THE STATE OF LAKE MICHIGAN IN 2011

Great Lakes Fishery Commission

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December 2012

THE STATE OF LAKE MICHIGAN IN 2011

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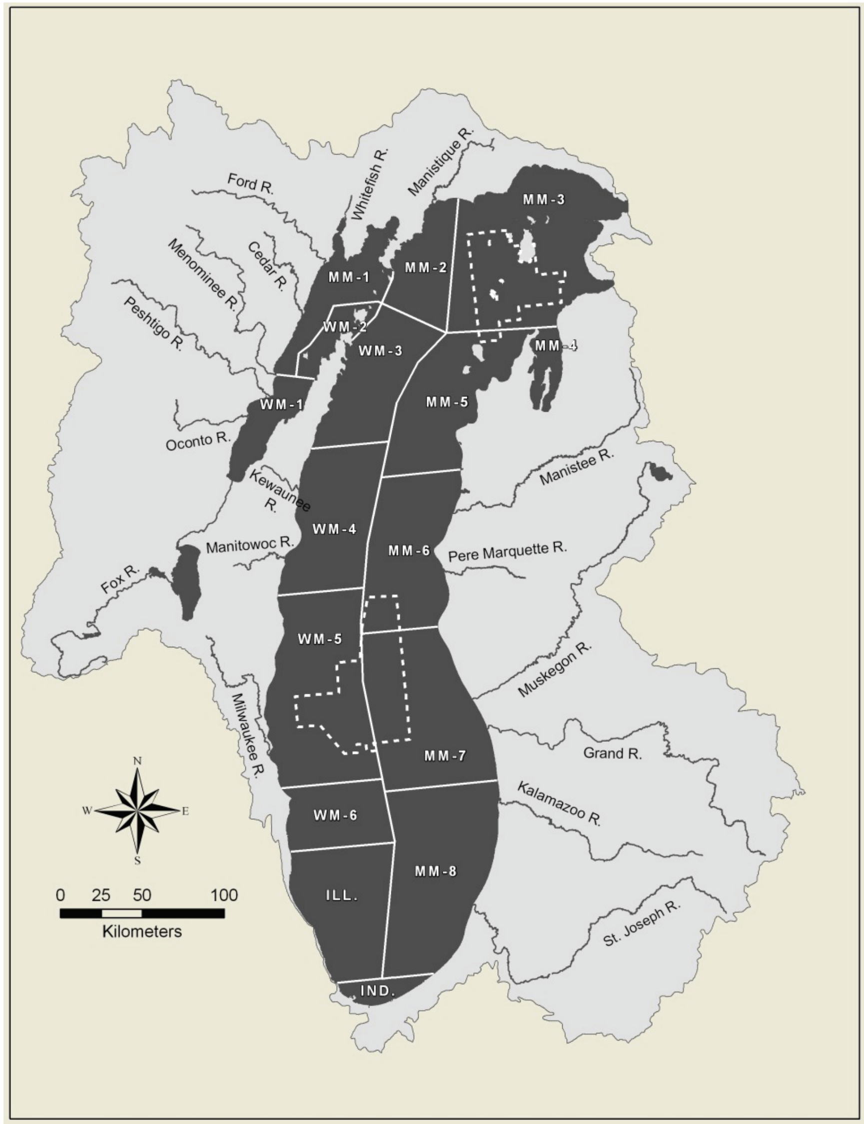

Lake Michigan (dark gray) and its watershed (light gray) depicting statistical districts and locations not otherwise identified in this publication. Areas within dashed lines represent the Northern Refuge and Mid-Lake Refuge for lake trout restoration.

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ABSTRACT

This third state of the lake report for Lake Michigan identifies progress made during 2005-2010 in meeting the fish-community objectives (FCOs) established for the lake in 1995. A conference, providing more extensive data than given here, was held in March 2011, and this document provides a summary of those presentations. Since 2005, major changes have occurred in the lower trophic levels of Lake Michigan: non-indigenous quagga mussels (*Dreissena bugensis*) largely replaced non-indigenous zebra mussels (*D. polymorpha*) and colonized depths out to >100 m. Quagga mussel proliferation was hypothesized to cause a 78% decline in primary production during the spring as well as a continuing population decline of *Diporeia* spp. Relative to earlier reports, the abundance of several prey-fish species, including alewife (*Alosa pseudoharengus*), bloater (*Coregonus hoyi*), rainbow smelt (*Osmerus mordax*), and deepwater sculpin (*Myoxocephalus thompsoni*) was lower during 2005-2010. In contrast, abundance of slimy sculpin (*Cottus cognatus*) and round goby (*Neogobius melanostomus*) increased. In response to prey-fish declines and increasing natural reproduction by Chinook salmon (*Oncorhynchus tshawytscha*) occurring since 2005, managers have adjusted fishing regulations and reduced stocking levels to decrease predatory demand. Harvest of lake trout (*Salvelinus namaycush*) comprised only 4-13% of the salmonine harvest from 2005 to 2010, short of the 20-25% goal in the salmonine FCO. Natural reproduction by lake trout remains undetectable, but the Lake Michigan Committee (LMC) approved a new implementation strategy for the rehabilitation of lake trout that could increase the probability of a sustainable lake trout population in future years. Remnant populations of lake sturgeon (*Acipenser fulvescens*) persist and consistently spawn in the lowermost sections of at least eight tributaries. Since 2005, considerable progress has been made in identifying suitable lake sturgeon habitat, and several agencies have initiated streamside rearing to promote imprinting and homing of hatchery fish. Yellow

perch (*Perca flavescens*) harvest during 2005-2010 was similar to the previous five-year period, and the 2005 year-class was one of the largest measured since the 1980s. Lake whitefish (*Coregonus clupeaformis*) remains the most valuable commercial species, and the 2005-2010 yield increased 13% over the previous reporting period. Although lake whitefish biomass has been steadily increasing since 2005, individual growth rates have continued to decline (following a trend that began in the 1990s). Abundance of mature sea lamprey (*Petromyzon marinus*) greatly exceeded target levels between 2005 and 2010, although abundance did decline following a peak in 2007. Concomitant with the elevated abundance of sea lamprey, lakewide lake trout marking rates since 2005 have remained 2-3 times greater than the target. In 2010, fishery and sea lamprey managers developed a detailed plan to enhance sea lamprey control over the next five years. Moderate progress has been achieved on prescribed habitat and environmental objectives. More than 480 km of streams and 750 ha of wetlands have been reconnected, and polychlorinated biphenyl levels in salmonines have trended downward. The impact of emerging contaminants and pharmaceutical compounds on fish-consumption advisories remains unknown. A new virulent virus, viral hemorrhagic septicemia, was first detected in Lake Michigan in 2007 and was responsible for fish kills in 2007-2008. However, despite broad surveillance, no fish kills attributed to this virus were observed in 2009-2010. Three new non-indigenous species were found in Lake Michigan since 2005: New Zealand mudsnails (*Potamopyrgus antipodarum*), the bloody-red shrimp (*Hemimysis anomala*), and a freshwater hydroid (*Cordylophora caspia*). Whether any of these species will become invasive (i.e., proliferate over an expansive area) and cause ecosystem-level changes remains to be determined. The Lake Michigan Technical Committee identified three high-priority recommendations that could lead to successful achievement of the FCOs: (1) develop more strategic stocking policies and management actions for salmonines via an annual red-flag analysis, reassessing triggers as suggested, in collaboration with decision analysis models that rank the performance of alternative actions in terms of their ability to meet objectives successfully, (2) promote rehabilitation of native fishes, and (3) reduce sea lamprey abundance by treating for two consecutive years those streams estimated to have the greatest production of larvae. The LMC included three impediments that fishery managers should consider when developing future management strategies: (1) blockage of fish runs by dams, (2) continuing losses of fish habitat, and (3) pollution. The LMC also identified three action items for 2011 through 2016: (1) revisiting the current FCOs given the changing food web and lake productivity, (2) encouraging the prioritization of research needs, and (3) facilitating the elimination of data gaps through coordinated sampling and increased involvement with other environmental disciplines to further promote ecosystem management through a multi-disciplinary approach.

INTRODUCTION

David B. Bunnell[1], Brian Breidert, Bradley T. Eggold, Thomas K. Gorenflo, Jay Wesley, and Steven R. Robillard

This state of Lake Michigan report provides an evaluation of progress, along with supporting information, toward the achievement of the fish-community objectives (FCOs) for Lake Michigan (Eshenroder et al. 1995) during 2005-2010. A state of the lake (SOL) conference and reporting process was initiated by the 1998 revision of A Joint Strategic Plan for the Management of Great Lakes Fisheries (Joint Plan) (Great Lakes Fishery Commission 2007). Previous SOL reports for Lake Michigan were produced following conferences in 2000 (Holey and Trudeau 2005) and 2005 (Clapp and Horns 2008). Although the previous reports share a common goal of evaluating progress towards achievement of the same FCOs, their format and organization differ. The chapters of the 2000 report were structured largely consistent with the themes of the FCOs (e.g., planktivores, salmonine

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community, sea lamprey), but the report also included chapters on lower trophic levels, physical and chemical habitat remediation, and fish health. In the 2005 report, the FCOs were covered in five chapters under the heading "Nearshore and Riverine Habitats and Fish Communities" and in seven chapters under the heading "The Salmonine Community and its Forage Base."

In this SOL report, the FCOs are similarly integrated within an organization that recognizes the relationship between fishes (see Table 1 for an alphabetical list of common fish names and their corresponding scientific names) and their major habitats, but it contains fewer chapters than the 2005 report. One chapter covers the offshore pelagic community where salmonines, their prey, and lower trophic level trends are discussed. A second chapter focuses on the nearshore and benthic communities in which key species are yellow perch (see Table 1 for scientific names of fishes), lake sturgeon, and lake whitefish.

These chapters are followed by two shorter chapters on sea lamprey and habitat, respectively. Each chapter contains a discussion of pertinent FCOs. We have artificially separated the fish community from its habitat for the purposes of the report; we acknowledge that in reality these communities do not operate independently of one another and are impacted at various levels by past and current deleterious changes to habitat and productivity, invasive (i.e., those that have proliferated over an expansive area) non-indigenous species, and the effects of sport and commercial fisheries. An important divergence from the two previous SOL reports involves greater input from the Lake Michigan Committee (LMC) in the evaluation of the FCOs and in the Introduction and Conclusions chapters.

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*
bloater	*Coregonus hoyi*
brook trout	*Salvelinus fontinalis*
brown trout	*Salmo trutta*
burbot	*Lota lota*
channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
cisco	*Coregonus artedi*
coho salmon	*Oncorhynchus kisutch*
deepwater sculpin	*Myoxocephalus thompsoni*
lake sturgeon	*Acipenser fulvescens*
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
muskellunge	*Esox masquinongy*
northern pike	*Esox lucius*
ninespine stickleback	*Pungitius pungitius*
rainbow smelt	*Osmerus mordax*
rainbow trout (steelhead)	*Oncorhynchus mykiss*
rock bass	*Ambloplites rupestris*
round whitefish	*Prosopium cylindraceum*
round goby	*Neogobius melanostomus*
salmon	*Oncorhynchus* spp.
sculpins	*Cottidae* spp.
sea lamprey	*Petromyzon marinus*

Table 1, continued.

Common name	**Scientific name**
slimy sculpin	*Cottus cognatus*
silver carp	*Hypophthalmicthys molitrix*
smallmouth bass	*Micropterus dolomieu*
sucker(s)	*Catostomus* spp.
walleye	*Sander vitreus*
white sucker	*Catostomus commersoni*
yellow perch	*Perca flavescens*

The LMC established FCOs in 1995 (Eshenroder et al. 1995) to provide a unified strategy for inter-jurisdictional fisheries management. These FCOs were derived, in part, from the Great Lakes Water Quality Agreement of 1978 (as amended 1987) and the Joint Plan (Great Lakes Fishery Commission 1981). Eshenroder et al. (1995) describes two overarching goals and then a series of more specific objectives that primarily address fish assemblages while providing measurable goals by which the productivity, health, and sustainability of a desired fishery can be assessed. Below, we restate the overarching goals and specific FCOs, and provide a brief commentary on each.

