubinway in Lake Michigan and Cheboygan and Detour in Lake Huron. Preliminary data show that Lake Michigan lake whitefish stocks have relatively low infection levels, compared to fish from Lake Huron.

Pathogens other than R. *salmoninarum* have also been isolated from lake whitefish. Examples include multiple species of motile aeromonads (*Aeromonas hydrophila* and *A. sobia*), *A. salmonicida* subsp. *salmonicida*, *Vibrio* sp., *Flovabacteria* sp., *Pseudomonas flourescens*, and *Canobacterium pisicola.* Many of the bacterial pathogens isolated thus far correspond to and account for observed lesions and other visual indicators (ulcers, external hemorrhages, and enlarged spleens) typically associated with mortality.

Cystidicola farionis (Nematoda: Cystidicolidae), which commonly resides in the swimbladder of infected fish, is the most-prominent parasite found in Lake Michigan lake whitefish. Infections of high magnitude cause severe damage to the swimbladder by causing irritation and subsequent thickening of the swimbladder wall. The prevalence of this parasite was higher in lake whitefish from Lake Huron than in those from Lake Michigan. Other parasites detected in the heart, liver, spleen, and the gastrointestinal tract include *Acanthocephalan* sp. and *Echinoryhncus* sp. What role these parasites play in the overall health of Lake Michigan lake whitefish is unclear, and research is continuing.

Recommendation

The Lake Michigan Committee should consider revising the fish-community objective for lake whitefish using new estimates of standing stock and harvest limits derived from statistical catch-at-age analysis, because accounting for the productive capacity of individual stocks should be more realistic than the existing approach based on lakewide historical yields. The present yield objective of 1.8-2.7 million kg is substantially greater than the average annual yields of 1.1 million kg during 1889-2004 and 0.92 million kg during 1889-1952. Yields prior to 1959 were produced by both a target fishery for lake whitefish and an incidental catch of lake whitefish in the lake trout fishery. In comparison, the present-day lake whitefish fishery is the only sizable commercial fishery on Lake Michigan, and modern fishing gear is much more efficient than fishing gear used prior to the 1960s (Brown et al. 1999). The historical yield of lake whitefish was reported mostly as dressed weight (without entrails), whereas at least half of the current yield is reported in round weight (about 17% greater than dressed weight). Consequently, present-day and historic yields of lake whitefish are not comparable and should not be used as the basis for establishing fish-community objectives.

YELLOW PERCH

Paul J. Allen and Brian Breidert[4]

Maintain self-sustaining stocks of yellow perch…Expected annual yields should be 0.9 to 1.8 million kg (2 to 4 million lb).

Status

As discussed in the first state-of-the-lake report, which covered status through 1999 (Clapp et al. 2005), a series of weak year-classes starting in 1995 caused yellow perch yields to fall below the above fish-community-objective target from Eshenroder et al. (1995). What caused the weak year-classes remains unknown, but the population bottleneck occurred in the first year of life. In response, management agencies adopted regulations, beginning in 1995, to restrict or eliminate commercial and recreational harvest (Francis et al. 1996). Formerly, yellow perch were taken in widespread commercial and sport fisheries; more recently, commercial fishing is limited to southern Green Bay, and the recreational fishery is reduced but still widespread. From 2000-2004, the combined lakewide recreational and commercial annual yield of yellow perch averaged 0.24 million kg, which amounts to only 26% of the target. Only 4% of the recent annual yield was taken by the commercial fishery in Green Bay, which is limited by an annual quota of 9,070 kg. Although the fisheries are nearly contiguous around the lake, the lakewide population comprises three genetically distinct stocks: Green Bay, northern Lake Michigan, and southern Lake Michigan (Miller 2003).

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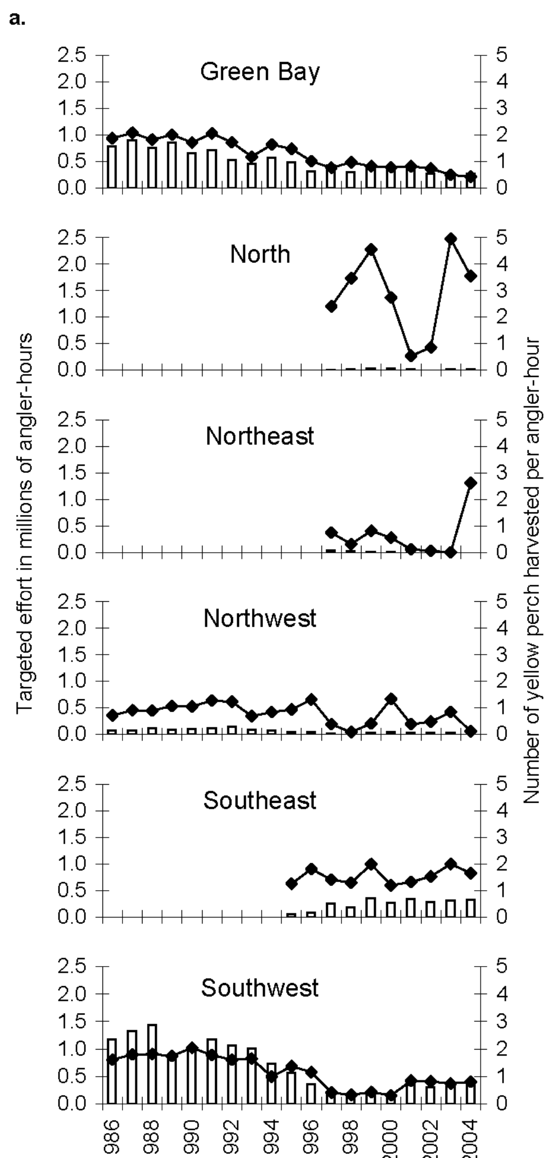
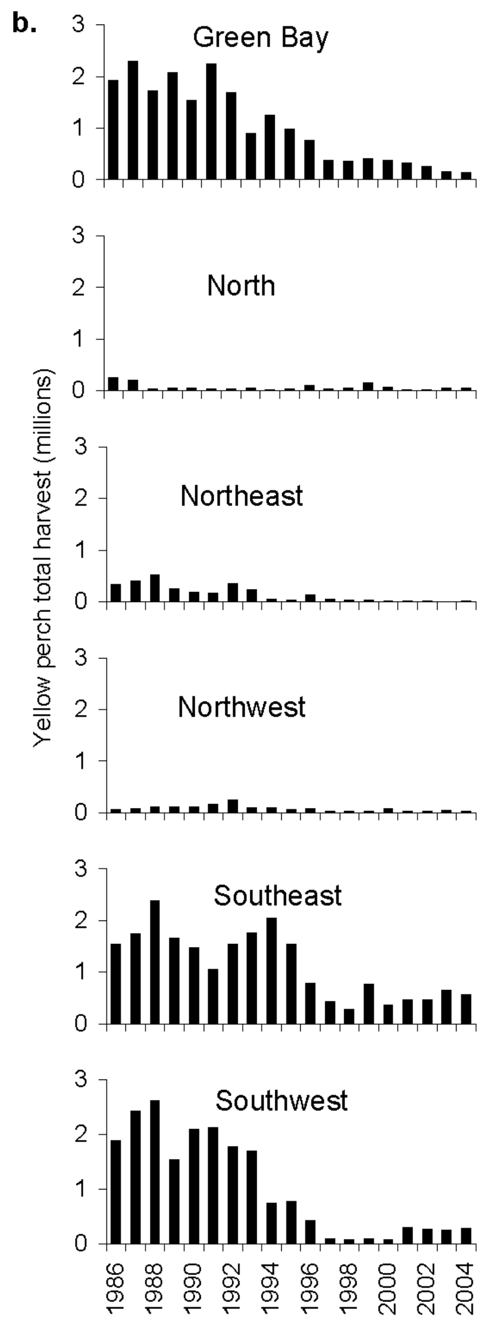
The total number of yellow perch harvested by recreational fishers each year has averaged 995,000 fish from 2000 to 2004, and the bulk of the catch is from the southern basin and Green Bay (Fig. 4). Since 2000, recreational harvest in Green Bay has declined to its lowest level going back to 1986 (Fig. 4). Although little harvest has been reported from northern waters, numbers caught from the southeastern and southwestern regions have increased or held steady since 2000. Targeted effort for yellow perch generally followed the same patterns as observed for numbers of fish harvested, with most of the effort focused in Green Bay and southern Lake Michigan. Likewise, trends in number of fish harvested per angler-hour were similar to trends in total harvest (Fig. 4). Since 2000, harvest rates in Green Bay and the southwestern region of the lake have been below 1.0 fish per angler-hour, and harvest rates in the southeastern region have ranged from 1.2 to 2.0 fish per angler-hour.

Fig. 4. (a) Targeted yellow perch effort in millions of angler-hours (bars) and number harvested per angler-hour (lines) for six regions of Lake Michigan, and (b) number of yellow perch harvested by the recreational fishery for the same regions (data from Hanson 2005).




b.
Green Bay
North
Northeast
Northwest
Southeast
Southwest
Yellow perch total harvest (millions)
0
1
2
3
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

The average weight of a yellow perch harvested by anglers has increased by more than 27%, from 177 g to 226 g from 2000 to 2004. Based on a length-weight relationship for yellow perch used at Ball State University (BSU), the average length of a yellow perch harvested by anglers has increased from 248 mm in 2000 to 267 mm in 2004, which is the highest average length since 1986. The increasing size of yellow perch is associated with the dominance of the 1998 year-class (Makauskas and Allen 2004). For example, in 2004, the 1998 year-class was age 6 and comprised 78% to 85% of the assessment gillnet catch. In Indiana waters, the average length of females from the 1998 year-class in 2004 was 257 mm (N = 307, SD = 47.3) (Allen and Lauer 2005). In Wisconsin's recreational fishery (outside of Green Bay), 92% and 68% of harvested yellow perch were from the 1998 year-class in 2003 and 2004, respectively. In the Wisconsin waters of Green Bay, the 1998 year-class dominated the combined sport and commercial harvest, comprising 88% and 81% of the catch in 2002 and 2003, respectively.

With more and larger females, the reproductive potential of the population has increased recently (Allen et al. 2005). This increase may account, at least in part, for the improved catch in 2003 of age-0 fish in assessment trawls, which was the highest observed since 1978 (Makauskas and Allen 2004). The 1998 year-class, albeit much smaller than the year-classes of the 1980s, has apparently shaped the fishery from 2000 to 2004. The continued success of the recreational fishery will be dependent on how well the 1998 year-class survives and on the abundance of replacement year-classes. Although very little recruitment has been observed for the 1999 to 2001 cohorts, the 2002 to 2004 year-classes have the potential to improve lakewide fisheries.

Progress

Recent efforts by state agencies and researchers have resulted in substantial advancements towards understanding the continuing recruitment bottleneck, which occurs sometime between the egg and age-1 life stages (Clapp and Dettmers 2004). Five major hypotheses, each pertinent to a particular life stage, have been advanced as potentially influencing recruitment of yellow perch (Table 2). Of these five hypotheses, those focusing on zooplankton and spawning-stock characteristics have been researched the most during 2000-2004. Shroyer and McComish (2000) observed a negative correlation between alewife abundance and yellow perch recruitment in southern waters, which may have resulted from alewife predation on larval yellow perch (Brandt et al. 1987) or from competition for zooplankton between alewife and larval yellow perch. Additional research on larval yellow perch diets in Green Bay, WI, suggests that survival of age-0 fish may be reduced when small zooplankton are scarce (Bremigan et al. 2003), and the number of recruits surviving to autumn is related to density and size of available zooplankton during the first exogenous feeding in southern Lake Michigan (Dettmers et al. 2003; Graeb et al. 2004; Hensler 2004). Alewife abundance in extreme southern Lake Michigan has increased fourfold from 1988 to 2003 (Allen et al. 2005). This increase coincided closely with the expansion of driessenid populations, whose filtering activities may have been a factor in the tenfold decrease in zooplankton density that started after 1988 (see the Impacts of Recent Invasive Species on Nearshore Fishes chapter). Thus, the competition (zooplankton) hypothesis is supportable, but direct evidence of significant predation is lacking.

Table 2. Likely importance of various hypothesized factors affecting different life-history periods of yellow perch (from Clapp and Dettmers 2004).

	Hypothesis				
Life-history period	**Temperature**	**Spawning stock**	**Water mass movement**	**Zooplankton**	**Predation**
Egg	X	X			
Early larval	X	X	X	X	X
Late larval/early pelagic	X		X	X	X
Early juvenile/late pelagic	X		X	X	X
Advanced juvenile/littoral	X				X

Recent research applicable to the “spawning stock” hypothesis (Table 2) has shown that larger females produce more and larger eggs (Lauer et al. 2005). Furthermore, older and larger females produce shorter larvae with larger yolk sacs, while smaller and younger females produce longer larvae with smaller yolk sacs (Heyer et al. 2001). Longer larvae may have a survival advantage when food is abundant, whereas larvae with larger yolk sacs may do better when food is limited. To achieve reproductive versatility (at the population level), female spawners should be of multiple sizes and ages.

Additional research suggests that the yellow perch population is composed of at least three genetically distinct stocks (Miller 2003), and movement of adult yellow perch among current management jurisdictions suggests biologically based management boundaries may be required (Glover et al. 2005).

The development of predictive models (Shroyer and McComish 1998, 2000) is providing managers with the ability to forecast recruitment of yellow perch to the fishery. Population models that recreate stocks and analyze changes in demographics have also been developed (Allen 2000; Wilberg et al. 2005). For example, Wilberg et al. (2005) found that fishing mortality rates were very high from the mid-1980s to the closure of the commercial fishery in 1997. The recent increase in spawning-stock biomass indicates that constraints placed on the recreational and commercial fisheries during the mid-1990s have been successful in reducing fishing mortality.

Recommendations

The fish-community objective of maintaining self-sustaining yellow perch stocks with expected annual yields of 0.9 to 1.8 million kg (Eshenroder et al. 1995) appears to be too optimistic at this time. However, the population historically has recovered quickly after abundance was suppressed (Allen et al. 2005). To help ensure recovery, fishing policies should remain conservative for the foreseeable future. Research using decision analysis is currently under way with the objective of developing an analytical tool for evaluating likely outcomes from different harvest policies and, ultimately, from tradeoffs among a defined suite of alternative harvest policies. Taking advantage of these and other new developments, a reevaluation of the yellow perch objective should be initiated.

STATUS AND TRENDS OF LAKE STURGEON

Robert F. Elliott[5]

Maintain self-sustaining stocks of…sturgeon…Sturgeon populations should be enhanced by improving lake and stream habitat, assuring fish passage over barriers in historically used spawning streams, and devising protective regulations.

History

Lake sturgeon, formerly a dominant nearshore species, continues to be the object of increased study and recovery effort, in keeping with the above objective from Eshenroder et al. (1995). The previous state-of-the-lake report (Schneeberger et al. 2005b) identified at least eight known remnant populations, the largest with annual spawning runs of several hundred fish and the smallest with only a handful. Several indications at that time suggested lakewide abundance, although low, was increasing. Despite these positive signs, the sturgeon continues to be considered either rare, endangered, threatened, a species of greatest conservation need, or a resource conservation priority by one or more of the state, tribal, or federal agencies with responsibilities for the lake's fishes.