The two overarching goals are:

> *To secure fish communities, based on foundations of stable, self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for: wholesome food, recreation, employment and income, and a healthy human environment; and*

> *To restore and maintain the biological integrity of the fish community so that production of desirable fish is sustainable and ecologically efficient.*

The first goal relies heavily on self-sustaining fish populations with supplemental stocking of salmonines and is influenced predominantly by management actions (e.g., stocking levels and regulations). Fishery managers continue to seek a balance between stocking levels and prey-fish production (as exemplified by a 25% reduction in Chinook salmon stocking in 2006) such that societal benefits can be maximized. These efforts, however, continue to be in jeopardy owing to the lack of progress towards the second overarching goal. To introduce the potentially abstract concept of biological integrity, Eshenroder et al. (1995) relied on the description by Kay (1990), whereby an ecosystem with biological integrity is one that could "maintain its organization in the face of changing environmental conditions." Eshenroder et al. (1995) argued that Lake Michigan lost its integrity in the 1960s when the effects of the sea lamprey and alewife invasions had decimated the fish community such that the piscivore trophic level was nearly extirpated, and diversity in the prey-fish trophic level was greatly diminished. By the 1980s, however, biological integrity had largely been regained due to management efforts, including the control of sea lamprey and pollutants, the stocking of salmonines, and improved fishery regulations (Eshenroder et al. 1995). Lake Michigan in the 1980s included a diverse salmonine-dominated piscivore community, along with resurging native populations of bloater, lake whitefish, and burbot. In the 2000s, however, the biological integrity of Lake Michigan was further challenged by non-indigenous species that proliferated since the mid-1980s. In particular, dreissenid mussels and water fleas (*Bythotrephes longimanus*) are altering energy flow within the food web, and the extent to which these changes are negatively influencing fish production and diversity is not well understood at this time.

The Salmonine (Salmon and Trout) Objectives, which address the offshore, pelagic fish community, are to:

> *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, and*
>
> *Establish self-sustaining lake trout populations.*

The Salmonine Objectives are intended to maintain a diverse fishery for salmonines and to foster re-establishment of wild lake trout populations. Lake trout and purposefully introduced salmonids (Chinook salmon, coho salmon, brown trout, rainbow trout) serve as the primary piscivores in the Lake Michigan fish community. Lake trout were extirpated from the lake by the 1950s, due primarily to overfishing (Eshenroder and Amatangelo 2002) and sea lamprey predation, and the population continues to be sustained only through stocking.

The Planktivore Objective, which also focuses on the offshore community, was designed to match prey production with the successful achievement of the following Salmonine Objective:

> *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).*

Alewife continues to be the primary prey species consumed by piscivores, but high levels of thiaminase in alewife and the ability of adult alewife to consume native fish larvae may impede full achievement of the salmonine objective. The planktivore prey-fish community also includes bloater, rainbow smelt, deepwater sculpin, slimy sculpin, and ninespine stickleback. Round goby, a non-indigenous species first documented in Lake Michigan in 1993, has expanded its distribution and increased its abundance over the past five years, and it is now considered an important component of the prey-fish community.

The Inshore Fish Objective addresses a portion of the fish community that has limited influence on salmonine predator-prey dynamics but has historically supported important sport and commercial fisheries. The dynamics of the inshore fish community are less studied and, thus, less understood than the interactions between salmonines and their prey. Based on harvest levels in the 1990s, the LMC sought to:

> *Maintain self-sustaining stocks of yellow perch, walleye, smallmouth bass, pike, catfish, and panfish. Expected annual yields should be 0.9 to 1.8 million kg (2 to 4 million lb) for yellow perch and 0.1 to 0.2 million kg (0.2 to 0.4 million lb) for walleye.*

Lake whitefish provide the most important Lake Michigan commercial fishery and are a key component of the Benthivore Objective:

> *Maintain self-sustaining stocks of lake whitefish, round whitefish, sturgeon, suckers, and burbot. Expected annual yield of lake whitefish should be 1.8-2.7 million kg (4 to 6 million lb).*

Re-establishment of self-sustaining lake sturgeon populations, an objective without a harvest expectation, has been a high priority for the LMC, the U.S. Fish and Wildlife Service, and numerous interested organizations.

Non-indigenous species that have become invasive, such as the sea lamprey and dreissenid mussels, have perturbed the Lake Michigan fish community and impeded the successful achievement of several of the FCOs. Since the 1950s, state and tribal fishery-management agencies and the governments of the U.S. and Canada have considered control of sea lamprey a high priority, and considerable progress has been made in reducing sea lamprey populations throughout the Great Lakes. Given the ability of parasitic sea lampreys to induce substantial mortality on salmonines and other fish, sea lamprey predation continues to be an impediment to successful achievement of the salmonine objective. The Sea Lamprey Objective is less quantitative than the other specific FCOs, although its inclusion highlights its importance:

Suppress sea lamprey to allow the achievement of the other fish-community objectives.

The Other Species Objective includes species that have a minimal role in the fishery but are important in maintaining ecosystem function and integrity. Most of these species are native and often overlooked, except when complex food-web dynamics are evaluated. To elicit a stable system, governments should:

*Protect and sustain a diverse community of native fishes, including other species not specifically mentioned earlier (for example, cyprinids, gars (*Lepisosteidus *spp.), bowfin (*Amia calva*), brook trout and sculpins). These species contribute to the biological integrity of the fish community and should be recognized and protected for their ecological significance and cultural and economic values.*

The Physical/Chemical Habitat Objective is the most unique of the FCOs in that it addresses physical habitat and abiotic (non-living) factors that influence achievement of other FCOs. The addition of this objective is a precursor to an acknowledgement that fish communities do not operate independently of their environment. To successfully achieve the other FCOs, two ideals were introduced:

Protect and enhance fish habitat and rehabilitate degraded habitats, and

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.

More recently, the physical habitat portion of this objective was elucidated with the identification of key habitat improvement and remediation projects in Rutherford et al. (2005).

This SOL report for Lake Michigan provides nominal background information and focuses on changes and progress toward meeting the FCOs during the years 2005-2010. Chapters were prepared by individuals with an intimate knowledge of assessment data, food-web dynamics, and management actions (e.g., sea lamprey treatments). Views presented in the chapters are those of the authors and not necessarily those of the LMC. For further information on historical trends or broader background on the physical characteristics of Lake Michigan or its fish community, interested readers are encouraged to review the previous SOL reports for Lake Michigan (Holey and Trudeau 2005; Clapp and Horns 2008).

OFFSHORE SALMONINE FOOD WEB

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Background

Implicit in the fish-community objectives (FCOs) is the desire to maintain a diverse salmonine community (salmonine objective) along with a diversity of prey fishes (planktivore objective) whereby predator demand does not exceed prey-fish production. Although some of the harvest expectations for salmonines have been met since 2005, authors in both the 2000 and 2005 state of the lake reports recommended moving away from harvest-based management benchmarks for the salmonine community (Jonas et al. 2005b; Bronte 2008). Part of the justification for not using harvest expectations as a management objective owed to the fact that predator-prey dynamics appeared to be unstable due to ongoing changes in the offshore community brought about by the proliferation of dreissenids, sharp declines in *Diporeia* spp. (hereafter, diporeia as a common name) and declines in prey-fish biomass. Since 2005, these bottom-up effects have become increasingly

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influential in the offshore ecosystem and have added to the variability in the salmonine and prey-fish dynamics in Lake Michigan.

Decreases in primary production may have contributed to the stress on prey fish because prey fish feed on zooplankton, which, in turn, feed ultimately on producers, such as diatoms. Primary production during the spring isothermal period in the offshore waters of southeastern Lake Michigan in 2007-2008 was 78% lower than in 1995-1998 (Fahnenstiel et al. 2010). This dramatic reduction in the spring diatom bloom was attributed to the proliferation of quagga mussels (*Dreissena bugensis*). In response to prey-fish declines and high salmonine abundances that occurred since publication of the previous report, fishery managers have adjusted fishing regulations (e.g., increased salmon (see Table 1 in the Introduction for scientific names of fishes) bag limits) and reduced stocking levels of salmonines (e.g., Chinook salmon and coho salmon) to decrease the predatory demand on pelagic prey fish. However, fishery managers also implemented a new lake trout rehabilitation strategy that included modest increases in stocking. Herein, our review of the salmonine and planktivore objectives will explore whether these recent management actions had an influence on a predator-prey balance that appeared unstable as recently as 2005.

Prey Fishes

Lakewide assessments of prey fish in Lake Michigan by the U.S. Geological Survey, Great Lakes Science Center (GLSC) date back to 1973 for the bottom-trawl (BT) survey and 1992 for the hydroacoustics (HY) survey (conducted in 14 of the 18 years up to 2009), which was augmented recently by the Michigan DNR. This long-term focus on the prey-fish community has resulted in improved understanding of prey-fish dynamics as well as of food-web dynamics. For each of six key prey fishes, we describe briefly the results of recent studies aimed at identifying the key factors that influence their abundance, growth, and/or distribution. We then report mean biomass during 2005-2010 relative to mean biomass from previous surveys (1973-2004 for the BT survey or 1992-2004 for the HY survey).

Alewife

Alewife serve as the primary prey for salmonines (Warner et al. 2008; Jacobs et al. 2010). Warner et al. (2008) found a linkage between strong alewife year-classes and production of age-1 Chinook salmon. The inference was that an abundance of young-of-year (YOY) alewife resulted in high survival of YOY salmon, whose abundance could not be measured until the next year when they reached age 1. Other food-web effects of alewife are negative, including predation on native fish larvae (Bunnell et al. 2006; Madenjian et al. 2008) and thiamine deficiency in alewife predators (Brown et al. 2005). The HY survey, which provides the best early index of year-class strength, indicated that the strongest alewife year-class since 1995 occurred in 2010 (albeit no survey in 1998). In the BT survey during the same six-year period, mean biomass was 2.5 kg/ha, which was only 23% of the mean biomass during the previous 32 years. In the HY survey, mean biomass averaged 10.8 kg/ha, which was 64% of the mean of HY surveys conducted during 1992-2004. Expansion of the HY mean biomass density to the lake proper (excludes Green Bay) resulted in a lakewide biomass of 0.06-billion kg during 2005-2011.

Bloater

Bloater abundance is well below levels in the 1980s and 1990s despite very little predation pressure from salmonines (Warner et al. 2008; Jacobs et al. 2010). As a result, research has focused on other mechanisms limiting recruitment, including interactions with alewives. However, with no support for alewife predation as a limiting factor (Bunnell et al. 2006), attention has focused on the role of skewed sex ratios (too few males) (Bunnell et al. 2006, 2009a) and excessive predation by sculpins (Cottidae) on bloater eggs (no results yet). In the BT survey, biomass averaged 2.4 kg/ha during 2005-2011, only 9% of the mean of the previous 32 years. Mean biomass in the HY survey during the same period averaged 1.8 kg/ha, only 10% of the average from 1992-2004. Expansion of the BT mean to the lake proper resulted in an average lakewide biomass of 0.01-billion kg during 2005-2011.

Rainbow Smelt

Biomass of rainbow smelt in the BT survey during 2005-2011 averaged 0.5 kg/ha, which was 20% of values from the preceding 32 years. Biomass in the HY survey during the same period averaged 2.6 kg/ha, which was 41% of the mean during 1992-2004. The resulting estimate of biomass for the lake proper in 2005-2011 was 0.014-billion kg. Possible factors responsible for the decline in rainbow smelt abundance are changes in precipitation and water levels, increased predator abundance, and selective harvest during spawning runs (Brown 1994; O'Brien 2010). Recent HY surveys in August indicate that most of the YOY were spawned in the lake in late June and/or early July because they were too small to have hatched in rivers in the spring (Michigan DNR and GLSC, unpublished data). If overwinter survival of YOY smelt is size dependent, the population shift to lake-spawned individuals could explain, at least in part, the recent decline in rainbow smelt biomass.

Deepwater Sculpin

Mean biomass of deepwater sculpin in 2005-2011 as estimated from the BT survey (benthic fish not sampled in the HY survey) was 2.7 kg/ha, which was only 32% of the mean for the previous 32 years. Expansion of the BT mean biomass density to the lake proper resulted in a lakewide biomass of 0.014-billion kg. The severe decline in the diporeia population may have caused the reduction in biomass density. Madenjian et al. (2005a) reported that deepwater sculpin biomass was negatively related to the abundance of adult alewife and burbot. Alewife biomass, however, is considerably lower now than in the 1980s when deepwater sculpin were much more abundant, so the theorized interaction may not be explanatory now. Burbot biomass, however, has recently increased (Madenjian et al. 2012), leaving this explanation attractive. Also explanatory, deepwater sculpin have shifted their distribution to depths not sampled by the BT (Madenjian and Bunnell 2008; Madenjian et al. 2012).

Slimy Sculpin

Slimy sculpin is one of the few species for which biomass has been increasing. Mean biomass in the BT survey during 2005-2011 was 0.98 kg/ha, which was 2.5 times greater than mean biomass over the previous 32 years. Expansion of this biomass density to the lake proper resulted in a lakewide biomass of 0.005-billion kg. Slimy sculpin are typically found at bottom depths of 60-80 m (Madenjian and Bunnell 2008), and the dynamics of the Lake Michigan population, as well as those of the other Great Lakes, have been negatively related to predation by juvenile lake trout (Madenjian et al. 2005a; Madenjian et al. 2008). The relatively low abundance of lake trout in addition to new alternative prey in the form of round goby has likely caused the increase in slimy sculpin abundance.

Round Goby

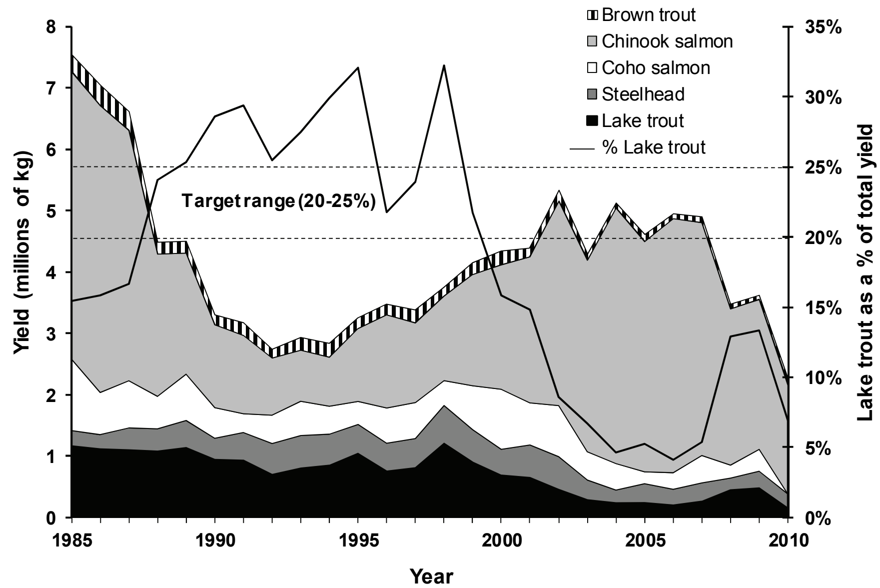
This non-indigenous species is becoming increasingly important in the diet of a number of fish in Lake Michigan, including yellow perch (Truemper and Lauer 2005), lake trout, and burbot (Michigan DNR, unpublished data). Round goby was first captured in the BT survey in 2003, and its distribution and abundance have since increased, although abundance has exhibited high inter-annual variability. The peak biomass since 2005 was 2.42 kg/ha in 2010.

Salmonines

Lake Trout

The salmonine objective for lake trout was not realized during the 2005-2010 reporting period. Lakewide lake trout harvest comprised only 4-13% of the total salmonine harvest, short of the 20-25% goal (Fig. 1). With regard to a self-sustaining population, few unclipped juvenile or adult lake trout were recovered in annual assessment surveys (<5% lakewide), indicating that natural reproduction remains below the detection limit despite eggs being spawned at various reefs in northern Lake Michigan (Claramunt et al. 2005; Jonas et al. 2005a; Marsden et al. 2005; Fitzsimons et al. 2007) and both eggs and fry having been collected on the mid-lake reef complex (Janssen et al. 2006).

Fig. 1. Salmon and trout yield (millions of kg) by species during 1985-2010. Also shown is the percent of the total yield that is lake trout (solid black line) and the target range for lake trout (dotted black lines) based on the salmonine objective.



Several factors are likely contributing to the inability of the Lake Michigan lake trout population to become self-sustaining (e.g., inadequate numbers of stocked fish and suboptimal stocking practices, excessive mortality from sea lamprey and fishing, and negative impacts from non-indigenous species). Adult lake trout densities (measured by spring assessment surveys) were below minimum levels of stock size (<25 fish per 305-m gillnet; Bronte et al. 2008) that are believed needed to support sustainable populations. In addition, sea lamprey marking rates (and associated lake trout mortality rates) were above target values for 2005-2010 (see the Sea Lamprey chapter). Even if sufficient spawning-age fish accumulated in the lake, several other impediments prevent their eggs from making a contribution to the adult population (Bronte et al. 2003, 2007). Recent findings suggest that inadequate levels of key fatty acids in eggs (Czesny et al. 2009), depressed egg-thiamine levels (Fisher et al. 1996; Brown et al. 2005; Tillett et al. 2005), predation on eggs by benthic predators (Claramunt et al. 2005; Jonas et al. 2005a; Marsden et al. 2005; Fitzsimons et al. 2007), and predation on lake trout fry by adult alewife (Krueger et al. 1995) remain the key bottlenecks to survival from egg to juvenile life stages.

Management actions and ecological changes since 2005, however, may increase the probability of achieving the lake trout component of the salmonine FCO in future years. From a management perspective, the Lake Michigan Committee (LMC) has approved a revised strategy (Dexter et al. 2011) for the rehabilitation of lake trout in Lake Michigan that calls for an increase in lake trout stocking in more favorable habitats. This revision favors increased stocking in the Mid-Lake and Northern Refuges (see Frontispiece), which began, in anticipation of the revised strategy, in 2008. In addition, the overall number of yearlings stocked lakewide increased from an average of 2.4 million during 2000-2004 to an average of 3.1 million during 2005-2010.

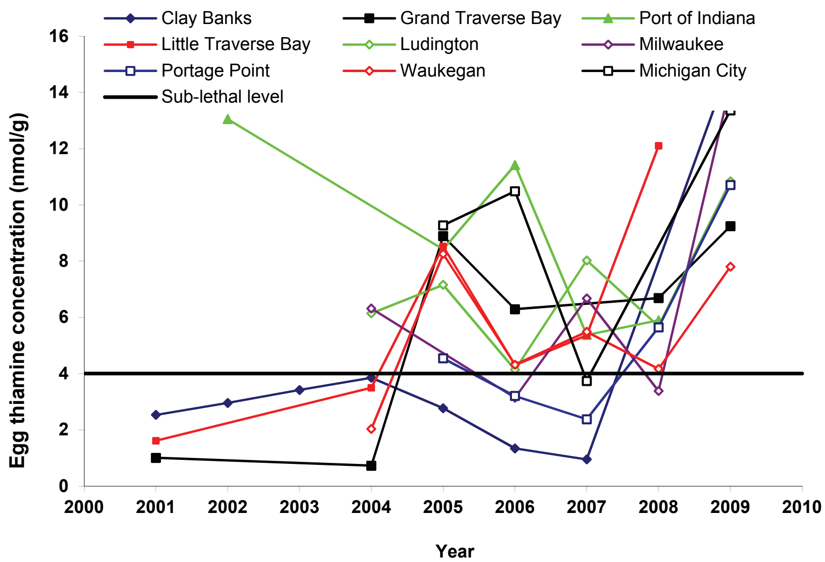
A new lake trout brood stock, based on the self-sustaining lake trout stock in the Parry Sound region of Georgian Bay, Lake Huron, is being developed by the U.S. Fish and Wildlife Service (FWS). This strain is scheduled to be available in 2013 for stocking into northern Lake Michigan. Further, the Klondike (colloquially, humper or banker) lake trout, a deepwater strain from Lake Superior, is already available for stocking. It is being considered by the LMC for limited use at the Mid-Lake Refuge (see Frontispiece). In addition to increased stocking levels, post-stocking mortality of stocked fish is expected to decrease because the FWS launched, in 2006, a new stocking vessel (M/V *Spencer F. Baird*) with enhanced offshore fish transportation and delivery capabilities. Evaluation of post-stocking survival, differential survival by strain and by stocking site, and movement of lake trout will be aided by the Great Lakes Mass Marking Initiative (Bronte et al. 2008), which will result in the application of coded wire tags and adipose fin clips to the entire 2010 year-class of lake trout (and subsequent year-classes).

From an ecological perspective, the Lake Michigan prey-fish community has become slightly more diverse with the establishment of round goby. Such diversification of lake trout diets, now consisting primarily of alewife, should result in higher egg thiamine concentrations and increase the likelihood of successful reproduction, although limited evidence to date shows a continued reliance on alewife (Jacobs et al. 2010; Michigan DNR, unpublished data). Thiamine levels in eggs, however, appear to be improving. In 2009, lake trout from all sampling locations had thiamine concentrations that exceeded the threshold for survival (4 nmol/g) suggested by Brown and Honeyfield (2004). These increases in egg thiamine levels (Fig. 2) and very recent declines (i.e., 2009-2010) in the abundance of spawning sea lamprey improve the likelihood of lake trout rehabilitation, but progress needs to be evaluated continually.

Chinook Salmon, Coho Salmon, Rainbow Trout, and Brown Trout

Although lake trout is singled out in the salmonine objective, other salmonines (Chinook salmon, coho salmon, rainbow trout (steelhead), and brown trout) are crucial for developing a diverse predator community that can meet the expectations for a world-class recreational fishery in Lake Michigan. To aid in the management of this fishery, which is dominated by Chinook salmon (>50% of the harvest), the Salmonid Working Group (SWG) of the Lake Michigan Technical Committee has been conducting a red-flag assessment annually since 2005. The goal of the exercise is to use a suite of biological indicators to (1) evaluate the balance between predators and prey, and (2) evaluate progress toward maintaining a diverse salmonine community with a view towards promoting ecosystem integrity. Details concerning the indicators used and the conditions under which a red flag is tripped or triggered are described in Clapp and Horns (2008) and Claramunt et al. (2008).