Progress

Recent mark-recapture estimates and direct counts indicate annual spawning runs of 199-577 adults in the lower Peshtigo River (see frontispiece for location of rivers) (Gunderman and Elliott 2004), 23-52 adults in the lower Manistee River (Gunderman 2001; Peterson et al. 2002; Lallaman 2003), 24-49 adults in the lower Fox River (Gunderman and Elliott 2004), and 15-23 adults in the lower Muskegon River (Peterson and Vecsei 2004). Although

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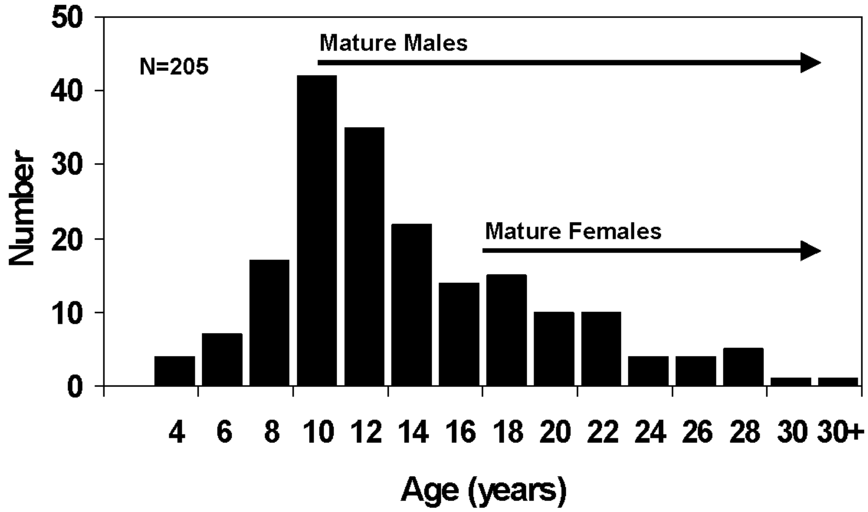
spawning-run size in the lower Menominee River (see frontispiece for river locations) has not been estimated, the resident population during summer was estimated at 457-1,329 fish in 1991 (Thuemler 1997), and spawners are thought to number in the hundreds each spring (G. Kornely, personal communication, 2005). Gillnet assessments and sightings suggest that annual spawner abundance in the lower Oconto (Gunderman and Elliott 2004), lower Manistique (Auer et al. 2004), lower Grand (K. Smith, personal communication, 2005), and lower Kalamazoo (Daugherty and Sutton 2004) Rivers is less than 25 fish per river. Sightings and samplings also suggest that adults may periodically spawn in the lower St. Joseph and Millecoquins Rivers and possibly on some shoals (Hay-Chmielewski and Whelan 1997). Populations also persist in two sections upstream of dams on the Menominee River (Thuemler 1997), in Indian Lake upstream of the lower dam on the Manistique River (Bassett 1981), and possibly upstream of the lower dam on the St. Joseph River (Daugherty and Sutton 2004). A large, self-sustaining population exists in the Lake Winnebago system upstream of the lower Fox River (Bruch 1999). Although fish from these systems can move downstream to Lake Michigan, they cannot return beyond the first dam.

Since 2000, production of sturgeon larvae has been documented in the lower Fox, Oconto, Peshtigo, Menominee, Manistee, Grand, and Muskegon Rivers, and fall young-of-the-year (YOY) have been documented in the Menominee, Manistee, Oconto, and Peshtigo Rivers (Benson 2004; Chiotti 2004; Gunderman and Elliott 2004; Peterson and Vecsei 2004). A single larvae has been collected in each of the St. Joseph and Kalamazoo Rivers (K. Smith, personal communication, 2005). The largest catches of drifting larvae and YOY have consistently come from the Peshtigo and Manistee Rivers (Benson 2004; Chiotti 2004). Benson (2004) estimated larval production in the Peshtigo River at 13,000-39,000 (95% CI) and YOY production at 160-390 (95% CI) for the 2002-2003 year-classes.

Populations of sturgeon are genetically structured with differences occurring geographically. Sturgeon populations in the Menominee, Peshtigo, Oconto, lower Fox, and Wolf Rivers (all of Green Bay) were genetically more similar to each other than to populations in the Manistee and Muskegon Rivers, which, in turn, were more similar to each other than to populations in Lake Huron tributaries (DeHaan 2003; Scribner et al. 2004). Small populations do not lack genetic diversity nor do they exhibit higher levels of genetic drift or inbreeding compared to larger populations (Scribner et al. 2004). The significant differences in allele frequency at microsatellite loci and in mitochondrial DNA among populations, including those in relatively close proximity, indicate that populations are reproductively isolated and that spawners exhibit a high degree of fidelity to their river of origin (Scribner et al. 2004). Tag returns also indicate that spawners return to the same river repeatedly to reproduce (RFE, unpublished data).

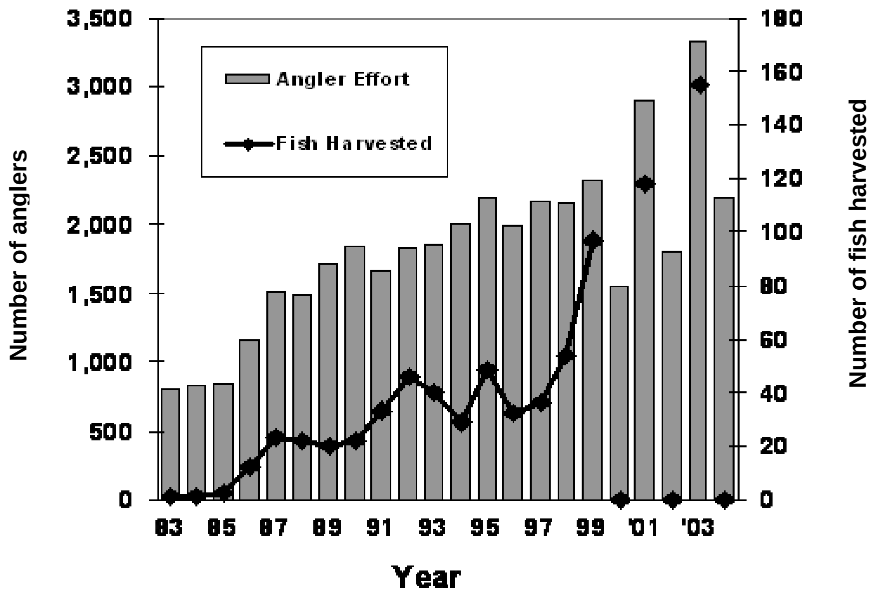
Spawning populations are composed primarily of fish less than 35 years of age and 175-cm total length (TL), although fish exceeding 50 years and 200 cm have been collected (Lallaman 2003; Gunderman and Elliott 2004; Peterson and Vecsei 2004). Sex ratios of spawning fish are highly skewed toward males (as expected), particularly in rivers with younger fish (Lallaman 2003; Gunderman and Elliott 2004; Peterson and Vecsei 2004). Open-water assessments targeting all sizes of sturgeon are dominated by fish less than 1,000-cm TL and younger than 12 years, suggesting recruitment to spawning populations may improve (Fig. 5; Gunderman and Elliott 2004; S. Lenart, personal communication, 2005). Observations of increased numbers of spawning fish in some tributaries (Gunderman and Elliott 2004; T. Thuemler and G. Kornely, personal communications, 2005) and reports of increased encounter rates by commercial and recreational fishers and in agency assessments suggest recruitment has improved in at least some areas of the lake during the 1980s and 1990s. If true, spawner abundance in some rivers may continue to increase in the near future as juveniles reach maturity.

Fig. 5. Age-frequency distribution of Lake Michigan lake sturgeon, projected from a subsample of 102 lake sturgeon captured during open-water assessments in Green Bay, 2002-2003. Maturity assignments reflect earliest maturity and are based on spawning assessments of Green Bay populations (from Gunderman and Elliott 2004).



Recaptures of marked sturgeon from the open waters of central and southern Green Bay indicate a population (fish ≥122 cm TL) of 920-4,455 (95% CI) (Gunderman and Elliott 2004). In a population of this size, a loss of more than 100 adult fish•yr^{-1} could be excessive (Bruch 1999). The recreational harvest in the lower Menominee River has increased steadily over the past 20 years, reaching a high of 150 fish (125-cm minimum length limit) registered during the 2003 season. While increasing harvest could be indicative of increasing abundance, effort also is increasing (Fig. 6). Other sources of mortality are from injury of fish released alive by recreational and commercial fishers, from fish struck by boat propellers or killed when passing through or around hydropower facilities, and from disease (RFE, unpublished data). Each summer since 2001, dead sturgeon have been reported washed up on numerous beaches around the lake. As many as 21 fish were reported in 2003, and most were from central Green Bay (Gunderman and Elliott 2004). Other dead fish have been recovered from near Michigan City (see frontispiece for location of ports), IN, and Manistee and Petoskey, MI. What proportion of this die-off was observed or reported is unknown. At the time of recovery, no obvious cause of death has been apparent, but laboratory examination of fresh specimens recovered from Green Bay found enough *Clostridium botulinum* in ingested prey items to suspect type-E botulism (R. Getchell, personal communication, 2005). Similar die-offs in Lake Erie and Lake Ontario since 2000 have been associated with type-E botulism (D. Carlson, personal communication, 2005).

Fig. 6. Harvest and effort for the recreational hook-and-line lake sturgeon fishery in the lower Menominee River (G. Kornely, personal communication, 2005). Zero catches in 2000, 2002, and 2004 reflect closures in alternate years.



Although sea lamprey related mortality has not been quantified for sturgeon, 82 of 212 fish collected in 2003 from the open waters of Green Bay bore a total of 128 marks. Type A-IV (feeding, healed) and Type B-IV (non-feeding, healed) marks (King 1980) were most common and amounted to 37 per 100 fish, indicating that sea lampreys commonly attached to sturgeon. Marking rates were 6 per 100 fish for A-I-III marks, which indicate more-recent attachments. The relationship between sea lamprey marking and mortality is currently being researched. The sensitivity of young sturgeon to the chemical 3-trifluoromethyl-4-nitrophenol (TFM) used to treat rivers for larval lamprey (Johnson et al. 1999) has led to the implementation in 1998 of a "sturgeon protocol" that reduces the concentration of TFM and defers treatments until after July 1 in rivers where YOY sturgeon are known or suspected to occur (U.S. Fish and Wildlife Service/Fisheries and Oceans Canada 2005).

Management

Substantial portions of the sturgeon's historical spawning and rearing habitats are impounded or blocked by dams, and no effective passage exists around these barriers. Passage, however, is being designed into a replacement for a dam on the Manistique River and for several dams on the Menominee River. Passage for native fishes, including sturgeon, also will be provided as a condition for operation of a barrier planned for the Cedar River. Careful regulation of flow over dams and through hydropower facilities is also necessary to ensure that river segments below dams remain usable by sturgeon.

In 2000, recreational harvest of sturgeon from Lake Michigan was banned, except in the Menominee River where harvest from a fall recreational fishery was reduced by increasing the minimum size limit from 50 inches to 70 inches (TL) in even-numbered years, creating essentially a catch-and-release fishery (M. Donofrio, unpublished data).

In 2004, the Little River Band of Ottawa Indians began a long-term rearing program on the Manistee River where wild-caught larvae are transferred into a streamside rearing facility for several months, to enhance early survival, before they are released in the river, typically in late summer (M. Holtgren, personal communication, 2005). The goal is to increase early survival before they are released.

In 2003, the Wisconsin Department of Natural Resources initiated a reintroduction of sturgeon into sections of the Milwaukee and Manitowoc Rivers having an unimpeded connection to Lake Michigan. Hatchery-reared larvae from egg-takes in the Wolf River were stocked into the Manitowoc (N = 119,793) and Milwaukee (N = 64,000) Rivers in the spring of 2003. In 2004, fingerlings (N = 2,000) and juveniles (N = 200) were stocked into the Milwaukee River and will be stocked in both rivers in 2005. In addition, 6-8 adults were transferred from the Wolf River into the Milwaukee River in each of these years (B. Eggold, personal communication, 2005). Details of these stocking programs spurred considerable debate among the agencies and institutions involved with sturgeon management and research. Concerns focused on the need to maintain and ensure genetic diversity among populations and on the potential risks posed to remnant populations if stocked fish were to stray and spawn in non-target rivers. In 2003, the Lake Michigan Committee formed the Lake Michigan Lake Sturgeon Task Group (LSTG) and charged it with reviewing stocking proposals and developing a restoration plan for sturgeon. Initial work on this plan resulted in draft *Guidelines for Genetic Conservation, Propagation and Stocking of Lake Sturgeon in Lake Michigan*. The agencies agreed to follow these guidelines when stocking fish in the future and began work to develop streamside facilities as means of rearing sturgeon in a manner that all agencies could support, beginning with the Milwaukee, Manitowoc, Cedar, and Whitefish Rivers in 2006.

Progress and Recommendations

Lakewide abundance and distribution of sturgeon in Lake Michigan remain low and restricted compared to historical levels. Although some populations appear to be self-sustaining and possibly increasing in abundance, the long-term status of other populations remains questionable. Research and assessment during the last five years represent progress in meeting the fish-community objective of maintaining self-sustaining stocks, but the objective of enhancing the lakewide population will require a larger effort. Existing agency restoration plans (Hay-Chmielewski and Whelan 1997; Wisconsin Department of Natural Resources 2000) and the current draft of the LSTG restoration plan provide additional objectives and strategies for maintaining and enhancing self-sustaining stocks of sturgeon. Specific strategies include inventorying populations and habitats so that areas for protection and restoration can be prioritized; augmenting remnant populations and reestablishing others; determining effects of exotic species, contaminants, and diseases on sturgeon; and implementing public education. A long-term commitment of additional resources will be required to implement and evaluate these strategies. With the eventual approval of a lake sturgeon restoration plan, more-specific objectives and strategies for sturgeon should be incorporated into a revision of the lake's fish-community objectives.

STATUS OF PLANKTIVORE POPULATIONS

Charles P. Madenjian[6], David M. Warner, David B. Bunnell, Randall M. Claramunt, and John M. Dettmers

Maintain a diversity of planktivore (prey) species at population levels matched to primary production and to predator demands. Expectations are for a lakewide planktivore biomass of 0.5 to 0.8 billion kg (1.2 to 1.7 billion lb).

Planktivore biomass during 2000-2004, estimated from bottom trawling, ranged from 0.05 to 0.09 billion kg (mean = 0.07 billion kg), an apparent order of magnitude drop below the above objective from Eshenroder et al. (1995), which was based on acoustic data. In the previous state-of-the-lake report, Fleischer et al. (2005), using acoustics, estimated that lakewide biomass of planktivores in the main basin of the lake during 1993-1996 ranged from 0.3 to 0.65 billion kg, and they concluded that the planktivore objective was obtainable but not sustainable. Fleischer et al. (2005) predicted that total planktivore biomass in Lake Michigan would not substantially change between 2000 and 2004, and, were acoustics used to generate biomass for these years, the change would have been much less

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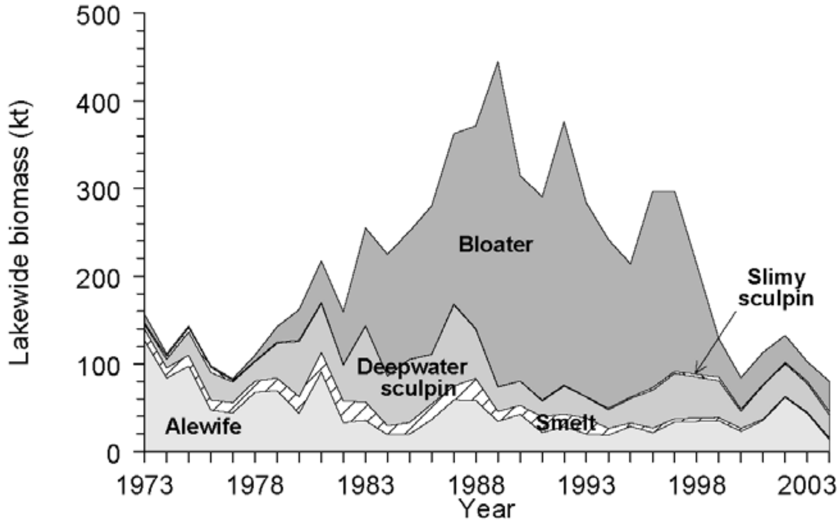
than indicated by bottom trawling. For this report, we will mainly focus on results from the U.S. Geological Survey (USGS) bottom-trawl survey. As USGS bottom trawling and hydroacoustic programs become better integrated, both bottom-trawl and hydroacoustic estimates will be used to address progress toward the planktivore objective in future reports.