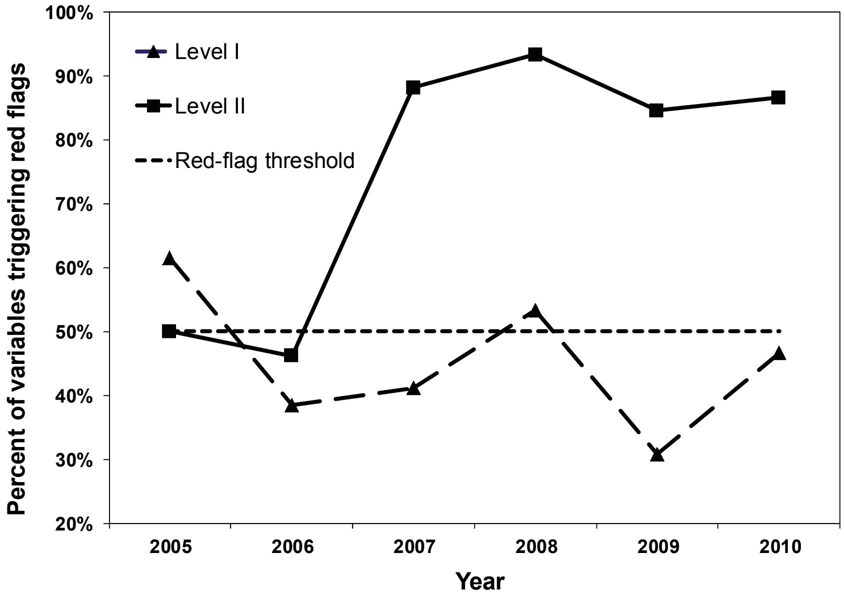
Fig. 2. Lake trout egg thiamine concentrations (nmol/g) from nine sites in Lake Michigan, 2001-2009. Sub-lethal effects may occur only below concentrations of 4 nmol/g (represented by the solid black line).



The first red-flag analysis in 2005 provides an interesting example of this process. Although the harvest target for salmonines was realized, even exceeding the level set forth in the salmonine objective, the analysis indicated that the high predator densities were not sustainable. Several indicators were trending downward (e.g., Chinook salmon size at age, diet (nutrition) indices, and prey-fish abundance), whereas indices of predator abundance were increasing (e.g., contribution naturally reproduced and creel and charter catch-per-unit-effort trends). This combination was interpreted as overly high densities of Chinook salmon and/or low prey abundance (Madenjian et al. 2005b; Warner et al. 2005; Claramunt et al. 2009). In addition to using the SWG's red-flag analysis, managers also had the output from a decision analysis (DA) (Jones et al. 2008). DA is a methodology used to rank the performance of alternative choices in terms of their ability to meet objectives successfully. The red-flag analysis, DA, and input from constituents were the basis for a coordinated lakewide 25% stocking reduction of Chinook salmon in 2006. In addition to the 2006 reduction, minor stocking reductions owing to budgetary limitations were implemented in 2007-2009 for coho salmon and in 2009 for Chinook salmon. Moreover, the daily bag limit for Chinook and coho salmon was increased from 3 to 5 fish per day in Michigan waters (Claramunt et al. 2009). Below, we provide a brief review of the 2005-2010 red-flag exercises to explore whether the resulting management actions improved a predator-prey balance that appeared unstable in 2005.

During 2005-2010, the percentage of all red-flag variables that reached trigger levels was 45.3% for year-to-year (Level I) comparisons and 74.8% for three-out-of-five-year (Level II) comparisons (Fig. 3). The Level I comparisons suggested that the predator-prey balance was acceptable (less than 50% of all variables reached trigger levels), whereas Level II comparisons were well above the 50% threshold. This discrepancy between Level I and Level II indicators may owe, in part, to a lag effect inherent in comparisons based on five years of data (Level II) versus those (Level I) based on one year of data. However, the failure of the Level II comparisons to trend downward over the last two years (2009-2010) (Fig. 3) suggests a systemic problem relating to selection of the trigger levels.

Fig. 3. Percent of Level I and II variables triggered in a red-flag analysis of Lake Michigan's salmonine prey-fish community during 2005-2010, conducted by the Lake Michigan Committee's Salmonid Working Group.



Summary

Fishery managers are utilizing appropriate tools to manage the offshore fish community for the greatest public good given the variability in the ecosystem. The approach of maintaining Pacific salmonine (e.g., Chinook and coho salmon, steelhead) populations at levels that provide recreational opportunities and that control non-indigenous forage fishes, while making a major commitment to rehabilitate native species, is a challenging but appropriate management approach given the biological and institutional realities, social concerns, and priorities. Given this challenge, we recommend the following priority research actions to increase the likelihood of achieving the FCOs in the coming years: (1) reassess the Level II triggers in the red-flag analysis and fuse this analysis with DA to provide for more strategic management actions, (2) ensure interagency lake trout sampling is sufficient to allow measurement of the benchmarks identified in the new implementation strategy, and (3) promote rehabilitation of native prey fishes, such as bloater and cisco.

INSHORE AND BENTHIVORE FISH COMMUNITIES

David F. Clapp[3], Robert F. Elliott, Steven J. Lenart, Randall M. Claramunt

This chapter addresses the inshore and benthivore fish-community objectives with specific focus on the current status of yellow perch, lake sturgeon, and lake whitefish populations (see Table 1 in the Introduction for scientific names of fishes). Other recreationally or commercially important inshore species include walleye and smallmouth bass. We direct readers to work by Roseman et al. (2010) and Kaemingk et al. (2011), which describes the recent status of these species in Lake Michigan. Round whitefish, suckers, and burbot, likewise, are important members of the benthivore community. Stapanian et al. (2010), Jacobs et al. (2010), and Flecker et al. (2010) document important aspects of these species.

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Yellow Perch

During 2005-2010, data from graded-mesh-gillnet surveys in all jurisdictions showed that adult abundance of yellow perch currently remains well below the peak levels observed in the late 1980s and early 1990s (Fig. 4). Survey catch rates of age-0 yellow perch in 2005 were the highest in recent years for most areas of the main basin (Makauskas and Clapp 2010; Madenjian et al. 2012), and, by 2009, the 2005 year-class comprised 25-60% of the adult population, depending on location (Makauskas and Clapp 2010). The persistence of the 1998 year-class was also recognized. It was well represented yet in 2008 in Illinois (>5% of the adult population) and Wisconsin (>10% of the adult population) waters.

Total harvest of yellow perch from Lake Michigan averaged 253,000 kg (558,000 lb) during 2005-2010, similar to that reported for 2000-2004 (240,000 kg; Allen and Breidert 2008). Most of this harvest was from the recreational fishery; commercial harvest of yellow perch ranged from 11,000 to 41,000 kg (24,000 to 91,000 lb). Recreational harvest rates have been increasing in recent years; for example, catch rates in Michigan waters in 2009 for anglers fishing for yellow perch specifically were the highest recorded since 1996 (Fig. 5).

Fig. 4. Yellow perch catch-per-unit effort (CPUE) (number of fish per 305 m of graded-mesh gillnets consisting of equal-length panels of 51-mm, 64-mm, and 76-mm stretched mesh) in the southern basin of Lake Michigan, 1984-2010. Data from Ball State University, Illinois DNR, Wisconsin DNR, and Michigan DNR. Michigan DNR values for 1997-2000 and 2002-2010 are estimates based on selectivity studies conducted in 1996 and 2001.

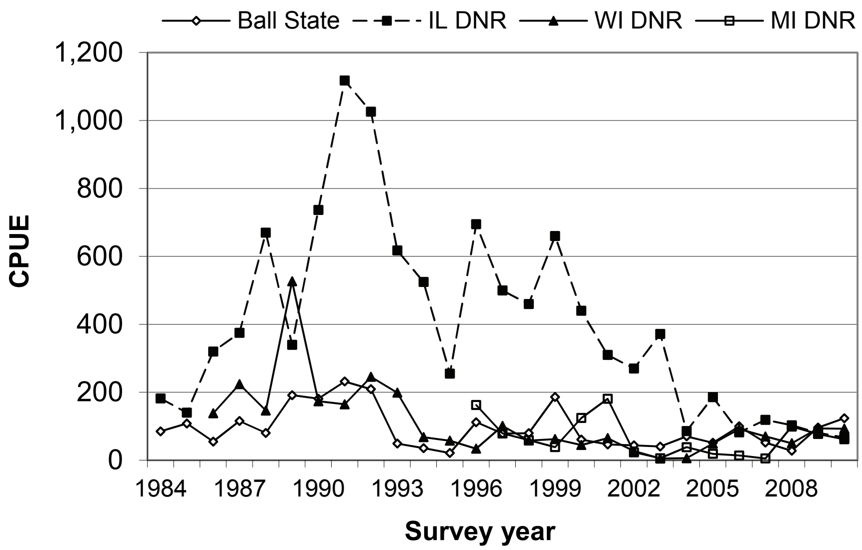
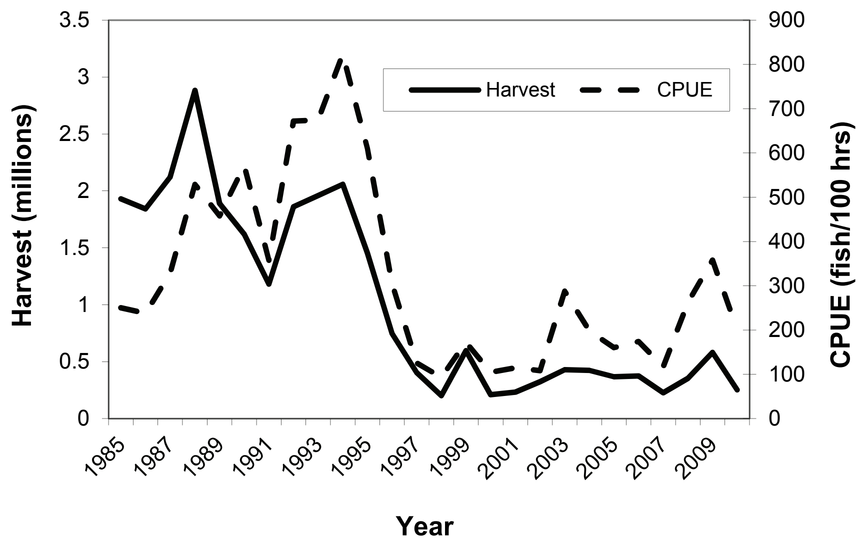


Fig. 5. Yellow perch recreational catch-per-unit effort (CPUE) (fish per 100 hr) in southern Lake Michigan statistical districts MM-6 to MM-8 (see Frontispiece), 1985-2010.



The regulation of the recreational fishery has not changed since 2005, and the only recent change to commercial regulations occurred in Green Bay in 2008, when the total quota was increased from 27,216 to 45,359 kg (60,000 to 100,000 lb). Regional statistical catch-at-age models developed previously for Lake Michigan yellow perch populations (Wilberg et al. 2005) formed the basis for development of decision analysis (DA) tools to be used in evaluating harvest policies for southern-basin populations (Irwin et al. 2008; Wilberg et al. 2008). A yellow perch DA workshop was held in 2008, and preliminary suggestions from this workshop were to change regulations adaptively and to use currently available assessments and other tools to measure the response of angler effort, harvest, and fishing mortality changes in regulations. However, subsequent discussions and the results of the most recent surveys led to a consensus recommendation that the Lake Michigan Committee maintain the current regulations. The rationale for this recommendation was that the population has not shown a measurable response that could be attributed to the reduced mortality levels brought about by the harvest regulations implemented during 1995-2000 (see Clapp and Dettmers 2004). The failure of adult yellow perch biomass to return to the peak levels observed in the late 1980s may be the result of a "regime shift" brought about by invasive (i.e., those that have proliferated over an expansive area) non-indigenous species like zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*). The uncertainty associated with this putative regime shift led fishery managers to conclude that an increase in yellow perch harvest would pose an unacceptable risk.