Current Status

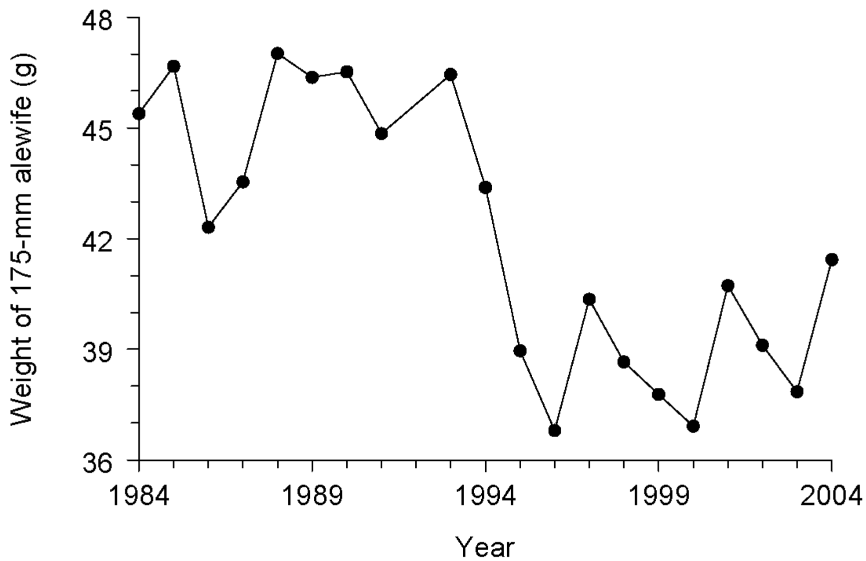
Alewife biomass, based on bottom trawling within the 5- to 114-m depth contours, increased from 23 kt (1,000 kt = 1 billion kg) in 2000 to 62 kt in 2002 and then decreased to 14 kt in 2004 (Fig. 7). The temporal trends in alewife biomass during 2000-2004 are explained by recruitment of the exceptionally large 1998 year-class to the adult population, although the abundance of this and other year-classes was tempered by high predation by salmonines (Madenjian et al. 2005a, b). Hydroacoustic estimates of alewife biomass (Warner et al. 2005) showed the same temporal trends as did bottom trawling. Bloater biomass ranged from 23 kt to 37 kt during 2000-2004 (Fig. 7). In contrast, peak bloater biomass in the USGS bottom-trawl time series occurred in 1989, when the lakewide biomass was estimated at 364 kt. The relatively low levels of bloater abundance observed during 2000-2004 continue a protracted period (1992-2003) of very low recruitment (Madenjian et al. 2002; 2005a). Rainbow smelt biomass ranged from 1 kt to 3 kt during 2000-2004 (Fig. 7). Lakewide biomass of rainbow smelt was estimated at 25 kt in 1988 but then declined rapidly during 1993-1997 and has remained low since then. Predation on rainbow smelt by salmonines was estimated to be greatest during 1983-1987, and, therefore, the recent low level of rainbow smelt abundance is difficult to explain (Madenjian et al. 2002; 2005a). Rainbow smelt abundance has decreased in Lakes Superior, Huron, Ontario, and Michigan during the 1990s and early 2000s (O'Gorman et al. 2005). Whether or not the same factors have driven these declines in all four lakes remains undetermined.

Fig. 7. Estimated lakewide biomass of prey fishes in Lake Michigan, 1973-2004, based on the USGS bottom-trawl survey.



Adult alewife condition decreased in 1995 and has remained at a low level since then (Fig. 8). Average condition during 1995-2004 was about 13% lower than average condition during 1984-1994. In addition, alewife weight-at-age decreased during the late 1990s (Madenjian et al. 2003). The decrease in alewife growth and condition during the 1990s has been attributed to a decline in *Diporeia*, spp. abundance (Madenjian et al. 2003). Also, the energy density of adult alewives during 2002-2004 was 23% lower than during 1979-1981 (Madenjian et al. 2006).

Fig. 8. Estimated weight of a 175-mm (total length) alewife in Lake Michigan, 1984-2004. Estimates based on length-weight regressions applied to measurements (total length) of alewives caught in USGS bottom trawling.



An analysis of USGS bottom-trawl data has shown that survival of alewives to age 3 has been influenced primarily by salmonine predation and secondarily by spring and summer water temperatures during an alewife's first year (Madenjian et al. 2005b). These results corroborated the contention that the decline in alewife abundance during the 1970s and early 1980s was driven by salmonine predation. Furthermore, the exceptionally strong year-class of alewives produced in 1998 was due likely, at least in part, to extraordinarily warm water during the spring and summer of 1998. Bloater recruitment in Lake Michigan appears to be cyclic (Madenjian et al. 2002, 2005a). Recruitment was very strong during 1980-1990 but very weak during 1992-2003. These cycles have a periodicity of approximately 30 years and seem to be largely independent of human interventions or interactions with other fishes.

Annual commercial harvest of bloaters from Lake Michigan ranged from 0.7 to 0.9 kt during 2000-2003, whereas commercial harvest of rainbow smelt ranged from 0.08 to 0.2 kt. The commercial fishery for alewives was closed in 1991, but some bycatch is still reported. Annual commercial harvest of alewives ranged from 0.02 to 0.09 kt during 2000-2003.

Progress

The current level of planktivore biomass in Lake Michigan is below the 500-800 kt sought in the planktivore objective. The lakewide biomass of planktivores has varied substantially during the past 30 years, and these fluctuations are due primarily to changes in the biomass of bloaters. If bloater abundance continues to cycle, the planktivore objective will be achieved during years (like in the late 1980s) when bloater biomass is at its apogee, which is expected within 10-15 years. The shortfall in planktivore biomass is unlikely to be met by alewives during the next five years if predation by salmonines remains high. In fact, increased predation could drive alewife biomass even lower. Because the factors responsible for the decline in rainbow smelt abundance during 1992-2002 have yet to be clearly identified, prediction of trends in rainbow smelt biomass in the upcoming five years is tenuous at best. Therefore, we do not foresee a recovery in the aggregate biomass of planktivores before the next reporting period (2005-2009). However, during the next 10-15 years, an expanding bloater population may result in a biomass of planktivores consistent with the fish-community objective.

Recommendations

Consideration should be given to scaling the planktivore objective to better account for the cyclical dynamics of the bloater population. In view of the now better-documented negative effects of alewives on important native species (Smith 1970; Wells and McLain 1973; Krueger et al. 1995; Fitzsimons et al. 1999; Madenjian et al. 2002), an assessment of the desired future role of alewives should also be considered. Important questions include: how low does alewife abundance have to be to allow for successful restoration of the lake trout population? and would such a low level of alewife abundance result in collapse of the Chinook salmon population and/or fishery? Inherent in these questions is a review of the compatibility of the salmonine and planktivore objectives.

GROWTH AND NUTRITIONAL STATUS OF SALMONINES

Amber K. Peters[7]

Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout.

Although the fish-community objectives for Lake Michigan (Eshenroder et al. 1995) are not specific for growth or robustness of the various salmonines, these characteristics are important if the above objective is to be achieved. Here I present growth data for lake trout taken from the spring lakewide assessment (Schneeberger et al. 1998) and for Chinook salmon, coho salmon, and steelhead taken at weirs in Michigan and Wisconsin. Growth data with good spatial and temporal coverage for lake trout and Chinook salmon were available. For the other salmonines, growth data that adequately describe temporal trends are available only for coho salmon and steelhead.

Mean weight of lake trout (all ages) caught in the spring changed little during 1999-2003, but, since 2000, the weight of returning fish trended upward for age-classes 3-7 (Fig. 9). The mean weight of returning Chinook salmon was trending in the opposite direction (Fig. 10). Following the bacterial kidney disease (BKD) epizootic in the late 1980s (Holey et al. 1998), growth of Chinook salmon trended upwards and reached a high in the early 1990s. The weight of returning fish at age 3 then declined and leveled out in 1998-2000 before peaking again in 2001. The weight of returning fish declined sharply in 2002-2003, such that, in 2003, Chinook salmon collected from the Strawberry Creek weir (Wisconsin) were below the 20-year averages for both weight and length (Fig. 10) (Peeters and Royseck 2003).

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The weight of returning Chinook salmon taken at the Little Manistee River weir (Michigan) in 2003 was at its lowest level since 1991, indicating (when viewed in conjunction with the Strawberry Creek data) that the decline occurred lakewide. Also, the weight of returning fish decreased during the summer of 2004, a time when Chinook salmon typically gain weight (R. Claramunt, personal communication, 2005).

Fig. 9. Mean weight of returning lake trout from the spring lakewide assessment in Lake Michigan, 1999-2003.

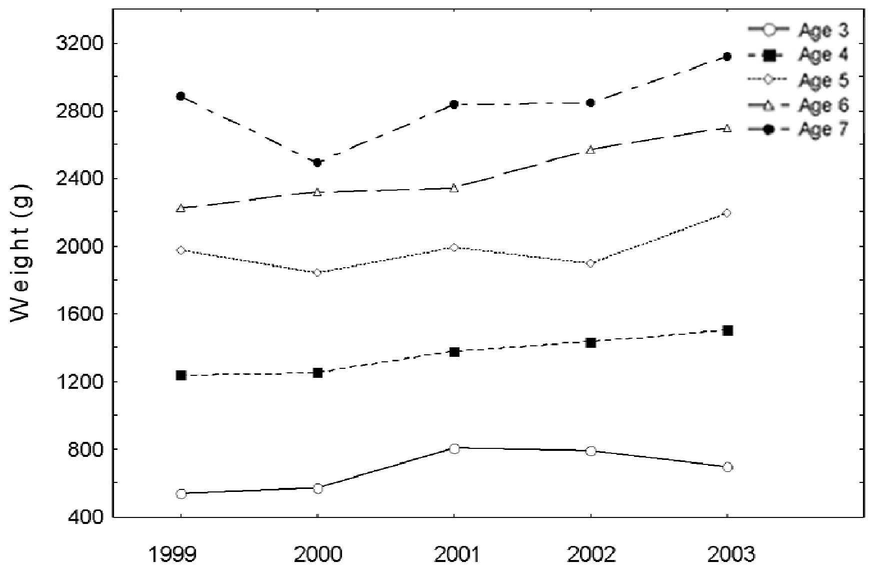
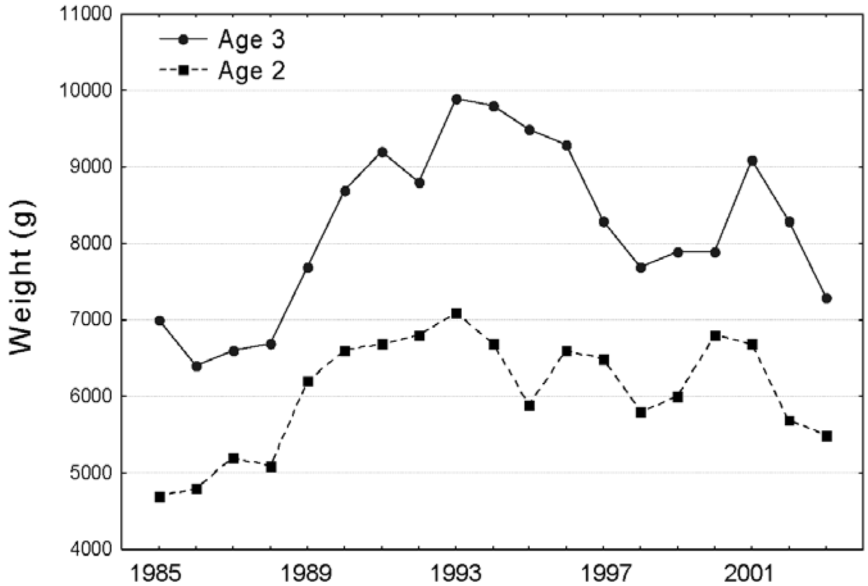
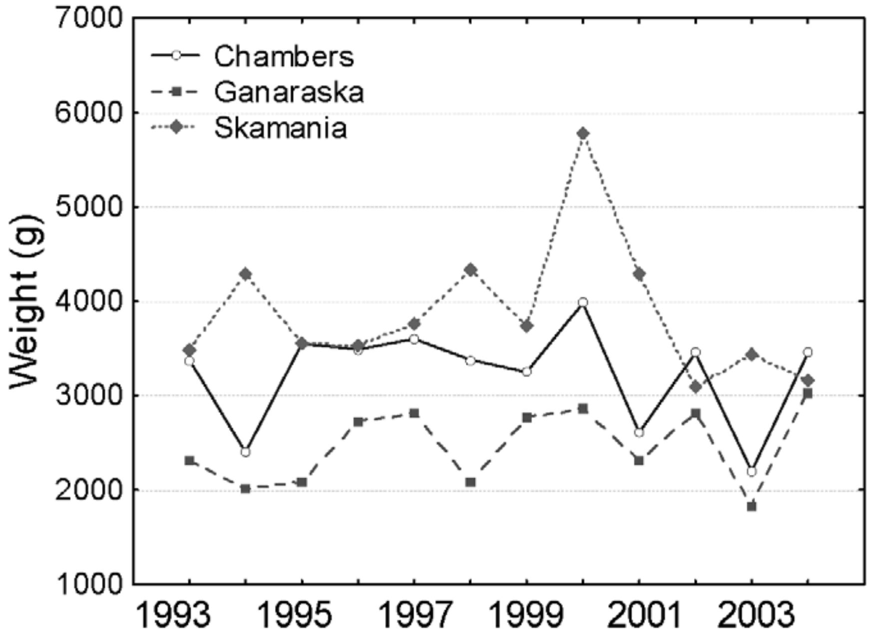


Fig. 10. Mean weight for age-2 and age-3 Chinook salmon taken at the Strawberry Creek weir, WI, 1985-2003.



Mean weight for age-2 coho salmon returning to the Besadny Anadromous Fisheries Facility (BAFF) in Wisconsin varied from 2.3 to 3.7 kg from 2000-2004, values which were below the recent high of 5 kg seen in 1997. During 2000-2004, mean weight of age-1 coho salmon ranged from 0.6 to 1.1 kg with no discernable trend. The spring run of steelhead in 2004 at the BAFF was the largest since 1998, but returns were still substantially lower than from 1991 to 1996 (Hogler and Surendonk 2004). Mean weight of three strains of steelhead taken at the BAFF varied without trend from 1993 to 2004 (Fig. 11). A similar lack of variation in weight of returning fish was observed for steelhead returning to the Little Manistee River weir during 1991-2006 (J. Jonas, personal communication, 2007).

Fig. 11. Mean weight of returning fish for the Chambers, Ganaraska, and Skamania strains of steelhead taken at the Besadny Anadromous Fisheries Facility, WI, 1993-2004.



The nutritional status of Chinook salmon continues to be of special concern because this fish is the dominant top predator in Lake Michigan, nutritional stress may have been responsible for the epizootic in this species in the late 1980s (Holey et al. 1998), and the recent declines in mean weight of returning fish may indicate a declining food supply. Whole-body lipids are an important indicator of nutritional status (Adams 1999, Madenjian et al. 2000), but lipids are expensive to measure. My research (Peters et al. 2007) showed that muscle water content was an adequate surrogate for whole-body lipid analysis. Based on this research, I recommend reporting the water content of muscle tissue for small Chinook salmon (<500 mm TL) collected in spring (April to mid-June) and the proportion of small fish in spring whose percent water in muscle exceeds 78%. These metrics should provide early indicators of nutritional stress in Lake Michigan Chinook salmon.

FISH HEALTH

Greg Wright[8], Dale C. Honeyfield, and Mohamed Faisal

Introduction

Although the lake's fish-community objectives (FCOs) did not directly address fish health, the subject was addressed in the previous state-of-the-lake report (Wright et al. 2005) and will be discussed further here. A well-publicized Chinook salmon die-off in Lake Michigan during the late 1980s resulted in more focus on fish health (Johnson and Hnath 1991). This epizootic was likely, but not entirely, a result of bacterial kidney disease (BKD), which is caused by the bacterium *Renibacterium salmoninarum* (Holey et al. 1998). Although the exact etiology and precipitating factors for the BKD-Chinook salmon epizootics of the late 1980s are not completely understood, fishing effort by 1995 declined by more than 50%, resulting in substantial economic losses throughout the basin (Holey et al. 1998).

In addition to infectious agents, non-infectious diseases, such as early mortality syndrome (EMS), have also been hypothesized to affect the productivity of salmonine populations (Brown et al. 2005b). Fecundity, predator-prey relationships, growth, and spawning behavior of fish can be adversely impacted by disease (Heins and Baker 2003; Brown and Honeyfield 2004). Stephen and Thorburn (2002) recommended shifting research and management paradigms from the current overemphasis on pathogen detection and the health of individual fish to a broader ecological approach that considers the impacts of disease at the population and community level. Overall, there is a need to determine how major diseases,

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such as BKD and EMS, impact the population dynamics of Lake Michigan fishes.

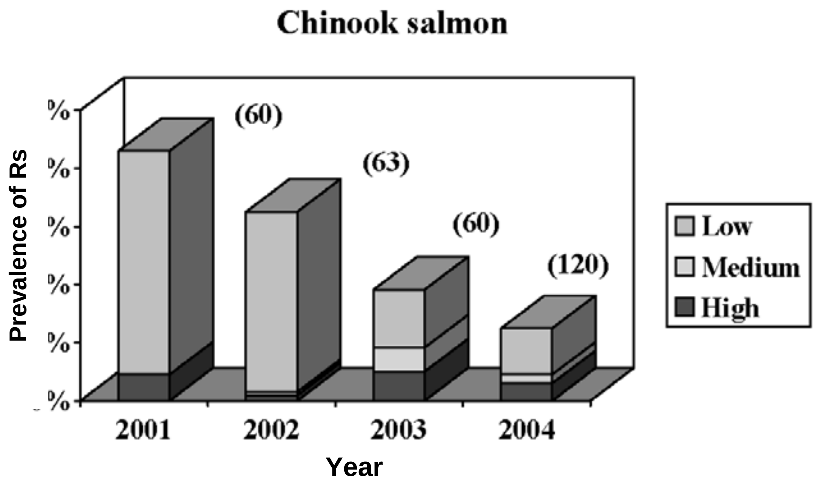
Bacterial Kidney Disease (BKD)

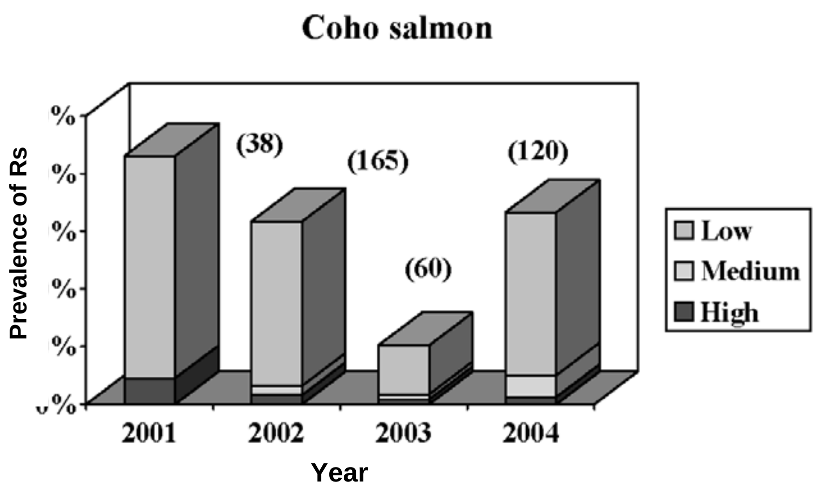
MacLean and Yoder (1970) reported a high prevalence of BKD (>50%) in coho and Chinook salmon from several sites in Lakes Michigan, and the disease occurs throughout the lake. Serological and molecular assays also revealed the presence of *R. salmoninarum* in bloater and lake whitefish from Lakes Michigan and Huron (Jonas et al. 2002) as well as in several forage fishes, including alewives (K. Scribner, personal communication, 2005). *R. salmoninarum* has also been isolated from the kidneys of sea lampreys, implicating them as a possible vector for the disease (Eissa et al. 2004).

To minimize BKD in culture facilities and subsequent introduction into the lakes after stocking, Michigan and Wisconsin began to cull adult salmon with clinical signs of BKD at egg-take weirs. In addition, Michigan began using field enzyme-linked immunosorbent assays in 1993. These efforts appear to have reduced the incidence of BKD at hatcheries (J. Hnath and S. Marquenski, personal communications, 2005). The prevalence of overt clinical disease of Chinook and coho salmon collected at harvest weirs dropped from 25% in 1990 to 1.6% in 2001 (J. Hnath, personal communication, 2005).

Despite the low incidence of overt clinical disease, the prevalence and intensity of *R. salmoninarum,* as measured by quantitative enzyme-linked immunosorbent assays, among Chinook salmon returning to spawning weirs during 2001-2004 remains high in Lake Michigan (50%) as compared to Lake Huron (13%), although most Lake Michigan fish have low antigen titers. Similar findings have been observed in coho salmon (Fig. 12). This information suggests that *R. salmoninarum* remains widely distributed in Lake Michigan. The impact of BKD on susceptible stocks remains unclear, but could impede achievement of many of the lake’s FCOs.

Fig. 12. Prevalence of *Renibacterium salmoninarum* in feral Chinook salmon spawners collected from the Little Manistee River weir and in the Michigan-adapted coho salmon strain collected from the Platte River weir, 2001-2004 (sample size at top of bar). Data were generated using a polyclonal antibody-based quantitative enzyme-linked immunosorbent assay performed on kidney tissues. Positive samples (absorbance ≥0.10) were assigned the following antigen-level categories: low (0.10-0.19), medium (0.20-0.99), and high (≥1.00).





Early Mortality Syndrome (EMS)

Within the Great Lakes basin, EMS is a salmonid fry mortality associated with low thiamine. In addition to fry mortality, growing evidence suggests that low thiamine adversely affects multiple physiological processes and life stages of fish. Evidence of brain lesions in thiamine-deficient fry that survived EMS (DCH, personal communication, 2005) suggested that these survivors might exhibit reduced fitness. Fry from eggs with <4.0 nmol/g total thiamine were subsequently shown to have behavioral and physiological anomalies (Brown and Honeyfield 2004):

- Detailed visual discrimination and motion detection differed between thiamine-deficient and thiamine-replete lake trout fry
- Low thiamine (<2.0 nmol/g) reduced the ability of lake trout fry to feed on *Daphnia*
- Fry growth was positively related to thiamine concentration in three wild stocks; growth rate followed a sigmoidal dose-response relationship with an inflection point near 4 nmol thiamine/g egg, and a significant effect on feeding was observed in 33% of families with egg thiamine concentrations <4 nmol/g egg
- Morbidity and mortality in adult lake trout, steelhead, and coho salmon have been observed at or below 500 pmol thiamine/g of muscle tissue (Brown et al. 2005c)

Egg thiamine concentrations in 179 female lake trout collected from Lake Michigan during 1996-2003 provide some insight into potential impacts of low thiamine on reproduction and recruitment. Overall mean thiamine concentration was 3.11 nmol/g, and, more importantly, the distribution of egg thiamine values around the mean was skewed downward (median 1.59 nmol/g) (Table 3), suggesting an even greater risk of reproductive failure. Some 48% of the eggs were at risk of direct fry mortality, and 75% of the eggs had thiamine concentrations below the threshold for growth effects (4.0 nmol/g). Between 1996 and 2003, the percentage of eggs with <1.5 nmol/g thiamine from western Lake Michigan averaged 47% (Table 3). In contrast, lake trout eggs from Parry Sound, Lake Huron, a stock considered to be self-sustaining, contain higher total thiamine, and only 17% of eggs exhibited thiamine concentrations <1.5 nmol/g egg (Table 3).

Table 3. Average and median total lake trout egg thiamine levels and the percent of eggs expected to show lethal (<1.5 nmol/g) and secondary (<4.0 nmol/g) effects at the fry stage for Lake Michigan, 1996-2003, and Parry Sound, Lake Huron, 2001-2002.

Location	Year	N	Average total egg thiamine (nmol/g)	Median total egg thiamine (nmol/g)	Percent of eggs <1.5 (nmol/g)	Percent of eggs <4.0 (nmol/g)
Lake Michigan:						
Overall	1996-2003	179	3.11	1.59	48	75
Western	1996-2003	154	2.93	1.46	47	75
Eastern	2001	19	1.46	1.31	63	100
Southern	2002	6	13.05	7.68	50	50
Lake Huron:						
Parry Sound	2001	29	3.91	3.76	17	66
	2002	13	4.02	3.81	0	62

Thiamine deficiency in lake trout is linked to the presence of thiaminase, a thiamine-degrading enzyme found in alewife (Honeyfield et al. 2005; Tillitt et al. 2005) and recently discovered in Great Lakes plankton (Brown and Honeyfield 2004). Evidence supporting the link between alewife containing thiaminase and reproductive failure of lake trout is growing (Brown et al. 2005b). EMS is highly correlated with low concentrations of unphosphorylated thiamine in unfertilized salmonine eggs. In addition to low egg thiamine concentrations in families expressing EMS, other biochemical markers (stable isotopes of nitrogen and carbon, fatty acid signatures, and lipid-soluble carotenoids and vitamins) suggest differences in the diet of females determine whether fish were affected or unaffected (Brown et al. 2005a). Small but significant differences occurred in egg carotenoids, retinoids, $\delta^{15}N$ depletion, and fatty acid profiles of fish producing no fry or low numbers of fry expressing EMS, relative to those producing higher numbers of fry with EMS (Brown et al. 2005a). These results are consistent with the hypothesis that a more-diverse forage base with fewer alewife may reduce the impacts of EMS on many Lake Michigan salmonines.

Research Needs

We recommend the following lines of research:

- Assess pathogen prevalence and incidence of clinical disease in important fishes
- Implement comprehensive fish health assessments for wild and naturalized Great Lakes fish populations (Faisal and Hnath 2005) with the goal of linking fish pathogens, host physiology, immunology, nutrition, life history, and anthropogenic factors to disease incidence and fish health
- Incorporate results of comprehensive assessments in development of risk-assessment models
- Monitor egg and tissue thiamine levels in self-sustaining salmonine populations to better understand the impacts of thiamine deficiency
- Survey the prevalence of thiaminase in lower trophic levels

SALMONINE REPRODUCTION AND RECRUITMENT

Jory Jonas[9], Randall M. Claramunt, and Edward S. Rutherford

Introduction

Fostering self-sustainability and protecting the genetic diversity of fish stocks are key features of the goals and guiding principles in the fish-community objectives for Lake Michigan (Eshenroder et al. 1995). Reliance on natural feedbacks between predator and prey to control recruitment can provide more-effective self-regulation, leading to greater system resilience and stability, than external actions, such as stocking or harvest, which entail time lags (Christie et al. 1987). The genetic fitness of self-sustaining populations likely exceeds that of stocked populations (Berejikian et al. 1999, 2001; Kostow et al. 2003), because self-sustaining populations benefit from natural selection and are able to adapt to unique and specific conditions in localized environments (Falkner and Falkner 2000).

Natural recruitment of Lake Michigan salmonine populations has been quantified historically by mark-and-recapture studies of hatchery-released fish, by counting out-migrating wild smolts in tributary streams, and, more recently, by surveys of lake trout eggs and fry on spawning reefs. Because hydrologically stable, groundwater-fed streams most conducive to natural reproduction of anadromous salmonids (Carl 1983; Seelbach 1985) are generally found in just the northern and eastern areas of the lake's basin, measures of smolt out-migration or of returning adults in streams can be

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difficult to translate into the whole-lake population, which also comprises stocked fish. In contrast, if recruitment of wild fish is quantified through recreational fisheries and independent assessments in the open lake, information regarding stream-specific influences on the lakewide population is not obtained. Given limited monitoring efforts, the recruitment dynamics of salmonines continues to be incompletely understood. Here we report on natural recruitment of four of the lake's major salmonines: coho salmon, Chinook salmon, steelhead, and lake trout. We do not report on brown trout because, although it is a major salmonine, its level of natural reproduction is minimal (Keller et al. 1990).

Progress

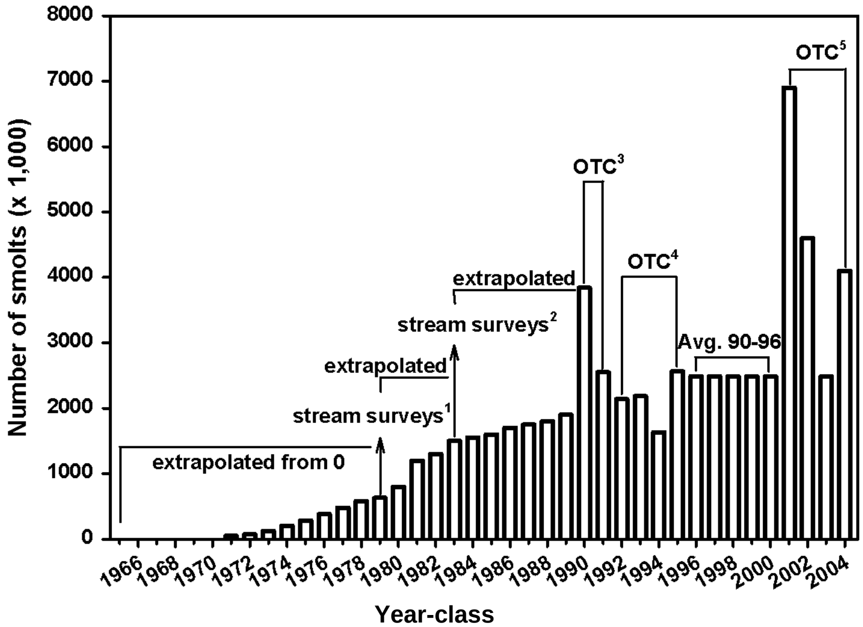
Coho Salmon

Spawning of coho salmon in the wild was encouraged as early as the fall of 1967 when adults were transferred to seven Michigan streams (Borgeson 1970). Reproduction was detected the following year in at least two of the streams, the Boyne and Boardman Rivers (see frontispiece for location of rivers) (Borgeson 1970), and since then has been observed in many tributaries (Taube 1974; Carl 1983; Seelbach 1985; Rutherford et al. 1999; T. Newcomb, personal communication, 2005). In 1979, all stocked coho salmon in Lake Michigan were fin clipped, allowing Patriarche (1980) to estimate that wild coho comprised 9% of the lakewide population. In recent years, smolt production has been measured in individual rivers, but there are no current efforts to estimate lakewide production.