The formation of the Yellow Perch Task Group in 1994 led to an increased effort to understand yellow perch population dynamics in Lake Michigan (Clapp and Dettmers 2004). This work has continued and resulted in research on offshore transport of larvae (Dettmers et al. 2005; Beletsky et al. 2007), foraging and prey selection (Fulford et al. 2006; Graeb et al. 2006), habitat suitability (Janssen and Luebke 2004), life-history determinants (Marsden and Robillard 2004; Czesny et al. 2005; Lauer et al. 2005), and stock structure and migration (Glover et al. 2008).

Lake Sturgeon

Remnant populations of lake sturgeon persist and spawn each year in the lowermost sections of at least eight Lake Michigan tributaries (Schneeberger et al. 2005b; Elliott 2008). The lower Menominee River and the Peshtigo River (see Frontispiece) support the largest populations with spawning runs of 200 or more adults (Elliott and Gunderman 2008). Also, upstream of the first two dams on the Menominee River, two landlocked populations persist, and stocked juveniles are being used to establish a third landlocked population, which are all separated by additional dams. An estimate made in 2009 of the number of adult fish (>127 cm total length) and its corresponding 95% confidence interval (CI) in each of the three landlocked spawning populations were: (1) uppermost—572 (470-717); (2) middle—488 (428-561); and (3) lower—1,182 (1,051-1,338) (E. Baker, unpublished data; M. Donofrio, unpublished data). Six other rivers (Lower Fox, Oconto, Manistee, Muskegon, Grand, and Kalamazoo Rivers) support spawning runs of between 20 and 100 fish (Baker 2006; Elliott and Gunderman 2008; K. Smith, unpublished data). Small numbers of sturgeon in spawning condition also have been captured or observed in the lower Manistique and St. Joseph Rivers (Baker 2006; K. Smith, unpublished data). The largest lake sturgeon population within the Lake Michigan watershed, numbering approximately 40,000 adults (ages 26-80, Bruch 2008), inhabits Lake Winnebago located upstream of the Lower Fox River. Tag-return data from fish recovered in Green Bay and in the Lower Fox River suggest that many of the sturgeon that now spawn below the lowermost dam on the Lower Fox River migrated downstream from Lake Winnebago as adults, passing through the 17 lock-and-dam structures that now separate Lake Winnebago from Green Bay.

Larval lake sturgeon and/or age-0 fish (age 3-4 months) have been captured regularly in many of the rivers identified previously (Baker 2006; Elliott and Gunderman 2008; K. Smith, unpublished data; Mann et al. 2011). In the Peshtigo River, the number (with 95% CI) of age-0 lake sturgeon in 2006 and 2007 was 108 (80-162) and 1,260 (1,127-1,431), respectively (Caroffino et al. 2010). In the Manistee River, a population of at least 70 age-0 lake sturgeon has been documented, although estimates have been highly variable between years (Mann et al. 2011; Chiotti 2004). The Muskegon River in recent years supported at times at least 100 age-0 fish, and smaller year-classes of wild age-0 fish have been documented for the Grand and St. Joseph Rivers (K. Smith, unpublished data).

Lake Michigan lake sturgeon populations are genetically structured (De Haan et al. 2006), suggesting that natal homing (return to stream of origin) occurs. Mixed-stock analysis indicates that most lake sturgeon recovered in the open waters of Green Bay and the coastal waters of southeastern and northeastern Lake Michigan originated from local rivers (Bott et al. 2009; Scribner et al. 2010). Genetic evidence indicates that few fish from eastern Lake Michigan populations migrate westward to Green Bay, and similarly few from Green Bay populations migrate to coastal waters of eastern Lake Michigan. However, there is both genetic and tag-recovery evidence that a few juvenile fish, introduced into the Milwaukee River, migrated to the coastal waters of southeastern Lake Michigan and to Green Bay (Scribner et al. 2010; B. Eggold, unpublished data; RFE, unpublished data).

During 2002-2006, the abundance of lake sturgeon >112 cm in the open waters of central and southern Green Bay was estimated by mark-recapture to be 5,593 fish (95% CI = 2,255-14,432), of which 1,353 were adults. Total mortality on this stock was estimated to be from 5.1-7.0% (Elliott and Gunderman 2008). Although sea lamprey induced mortality has not been quantified in the wild, 34-58% of adults sampled in Green Bay during 2002-2006 had lamprey scars or marks (Elliott and Gunderman 2008), and lab studies have shown that sea lamprey can kill juvenile lake sturgeon (Patrick et al. 2009). Dead adult lake sturgeon continue to be found on beaches around the lake each summer and fall, presumably victims of botulism. Although occurrences remain few and similar to 2001-2005 (see Elliott 2008), reports from northeastern Lake Michigan have become more common and from Green Bay less common. Fishing for lake sturgeon has been limited to catch and release in the lower Menominee River since 2006 (following a permitted harvest that removed 506 adults during 1999-2005; Donofrio 2008).

Progress in quantifying and characterizing lake sturgeon habitat in Lake Michigan tributaries (Peterson and Vecsei 2006; Zeiber et al. 2006; Chiotti et al. 2008; Daugherty et al. 2009) has allowed the identification of habitat needs that are now being addressed. A spawning-habitat enhancement project is planned for the lower Kalamazoo River, and construction of a fish passage around the lower two dams on the Menominee River is scheduled to begin in 2012. One dam has been removed on the Milwaukee River, and a fishway suitable for lake sturgeon has been installed at a second dam and is planned for a third dam.

Several agencies have initiated and are evaluating the coordinated use of streamside rearing facilities (Table 2, Holtgren et al. 2007) to rehabilitate at-risk or to reintroduce extirpated river-spawning lake sturgeon populations. Streamside rearing aims to imprint cultured fish to the target river consistent with “The Genetic Guidelines for the Stocking of Lake Sturgeon in the Great Lakes Basin” (Welsh et al. 2010). Since 2004, the Little River Band of Ottawa Indians has reared wild-caught Manistee River eggs and larvae in their streamside facility for 4-5 months before releasing them back into the river. Preliminary evaluations indicate this effort is approximately doubling the annual age-0 production (M. Holtgren, unpublished data). The Wisconsin DNR switched in 2006 to streamside rearing for the Milwaukee and Manitowoc River reintroduction projects; the Manitowoc facility was moved in 2009 to the Kewaunee River. The Michigan DNR in 2006 began using streamside rearing to reintroduce lake sturgeon to the Cedar and Whitefish Rivers. Each year, gamete collection and culture have improved and stocking targets of 1,000-1,500 fish per facility are now being met (Table 2). Over the next 25 years, fish released from these facilities are expected to return and spawn in sufficient numbers to sustain populations.

Table 2. Number of fingerling lake sturgeon stocked into Lake Michigan rivers from streamside rearing facilities, 2005-2010. The Manitowoc facility was moved to Kewaunee in 2009.

	River/rearing facility				
Year	**Manistee**	**Milwaukee**	**Kewaunee (Manitowoc)**	**Cedar**	**Whitefish**
2010	74	1,192	17	951	1,420
2009	34	2,038	2,388	75	198
2008	47	767			
2007	29	158	(67)	189	722
2006	89	27			25
2005	51				

Lake Whitefish

Lake Michigan lake whitefish stocks generally are managed on a relatively fine spatial scale, with management areas established to encompass the distribution of an individual stock (Ebener et al. 2010b), although recent studies on genetic stock structure (VanDeHey et al. 2009) and fish movement (Ebener et al. 2010b) have identified the need to better quantify stock intermixing. Average lakewide commercial yield of lake whitefish during 2005-2010 was approximately 2.3-million kg (5.1-million lb), a 13% increase from 2000-2004 (Fig. 6). Between 60% and 70% of the harvest occurred in Michigan waters and the trapnet fishery accounted for roughly 65% of the total yield. During 2005-2010, average reported gillnet effort was approximately 4.4-million m (14.4-million ft), similar to the average during 2000-2004, yet substantially lower than the 7.7-million m (25.3-million ft) reported during 1995-1999. Trapnet effort declined from an average of 12,000 lifts during the late 1990s to 6,300 lifts in 2005. Since then, trapnet effort has increased steadily, and the 8,800 lifts reported in 2009 were the highest recorded since 2002. Fishery catch rates (based on aggregate lakewide commercial catch and effort), which had declined during the mid- to late 1990s, increased through the middle part of the next decade and remain relatively high, a pattern that generally mirrors trends in estimated biomass (Fig. 7). However, since the middle of the 2000s, the prevalence of net-fouling benthic algae has been a major impediment for commercial operators in late spring/early summer and has undoubtedly reduced the catch efficiency of commercial gear.

Although overall population biomass has been steadily increasing, lake whitefish growth rates, particularly in the northern stocks, declined markedly through the middle part of the decade, following the well-described trend that began in the early 1990s (see Schneeberger et al. 2005a). During 2009, growth appeared to have increased for some of the younger age-classes (ages 5-7, generally), though it remains to be seen whether this is a temporary response. As a consequence of declining growth, the mean age in the commercial harvest has steadily increased from ages 5-6 in the mid-1990s to at least age 8 in 2007.

Fig. 6. Commercial yield of lake whitefish from Lake Michigan, 1990-2010, and the yield objective instituted in1995.

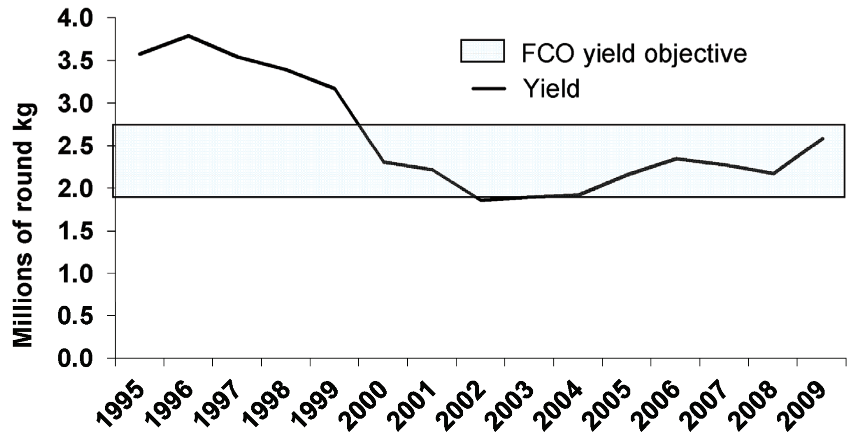
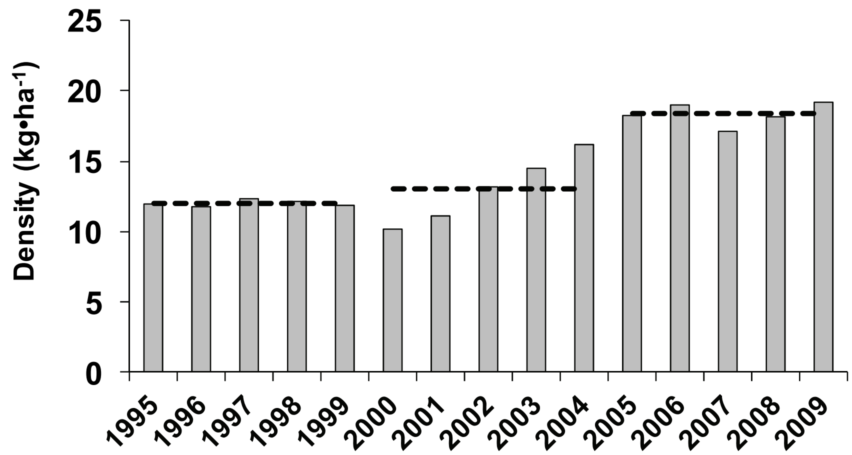


Fig. 7. Density (kg•ha^{-1}) of adult lake whitefish biomass per hectare of surface water <73-m deep (240 ft) as estimated from statistical catch-at-age models in 1836 treaty-ceded waters of Lake Michigan, which encompass all state of Michigan waters from the mouth of the Escanaba River east and south to the mouth of the Grand River (see Frontispiece). Leland and Ludington stocks excluded from analysis. Dashed lines represent five-year means.