Chinook Salmon

Five investigations conducted over the past 35 years suggest that natural recruitment of Chinook salmon, the most productive of the lake's salmonines, has increased (Fig. 13). By the late 1970s, approximately one decade after stocking began, lakewide smolt production was estimated at 600,000 smolts. By the early 1990s, smolt production was estimated at 2.5 million, and estimates in recent years indicate more than 4 million smolts have been produced annually (Fig. 13). Data from lakewide surveys and smolt monitoring in indicator streams suggest recruitment levels can vary from three- to fourfold in any given year, due in part to changes in stream flow during the three- to four-month nursery period after hatch (Zafft 1992; ESR, unpublished data). Management objectives for production of wild fish relative to stocking needs have not been determined for Chinook salmon.

Fig. 13. Estimates of wild Chinook salmon smolt production from Lake Michigan tributaries, 1965–2004. OTC refers to the recapture of adults marked as smolts with oxytetracycline ([1]Carl 1982; [2]Keller et al. 1990; [3]Hesse 1994; [4]ESR and DFC, unpublished data; [5]RMC and J. Johnson, unpublished data).



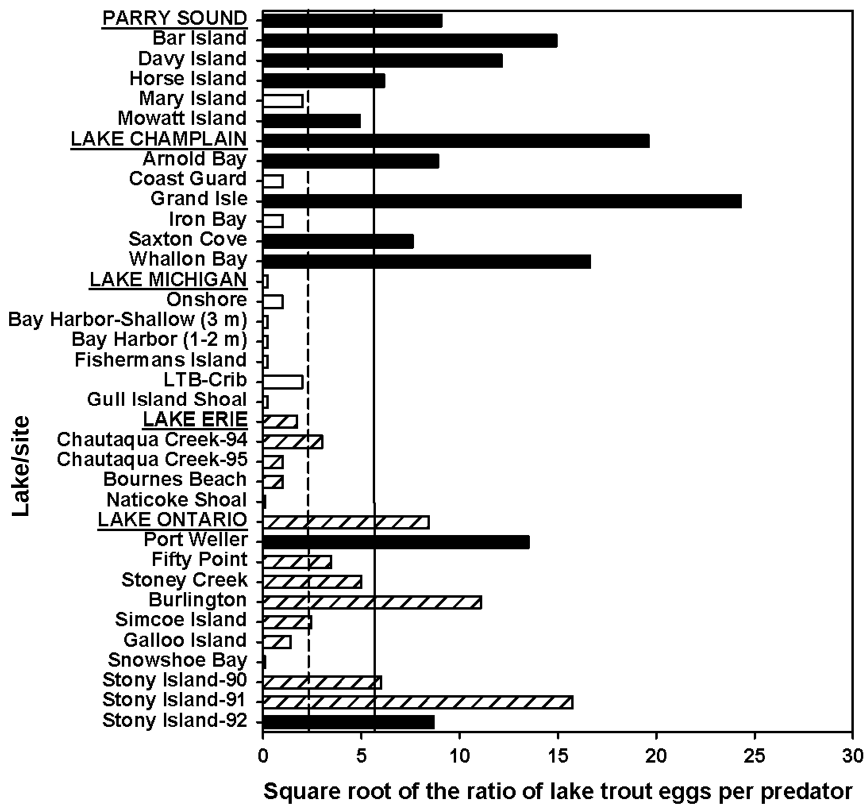
Steelhead

Production of wild steelhead in Lake Michigan is relatively simple to estimate because differential growth patterns on scales can be used to distinguish hatchery from wild fish (Seelbach and Whelan 1988). Current annual recruitment estimates average 250,000 to 300,000 smolts, but, as with Chinook salmon, recruitment varies three- to four-fold annually due to fluctuations in temperature in tributary nursery habitats and in stream flows (Seelbach 1987a, b; Newcomb 1998; Woldt and Rutherford 2002). The majority of investigations into steelhead recruitment dynamics have been river-specific (e.g., Seelbach et al. 1994; Newcomb 1998; Rutherford et al. 1999; Woldt and Rutherford 2002; Swank 2005), but some lakewide estimates have been made. As with Chinook salmon, management objectives for production of wild steelhead relative to stocking needs have not been established. To better inform management, factors influencing recruitment success, with an emphasis on forecasting and prediction, need to be investigated. Changes in stocking practices (fingerlings to yearlings) have greatly improved survival of stocked steelhead. Estimated percentages of hatchery steelhead in the lakewide population have increased from 4.1% during 1979-1982 to 83.2% during 1993-1997 (Rand et al. 1993; Bartron and Scribner 2004). Recent genetic and demographic studies of steelhead indicate naturalized steelhead populations have growth, survival, and maturity schedules specific to stream environments, suggesting they have evolved quickly both within Lake Michigan and among the Great Lakes (Bartron and Scribner 2004; Swank 2005). Given these findings, the role of stocking will need to be reconsidered.

Lake Trout

The fish-community objective for lake trout is to "establish self-sustaining lake trout populations" (Eshenroder et al. 1995), and much time and effort have been spent toward rehabilitating this species, which was extirpated during the mid-1900s. Although egg deposition occurred and hatched fry were observed infrequently, no meaningful survival past age 1 has been detected. Revisions are being made to the 1985 rehabilitation plan for lake trout with the goal of enhancing production of wild lake trout (Bronte et al. 2008). Management targets have traditionally focused on abundance of spawning adults in gillnet surveys. Jonas et al. (2005b) have identified a better estimate of potential recruitment: the number of lake trout eggs deposited per egg predator on specified spawning habitats (Fig. 14). Egg-to-predator ratios at surveyed lake trout spawning reefs in Lake Michigan are well below those from sites where fry emergence was measurable (Fig. 14). Consequently, management should focus on achieving higher concentrations of spawning fish near the best habitat to increase the egg-to-predator ratio and the probability of increased recruitment (Bronte et al. 2003a).

Fig. 14. Suggested metric for measurement of success of lake trout spawning: the ratio of lake trout eggs deposited •egg predator^{-1}•m^{-2}. Bars next to site names represent the square root of average ratios for the site. Black bars indicate sites where emergence was detected, white bars indicate sites with no emergence, and hatched bars indicate sites where fry emergence was not assessed. The broken line represents the largest ratio where fry emergence was not detected, and the solid line represents the lowest ratio at sites with detectable fry emergence.



Recommendations for Revision of Salmonine Recruitment Objectives

Naturalized salmonines are a major component of the Lake Michigan fish community, and an understanding of their population dynamics is critical to developing effective lakewide management plans. Given the high temporal and spatial variation in survival rates of offspring from naturalized salmonines, improved methodologies for estimating and predicting natural recruitment and an improved understanding of factors causing variation (e.g., parent stock, stream discharge, stream temperature, and forage abundance) is increasingly important. Lake trout are currently the only species with defined stocking and reproductive targets. We recommend further refinement of lake trout rehabilitation targets by incorporating the egg-to-predator target discussed above. Management objectives for natural production of other salmonines need to be developed, and key questions are: (1) what level of natural recruitment is desirable? and (2) how should stocking rates be adjusted as targets for natural recruitment are approached? Consideration of species interactions, density-dependent responses, and the sustainability of the community should be included when establishing new management targets. Given the current understanding of genetic stock concepts, management objectives and stocking strategies should be revised to reflect more-recent findings. For example, stocking practices may inadvertently harm naturalized fish populations or, at the least, interfere with selective processes. Fishery managers should consider commitments to genetic stock concepts and revise stocking strategies accordingly. A long-term, multi-agency strategy for assessing natural reproduction on a lakewide basis should be developed.

STATUS OF CHINOOK SALMON

Randall M. Claramunt[10], David F. Clapp, Brian Breidert, Robert F. Elliott, Charles P. Madenjian, David M. Warner, Paul Peeters, Steven R. Robillard, and Greg Wright

Introduction

Restore and maintain the biological integrity of the fish community so that production of desirable fish is sustainable and ecologically efficient.

Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg, of which 20-25% is lake trout.

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Inherent in the above overall goal for the fish community and the specific objective for salmonines (Eshenroder et al. 1995) is a desire to maintain a salmonine fishery dominated by Chinook salmon (i.e., target annual yield of 3.1 million kg), whose abundance is sufficient to suppress alewife populations but not beyond levels where predator consumption would threaten food-web integrity. The salmonine and planktivore objectives (see the Status of Planktivore Populations chapter) are based on the understanding that large populations of exotic forage fishes, such as alewife and rainbow smelt, have negative impacts on recruitment of native fishes, and controlling exotic prey fishes presents an opportunity to create new, diverse fishing opportunities. Therefore, progress towards these objectives is based on an evaluation of the balance between predator and prey (e.g., Chinook salmon and alewife interactions) rather than on suppression of alewife populations through extreme top-down predation.

A Salmonid Working Group (SWG) was established under the Lake Michigan Technical Committee (LMTC) to evaluate the health of the Chinook salmon population, evaluate potential threats to predator-prey balance, and make recommendations for management. To conduct its evaluation, a suite of biological indicators was selected by the SWG: population abundance estimated from creel and fishery-independent surveys, amount of natural reproduction, size-at-age and ration, forage-fish abundance, and indices of fish health. Several data sources are available for assessment of each indicator, but only a few data sets that are representative are presented here. An indicator was determined to reflect an unhealthy population when its current value(s) in relation to the distribution of such values reached one of two levels (triggers), referred to colloquially as red flags:

- Level I: the most-recent value exceeds the 20th percentile
- Level II: values in three out of the last five years exceed the 40th percentile

When 50% or more of the indicators are red flagged under either level, the SWG will recommend that the Lake Michigan Committee (LMC) consider revising management (e.g., cut stocking rates) of Chinook salmon (for an overview of the red flag approach, see Claramunt et al. 2004, 2006).

Current Status

Abundance

Lakewide harvest of Chinook salmon was highest in the late 1980s, declined substantially during 1989-1994, and has been slowly increasing since 1995 (Fig. 15). Annual lakewide harvest has ranged from 0.6-4.7 million kg with an average (±SE, throughout chapter) harvest of 1.9 ± 0.3 million kg (Table 4). The 2004 harvest was approximately 3.9 million kg—above the 3.1-million-kg objective. In parallel with harvests, catch rates (fish/h) in the recreational fishery declined in the late 1980s, were low during 1992-1994, but have been rising since 1995 (Fig. 15). Average catch rates over the entire time series were 0.05 ± 0.01 fish per hour (range 0.01-0.13 fish per hour) (Table 4). Catch rates in 2004 were extremely high (>0.1 fish per hour) and may be indicative of overly high densities of Chinook salmon, low prey abundance (Madenjian et al. 2005a; Warner et al. 2005), or a combination of both.

Fig. 15. Lakewide harvest of Chinook salmon from Lake Michigan and catch rates from Michigan waters, 1985-2004.

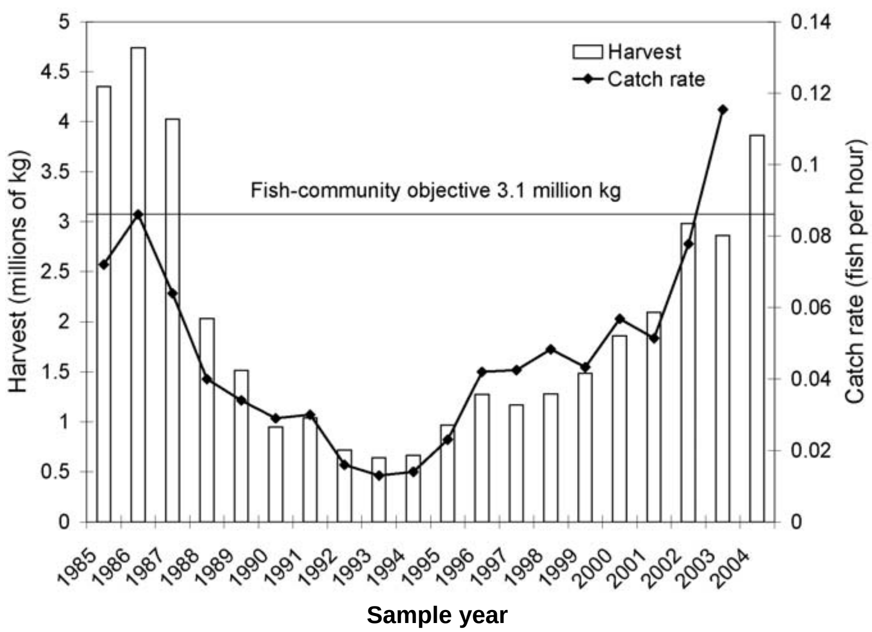


Table 4. Selected 2004 Chinook salmon red flag indicators and their 20th (Level I) and 40th (Level II) percentiles for various periods during 1985-2004. A red flag is triggered when the Level I value is exceeded in the current year (2004) or when the Level II value is exceeded in three of the last five years (2000-2004) (see Claramunt et al. (2004, 2006) for a more-complete explanation).

	Values for 1985-2004				Values	Level I		Level II	
Biological indicator	**Min.**	**Max.**	**Mean**	**SE**	**for 2004**	**<20%**	**Red flag**	**<40%**	**Red flag**
Harvest (millions of kg)	0.64	4.74	1.94	0.29	3.89	0.95	No	1.27	No
Catch Rate (no. per hr.)	0.010	0.132	0.047	0.001	0.132	<0.02->0.06	Yes	<0.04->0.05	Yes
Fraction of returns OTC marked	0.23	0.5	0.37	0.05	0.5	<0.22->0.52	No	<0.26->0.48	NA
Returns marked—observed vs. expected	0.01	5.12	0.77	0.35	0.17	<0.20->0.55	Yes	<0.34->0.66	No
Survey weight-at-age 2 (g)	1,690	4,050	2,430	141	2,360	1,900	No	2,300	No
Weir weight-at-age 3 (g)	6,400	9,900	8,120	256	6,400	6,700	Yes	7,700	No
Ration age 2 (g)	7.6	32.1	17.0	2.2	10.7	9	No	15	No
Ration age 3 (g)	8.9	38.0	25.0	2.3	19.8	20	Yes	23.5	No
Alewife biomass—bottom trawl (kt)	10.1	61.1	25.4	28.2	13.6	15.5	Yes	21.3	No
Alewife biomass—acoustic (kg/ha)	5.1	16.8	10.6	2.7	5.1	5.1	Yes	7	No
Gross signs disease at weirs (%)	1.4	12.2	4.9	0.8	2.1	10	No	8	No
Gross signs disease in surveys (%)	1.0	54.6	13.8	4.7	1.0	22	No	18	No
% positive BKD at Strawberry Creek weir (Wisconsin)	0	67.0	10.8	3.7	0	>15.0	No	>6.8	No

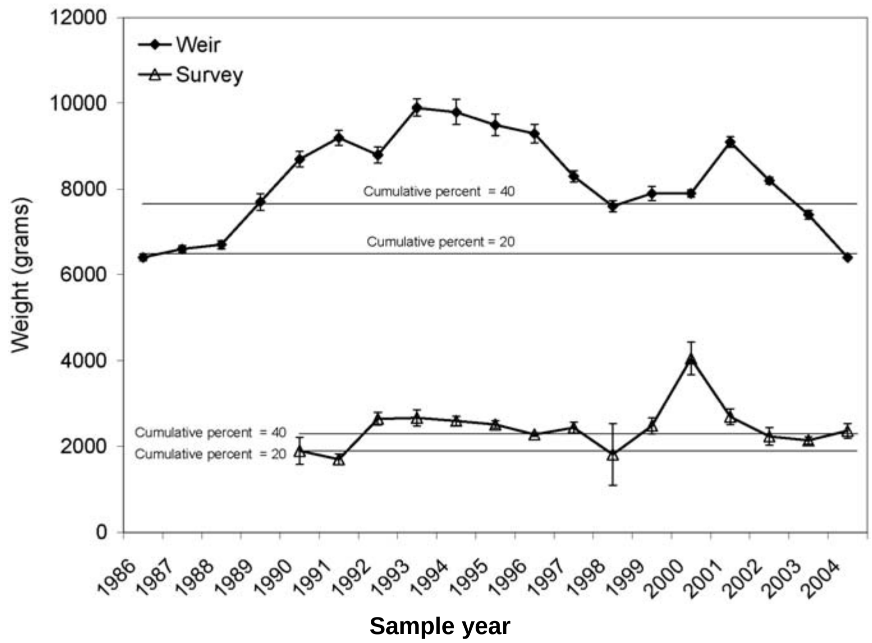
Natural Reproduction

Recruitment of naturally produced Chinook salmon smolts has increased since the species was introduced in 1967 (Fig. 13). Estimates in the early 1990s from oxytetracycline (OTC) studies suggested that natural recruitment accounted for 29-35% of the lakewide adult stock when stocking levels were near their highest (6-7 million smolts) (Hesse 1994). Based on these studies, we assumed that, after 1996, annual wild recruitment amounted to approximately 2.5 million smolts. Recent estimates from OTC-marked fish collected in 2004 by the Michigan Department of Natural Resources indicate that wild-fish recruitment has continued to increase, and natural recruits may account for 50% of the lake population (Table 4).

Growth and Ration

Mean weight-at-age has been variable, suggesting that the conditions that regulate growth have changed over time, presumably from changes in Chinook salmon abundance, forage levels, and environmental factors. To assess changes in growth, we selected weight at age 2 from the open-water survey (males and females combined) and weight at age 3 (females) from returns to the Strawberry Creek (WI) weir. Chinook salmon were sampled during June and July in the open-water survey; weir return data were from September. We chose these sources because the data were collected over a relatively short time period during two different seasons, and the large sample sizes reduced variability in size-at-age estimates. For most of the data sources, weight-at-age peaked in 2000-2001, following the production of an abundant year-class of alewife in 1998 (Madenjian et al. 2005b; Warner et al. 2005). Weight at age 2 from the open-water survey in 2004 averaged 2,430 g, which was somewhat low for the 1986-2004 period (range 1,690-4,050 g) but similar to values in the preceding two years (Table 4; Fig. 16). Weight at age 3 at the weir in 2004, however, was 6,400 kg, the lowest level observed since 1990 (range = 6,400-9,900 g) (Table 4), suggesting that growth conditions for maturing fish during summer 2004 were very poor.

Fig. 16. Mean weight of age-2 Chinook salmon caught in Michigan DNR gillnet surveys, and of age-3 fish taken at Strawberry Creek weir (WI) during 1986-2004, compared to the 20^{th} and 40^{th} red flag percentiles (Table 4) established by the Salmonid Working Group.



Only five Master Angler Awards were granted by the state of Michigan in 2004, suggesting that it was a poor year for growth of Chinook salmon. Only fish that exceed 27 pounds (59,535 g) qualify for an award. An average of 91 ± 17 (range 5-245) Master Angler Awards have been given annually, and the number granted for 2004 was the lowest ever, further confirming a scarcity in 2004 of larger Chinook salmon, as suggested by the weir data.

Trends in ration (grams of prey per stomach) suggest that food availability for Chinook salmon has declined in recent years. For most age-classes of Chinook salmon, ration was low in 1998, increased for several years in association with the strong 1998 year-class of alewife, and then declined beginning in 2002 (Elliott 1993; Rybicki and Clapp 1996; RMC, unpublished data). Average ration for 1990-2004 was 17.0 ± 2.2 g and 25.0

± 2.3 g for age-2 and -3 Chinook salmon, respectively. In 2004, however, ration was 10.7 ± 2.6 g and 19.8 ± 5.6 g for age-2- and 3-year-old fish, respectively—well below the average (Table 4).

Forage-Fish Abundance

In 2004, the biomass of age-1 and older alewife, as measured in bottom-trawl surveys (13.6 ± 5.3 kt), was half of the 1985-2004 average: 25.4 ± 28.2, range 10.1-61.1 kt (Table 4) (Madenjian et al. 2005a). A decline of similar magnitude was seen in the acoustic survey: biomass of age 1 and older alewife in 2004 was 5.1 ± 0.8 kg/ha, as compared to the 2001-2004 average (10.6 ± 2.7 kg/ha, range 5.1-16.8 kg/ha, Table 4) (Warner et al. 2005). The 1998 year-class of alewife comprised most of the biomass of adult alewife during 1999-2004, and the depletion of that year-class by predation and natural mortality likely accounted for the drop in biomass observed in both surveys. Recent (2001-2004) acoustic estimates of young-of-the-year production averaged approximately 1.8 kg/ha, suggesting that alewife recruitment levels have been low to moderate since the 1998 year-class recruited to the adult stock (Warner et al. 2005).

Fish Health

Stress-mediated diseases, such as bacterial kidney disease (BKD), have strong regulatory influences on Chinook salmon populations in Lake Michigan (Holey et al. 1998). Using consistent methods, gross (visual) signs of diseased organs have been recorded for fish captured in the open-water survey since 1994 and at weirs since 1991. On average, about 13.8 ± 4.7% (open-water surveys) and 4.9 ± 0.8% (weirs) of Chinook salmon show gross signs of disease (Table 4). Gross signs of disease from both data sources have declined through time, and currently less than 2% of fish show gross signs of disease—an all-time low. In fact, none of the Chinook salmon taken at the Strawberry Creek weir tested positive for BKD in 2004. Nonetheless, BKD remains a concern (see Fish Health chapter) and monitoring will continue.

Progress

The harvest of Chinook salmon in 2001-2003 was below the salmonine objective (3.1 million kg), but harvest in 2004 (3.9 million kg) exceeded the objective (Fig. 15). Our analysis of the red flag indicators, however, suggests that this harvest level is not sustainable. Frequency distributions of the selected indicators showed that 46% (6 of 13) triggered a red flag at Level I. Only 8% (1 of 12) of the indicators had Level-II red flags. Many of the indicators (e.g., growth, ration, forage abundance) have been trending downward recently, and a number of the 2004 estimates were well below long-term averages, implying that Chinook salmon growth and survival may decline further in 2005.

Chinook salmon stocking levels were reduced in 1999 to minimize the risk of a population crash and its effects on the fishery. This stocking reduction was based on a review of biological indicators and reflected a consensus of managers from each agency involved in stocking. To determine if our approach to evaluating progress toward meeting fish-community objectives (FCOs) was consistent with past management actions, the SWG did a post facto red flag analysis of indicators in 1998, one year before the stocking cut was made. The post facto analysis red flagged seven of 13 Level-II indicators, which would have resulted in a recommendation to reduce stocking in 1999. Therefore, the red flag decision process is consistent with the analysis that led to the 1999 stocking cut, but the red flag approach is an improvement in that criteria are identified in advance, thus streamlining the work and improving communications with the public.

Our evaluation suggests that top predators are suppressing alewife populations, a need identified in the salmonine objective for the lake. This objective envisions imposing enough suppression to allow for recovery of native species without threatening the integrity of the food web. Recent declines in forage-fish abundance and Chinook salmon growth have apparently not resulted in disease-mediated increases in Chinook salmon mortality. What level of predator consumption would threaten the integrity of the food web is unknown. Research has documented the direct negative impacts of alewife on native fishes (e.g., Krueger et al. 1995), but recent trends in Lake Huron suggest that alewife must be suppressed to extremely low levels before a substantial amount of natural recruitment of lake trout (and other species) occurs. Ultimately, the Lake Michigan Committee should identify a long-term strategy for manipulation of Chinook salmon populations that resolves the conflicting goals of allowing for recovery of native species and maintaining sufficient prey to support healthy Chinook salmon populations.

Recommendations

As stated in the previous state-of-the-lake report (Holey and Trudeau 2005), stocking levels and harvest expectations for all salmonines should be reviewed and revised as necessary at five-year intervals. In contrast to what was reported in 2000, planktivore populations in 2005 do not appear to be balanced with predator demand. If balancing predator demand with planktivore production is the top priority for managers, then stocking reductions will likely be necessary in the near future. We recommend that the lake's FCOs be revised, incorporating benchmarks for Chinook salmon that take into account their role in suppressing alewives, their relationship to native predators, and their potential for a sustainable yield.

ASSESSING STOCKING POLICIES FOR LAKE MICHIGAN SALMONINE FISHERIES USING DECISION ANALYSIS

Michael L. Jones[11], James R. Bence, Emily B. Szalai, and Wenjing Dai

Stocking of hatchery-reared fish is one of the primary management tools available to fishery managers working on Lake Michigan. Since the advent of major salmonine stocking programs in the mid-1960s, hundreds of millions of Chinook salmon, lake trout, rainbow trout, brown trout, and coho salmon have been stocked (Kocik and Jones 1999; Hansen and Holey 2002) to provide recreational fishing opportunities, restore native lake trout populations, and reduce the abundance of alewife. Since the early 1980s, experts recognized (Stewart et al. 1981) that a tradeoff existed between stocking too few predatory fish, thereby allowing alewife abundance to rise to undesirable levels and foregoing potential harvest of predators, and stocking too many predators, thereby exceeding the productivity of the alewife population. The dramatic rise in Chinook salmon mortality rates and the subsequent decline in recreational harvest of this species that occurred during the late 1980s in Lake Michigan are widely viewed as having resulted from excessive abundance of stocked predators during this period (Holey et al. 1998; Hansen and Holey 2002). Therefore, a critical question faced by Lake Michigan fishery managers is "how many salmon and trout should be stocked each year?" Here we describe a decision analysis (DA), the goal of which was to assist fishery managers by assessing the performance of alternative stocking strategies in light of the critical uncertainties that make selecting the best strategy difficult.

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DA is a methodology, developed in the field of operations research (Raiffa 1968), that is used to rank the performance of alternative choices in terms of their ability to successfully meet one objective or a set of objectives. DA is enjoying increasing application to fisheries management (Peterman and Anderson 1999), primarily because it offers an approach to systematically account for the effect of uncertainty on the performance of alternative decisions. Both fishery scientists and managers have begun to recognize the critical importance of considering uncertainty and risk when evaluating management options (e.g., Rosenburg and Restrepo 1994). Applications of DA involve several steps: (1) identifying management objectives and options, (2) identifying and quantifying critical uncertainties, (3) developing and applying a model to forecast the outcome of management options, (4) ranking options in terms of their performance at meeting objectives, and (5) evaluating the sensitivity of the conclusions of the analysis to various assumptions.

We conducted a DA for Lake Michigan salmonine stocking in four stages:

1. We met with experts, fishery managers, and stakeholders in March 2000 to discuss and agree upon management objectives, options, and critical uncertainties (Table 5).

2. We used historical data on salmonine harvests, diet, growth rates, and prey-fish abundance to estimate parameters of a salmonine prey-fish population model and the uncertainty associated with the parameter estimates (Szalai 2003).

3. We developed a decision model to forecast the consequences—for alewife abundance, Chinook salmon growth, and Chinook salmon harvests—of alternative stocking strategies.

4. We met again with experts, managers, and stakeholders to demonstrate and discuss the model.

Table 5. The management objectives, management options, and critical uncertainties that were identified at the start of a decision analysis of predator stocking in Lake Michigan that were used to guide the development of a forecasting model.

Management objectives	Management options	Critical uncertainties
• Maintain acceptable catch rates for salmonines in the recreational fishery • Minimize the risks of elevated Chinook salmon mortality caused by poor growth conditions • Maintain a predator-prey balance that minimizes negative effects of alewife predation on native species	• Adjustments to annual stocking rates of salmonines	• Alewife recruitment dynamics (how much predation pressure can the alewife population support?) • Chinook salmon feeding effectiveness (how successful are Chinook salmon at finding prey when the prey become relatively scarce?) • Chinook salmon growth-survival linkages (how strongly coupled is Chinook salmon growth to natural mortality rates?)

The methods for quantifying uncertainties in the parameters of the forecasting model are described in detail in Szalai (2003). Briefly, we developed an estimation model similar to statistical catch-at-age models to reconstruct the historical dynamics of Lake Michigan prey-fish (alewife, bloater, and smelt) populations, but including salmonine predators rather than fishing as an additional source of mortality. The model estimated prey-fish abundance and recruitment from 1962-1999 and the effective search rate of Chinook salmon (i.e., how successfully Chinook salmon can feed when prey fish become relatively scarce). Data sources for model estimation included the U.S. Geological Survey bottom-trawl time series of alewife and bloater catches, recent hydroacoustic survey data on prey fish, and various agency data sets on salmonine catches, sizes-at-age, and diets. Estimated alewife abundance and recruitment were used in a subsequent step to estimate the parameters of a Ricker-type stock-recruitment relationship for alewife. Finally, we used estimates of Chinook salmon mortality rates and size-at-age from the late 1980s and early 1990s (during the period of Chinook salmon collapse and recovery) to model the dependence of mortality on growth. We hypothesized that reduced growth results in an increased probability of elevated mortality, potentially due to disease. We hypothesized further that, when elevated mortality occurs, there is a delay after growth rates recover before mortality rates decline again. This model is consistent with observations during the period of elevated Chinook salmon mortality, but there is great uncertainty because evidence supporting this relationship comes from a single event. For each of the estimation models, we used Monte Carlo-Markov Chain methods to describe the uncertainty associated with all model parameters.

To evaluate stocking policy alternatives, we developed a model that forecasts the future abundances of alewife and both abundances and sizes of Chinook salmon that result from a specific policy. The model includes all major stocked salmonine species as predators, but the abundances and sizes of species other than Chinook remain fixed over time (unless they are altered by a policy action). The model also includes alewife, bloater, and rainbow smelt, but only alewife abundance varies over time. The other predators and prey are included in the model to reasonably represent alternative sources of predation mortality on alewife and alternative prey for salmonines when alewife become scarce.

Because the parameters of the model are uncertain, we repeated each simulation multiple (1,000) times, each time selecting a different set of parameters from the probability distribution of plausible parameter values. Therefore, each stocking policy can have a variety of possible outcomes. We compared the performance of different policies by looking at the distribution of outcomes, the median outcome, and the proportion of outcomes that exceeded or fell below a threshold value deemed to be undesirable. For this report, we consider five alternative stocking policies and six performance indicators (Table 6).

Table 6. Alternative stocking policies and performance measures used to evaluate achievement of objectives in a decision analysis of predator stocking in Lake Michigan.

Stocking policies	Performance measures
• Status quo–continue stocking at current levels • Reduce only Chinook salmon stocking by 50% • Feedback policies—stocking is reduced 50% if fall weight of age-3 Chinook salmon falls below 7 kg and is restored to current levels if fall weight increases above 8 kg: – Option 1: reduce stocking of only Chinook salmon by 50% – Option 2: reduce stocking of all species by 50%, except lake trout – Option 3: reduce stocking of all species by 50%	• Median forecasted average annual Chinook salmon harvest (number harvested per year) • Proportion of outcomes with Chinook salmon harvest below 100,000 fish per year • Median forecasted Chinook salmon weight (kg) • Proportion of outcomes with Chinook salmon weight <6 kg • Median alewife biomass (kt) • Proportion of outcomes with alewife biomass >500 kt*

* The value of 500 kt is an arbitrary threshold that is indicative of a relatively large alewife biomass in the status quo simulations. It is not based on an independent assessment of alewife biomass levels that are considered detrimental to native fish species, but does represent a relatively large biomass compared to recent (1980-1999) levels in Lake Michigan. This value may seem high relative to estimates reported elsewhere; the difference derives from the fact that this value represents an estimate of biomass for the entire population (all age-classes), as opposed to swept-area estimates of those alewife vulnerable to bottom trawling.