The declines in lake whitefish growth and condition—likely due to the increasing importance of dreissenid mussels, declining importance of *Diporeia* spp., and intraspecific competition—have led to concerns about the ability of lake whitefish stocks to retain their current levels of biomass (Nalepa et al. 2005; Kratzer et al. 2007; Wright and Ebener 2007; DeBruyne et al. 2008; Rennie et al. 2009). Recent research in Lakes Michigan and Huron sought to determine if poor condition of lake whitefish has led to increased natural mortality. Ebener et al. (2010a) found that, while estimates of *M* (natural mortality rate) did vary among stocks, rates were generally consistent with previously published estimates for Great Lakes lake whitefish stocks; they concluded that reduced growth has not led to measurable increases in natural mortality. Lake-specific differences likely were explained by differential sea lamprey induced mortality. The investigators did not find relationships between spatial patterns in fish-health indicators and estimates of natural mortality rates, suggesting a complex interaction between health indicators and mortality (Wagner et al. 2010). However, the widespread prevalence of pathogens, such as *Renibacterium salmoninarum* and the swimbladder nematode *Cystidicola farionis*, in these stocks (Faisal et al. 2010a, 2010b) suggests the need to enact more comprehensive monitoring of stock health. The ability of managers to reach harvest objectives in the future may be compromised if the factors influencing mortality are not well documented and accounted for in management efforts.

Considerable effort has occurred in recent years to determine if poor condition of larger lake whitefish (and other environmental factors) influences the production of age-0 lake whitefish. As is common for many fishes, the quality of sperm produced by lake whitefish increased with fish size (Blukacz et al. 2010). Furthermore, female condition and egg quality influenced offspring condition, although site-specific environmental conditions had a larger impact on the abundance of age-0 lake whitefish (Claramunt et al. 2010a, 2010b; Muir et al. 2010). Variation in larval lake whitefish densities was best explained by larval fish size, wind intensity at emergence, and biomass of spawners (Claramunt et al. 2010b). Overall, both environmental factors and spawning-stock characteristics appear to regulate the production of age-0 lake whitefish. Fishery monitoring suggests that recruitment (the number of lake whitefish surviving to age 3) appears to have been relatively strong basinwide in the late 1990s and early 2000s. In recent years, however, regional trends in recruitment are increasingly becoming apparent. Strong year-classes produced during 1997-1999 were evident in the southernmost stocks, while, in the north, the 2001 and 2002 year-classes appeared quite strong. Since the 2003-2010 year-classes have not yet recruited fully to the commercial fishery, the relative strength of these year-classes is still somewhat uncertain. Given that reduced growth has delayed recruitment, management agencies, to better manage the fishery, should consider incorporating pre-recruit surveys into their long-term monitoring plans.

Progress in Meeting Fish-Community Objectives

Recreationally and commercially important inshore fish stocks continue to be self-sustaining, although the average yield of yellow perch from 2005 to 2010, amounting to 253,000 kg (558,000 lb) remained well below the target range of 0.9- to 1.8-million kg (2- to 4-million lb). Walleye yield averaged 0.095-million kg (0.21-million lb) during 2005-2010, very close to the target range of 0.1- to 0.2-million kg (0.2- to 0.4-million lb). Little information is available from which to evaluate the status of other inshore fish populations (e.g., northern pike, channel catfish, and various panfish). Lake whitefish yield has been within the target range of 1.8- to 2.7-million kg (4- to 6-million lb) since 2000. The ability of managers to meet lake whitefish harvest objectives in the future may be compromised if growth continues to decline and diseases are not abated. Although most lake sturgeon populations are below target abundances (Hay-Chmielewski and Whelan 1997; Wisconsin Department of Natural Resources 2000; Little River Band of Ottawa Indians 2008; Welsh et al. 2010), coordinated lakewide rehabilitation efforts are designed to achieve abundance targets that better ensure sustainability within the next 20-25 years. Other objectives for lake sturgeon outlined in Eshenroder et al. (1995)—habitat improvement, fish passage, and protective regulations—are being met or addressed.

Summary

Achieving those Inshore and Benthivore Objectives that were unmet may require modifying the management approach. For example, implementation of the previously developed DA model (Irwin et al. 2008) would formalize and improve management of yellow perch. For other fishes, adopting improved indicators that trigger management action would be beneficial. Inclusion of pre-recruit indexes in lake whitefish stock assessment models would improve management of this species, and management of most nearshore and benthivore species would be improved by adoption of comprehensive fish-health monitoring, including management triggers for emerging fish-health issues. By improving habitat (in combination with temporary supplementation of recruitment through techniques, such as streamside rearing) where degradation has depressed recruitment of inshore and benthivore fishes, good progress can be made towards achieving objectives. Improvement of fish passage for lake sturgeon would provide the greatest immediate dividends for this species as well as others. Additionally, wetland and river restoration activities would benefit a wide variety of species, including northern pike, muskellunge, and walleye.

A program of focused research is also critical to achievement of objectives for the inshore and benthivore fish communities. For example, determining how fish transport from drowned-river-mouth lakes influences inshore fish abundance may improve management of these populations. Likewise, a synthesis of recent findings from lake whitefish movement and genetic studies would help to refine management of these stocks. For lake sturgeon, long-term field assessments of all remnant and introduced populations are needed as streamside-reared fish disperse, mature, and seek spawning sites. Additionally, the potential effects of invasive non-indigenous species, contaminants, and diseases on lake sturgeon rehabilitation are poorly understood. Basic evaluations of the available population and harvest data are needed for smallmouth bass, northern pike, muskellunge, channel catfish, panfish, and suckers. This research priority was also included in previous state of the lake reports (Holey and Trudeau 2005; Clapp and Horns 2008) but remains relevant today. Evaluation and management of these inshore fishes continues to be a lower priority than management of yellow perch, lake whitefish, and lake sturgeon.

SEA LAMPREY

Jeff Slade[4]

Sea lamprey (see Table 1 in the Introduction for scientific names of fishes) control was critical to the biological and socioeconomic recovery of the Lake Michigan fishery (Fetterolf 1980), remains instrumental in maintaining the current fish community (Eshenroder 1987; Holey et al. 1995; Lavis et al. 2003), and is essential for achieving many of the lake's fish-community objectives (FCOs) (Eshenroder et al. 1995). By the mid-1960s, implementation of integrated pest management techniques resulted in large reductions in sea lamprey abundance (Smith and Tibbles 1980; Lavis et al. 2003), but sea lampreys continue to inflict high levels of mortality on host fishes and remain a major impediment to lake trout rehabilitation (Bronte et al. 2008; Lake Michigan Committee 2010). In addition, major gaps exist in the understanding of sea lamprey-host interactions, which ultimately influence estimates of host mortality (Bence et al. 2003). Achievement of the FCOs will likely require increased use of lampricides on streams that produce large numbers of larval sea lampreys, repairs to barriers, and a better understanding of sea lamprey induced mortality on the entire fish community (Great Lakes Fishery Commission 2012).

Current Status

In 2004, the Lake Michigan Committee (LMC) set a target level of abundance for adult (spawning-phase) sea lampreys of 57,000 ± 13,000 (95% confidence interval) and a target marking rate of no more than 5 per 100 lake trout (Bronte et al. 2008). These metrics were based on estimates of the average abundance of adults during 1988-1992 when marking rates were nearest to 5 marks per 100 fish (4.7 Type A, Stages I-III, marks combined per 100 lake trout >532 mm; see Ebener et al. 2006). Marking rates of no more than 5 per 100 fish were found to result in a tolerable annual rate of sea

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lamprey induced mortality of less than 5%, based on a relationship between marking rates and the probability of surviving a sea lamprey attack (Eshenroder and Koonce 1984).

From 2005 to 2007, adult abundance (Fig. 8) increased and greatly exceeded the target level. However, from 2007 to 2010, adult abundance declined sharply and was within the target range in 2009. Possible explanations for increases in adult abundance include increased production from the Manistique River due to deterioration of its dam, changes in lampricide application strategies that led to decreases in treatment efficacy, implementation of new stream-treatment selection criteria, concerns regarding effects on nontarget species, and changes in the fish community that led to increased survival of larval and juvenile (parasitic-phase) sea lampreys. These factors, combined with intentional efforts to reduce lampricide usage (Brege et al. 2003), likely contributed to a greater number of residuals (sea lampreys that survive treatment). The decline in adult abundance between 2007 and 2010 was likely attributable to increases in lampricide control effort, particularly on the Manistique River, and to efforts to improve the efficacy of lampricide applications.

The trend of marking on lake trout generally tracks the abundance of adult sea lampreys, and, since 2001, both measures have exceeded their target levels (Fig. 8). Lake trout marking rates increased steadily lakewide from 2000 until reaching a peak in 2006, which was nearly five times the target, after which marking declined to twice target levels by 2009-2010. Outputs of statistical catch-at-age models developed for the 1836 Treaty waters of Lake Michigan indicate that sea lamprey induced mortality has equaled or exceeded the target in all statistical districts and years and has increased substantially over the past 15 years in northern Lake Michigan (Fig. 9).

Fig. 8. Target and 95% confidence interval for abundance of adult sea lampreys, target for sea lamprey marks (Type A, Stages I-III, combined) on lake trout, and trends in adult sea lamprey abundance and marking in Lake Michigan, 1977-2010.

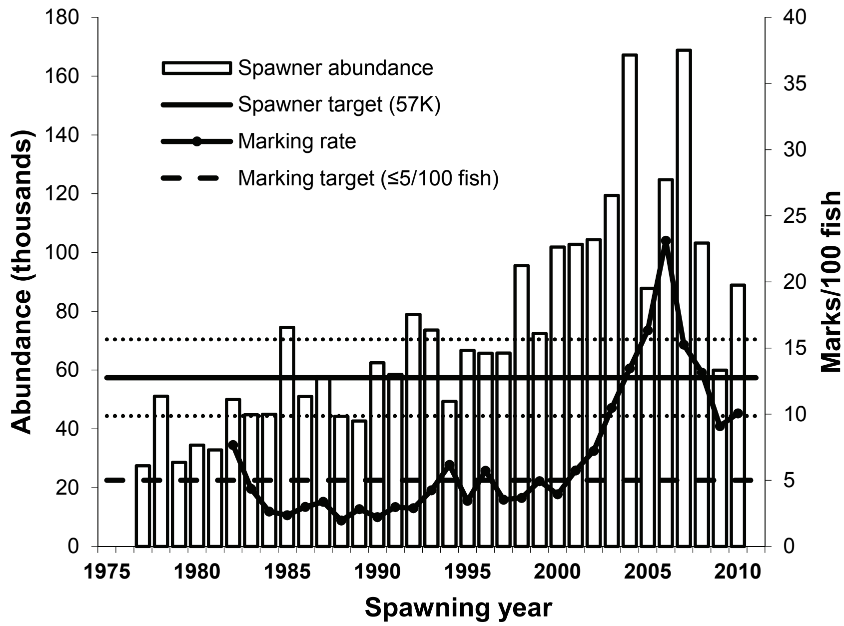
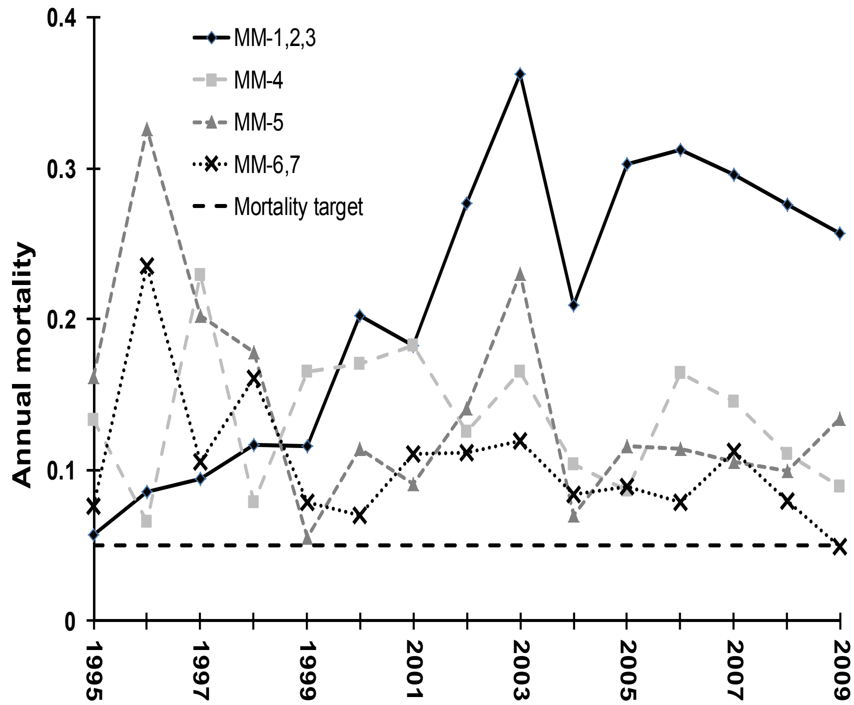


Fig. 9. Average estimated sea lamprey induced mortality on ages 6-11 lake trout in the 1836 Treaty waters of Lake Michigan, 1995-2009 (Modeling Subcommittee of the Technical Fisheries Committee of the 2000 Consent Decree). See Frontispiece for locations of statistical districts.



Summary

Although targets for sea lamprey abundance and marking of lake trout have not been achieved, increases and enhancements in lampricide control effort since 2005 appear to have resulted in declines in sea lamprey abundance and in marking on lake trout. Fishery and sea lamprey managers have recently developed a Great Lakes Sea Lamprey Control Plan (Great Lakes Fishery Commission 2012) that identifies strategies to enhance control of sea lampreys over the next five years with the goal of meeting and maintaining targets established by the LMC. Recommendations from the plan that are intended to foster achievement of the sea lamprey FCO include: (1) reduce adult sea lamprey abundance by treating for two consecutive years those streams with the highest larval production, such as the Ford, Manistique, Big Manistee, and Pere Marquette Rivers; (2) reduce recruitment from the Manistique River by constructing a barrier by 2014; and (3) improve the metrics used to measure program success and the effects of sea lampreys on Lake Michigan's fish community.

Habitat Conditions in the Lake Michigan Watershed

Stewart F. Cogswell[5], Gary E. Whelan, and Rochelle Sturtevant

Habitat comprises not only physical structure (e.g., reefs and marshlands) but also water chemistry, contaminants, and biota to which fishes are exposed (including pathogens and non-indigenous nuisance species). Alterations to fish habitat have constrained the achievement of the fish-community objectives (FCOs) for Lake Michigan. The Lake Michigan Environmental Objectives (EOs) (Rutherford et al. 2005) identify habitat improvements in five focal areas necessary for minimizing the impacts of past perturbations on fish production: (1) connectivity of tributary habitats, (2) connectivity of coastal wetlands, (3) spawning reefs, (4) nearshore habitats, and (5) water quality. Below, we discuss these focal areas and, in addition, review changes in and impacts of pathogens and non-indigenous nuisance species. We offer recommendations that will facilitate habitat-improvement efforts in the coming years.

Connectivity between the lake and its tributaries is vital to lake sturgeon (see Table 1 in the Introduction for scientific names of fishes), walleye, and other important sport and forage fishes that spawn in rivers. In keeping with the EOs, from 2005 to 2010, over 480 km of riverine habitat in the Lake Michigan basin was reconnected through the Great Lakes Fish and Wildlife Restoration Act and through projects funded by the U.S. Fish and Wildlife

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Service. An additional benefit to these restoration projects was the reconnection of over 750 ha of riverine wetlands to the lake. Coastal wetlands provide critical nursery and spawning habitat for important lake fishes, such as northern pike (Jude and Pappas 1992). Lake Michigan's coastal wetlands amount to nearly 44,000 ha (Ingram et al. 2009), but they are impacted by filling, dredging, agriculture, urban development, invasive (i.e., those that have proliferated over an expansive area) non-indigenous plants (e.g., *Phragmites australis*), drainage, and hardened shorelines (Schneider et al. 2009). Shoreline hardening can negatively affect fish populations due to increased wave energy, turbulence, and blockage of longshore transport of materials and biota, which in turn can negatively affect fish populations by preventing newly hatched larvae from reaching nearby nursery areas (Mackey 2009) and inputs of large woody debris and sediment. Offshore reef habitats are poorly described and may face threats in the future due to wind-farm development.

Reducing chemical toxins in Lake Michigan is critical for elimination of fish-consumption advisories. Polychlorinated biphenyls (PCBs) and mercury are the only two toxins common to consumption advisories across all four Lake Michigan states. The state of Michigan has a consumption advisory based on dioxins, and Illinois has one based on chlordane. Although PCBs have persisted in fish for decades, their levels in Chinook salmon, coho salmon, and lake trout have trended downward (U.S. Environmental Protection Agency 2008). Recent modeling predicts that PCB levels in ages 5-6 lake trout should decline by over 50% as early as 2033, which would result in the relaxation of sport-fish-consumption advisories (Kreis et al. 2009). Mercury levels in most top-predator fish continue to be below the advisory threshold (0.5 ppm). While still below the threshold, lake trout concentrations have shown a slight increase over the past decade (J. Bohr, Michigan Department of Environmental Quality, personal communication, 2011). In addition to these long-recognized toxins, several others are now being detected, including polybrominated diphenylethers (PBDEs). Advisories for PBDEs, an industrial flame retardant, have yet to be established for fishes. Additionally, pharmaceutical compounds have been found increasingly in drinking water within the basin (U.S. Environmental Protection Agency 2008), and their effect on fish and how they will be addressed in fish-consumption advisories remain to be determined.

Fish pathogens and resulting diseases remain a threat to fish production both in hatcheries and in the wild. A new virulent pathogen, viral hemorrhagic septicemia virus (VHSv), was first detected in Lake Michigan in 2007 after being detected earlier in Lakes Huron, Erie, St. Clair, and Ontario. Detection occurred through surveillance (collection of fish for presence of virus) and investigation of fish kills. VHSv was first detected in brown trout, lake whitefish, and smallmouth bass in May-June 2007 in Green Bay and in the lake proper in Door County, Wisconsin. Round goby and yellow perch die-offs in May-June 2008, near Milwaukee, Wisconsin, were attributed to VHSv. During the same period, round goby and rock bass from Winthrop Harbor, Illinois, were positive for VHSv, although no mortalities were reported. Although surveillance in 2009-2010 continued to find fish (e.g., smallmouth bass) positive for VHSv, no fish kills were attributed to VHSv, and the virus has yet to be detected in hatcheries.

As for long-recognized fish-health problems and pathogens, previously implemented control measures have kept bacterial kidney disease (BKD) at a low prevalence; no new outbreaks were observed in either wild or hatchery stocks. Several other long-recognized diseases with uncertain implications became more prevalent during 2008-2010: whirling disease (caused by *Myxobolus cerebralis*), infectious pancreatic necrosis virus (IPNv), furunculosis, and various diseases caused by flavobacteria. The implications of these detections are uncertain. The overall status of fish health in wild and hatchery stocks can be characterized as stable, but the uncertain effects of emerging pathogens make the future unclear.

Since 2005, three non-indigenous species have established in Lake Michigan. A deepwater population of New Zealand mudsnails (*Potamopyrgus antipodarum*) has established at a single location near Waukegan, Illinois. While isolated from other populations, it is extremely dense. The bloody-red shrimp (*Hemimysis anomala*) has been reported in five locations around the lake and likely is firmly established and spreading to other suitable nearshore habitats. Last, a freshwater hydroid (*Cordylophora caspia*) was documented in 2007 near Chicago, Illinois. This species is poorly studied and may be more widespread than reports indicate. In addition, six species of aquatic plant were reported as established in Lake Michigan proper in 2008, including marsh thistle (*Cirsium palustre),* yellow iris (*Iris pseudacorus*), bittersweet nightshade (*Solanum dulcamara*), water bentgrass (*Agrostis gigantea*), true forget-me-not (*Myosotis scorpioides*), and spotted knotweed (*Plygonum persicaria*). The extent to which these plants will influence native species in coastal and wetland communities remains unclear.

Regarding non-indigenous species that became invasive prior to 2005, quagga mussels (*Dreissena bugensis*) have virtually eliminated zebra mussels in nearshore waters and colonized deeper waters (>100 m) not inhabited previously by zebra mussels (*D. polymorpha*) (Nalepa et al. 2009; Bunnell et al. 2009b). The spiny water flea (*Bythotrephes longimanus*), first reported from the lake in 1986, is inducing migration of native cladocerans to cooler, less suitable waters (Pangle et al. 2007). In Lake Huron, its predation on zooplankton could exceed that of fish (Bunnell et al. 2011). The round goby, first observed in Lake Michigan in 1993, is now widespread and increased its abundance during 2005-2010. As predatory fish learn to make round goby a primary food source, its abundance may level off or even decline (Madenjian et al. 2012). Bighead carp and silver carp, potentially devastating non-indigenous species due to their voracious appetite for phytoplankton and zooplankton, have migrated up the Chicago Sanitary and Ship Canal to within miles of Lake Michigan.

Summary

During 2005-2009, there was moderate progress toward achievement of the chemical/habitat FCOs and EOs for Lake Michigan. Beginning in 2010, restoration of habitat conditions has been greatly accelerated by the $450-million Great Lakes Restoration Initiative (GLRI). GLRI focus areas include: (1) cleaning up toxics and areas of concern, (2) combating invasive non-indigenous species, (3) promoting nearshore health by reducing phosphorus inputs, (4) restoring and protecting habitat and wildlife, and (5) tracking progress. In 2010, over $138 million of GLRI funds were spent on 240 projects within the Lake Michigan watershed (http://greatlakesrestoration.us/granteeinfo.html). Although considerable progress has occurred in reducing the lakewide loads of PCBs in Lake Michigan, other emerging contaminants (PBDEs, pharmaceuticals) pose new threats to fish and safe fish consumption. Finally, non-indigenous species continue to colonize, and some subset may ultimately become invasive, compounding the impacts on the food web caused by invasive species established previously.

Prioritized recommendations for habitat include: (1) inventory stream barriers and prioritize reconnection projects based on biological benefits and cost-effectiveness, as regards native species restoration; (2) develop and implement across the Lake Michigan basin a standardized fish-pathogen surveillance program and reporting system for wild fish that measures and reports on the prevalence and intensity of those emergency and restricted diseases listed in the Great Lakes Fish Disease Control Policy and Model Program (Hnath 1985), as well as emerging diseases, and incorporates all existing hatchery-fish health and certification information; (3) develop a methodology to facilitate the early detection of and rapid response to new non-indigenous species throughout the Great Lakes and Mississippi River systems.

CONCLUSIONS

Steven R. Robillard[6], Brian Breidert, Bradley T. Eggold, Thomas K. Gorenflo, and Jay Wesley

When evaluating the status of Lake Michigan's fish-community objectives (FCOs) and the progress made toward achieving a desired state, the entirety of the FCOs, as described in Eshenroder et al. (1995), should be considered. In particular, Eshenroder et al. (1995), before describing specific objectives for the most important fishes (which have received the most attention), provided an overarching goal of maintaining the biological integrity of the system. In addition, ten guiding principles were identified, covering a wide range of topics that together define a multi-jurisdictional fishery-management philosophy for Lake Michigan. Arguably, the most relevant of these ten principles for this report focus on: (1) recognition of lake productivity limits, (2) preservation and restoration of fish habitat, (3) prioritization of native species restoration, (4) naturalization of non-indigenous salmonines, and (9) prevention of the unintentional introduction of non-indigenous species.