A wide variety of outcomes are possible from a particular policy (Fig. 17). For continued stocking at current levels (status quo), we forecasted average annual Chinook salmon harvests ranging from 6,500 to 360,000 fish per year. For this policy, forecasted average harvests lower than 100,000 fish per year were relatively common (29.7% of the time) (Table 7), with the most-common result being between 50,000 and 75,000 fish harvested per year

(Fig. 17, solid bars). In contrast, a policy in which stocking of all salmonines is reduced by 50% when age-3 Chinook salmon weights measured in the fall decline below 7 kg (and restored to status quo levels when fall weight recovered to 8 kg) resulted in a substantially lower proportion of outcomes (15.7%) with harvests below 100,000 fish per year (Table 7), although the range of possible future harvests was only slightly narrower (18,000-315,000 fish per year).

Fig. 17. A comparison of the distribution of forecasted Chinook salmon harvests (numbers of fish) for two contrasting stocking policies. Shaded bars are for a policy representing continued stocking at current levels. Open bars represent a feedback policy with reductions in stocking of all species when forecasted Chinook salmon age-3 weight falls below 7 kg, and increases in stocking to current levels if age-3 weight subsequently rises above 8 kg.

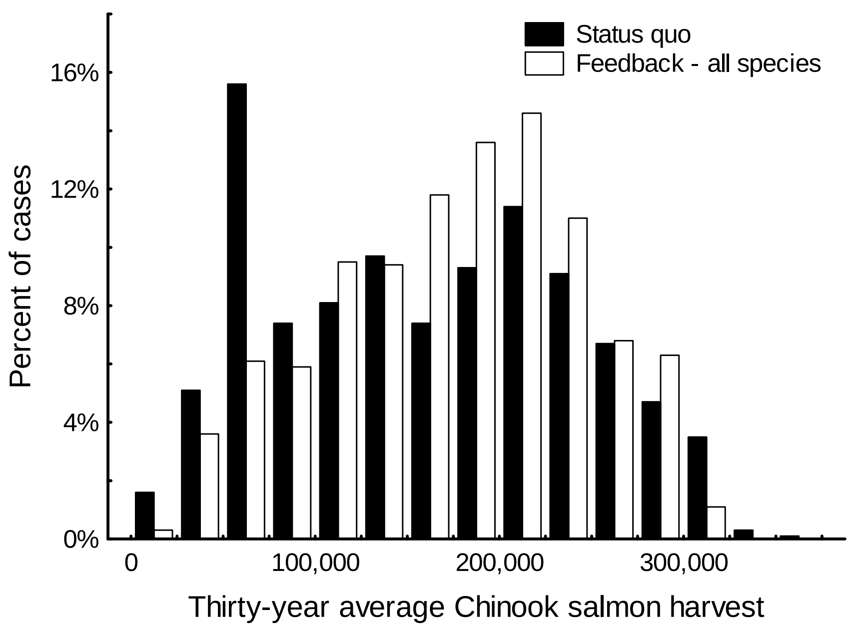

Table 7. Values of performance measures for five stocking policies (see Table 6) in a decision analysis of predator stocking in Lake Michigan.

	Harvest		Weight		Alewife	
Stocking policy	**Median Chinook harvest**	**Proportion of harvests <100,000**	**Median Chinook weight (kg)**	**Proportion of weights <6 kg**	**Median alewife biomass (mt)**	**Proportion of biomasses >500,000 mt**
Status quo (current level)	160,000	29.7	7.0	47.6	417,000	47.8
Reduce Chinook 50%	126,000	35.4	9.9	41.2	667,000	53.6
Feedback option 1: reduce Chinook only	156,000	28.1	8.4	44.6	510,000	50.2
Feedback option 2: reduce all but lake trout	176,000	19.6	10.7	37.3	766,000	56.7
Feedback option 3: reduce all species	182,000	15.7	11.6	33.9	870,000	59.5

The feedback policy in which stocking of all salmonines was reduced by 50% (option 3) resulted in the best outcome relative to two performance measures (Chinook harvests and Chinook weights, Table 7) but had the worst performance with respect to the third measure (alewife biomass). This was true for both the medians and the proportions of extreme cases (Table 7). The feedback policy that targeted only Chinook salmon (option 1) had performance characteristics similar to the status quo policy—lower harvests, lower Chinook salmon weights, and lower alewife biomass than feedback option 3. If all species other than lake trout were included in stocking cuts, performance with respect to Chinook salmon harvests and weights improved but at the expense of increased alewife biomass. This policy was not quite as effective as option 3 at meeting Chinook salmon harvest and weight objectives but resulted in lower median alewife biomass.

The policy analysis presented above suggests two important consequences for decision makers seeking an appropriate policy for salmonine stocking. First, feedback policies, where stocking levels are dynamically adjusted in response to evidence of a deteriorating situation, substantially reduce the risk of poor outcomes with respect to the Chinook salmon harvest and growth performance measures, particularly if the policy actions include all or the majority of predators in the lake. None of the policies considered here involved increasing stocking in the face of a growing alewife population, a strategy that could reduce the risk of high alewife biomass, which is an outcome of the policies analyzed here. Second, the uncertainties included in the forecasting model, particularly with respect to alewife recruitment, give rise to a very wide range of possible outcomes from a single policy. We expect that policies can be found that reduce the range of likely outcomes relative to the policies shown here. Nevertheless, we believe that any feasible strategy will still admit a substantial possibility of undesirable population trajectories for Chinook salmon and alewife. Flexibility and careful monitoring will be essential to good management of this fishery.

The results of this DA provide important insights for Lake Michigan fishery managers and stakeholders, but there are a number of important extensions of the analyses presented here that should be considered for future work. First, we have only begun to explore the range of possible policies that could be used to manage stocking. Other priorities should include upward adjustments to stocking to reduce risks of extremely high alewife biomass and exploration of stocking triggers other than Chinook salmon weight (e.g., alewife recruitment indices). Second, the sensitivity of the decision model to uncertainties other than those explicitly included in the analysis should be investigated. One obvious example is uncertainty about future wild production of salmonines. Finally, we need to explore methods for effective communication of the results of this analysis to managers and stakeholder groups.

LAKE TROUT REHABILITATION

Charles R. Bronte[12]

Status and Progress

Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout.

Establish self-sustaining lake trout populations.

Rehabilitation of lake trout in Lake Michigan has been an ongoing effort since the 1960s. This effort has consisted mainly of stocking various strains of yearling fish in both nearshore and offshore locations (Holey et al. 1995; Jonas et al. 2005a) and of controlling sea lamprey populations with the lampricide 3-trifluoromethyl-4-nitrophenol (Lavis et al. 2003). Stocking during 2000-2004 (1999-2003 year-classes) has averaged 2.3 million fish annually (Fig. 18), which is lower than the 3-6 million fish called for in the 1985 rehabilitation plan (Lake Michigan Lake Trout Technical Committee 1985; Holey et al. 1995). Rehabilitation efforts have resulted in low to modest standing stocks lakewide (Fig. 19). Catch per effort (CPE) (no. fish/304.8 m of gillnet) of lake trout was highest in southwestern waters and lowest in northern waters. Large spawning aggregations occurred in the fall in the southern refuge (see Fig. 19 for location) and at a few nearshore locations; otherwise, spawning adults were generally low in number (average CPE equals approximately 29 per site during 1999-2001) and relatively young (average = 8 yr) (Bronte et al. 2007). The average age of lake trout captured in graded-mesh gillnet surveys in spring declined continuously, from 6.6 yr in 1998 to 5.0 yr in 2003, which was consistent with the dearth of older spawners—a setback for rehabilitation. Significant declines in lake trout abundance following 2000 (Fig. 20) are a result of

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increased mortality from sea lamprey predation (Woldt et al. 2005); adult lamprey populations and wounding on lake trout have increased significantly since the mid-1990s (Lavis et al. 2003) (Fig. 21). Since 2001, increases in sea lamprey populations and mortality on lake trout have been most acute in northern Lake Michigan. Undetected larval populations above a dam on the lower Manistique River (see frontispiece for location, a northern tributary, went untreated; these populations infested over 190 km of stream and numbered in the millions. Extensive chemical treatments in 2003 and 2004 should reduce the numbers of returning adult sea lamprey beginning in 2005.

Fig. 18. Numbers of lake trout of the 1995-2003 year-classes stocked by strain in Lake Michigan.

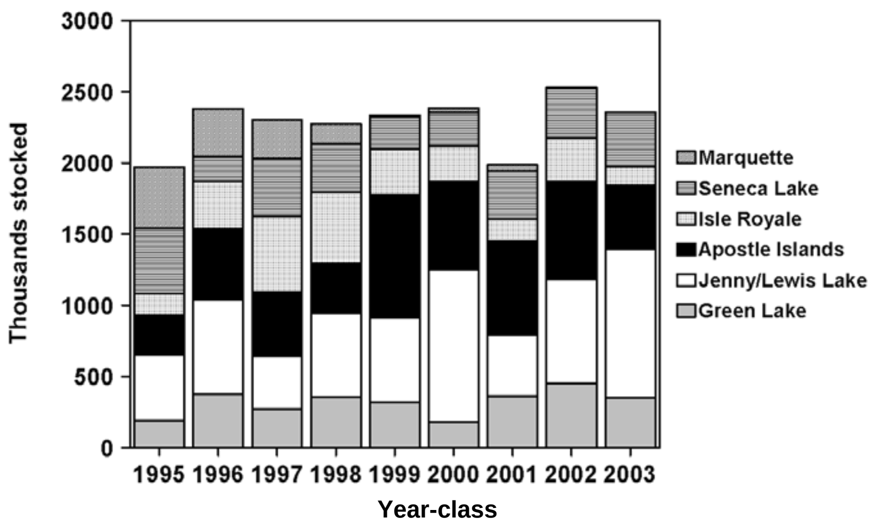


Fig. 19. Lake Michigan statistical districts. Numbers beside district designations indicate recent (2003-2004 average) catch per effort (number of fish/304.8 m of net) of lake trout in spring gillnet assessments. Districts with no numbers indicate no data.

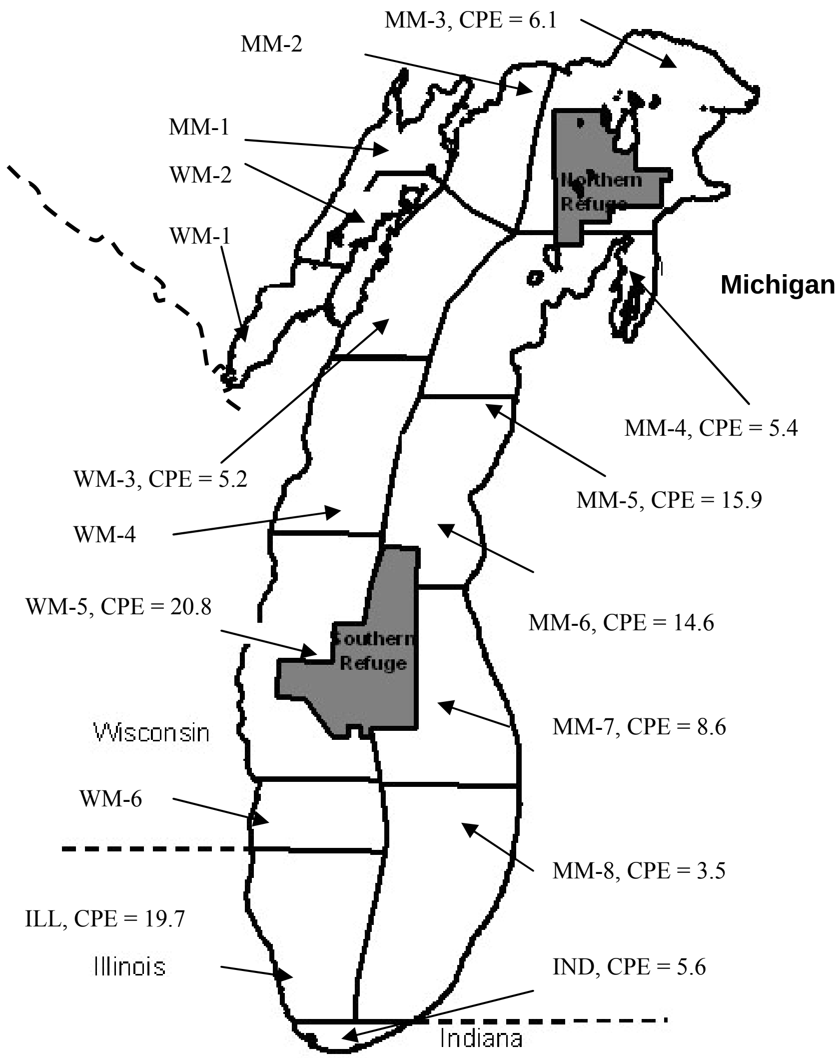


Fig. 20. Geometric mean catch per effort (95% CI) of lake trout in Lake Michigan from graded-mesh (2.5-6-inch stretch-measure) gillnets in spring, 1998-2004.

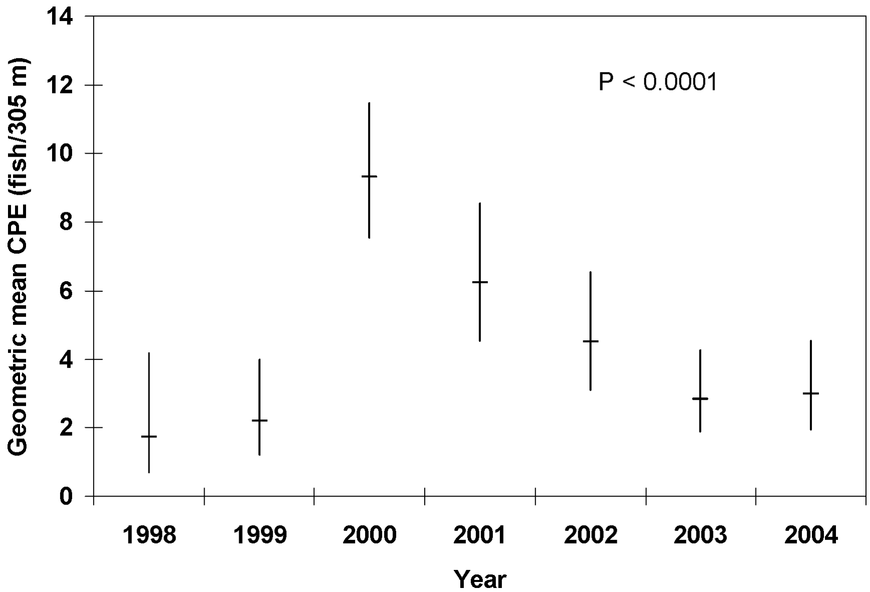
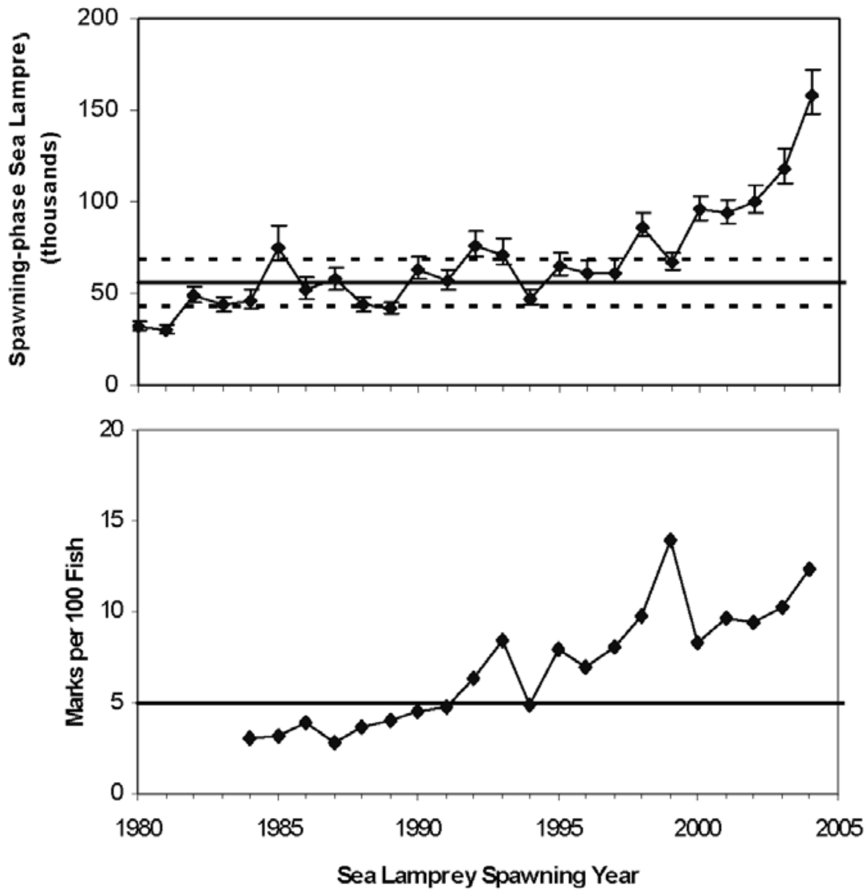
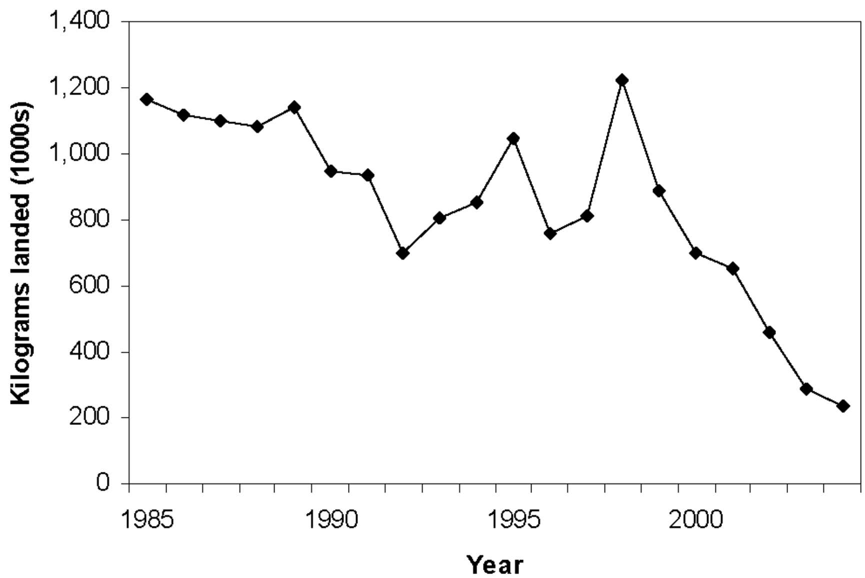