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In this concluding chapter, we, the Lake Michigan Committee (LMC), evaluate what has transpired during this reporting period, 2005-2010, in relation to specific objectives, as well as to the maintenance of biological integrity, all within the context of the ten guiding principles. We also include three recommendations endorsed by the Lake Michigan Technical Committee (LMTC), which may provide guidance for the achievement or maintenance of the specific objectives. Lastly, we offer our own considerations regarding the biological integrity of the Lake Michigan ecosystem and the impediments to the ultimate achievement of our FCOs.

Progress towards Specific Fish-Community Objectives

As regards the offshore food web, the Salmonine Objective was partially met, despite lower system productivity and ongoing changes in lower trophic levels. Notwithstanding the inherent instability in the system, salmonine harvests were consistent with the objective (2.7- to 6.8-million kg), but lake trout (see Table 1 in the Introduction for scientific names of fishes) did not comprise 20-25% of the harvest, as was envisioned. Despite prolonged efforts to rehabilitate lake trout, numerous factors (e.g., excessive mortality from sea lamprey and negative effects of alewife) limited the number of spawning lake trout and inhibited both natural reproduction and the capacity for more harvest. On a more positive note, natural reproduction does currently account for at least 50% of the Chinook salmon population, and this natural reproduction aligns with the fourth guiding principle, which seeks increased self-sustainability of native and non-indigenous salmonines. Natural reproduction enables natural feedbacks between predators and prey and likely confers greater biological integrity, our over-arching goal, than do hatchery-dependent populations.

The lakewide level of planktivore biomass during this reporting period was only 13-20% of that cited in the Planktivore Objective, which also aims for a diversity of prey species to meet predator demand. Prey diversity increased with the addition of the non-indigenous round goby, which is ubiquitous and increasing in abundance; conversely, densities of two native fishes, bloater and deepwater sculpin, have continued to decline. In addition, two other non-indigenous planktivores (alewife and rainbow smelt) have also declined in abundance. The biomass values developed for the objective were intended to provide harvest opportunities and to satisfy predator demand for a successful achievement of the Salmonine Objective. Current planktivore levels, however, imply a serious imbalance between predators and prey that could lead to further instability in the food web.

The abundance of walleye was sufficient in most years to allow harvest within the range indicated in the Inshore Fish Objective, but yellow perch are likely underpopulated, as harvest was only 28% of the minimum yield expectation (0.9-million kg). Numerous factors can affect harvest, including regulations and weather, but ongoing population assessments indicate that yellow perch abundance is well below that necessary to allow sustainable harvests at the level indicated in the Inshore Fish Objective. All species mentioned in this objective appeared to be maintaining self-sustaining populations, although a regime shift may reduce the likelihood of yellow perch reaching the biomass attained in the 1980s.

The goal of self-sustaining stocks in the Benthivore Objective was met for all species except lake sturgeon. Remnant populations of lake sturgeon persist and spawn each year in the lowermost sections of at least eight Lake Michigan tributaries. Use of in-stream rearing facilities to boost larval survival and subsequent population increases are consistent with the guiding principles of preserving native species, protection and enhancement of threatened and endangered species, and the genetic stock concept. The lake whitefish component of the Benthivore Objective, which calls for achieving populations capable of sustaining annual yields ranging from 1.8- to 2.7-million kg (4- to 6-million lb), was achieved throughout the reporting period despite ongoing declines in whitefish growth and condition thought to be caused by dreissenid mussels.

The aim of the Sea Lamprey Objective is to suppress sea lamprey numbers such that other FCOs can be achieved. The Salmonine Objective is the objective most impacted by an excessive abundance of sea lampreys, but sea lampreys do affect other species and have indirect impacts on multiple trophic levels. Sea lamprey impacts on adult lake trout, implied from high lamprey marking rates (2-3 times target levels), are likely a factor in the near absence of lake trout reproduction in Lake Michigan.

Progress towards Environmental Objectives in Lake Michigan (Rutherford et al. 2005), which built upon the Physical/Chemical Habitat Objective in Eshenroder et al. (1995), was evaluated in the preceding Habitat Conditions in the Lake Michigan Watershed chapter. Minimal progress has been made toward protecting or restoring fish habitat at a lakewide scale, although the Great Lakes Restoration Initiative, a federal program initiated in 2010, has been beneficial in promoting restoration of degraded habitats. Both Eshenroder et al. (1995) and Rutherford et al. (2005) highlighted the importance of restoring tributary and nursery areas, yet no basinwide evaluation has been developed by which progress towards restoring these key habitats could be monitored. Besides the physical-habitat shortcomings, the authors note that emerging contaminants (e.g., pharmaceuticals) may impact the safety of fish for human consumption, and, while hatchery control measures have been effective at abating threats from bacterial kidney disease, fish pathogens and resulting diseases remain a threat to both wild and hatchery fish. In addition, since 2005, three more non-indigenous species have established in Lake Michigan. The collective impact of invasive (i.e., those that have proliferated over an expansive area) non-indigenous species on achievement of the FCOs is of great concern.

Technical Committee Recommendations

Each of the two previous state of the lake reports (Holey et al. 2005; Clapp and Horns 2008) advanced a series of recommendations made within chapters and, in addition, the special editors of the second report provided an overview of those recommendations considered to be most important. These recommendations, however, were not addressed by the LMC and little became of them owing to publication delays and the fact that the recommendations had not been formally endorsed by the LMTC. In this report though, publication is timely and all of the recommendations were approved by the LMTC. The following three recommendations were considered to be of highest priority, and will be addressed by the LMC during the next reporting period:

- Develop more strategic stocking policies and management actions for salmonines via an annual red-flag analysis, reassessing triggers as suggested, in collaboration with decision analysis.

- Promote rehabilitation of native prey species (e.g., bloater and cisco).

- Reduce sea lamprey abundance by treating for two consecutive years those streams producing the most larvae, such as the Ford, Manistique, Big Manistee, and Pere Marquette Rivers.

The Quest for Biological Integrity

Eshenroder et al. (1995) stated that fishery managers should aim for a Lake Michigan fish community that possesses biological integrity whereby "production of desirable fish is sustainable and ecologically efficient." High ecological efficiency could be characterized by multiple energetic connections between and within trophic levels where each trophic level has a diversity of species. In contrast, an inefficient system would be described by a low diversity of taxa within each trophic level where some of the dominant species would be largely "disconnected" from the ecosystem because it had few predators (i.e., an ecological "dead end" that reduces the transfer of energy up to those fish that provide the most benefits to society). Given the information presented in this report, we conclude that the sought-after biological integrity is lacking in Lake Michigan.

Ongoing, deleterious change in lower trophic levels is the bellwether of ecological inefficiency in the Lake Michigan ecosystem. A relatively recent wave of invasive non-indigenous species (dreissenid mussels, *Bythotrephes longimanus*) is undoubtedly altering the environment of the lake. Although a full understanding of their effects is incomplete, dreissenids have reduced phytoplankton production in the spring, are implicated circumstantially in the collapse of *Diporeia* populations, and have depressed the growth and condition of alewife, lake whitefish, and bloater. Whether the zooplankton, prey-fish, and benthivore and piscivore communities are able to maintain their biomass and species composition remains unclear. Among the non-indigenous species, the range expansion of quagga mussels (*Dreissena bugensis*) in Lake Michigan may be the biggest driver of reduced efficiency.

As more and more nutrients are bound within the shells and soft tissues of quagga mussels, one could argue that fewer nutrients will be available to the fish community, given the relative paucity of fish species that consume quagga mussels.

Eshenroder et al. (1995) acknowledged the several realities that could prevent attainment of the lake's FCOs, and they have not gone away. To paraphrase, fishery management is inexact in its ability to influence the future state of the fish community, management options are limited and fraught with uncertain outcomes, and expectations for the fish community are greatly complicated by the impacts of invasive non-indigenous species. The impacts of long-established non-indigenous species, such as sea lamprey, are well documented, whereas the full impacts of those recently established remain to be determined. In our view, the recently established ones are the greatest impediment to achievement of our FCOs, a view well supported by this report. Ineffectual government action to prevent future introductions (e.g., ballast discharge regulation) will continue to impede achievement and maintenance of our FCOs. In addition, U.S. Environmental Protection Agency monitoring has found that offshore concentrations of total phosphorus averaged only 3.1 mg/L in 2005-2010, which was a 37% decline from the average in 1983-1998 (R. Barbiero, personal communication, 2012). Because Lake Michigan is less productive now than when the FCOs were developed and invasive species are increasingly perturbing lower trophic levels, it is not surprising that the biological integrity of the Lake Michigan ecosystem is threatened.

In addition to those impediments identified in Eshenroder et al. (1995) that persist, three new impediments and management challenges are of much concern:

1. While sizeable restoration of riverine habitats and reconnection to wetlands has been accomplished recently, much to the benefit of migratory fishes, debate remains regarding removal of lowermost dams due to potential range and population expansion of non-indigenous species (e.g., sea lamprey, round goby, viral hemorrhagic septicemia virus). This debate will intensify in coming years as many dams are coming up for relicensing, require repairs, or are being abandoned at the

same time that the desire to reconnect migratory fish with river habitats is growing. Currently, there is much support and funding for removal of these barriers, but the potential benefits must be weighed against expansion, for instance, of sea lamprey spawning habitat. The result may be additional strain on sea lamprey control, which, in recent years, has been unable to consistently reduce sea lamprey abundance to target levels.

2. Restoration and maintenance of several native species are impeded by loss of habitat for some or all of their life stages. Shoreline development and hardening impedes restoration of historically important fish-production areas. Recent emphasis on mitigating such losses (e.g., coastal zone programs) may not be sufficient to ensure sufficient restoration of these nearshore habitats.
3. As regards effects on Great Lakes fisheries, pollution, particularly point source, is the most underrated and under-discussed issue. The quality of habitat and the biological integrity of the lake are degraded by oil spills (Michigan in 2010), coal ash spills (Wisconsin in 2011), mercury deposition and thermal pollution from coal burning, and ineffective sewage and storm-overflow treatment and containment. The latter is likely the result of aging infrastructure and inadequacy of many of the facilities around the lake. Proper sanitation infrastructure is extremely expensive to rebuild or refurbish, and only governments can do it. A coordinated effort among municipalities, states, and the federal government is necessary to ensure reductions of pollutants to Lake Michigan.

Lake Michigan Committee Action Items, 2011-2015

The LMC proposes the following three actions for the next five-year reporting period. These actions are not to be confused with our normal management actions, strategies to abate impediments to the FCOs, or process procedures; rather, they are intended to focus us over the next five years on our FCOs. Thus, the LMC will:

- In collaboration with the LMTC, examine its FCOs with respect to changing conditions in Lake Michigan. We will reaffirm, redefine, or modify some or all of them or embark on the production of a completely new document.

- Encourage the development and prioritization of research needs, foster other data collection/analysis processes, and assist, where possible, in alleviating potential shortfalls in information. Many of these shortfalls and needs are specified in this report—we recognize the value of presenting a very focused and current list of research priorities to guide grant and agency funding.

- Increase coordination with other environmental organizations, whether directly or through the LMTC, to further promote ecosystem management through a multi-disciplinary approach. For example, better integration of lower trophic-level dynamics and climate-change effects, along with greater involvement in the lakewide management plan process, could ensure greater participation by the Great Lakes community in achievement of our FCOs.

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