Fig. 21. Top panel: numbers of spawning-phase sea lampreys, 1980-2004 (Mullett et al. 2003). Bottom panel: sea lamprey marking rates on lake trout in fall, 1984-2004. Horizontal lines indicate targets ± 95% CI (top panel only).



Estimated losses from treaty-commercial and recreational fishing have declined greatly since 1999 (Fig. 22) and, though high in the past (1997-2000), were not responsible for the recent declines in overall abundance. Implementation of the 2000 Consent Decree (United States v. State of Michigan 2000) drastically reduced fishing mortality since 2000 in northern waters of Lake Michigan (Woldt et al. 2005). Future increases in lake trout populations will only occur with increased stocking, continued low fishing mortality, and sizeable reductions in sea lamprey populations.

Fig. 22. Total estimated commercial and recreational harvest of lake trout from Lake Michigan, 1985-2003.



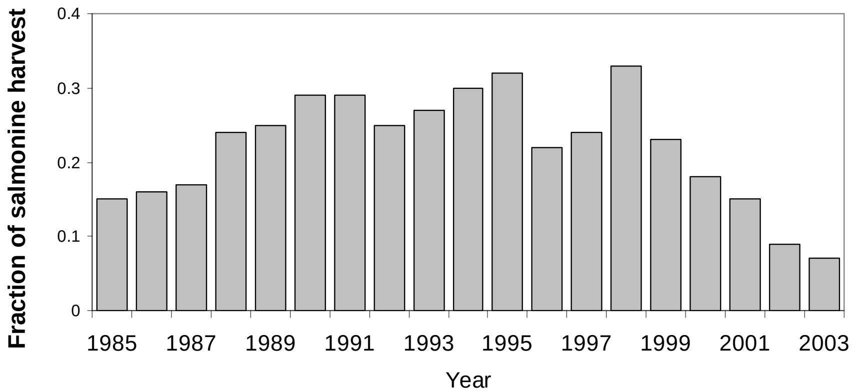
Evidence of sustainable natural reproduction of lake trout was lacking (Holey et al. 1995; Jonas et al. 2005a; Bronte et al. 2007). Since 1998, unclipped lake trout, which were presumed to be wild (all stocked fish received a fin clip), comprised about 2% of the population, which was within detection error. Only small numbers of fertilized eggs and fry were collected recently in northern Lake Michigan (Claramunt et al. 2005; Jonas et al. 2005b) and at the Southern Refuge (Janssen et al. 2006).

The general lack of sustained reproduction led to a reevaluation of rehabilitation strategies for lake trout. Potential impediments to rehabilitation were reviewed and analyzed to determine their potential importance (Bronte et al. 2003b). These impediments were then grouped into three categories: (1) lakewide lake trout populations are too low, (2) spawning aggregations are too diffuse and in inappropriate locations, and (3) survival of eggs and fry is too low and results from early mortality syndrome (EMS) and predation. The revised rehabilitation plan is expected to call for increased stocking of deepwater and shallow-water strains in areas of good reproductive habitat. Increased lake trout densities in this habitat should result in higher egg deposition rates, increased predation by lake trout on potential egg and fry predators, and better survival of lake trout eggs and fry.

Progress

The salmonine objective for Lake Michigan calls for a lake trout population that will contribute 20-25% of the total salmonine harvest (2.7-6.8 million kg) each year, while also establishing self-sustaining populations lakewide (Eshenroder et al. 1995). Since 2000, lake trout yield was below 0.9 million kg and had declined to about 0.23 million kg by 2004. In contrast, total salmonine yield was increasing due to large landings of Chinook salmon. As a result, lake trout comprised less than 20% of all salmonines harvested since 2000 (Fig. 23). Therefore, fish-community objectives for lake trout populations, harvest, and rehabilitation have not been met in this 2001-2004 reporting period.

Fig. 23. Fraction of total salmonine harvest in Lake Michigan made up of lake trout, 1985-2003.



Recommendations

The current salmonine objective (includes lake trout) specifies harvest targets that are appropriate for species like salmon, but they are inappropriate for lake trout, a species that is not responding well to rehabilitation efforts. Any harvest objective for lake trout should be secondary to rehabilitation needs, because harvest works against building up populations of mature fish that can replace themselves. Failure to meet a harvest objective actually favors rehabilitation, because a reduced take will increase the adult population and longevity, which are favorable for rehabilitation. A revised lake trout objective should focus on the population characteristics required for recovery (e.g., lower mortality, larger parental stocks, higher egg deposition) rather than expectations of harvest. In this regard, the fish-community objective for lake trout should parallel the objectives in the revised rehabilitation plan now being considered for adoption. Therefore, adoption of a revised rehabilitation plan should precede adoption of a revised salmonine objective.

Although a revised lake trout rehabilitation plan remains under review, establishing self-sustaining populations of lake trout under the current salmonine objective will require management actions that respond to the impediments inhibiting rehabilitation (Bronte et al. 2003b). Such management actions include: (1) increasing stocking in selected areas with good habitat, (2) stocking strains with good survival that are best adapted for shallow-water and deepwater habitat, (3) maintaining low fishing mortality and significantly reducing sea lamprey mortality, (4) increasing adult lake trout densities to achieve higher egg deposition and to control egg and fry predators through predation, and (5) restoring native ciscoes to diversify the diet of lake trout and thereby reduce the egg and fry mortality caused by EMS.

PRIORITIES FOR THE FUTURE

David F. Clapp[13] and William Horns

Based on our analysis of this report, we see that the major challenges before the Lake Michigan Committee are (1) developing a process for promptly reviewing and implementing recommendations from state-of-the-lake reports, (2) fully implementing A Joint Strategic Plan for Management of Great Lakes Fisheries (hereafter, Joint Plan) (Great Lakes Fishery Commission 1997) and its commitment to an ecosystem approach in fisheries management, (3) updating and expanding the lake's geographical information system (GIS), and (4) revising the lake's fish-community objectives (FCOs) to account for ecosystem changes that have occurred since 1995. In particular, the proliferation of dreissenids, sharp declines in *Diporeia* spp. populations, and associated changes in planktivore abundance require a reassessment of the objectives for salmonines, including how many should be stocked.

The recommendations of the 2000 state-of-the-lake report have not been completely addressed. Harvest expectations and stocking goals for some salmonines (Chinook salmon and lake trout) have been reviewed, but salmonine population objectives have yet to be adopted. A comprehensive Lake Michigan or Great Lakes-wide marking plan for Chinook salmon has been implemented, but continued work is needed to continuously assess and monitor the proportion of naturally reproduced fish in the population. Also, information concerning natural reproduction by other salmonines remains sparse. As part of the 2000 Consent Decree implementation, population models have been developed for lake trout for certain areas of the lake, and preliminary work has been completed on Chinook salmon statistical catch-at-age models (Benjamin and Bence 2003). The Consent Decree models provide some of the information on lake trout age-specific harvest and on

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sea lamprey marking and abundance sought in the 2000 report. However, a lakewide commitment to maintain population models for all salmonine species has yet to be made. Although the impediments to lake trout rehabilitation (Bronte et al. 2003b) and guide to rehabilitation (Bronte et al. 2008) reports have been approved by the Lake Michigan Committee (LMC), an implementation strategy for lake trout remains to be formally adopted. In the aggregate, these unfinished tasks before the LMC indicate that the committee needs to develop a more-responsive process for addressing the concerns and recommendations in each state-of-the-lake report and in other such reports.

The Joint Plan addresses the "ecosystem approach" and "ecosystem management" in several places. It says that, "The Parties must exercise their full authority and influence in every available arena to meet the biological, chemical, and physical needs of desired fish communities." This directive includes working more closely with professionals in other related arenas (for example, lower trophic-level experts), creating cross-lake partnerships to improve our understanding of common issues, continuing to strive to expand the knowledge base, and bringing the environmental needs of fishes to the attention of sister environmental agencies through the development of environmental objectives. The latter goal is addressed by Strategic Procedure No. 6 in the Joint Plan:

> *The Lake Committees will identify environmental issues which relate to or may impede achievement of their fish community objectives and will work with other ecosystem initiatives, such as LaMPs, in developing and furthering plans for achieving, refining, and assessing progress on environmental and fish community objectives.*

In keeping with this commitment, a set of environmental objectives (note that "environmental objectives" as used here is considered to be a synonym for "environmental issues" in the above quotation) has been developed by Rutherford et al. (2007), and was under review by the LMC as this report was being completed. A major step toward achievement of the second part of this strategic procedure ("developing and furthering plans for achieving, refining, and assessing progress") was the completion of the first Lake Michigan GIS, which has been distributed as part of the larger Great Lakes GIS (www.glfc.org/glgis/GLGIS_User_Guide.htm). Recently, the Great Lakes Regional Collaboration (http://www.glrc.us) developed a set of recommendations for Great Lakes habitat protection and restoration. That exercise benefited by participation from a broad array of government and nongovernment groups and individuals, but it was limited by the lack of an up-to-date, detailed, and accessible GIS. The challenge now is to make the Great Lakes GIS into an accessible tool that is kept current and expanded, as needed. This challenge will require some continued investment from traditional fisheries-related funding sources, and will also benefit from, and may require, aggressive partnerships with other governmental and nongovernmental organizations.

Several chapters in this volume point to shortcomings in the current FCOs (Eshenroder et al. 1995). The chapter on lake whitefish calls for rejecting the current harvest-based standard in favor of a lake whitefish objective that is based on modern-day estimates of standing stock and harvests. The yellow perch chapter states that attainment of the current yellow perch objective appears improbable and notes that the current objective is not a useful guide for management. The lake sturgeon chapter suggests incorporation of more-specific objectives and strategies, and the fish health chapter recommends providing objectives for fish health. The lake trout rehabilitation chapter recommends that the salmonine objective be recast in measures that are relevant to lake trout rehabilitation, and several chapters recommend resolving the incompatibility of the planktivore and salmonine objectives. Some of these suggestions reflect gains in quantitative knowledge of these fish populations. Working statistical catch-at-age models of lake whitefish and yellow perch were completed, so, for those species, harvest-based objectives can be replaced with abundance-based objectives (see the Lake Whitefish and Yellow Perch chapters). Other suggestions reflect an expanding knowledge of the mechanisms influencing recruitment and call for objectives that refer to biological milestones and strategies for species being rehabilitated (see the Status and Trends of Lake Sturgeon and Salmonine Reproduction and Recruitment chapters). But the larger message here is that authors are calling for the LMC to confront the difficult tradeoffs between restoring native species (especially lake trout) and sustaining the remarkable fisheries for introduced species. This tension between the goals of sustaining Pacific salmon fisheries and restoring naturally reproducing lake trout and other native species is stated most explicitly in the Status of Chinook Salmon chapter, which calls upon the LMC to "…identify a long-term strategy for manipulation of Chinook salmon populations that resolves the conflicting goals of allowing for recovery of native species and maintaining sufficient prey to support healthy Chinook salmon populations." That recommendation is perhaps the challenge that the lake committee should place at the top of its agenda.

ACKNOWLEDGEMENTS

The following individuals provided comments, ideas, or reviews that significantly improved this document: Nancy Auer, Ed Baker, Kate Barrett, Brian Breidert, Charles Bronte, Scott Brown, John Dettmers, Mike Donofrio, Mark Ebener, Brad Eggold, Randy Eshenroder, John Fitzsimons, John Gannon, Ji He, Mark Holey, Marty Holtgren, Jory Jonas, David Jude, Roger Knight, Charles Krueger, Steve Lapan, Steve Lenart, Charles Madenjian, Archie Martell, Thomas McComish, Patrick McKee, Thomas Miller, Lloyd Mohr, Erik Olsen, Richard O'Neal, Paul Peeters, Steve Robillard, Shawn Sitar, Tim Smigielski, Jason Stockwell, Michael Toneys, and Greg Wright. John Dettmers and Mark Ebener are accorded special recognition for their thorough, helpful reviews of the entire document. Cathy Sullivan provided significant editorial assistance. Christine Geddes' work in producing the frontispiece is greatly appreciated. The Yellow Perch chapter is the product of contributions from the Lake Michigan Yellow Perch Task Group. The Status and Trends of Lake Sturgeon chapter is the product of contributions from the Lake Michigan Lake Sturgeon Task Group. The Status of Chinook Salmon chapter is the product of contributions from the Lake Michigan Salmonid and Planktivore Working Groups. The Lake Trout Rehabilitation chapter is a product of contributions from the Lake Michigan Lake Trout Task Group. The strong, cooperative working relationships of the Lake Michigan Committee and Lake Michigan Technical Committee's task and working groups were integral to the completion of the work presented here. The lake committee and Lake Michigan Technical Committee gratefully acknowledge the additional contributions to this work made by the member agencies, including the Chippewa/Ottawa Resource Authority, the Grand Traverse Band of Ottawa and Chippewa Indians, Illinois Department of Conservation, Indiana DNR, Little River Band of Ottawa Indians, Little Traverse Bay Band of Odawa Indians, Michigan DNR, U.S. Fish and Wildlife Service, U.S. Geological Survey, and Wisconsin DNR. We additionally acknowledge the support provided by the Lake Michigan Advisors and the valuable facilitation and editorial work of the staff of the Great Lakes Fishery Commission.

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